School of Mining Engineering

UNIVERSITY OF THE
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METHODOLOGY TO QUANTIFY APPARENT LOSSES VERSUS REAL LOSSES IN NARROW TABULAR PRECIOUS METAL ORE FLOWS

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

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ABSTRACT

This research examined the methodology to quantify apparent losses versus real losses in narrow tabular precious metal ore flows, and to investigate the uncertainty in the estimations used to determine the monthly and annual MCF. The apparent losses are caused by incorrect sampling, incorrect survey measurements, geological modeling, incorrect relative density applied, and incorrect assaying.

Real losses are a result of fines trapped in the stopes footwall cracks, sweepings not continuously done with blasting, spillages, gold theft, and spillage during tramming. Due to the measurement uncertainties used to determine the metal called for in the MCF calculation, these uncertainties could then be used in a Monte Carlo simulation to estimate the range of the MCF and thus estimate the real and apparent loss split. Both apparent grade and real grade loss occurred in the period under review for Sibanye-Stillwater gold operations.

Sibanye-Stillwater gold mines operations, grade loss amounts to 21%, while the tonnage gain amounts to 6.3%, with the survey shortfall of +5.6%, and the MCF of 84% for 2017. It is both apparent and real gain for the tonnages and apparent and real loss on the grade which affects the MCF, which ultimately affects the revenue, which equates to R4,18bn for the year under review. It has been shown that there are losses, and are between 10 and 14% on the Sibanye-Stillwater gold mines. This range includes the uncertainties in estimations. Monte Carlo simulation is been used to determine the range of the MCF due to estimation uncertainties. It can be concluded that the real losses are at least 10%.

DEDICATION

In memory of my mother Rebecca Selomba Mhlongo.

ACKNOWLEDGMENTS

Firstly, I would like to thank God who guided and protected me throughout my entire life up until today. My appreciation and gratitude to my supervisor Mr. Clinton Birch, for the time, knowledge, and effort in making sure that this report came to fruition. Your guidance and advice are highly appreciated.

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1 INTRODUCTION

1.1 Background of Sibanye-Stillwater Mining Operations

Sibanye-Stillwater was unbundled from Gold Fields in 2012 and it was listed as Sibanye Gold in 2013. Sibanye-Stillwater is a South African mining company and owns the Mimosa mine in Zimbabwe. Sibanye-Stillwater is the largest individual gold producer in South Africa and is in the top 10 of largest gold producers globally, and it is also the largest platinum group metals (PGMs) producer in the world, (Sibanye-Stillwater, 2019). The gold operations in the South African region include Kloof, Cooke, Driefontein, and Beatrix. In March 2016 Sibanye-Stillwater acquired Aquarius-Platinum Limited, which includes the Mimosa Mine in Zimbabwe the same year, Sibanye-Stillwater acquired Rustenburg Platinum mines from Anglo American Platinum. In December 2016, Sibanye announced the proposed acquisition of Sibanye Mining Company in the United States (US) and the first production took place during 2017 from the Blitz project in the US operations (Sibanye-Stillwater, 2017). Sibanye also acquired Lonmin Platinum Mines at the end of 2019.

Figure 1 shows the location of the Sibanye-Stillwater, South African operations.

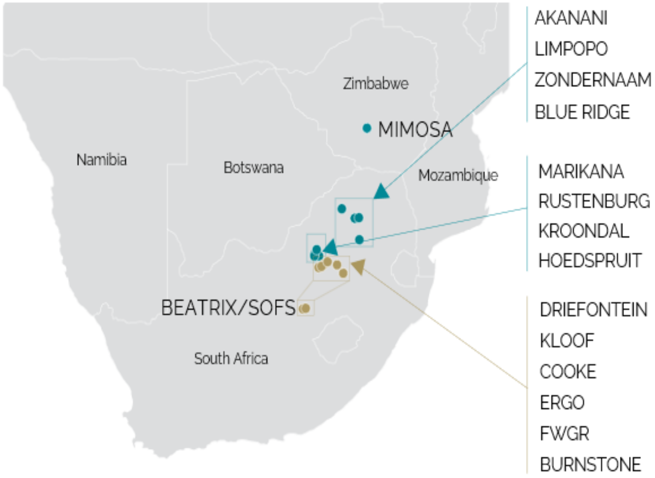


Figure 1: Sibanye-Stillwater operations *(Sibanye-Stillwater, 2018).*

1.2 Background of Sibanye-Stillwater Gold Mines Operations

The report will focus on three of the Sibanye-Stillwater gold mines operations, namely Kloof, Driefontein, and Beatrix mines.

1.2.1 Kloof Mine

Kloof is situated in the Magisterial District of Westonaria, the mine is located about 60km west of Johannesburg in the Gauteng Province (Figure 2) (Sibanye-Stillwater, 2018). Kloof has five shafts namely Thutukani, Hlanganani, Ikamva, Manyano, and Masimthembe Shafts (Sibanye-Stillwater, 2018). Kloof is an underground mine operation with a production rate of 160,000t per month (Sibanye-Stillwater, 2018). The mining layout is breast-stoping with dip pillars and a minor contribution from scattered mining. Processing of ore is at two mineral processing plants, Kloof Plant 1 and Kloof Plant 2, with a capacity of 180, 000t per month. There are also mining operations on surface rock dumps (Sibanye-Stillwater, 2018). The life of mine is currently forecasted to be 12 years (Sibanye-Stillwater, 2018).

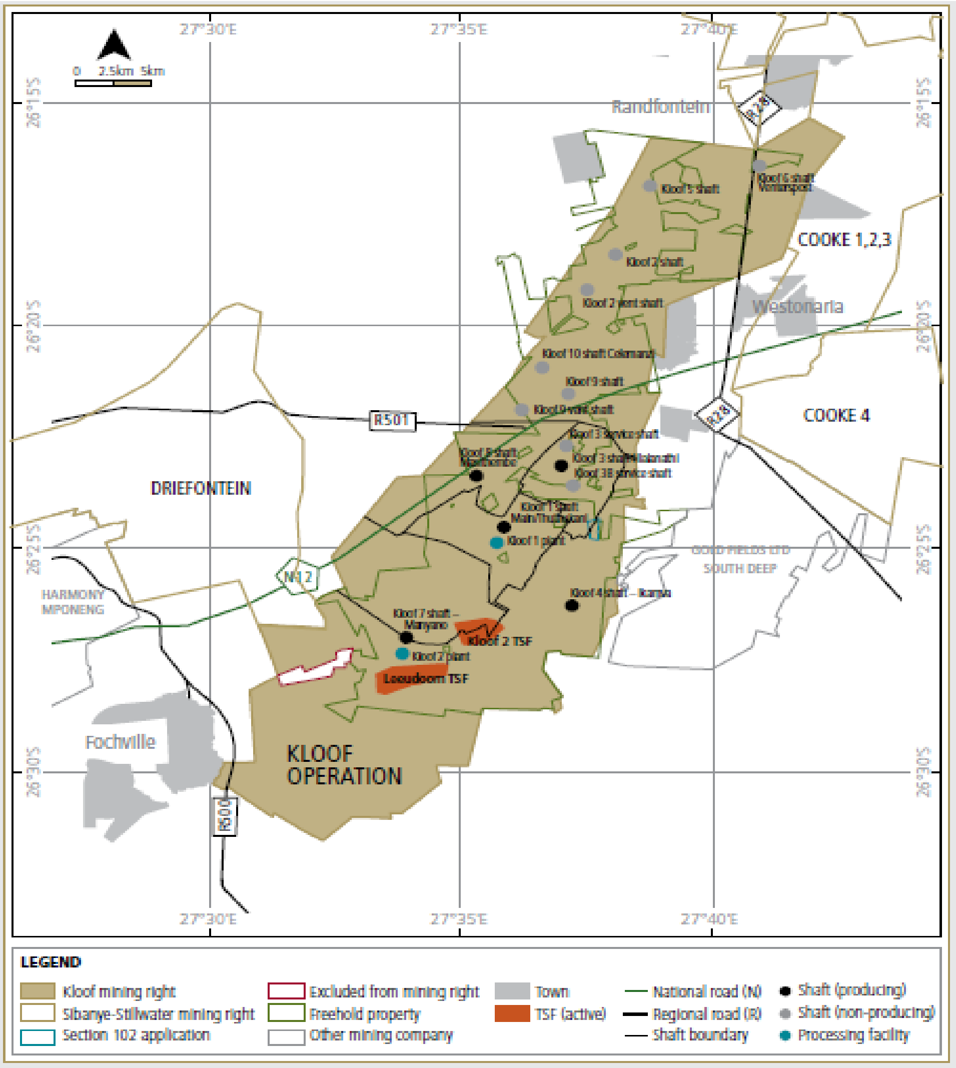


Figure 2: Kloof Operations *(Sibanye-Stillwater, 2018).*

1.2.2 Geology and Mineralization of Kloof Mine Operations

Kloof mine is located in the West Wits Goldfield of the Witwatersrand Basin (Sibanye-Stillwater, 2018). The goldfield is divided into two parts namely, the far West Rand and the West Rand areas. The West Rand area structure is dominated by the West Rand and Panvlakte horst blocks (Sibanye-Stillwater, 2018). Most faults are high-angle to normal faults trending north-northwest and eastwards with throws of less than 70m, and faulting generally decreases eastwards (Sibanye-Stillwater, 2018). In the far West Rand area the Venterdorp Contact Reef (VCR), which is located at the top of the Central Rand Group is the primary reef mined (Sibanye-Stillwater, 2018). The Basal Middlevlei Reef (MVR), which strategically occurs some 50m to 70m above the Central Rand Group, is mined as a secondary reef. The average regional dip of the reef at Kloof mine is 21 degrees. Ore bodies at Kloof mines are VCR, Kloof Reef (KR), and Libanon Reef (LB).

1.2.3 Driefontein Mine

Driefontein is situated 70km west of Johannesburg in the Gauteng Province, near Carletonville (Figure 3), (Sibanye-Stillwater, 2018). Driefontein consists of six shafts, Masakhane, Pitseng, Ya Rona, Hlanganani, Khomanane, and D6 Shafts (Sibanye-Stillwater, 2018). Driefontein is an underground mine operation with a production rate of 167,000t per month (Sibanye-Stillwater, 2018). The mining layout is shaft pillar mining, breast mining with dip pillars, and a minor contribution from scattered mining. Processing of ore is at three mineral processing plants, Number 1, Number 2, and Number 3 with a capacity of 172, 000t per month. The life of mine is currently forecast to be 9 years (Sibanye-Stillwater, 2018).

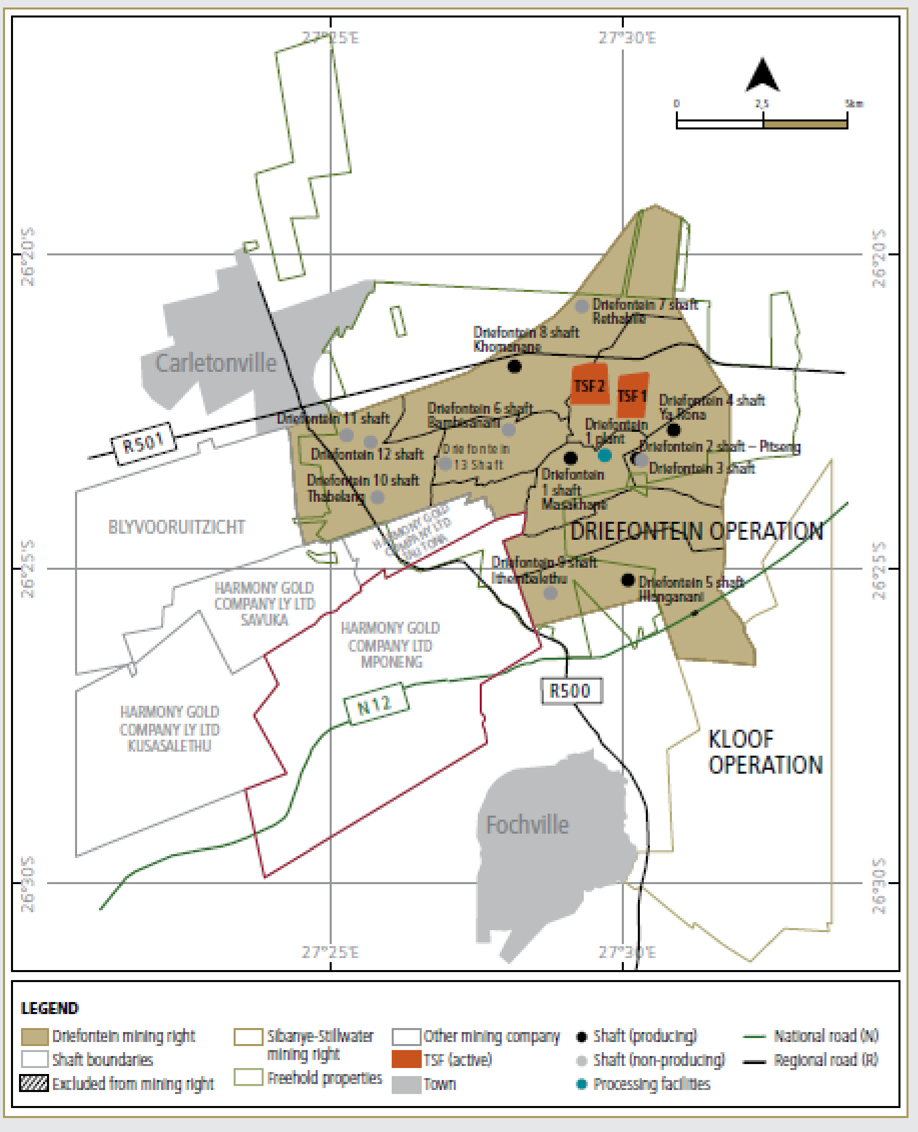


Figure 3: Driefontein Operations *(Sibanye-Stillwater, 2018).*

1.2.4 Geology and mineralization of Driefontein Mine Operations

Driefontein mine is located in the West Wits line which forms part of the far west rand of the Witwatersrand Basin (Sibanye-Stillwater, 2018). The goldfield is divided into two parts namely, an eastern section and a western section. The faulting in the Driefontein mining area is characterised by easterly striking strike-slip faults with horizontal displacement of up to 450m (Sibanye-Stillwater, 2018). Three primary reefs are mined at Driefontein, the VCR, Carbon Leader Reef (CLR), and the Main Ventersdorp Reef (MVR), which stratigraphically occurs some 50m to 75m above the CLR (Sibanye-

Stillwater, 2018). The separation between the VCR and CLR increases east to west from 0m to over 1300m, as a result of the relative angle of the VCR (Sibanye-Stillwater, 2018). The average dip of the reef at Driefontein mine averages 25 degrees (Sibanye-Stillwater, 2018).

1.2.5 Beatrix Mine

Beatrix is situated in the southern Free State in the Free State Province, (Figure 4), (Sibanye-Stillwater, 2018). Beatrix consists of three shafts, North, South, and West, Shafts (Sibanye-Stillwater, 2018). Beatrix is an underground mine operation with a production rate of 150,000t per month (Sibanye-Stillwater, 2018). The mining layout is shaft pillar mining and a minor contribution from scattered mining. Processing of ore is at two mineral processing plants, Beatrix Number 1, and Beatrix Number 2 with a capacity of 152, 000t per month. The life of mine is currently forecast to be 4 years (Sibanye-Stillwater, 2018).

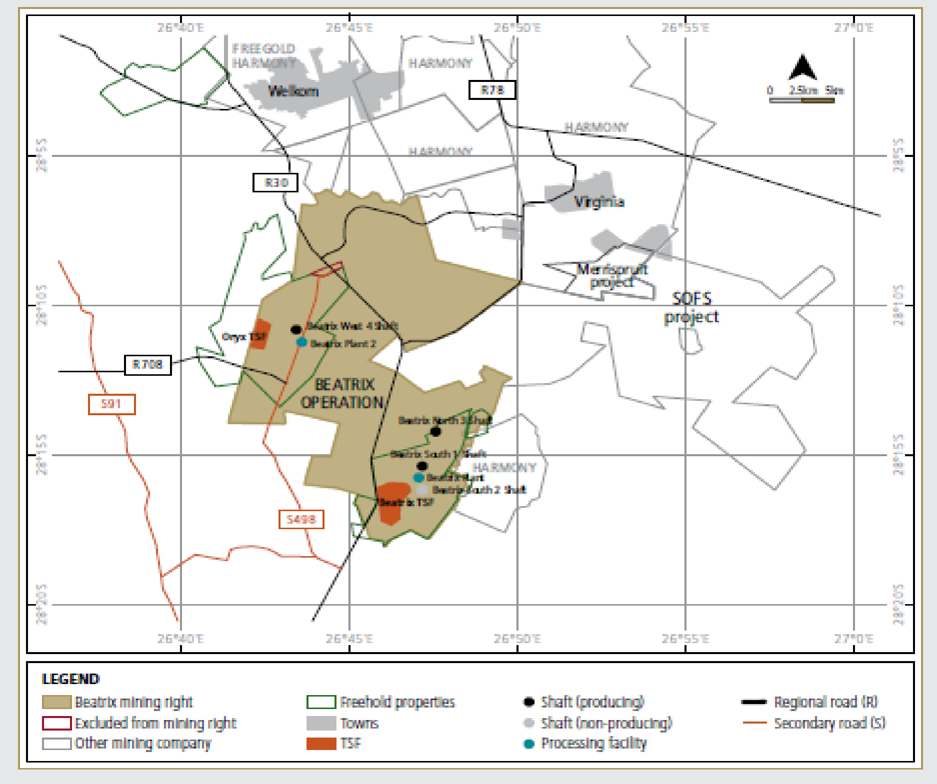


Figure 4: Beatrix Operations *(Sibanye-Stillwater, 2018).*

1.2.6 Geology and Mineralization of Beatrix Mine Operations

Beatrix deposit is located in the Witwatersrand Basin, which consists of a vertical thickness of argillaceous and arenaceous sedimentary rocks situated within Kaapvaal Craton (Sibanye-Stillwater, 2018). The reefs which are mined at Beatrix mines are Beatrix Reef (BXR), Aandenk Reef (AAR), VS5 Reef (VS5), and Kalkoenkrans Reef (KKR). (Sibanye-Stillwater, 2018).The dip at the Beatrix mine averages between 10 degrees to 25 degrees (Sibanye-Stillwater, 2018). The reef's thickness ranges between 1m to 2.5m. The sedimentary rocks dip at shallow angles towards the centre of the basin (Sibanye-Stillwater, 2018).

Figure 5 shows the geology of the Sibanye-Stillwater gold mines operation, in the Witwatersrand Basin.

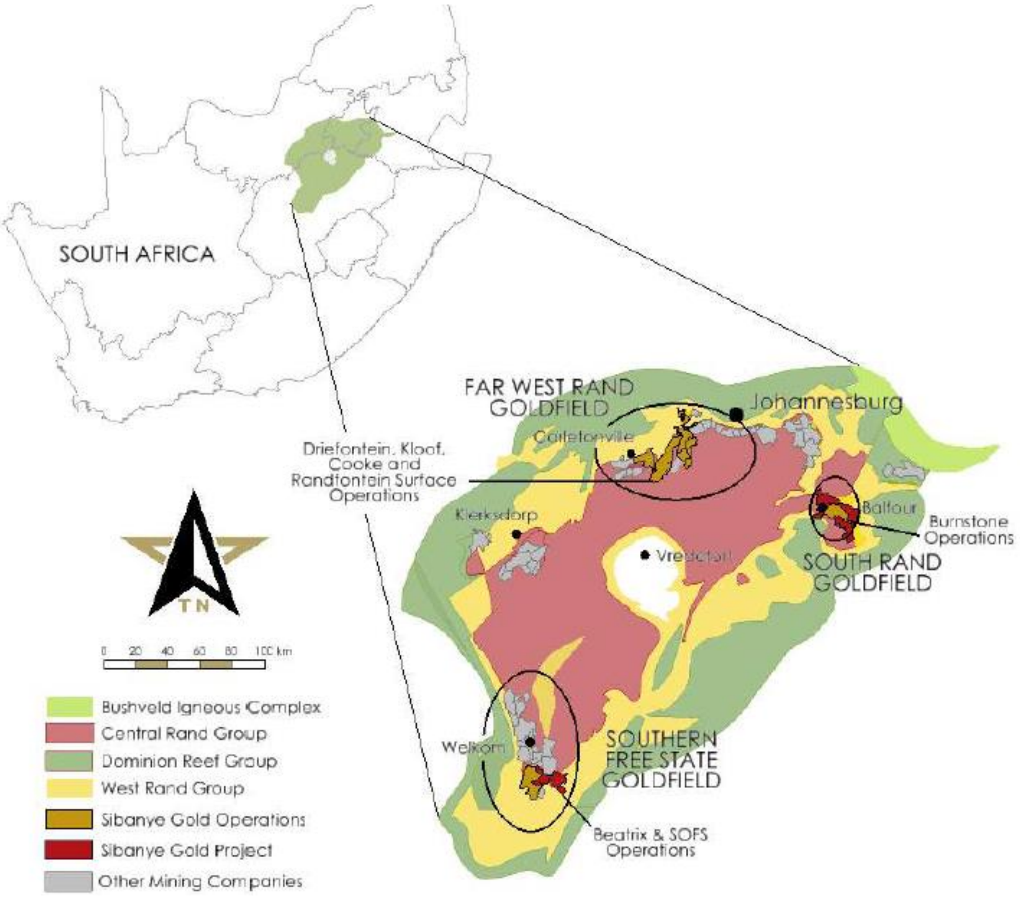


Figure 5: Geology of the Witwatersrand Basin (Sibanye-Stillwater, 2018).

1.3 Problem Statement

Mine call factor (MCF) has been used as a performance measure for production performance in precious metals production. Sibanye-Stillwater's gold operations have not achieved the planned MCF for the past five years. Figure 6 depicts that the gold accounted for (metal recovered and residue), has always been lower compared to the gold called for at the mines and this has a major financial implication on a business. Figure 6 also indicates that there are losses along the mining value chain. The apparent losses are caused by errors introduced during sampling, assaying, and resource modelling. Real losses are those caused by blasting during mining, tramming, hoisting, and gold theft.

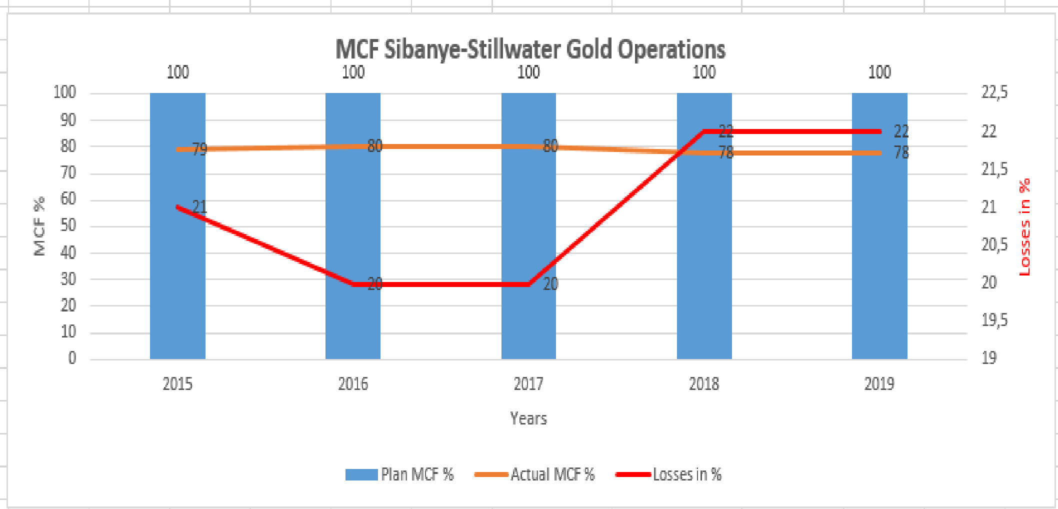


Figure 6: MCF of gold operations 2015-2019 (Sibanye-Stillwater, 2019).

1.4 Justification for Research

The main objectives of this report are to:

- Quantify the apparent losses/gains and the real losses in a narrow tabular precious metals ore flow, at Sibanye-Stillwater (Gold Sector);
- Investigate the uncertainty in the estimations used to determine the monthly and annual MCF;
- Identify whether it is a tonnage or grade discrepancy;
- Apply Monte Carlo simulation to estimate apparent gain/loss and thus determining real losses.

1.5 Previous Work

Previous work on the mine has been done and is not available in the public domain. Several investigations were conducted on the causes of low MCF at the following gold mines:

- De Jager (1997), undertook an analysis of the MCF with specific reference to the Western Holdings in South Africa to establish the causes of low MCF;
- Two open pit gold mining operations in Brazil (Chieragati & Pitard, 2009);
- Induapriem open pit in Ghana (Tetteh, 2014);
- Ives in Western Australia (Donaldson, 2014); and
- Mazowe mine in Zimbabwe (Mugwagwa, 2015).

The results at Western Holdings and Ives, show that MCF is affected by several factors but the primary cause of low MCF is due to real and apparent losses of grade. Tetteh (2014), during the research at the Induapriem, focused on establishing the relationship between measurement and measurement protocols, as well as discrepancy at measurement points, and did not establish the sources of the discrepancies at the points of measurements, and recommended a further study to investigate the measurements (mass and sampling) procedures at the plant and stockpile.

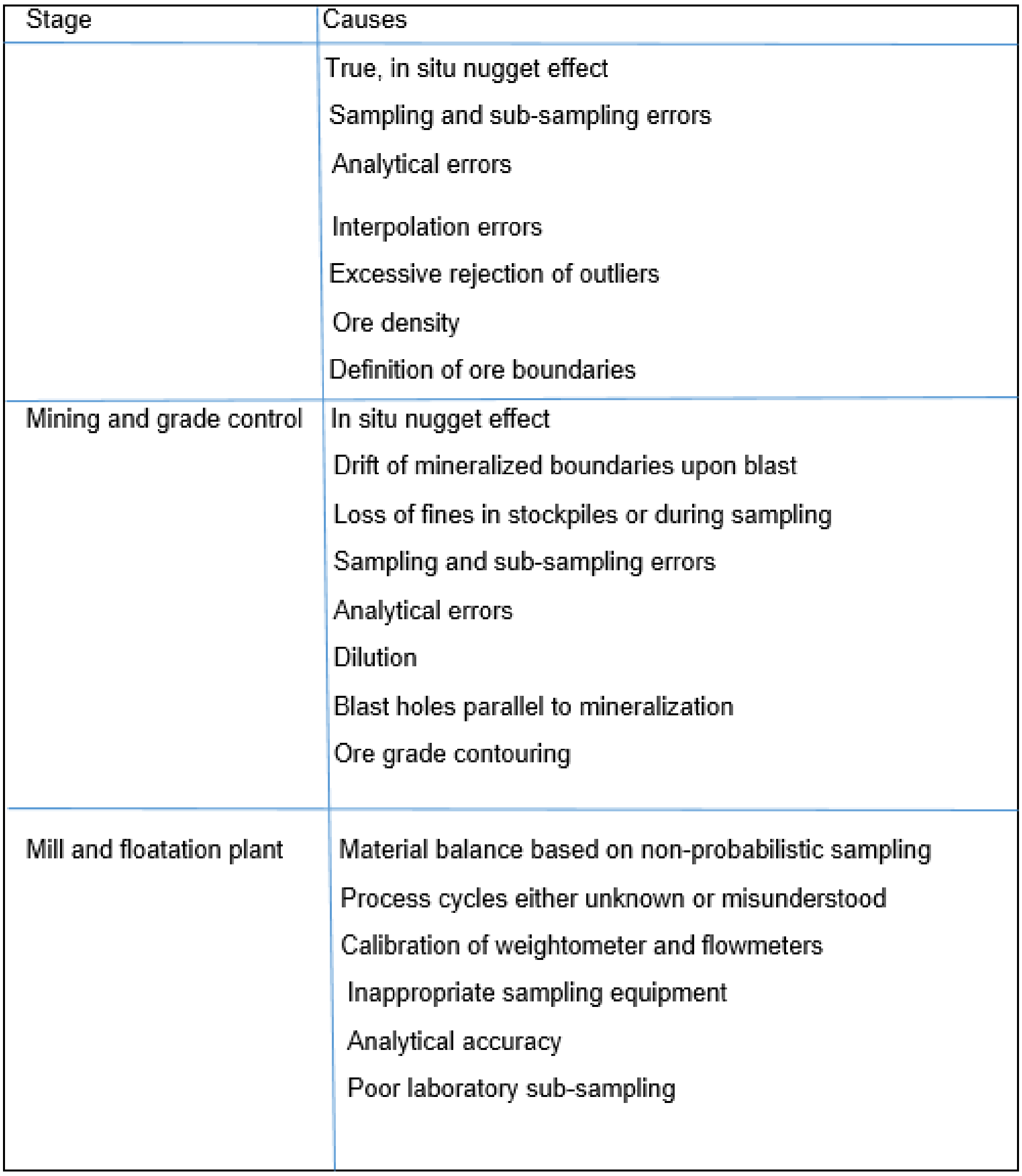
Chieragati & Pitard (2009), the two open pits in Brazil focussed on mine planning, sampling, and reconciliation to determine the losses of grade. The results indicated that small improvements in sampling practices will result in significant improvements in reconciliation (Chieragati & Pitard, 2009).

De Jager (1997), undertook an analysis to investigate and establish the cause of low MCF at the Western Holdings Mine. The investigation was to determine and explain the gold unaccounted for, by determining the real gold loss and apparent gold loss. He indicated that 35% of gold mined was accounted for at the Western Holdings Mine during the research. Furthermore, he concluded that real gold loss primarily occurs because the blasted ore underground is not all trammed, and hoisted from underground to the metallurgical plant. He identified that none of the cracks in the footwall where gold could be trapped was vacuumed, however, no significant quantities of gold were found. The challenge of sampling gold in two low-grade deposits in Brazil was studied by (Chieragati & Pitard, 2009). Sampling problems and solutions were discussed, solutions were adopted for reconciliation between the mine and the mine (Chieragati & Pitard, 2009).

The mine to mill reconciliation concept was introduced to reduce the costs of mining operations and can be defined as the integration of the mining processes from geology to the mill feed (Chieragati & Pitard, 2009).In the mining industry reconciliation equates to the comparison of estimate (resource, reserves, and grade control models) with a measurement (information or the official production of the processing plant) (Chieragati & Pitard, 2009). The outcome of these comparisons is often a group of factors such as MCF, which indicates how accurate an estimate turned out to be (Chieragati & Pitard, 2009).

The two mining operations studied were low-grade gold deposits, which were evaluated for a year with a focus on sampling, mine planning, and reconciliation. The objective of the evaluation was to observe Pitard’s condition for minimizing sampling errors which were the basis of the work (Chieragati & Pitard 2009). Table I indicates the problems identified during the study.

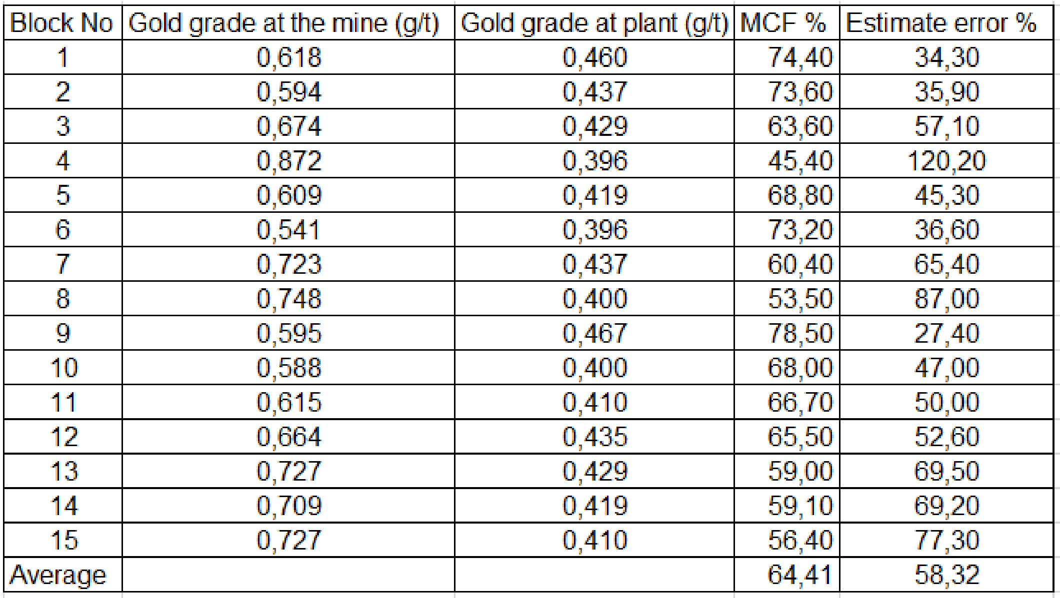
Table I: Pitard's causes of mine to mill reconciliation problems (Chieragati & Pitard 2009).



Stage	Causes
	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 Blast holes parallel to mineralization Ore grade contouring
Mill and floatation plant	Material balance based on non-probabilistic sampling Process cycles either unknown or misunderstood Calibration of weightometer and flowmeters Inappropriate sampling equipment Analytical accuracy Poor laboratory sub-sampling

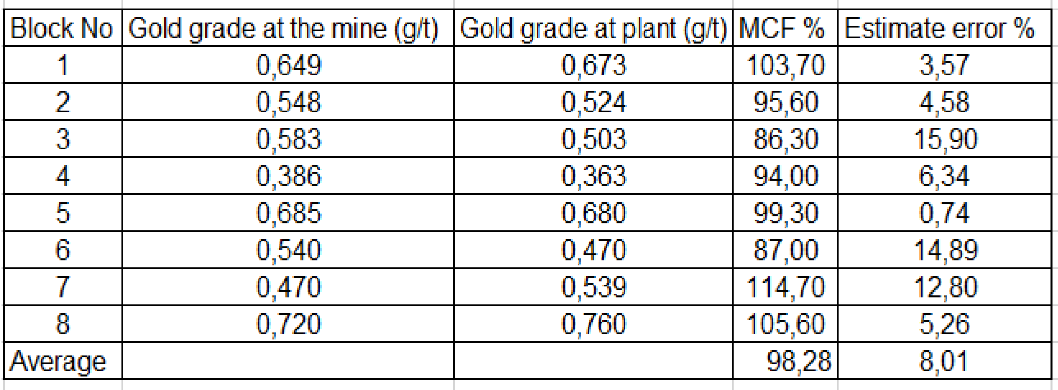
Table II indicates the errors of the estimate before adjusting reconciliation, and Table III indicates the errors of components after adjusting the reconciliation factors.

Table II: Errors of estimates before adjusting the reconciliation components (Chieragati & Pitard 2009).



Block No	Gold grade at the mine (g/t)	Gold grade at plant (g/t)	MCF %	Estimate error %
1	0,618	0,460	74,40	34,30
2	0,594	0,437	73,60	35,90
3	0,674	0,429	63,60	57,10
4	0,872	0,396	45,40	120,20
5	0,609	0,419	68,80	45,30
6	0,541	0,396	73,20	36,60
7	0,723	0,437	60,40	65,40
8	0,748	0,400	53,50	87,00
9	0,595	0,467	78,50	27,40
10	0,588	0,400	68,00	47,00
11	0,615	0,410	66,70	50,00
12	0,664	0,435	65,50	52,60
13	0,727	0,429	59,00	69,50
14	0,709	0,419	59,10	69,20
15	0,727	0,410	56,40	77,30
Average			64,41	58,32

Table III: Errors of estimates after adjusting the reconciliation components (Chieragati & Pitard 2009).



Block No	Gold grade at the mine (g/t)	Gold grade at plant (g/t)	MCF %	Estimate error %
1	0,649	0,673	103,70	3,57
2	0,548	0,524	95,60	4,58
3	0,583	0,503	86,30	15,90
4	0,386	0,363	94,00	6,34
5	0,685	0,680	99,30	0,74
6	0,540	0,470	87,00	14,89
7	0,470	0,539	114,70	12,80
8	0,720	0,760	105,60	5,26
Average			98,28	8,01

Table III shows the results of the work performed during the adjustment of sample preparation equipment, and after adjusting the six reconciliation components. The comparison of Table II and Table III indicates that small improvements in the sampling practices result in significant improvement in the reconciliation process (Chieragati & Pitard, 2009). An average MCF from 64.4% to 98.3% is noted while the average estimate error drops from

58% to 8% after the adjustment of the reconciliation component. These results indicated that small improvements in sampling practices result in significant improvements in reconciliation and process control (Chieragati & Pitard, 2009).

A MCF investigation was conducted at Induapriem Mine in Ghana to determine the relationship between the actual measurement and the measurement protocols (Tetteh, 2014). The spot tonnages were consistently higher than survey tonnages, with a correlation of 0.945 between the spot tonnage and survey tonnage (Tetteh, 2014).

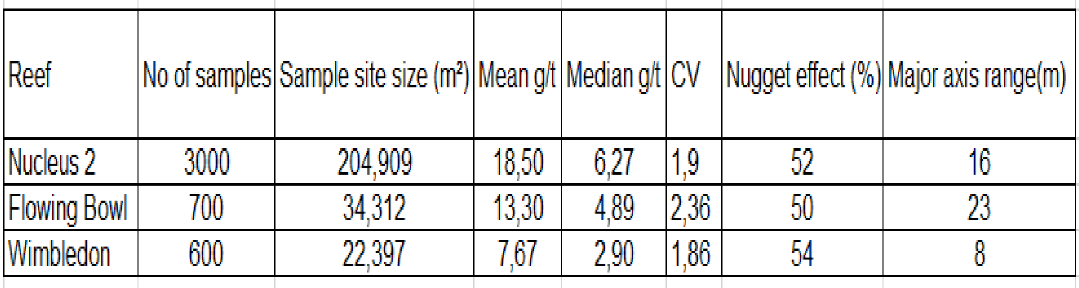
The mine to mill reconciliation compared production estimates from various sources, and measurement points were established between any two sources and reconciliation factors determined using tonnage, grade, and ounces (Tetteh, 2014).

The Ives Gold mine consists of 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). The mine consists of underground, open pits, and historical stockpiles which makes it very complex with multiple sources of ore at any one time (Donaldson et al., 2014). During 1993 mine to mill reconciliation data was implemented every month, analyzed, and interpreted (Donaldson et al., 2014). Since the data collection commenced, a slow but steady improvement in the MCF was noted, this is due to improved spotting and appropriate estimation techniques, sampling methods, mining and QA/QC protocols, and understanding of geology (Donaldson et al., 2014).

Mugwagwa (2015), conducted study research at Mazowe Mine in Zimbabwe. The main objective was to establish whether resource estimation is a major factor contributing to the low MCF (Mugwagwa, 2015). The study mainly focused on resource estimation and the results from experimenting with different techniques, inverse distance weighting, method of polygons, and geostatistics (kriging and indicator kriging). The estimates were compared with the face samples and geology of each mining block (Mugwagwa, 2015).

The research study focused on three reefs namely, Nucleus, Flowing Bowl, and Wimbledon (Mugwagwa, 2015). The descriptive statistics of the sample data taken at the Mazowe mine are illustrated in Table IV.

Table IV: Descriptive statistics (Mugwagwa, 2015).



Reef	No of samples	Sample site size (m²)	Mean g/t	Median g/t	CV	Nugget effect (%)	Major axis range(m)
Nucleus 2	3000	204,909	18,50	6,27	1,9	52	16
Flowing Bowl	700	34,312	13,30	4,89	2,36	50	23
Wimbledon	600	22,397	7,67	2,90	1,86	54	8

Table IV indicates that the coefficients of variation (CV) for all three reefs are greater than 1.5, and in such cases, high values are normally removed and the CV is recalculated. Mugwagwa (2015), states that coarse gold contributes to estimation errors, which adversely impact the MCF.

1.6 Research Methods

This research is based on the primary analysis of the ore flow document, utilizing Monte Carlo simulation to try and estimate the degree of uncertainty in the MCF for both real and apparent losses, by:

- Reviewing the ore flow;
- Identifying the extent of grade and tonnage losses;
- Using Monte Carlo simulation to estimate the possible range of MCF due to estimation uncertainties and thus identifying apparent losses; and;
- Including experimentation to establish possible uncertainty ranges, sending mine surveyors to the same panel to measure area mined, and sending photographers in the same panel to measure the stope widths.

This research used the 2017 ore flow balance sheet. Due to the Covid 19 pandemic, the 2020 ore flow was not used. As it is not a true reflection of the production from the operations.

1.7 Sources of Data

Ore flow balance sheet from Sibanye-Stillwater gold mines operation was used to determine the major contributors to the low MCF by using Monte Carlo simulation. Consultations and experiments were conducted to determine the uncertainty of measurements used in the MCF calculation.

1.8 Structure of the Research Report

This research report comprises nine chapters. The first chapter presents the introduction, background of Sibanye-Stillwater mining operations, geology and mineralization of Sibanye-Stillwater gold operations, problem statement, and methods. The second chapter reviews the relevant literature involving the MCF. Chapter Three focuses on Monte Carlo simulation, background, and case studies. The Fourth chapter focuses on the research methodology, qualitative research, and quantitative research focussing on the introduction of ore flow. Chapter Five focuses on the ore flow to determine percentage tonnage/grade gain or loss, analysis of the ore flow balance sheet. Chapter Six focuses on apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss, and real grade loss. The Seventh chapter focuses on Monte Carlo simulation to estimate the ore flow uncertainty, methodology for establishing distributions, estimations of the uncertainty in the Survey Called for volume and grade. Chapter Eight summarises the key findings from Chapters Five and Six, concludes by identifying whether it is primarily apparent gain/loss or real loss. It also summarises the key findings from the Monte Carlo analysis. Chapter Nine presents the recommendations of the study.

2 THEORY OF THE MINE CALL FACTOR

2.1 Introduction

The mining industry has until recently (1996) been in survival mode due to a constant gold price in dollar terms (De Jager, 1997). The devaluation of the Rand is responsible for a more comfortable financial position for gold mines and capital investment for expansion to a lesser degree (De Jager,1997). The concern of not achieving the planned MCF has a massive financial implication of fewer ounces being declared to the operation. The theory of MCF, through well-known is not fully understood and MCF issues are mine specific (Tetteh & Cawood, 2014). The ultimate gold mining efficiency measure is the Mine Call Factor (De Jager,1997). It is the ratio, expressed as a percentage, of the specific product accounted for in recovery plus residues versus the corresponding product called for by the mine's measuring methods (De Jager, 1997). Theoretically, MCF should be 100% if the sampling, assaying, and tonnage measurements are without any mineral loss along with the ore flow.

Gold unaccounted for as indicated by the MCF traditionally attracted some exotic explanations, some of which are still in vogue today (De Jager, 1997). The history of lower than expected MCF draws back to the evolution of gold mining (Mugwagwa, 2015), This was also highlighted by (Pitard 2014, p749) who stated that "major discrepancies between mining estimates and estimates from plant metallurgical balances are a common problem in many gold and base metal mines the world over". Mugwagwa (2015), indicated that mining has to make a profit in the shortest time possible because of fluctuations in metal prices. Mugwagwa (2015), also indicated that MCF is used as a mining modifying factor when estimating the reserves, as well as a technical performance indicator. The monthly difference between the gold called for (estimated by the surveyors to be in the ore mines), and the corresponding gold accounted for (gold recovered plus residues, which is finally weighted by the metallurgist in the plant) is referred to as the gold unaccounted for (Fourie & Minnit, 2016).

Storrar (1981), defines MCF as the ratio, expressed as a percentage which the specific product accounted for in recovery plus residue bears to the corresponding product called for by the mine’s measuring methods. The formula is mathematically expressed in equation:

$$\text{MCF} = \frac{\text{Metal produced in recovery + residue} \quad \text{x100\%}}{\text{Metal called for by the mine evaluation method}} \qquad [1]$$

In the MCF equation, the gold accounted for minus the gold called for equals accounted for (De Jager, 1997). The MCF is believed to be strongly influenced by both the quantity and quality of sweepings done during a specific production period (De Jager, 1997). De Jager (1997), indicated that sweepings are not the major contributor to a good MCF, but it is rather an indicator that the majority of the tonnage was removed from the stope.

If the ore measured at the mine during the production period is equivalent to the ore received and processed with the same grade at the plant, then the MCF should be 100 %. De Jager (1997), also declares that the mining industry is sometimes faced with various challenges with regards to the possible causes of unaccounted for gold. He further concluded that the unaccounted for gold in the mining amounts to millions of rand daily. De Jager (1997), stated that the broken ore that is not brought to the surface for processing also contributes to a low MCF, and he recommended it is important that ore blasted is all removed to the metallurgical plant timeously. Cawood (2003), investigated the Underground face sampling on narrow reefs and found out that the MCF is not a reliable indicator when used to identify the location of the gold loss.

Andersen (1999), stated gold accounted for is equal to the recovery plus residues and that the recovery is simply the quantity of the physical product, at the end of the specific production period, which would include by-products from the processing. He further stated that residues are derived from the treated tons multiplied by the average residue grade of the same period.

Anderson (1999), defined metal called for by the mine evaluation, as area mined in situ which is the face length (FL) worked, multiplied by face advance (FA), multiply by Insitu value, multiplied by the density of the rock. He further did a breakdown of what makes up the gold called for (GCF).

Gold called for (GCF) = Area mined (m^2)*Insitu value(cmg/t) * relative density of the rock.Andersen, (1999), thus rewrote the MCF formula as follows:

$$\text{Mine Call Factor} = \frac{\text{Recovery + (Treated Tons Average Residue Grade}}{\text{FL*FA*average grade*stoping width*RD}} \text{*100} \qquad [2]$$

Stope width, face advance, face length, rock density, the height of the on reef drives, and grade plays an important role in the ore flow balance sheet.

2.2 Theories and Case Studies of MCF

2.2.1 Apparent and real losses

Losses are further classified as either “Apparent or Real” (Cawood, 2003). The real gold loss should be traceable and if lost during mining operations it should be able to be found underground (De Jager, 1997). De Jager (1997), indicated that if the gold cannot be found underground, then it can only be ascribed as an apparent gold loss. Cawood (2003), further explains that apparent losses result from issues such as over-estimation of metal content, inappropriate sampling standards, and an incorrect relative density being applied. Real losses are actual, physical metal losses such as metal locked up the plant as well as ore being lost. The gold called for as per the mine’s measuring system including sampling, assaying and tonnage is an estimate (De Jager, 1997).

Springett (1993), indicates that MCF should not just serve the purpose of simply balancing the books and overlooking the real problems which when dealt with can increase profitability. Tetteh & Cawood (2014), further explained that the MCF issues vary from mine to mine, and therefore it is rather appropriate to follow a systematic scientific approach to distinguish between fallacies and facts. Hence an investigation into the mine call factor should not concentrate on “finding, fingering and fixing” losses (Cawood, 2003). De Jager (1997), concluded that the primary causes of apparent gold loss at Western Holdings Mine were the underground sampling method and an overstate specific gravity applied. The variable components of MCF vary from mine to mine and depend on the ore flow diagram from underground to the smelter. Storrar (1981), suggested a systematic examination of the following variables for typical underground gold mine at that time:

- Mine surveyor’s measurements and calculations;
- Current sampling of ore sent to mill;
- Rock packed underground as waste;
- Ore picked on the surface from waste;
- Tipping of ore and car factors;
- Accumulation of ore and sweepings;
- Losses or theft of gold in the plant; and
- Assay bias and allowance for silver content in gold assaying.

A similar approach is recommended for underground platinum mines to trace potential losses. Cawood (2003), outlined a seven-step approach on how to do MCF investigations namely “review the existing protocols and establish compliance, literature survey, understanding the process of ore flow to the smelter, Identifying and quantifying risks, introduce tests and observe responses. Distinguishing between long term and short term research topics and adjusting existing protocols as a consequence of research outcomes” (Cawood, 2003).

2.2.2 Tonnage gains/loss

Tonnage gains occur because tonnes accounted for at the processing plant are higher than the tonnes called for at the mine, by the mines survey department. Tonnage loss is because tonnes accounted for at the processing plant are lower than the tonnes called for at the mine, by the mines survey department. Sources which contribute to the tonnage losses are inefficient stope lashing, lack of blasting barricades, derailments, inaccurate weightometer measurements, spillage, and leaks in the processing plant.

2.2.3 Grade loss/gain

Grade loss is a result of when the accounted for grade is lower than called for grade. Grade losses impact the MCF and the sources which contribute to grade losses are, shaft spillages, waste to ore tipping, drilling water, footwall cracks, unplanned dilution, fragmentation, sampling, and stope sweepings.

2.2.4 Metal accounting

Metal accounting is an important component in mineral resource management and its main objective is to balance the physical metal content, across the mining value chain (Hills, 2000). The flow of metal from stopes and development is a complex process. Figure 7 shows the underground material flow.

Hills (2000), indicated that the complexities are as a result of:

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

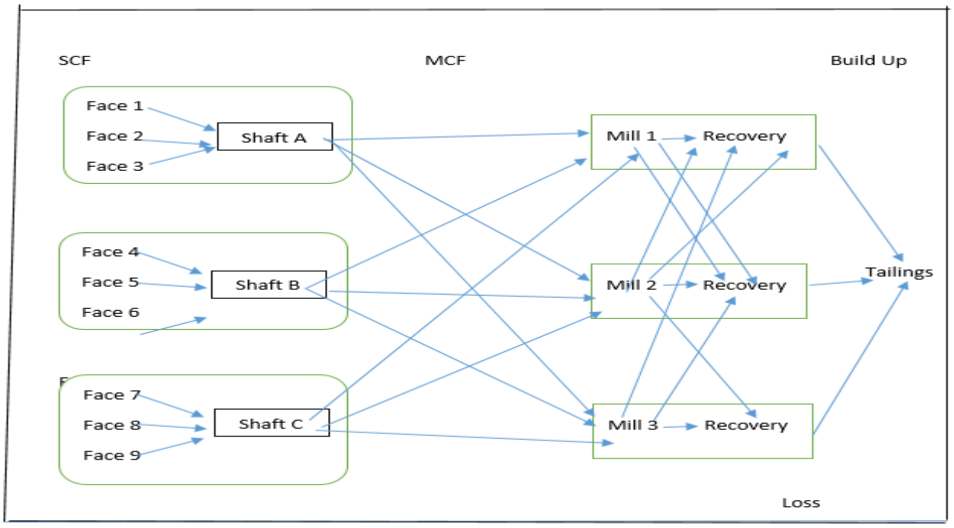


Figure 7: Underground material flow (Hill, 2000).

Figure 8 depicts the flow for surface operation, consisting of three open pits.

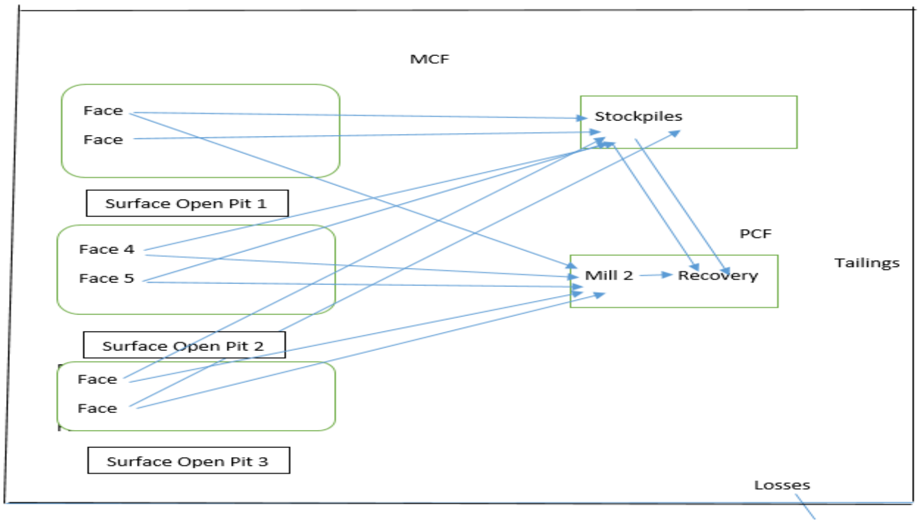


Figure 8: Opencast material flow (Tetteh, 2014).

Janisch (1973), indicated that a metal accounting procedure requires systematic documentation for recording and representing ore valuation, mine grade, and ore processing on the mine. Tetteh, (2014), indicated that the main objective is to generate statistical data in a way that the information is presented and easy to understand, to track and monitor the flow along the mine value chain. ”These statistics are used to generate reconciliation and efficiency factors such as MCF which is used by management for planning purposes” (Tetteh, 2014). The survey department measures the tonnages mined during measuring periods and the sampler measures the quality of ore, processing department measures the final product accounted for at the plant.

2.3 Key Debates and Controversies

The theory of MCF says metal produced plus residue should be equal to the metal called for, however, we plan less than 100 % because there is a loss of metal from stopes to the plant. There is uncertainty in all the numbers which are used to calculate the MCF, therefore the Monte Carlo simulation will be applied to try and determine the apparent losses in the ore flow.

2.4 Gaps in the Existing Knowledge

Researches have been conducted in the gold mines to determine the causes of low MCF, and it was concluded that MCF is affected by real losses and apparent losses (De Jager, 1997). However, the main objective of this research is to quantify the apparent losses/gains and the real losses in narrow tabular precious metal ore flows. Monte Carlo simulation software will be applied to estimate apparent gain/loss and thus eliminating real losses. Investigating the uncertainty in the estimations used to determine the monthly and annual MCF. No one has used the Monte Carlo simulation to try and determine the uncertainty of MCF in Sibanye-Stillwater mines.

2.5 Summary Chapter

Anderson (1999), stated that “accepting some losses to occur during the blasting and moving stages is standard”. In this chapter, the key concepts, theories of MCF were discussed. Tonnage and grade gain/loss was discussed and, the difference between apparent and real loss/gain was also discussed. The third chapter gives an insight into the Monte Carlo simulation, case studies, and conclusion.

3 MONTE CARLO SIMULATION

3.1 Introduction

This research will assist in investigating the uncertainty in the estimations used to determine the monthly and annual MCF, which will give more options towards the business plan. Monte Carlo simulation is used to show the range of uncertainty, and to quantify the uncertainty in the ore flow. The main objective of employing the Monte Carlo simulation is to try and understand the range of uncertainty in the ore flow.

3.2 Background of the Monte Carlo Simulation

Paulos (2000), stated, “uncertainty is the only certainty there is, and knowing how to live with insecurity is the only security”. The method of handling risks in mining projects may have a major effect on the decisions made by the management team (Kuhn & Visser, 2014). Kuhn & Visser (2014), stated, “ uncertainties, as in any typical project, can have either positive or negative effects on the final project evaluation”. Monte Carlo simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. Tolmay (2009), indicated that operational management risk analysis is important in dealing with the root causes of which affect the final product. Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values, a probability distribution for any factor that has inherent uncertainty (Palisade, n.d). It then calculates results repeatedly, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is completed. Monte Carlo simulation produces distributions of possible outcome values (Palisade, n.d).

3.3 Case Studies of the Monte Carlo Simulation

Tolmay (2009), has indicated that the use of Monte Carlo Simulation as a business tool was introduced in 1964 by Hertz, but it has only been in the last 30 years that it has gained increasing acceptance within the mining industry. He further indicated that the use of Monte Carlo simulations in the mining industry is to assess the “Root Cause” criteria critical to the operations management of existing mining operations. Root causes are to determine realistic remedial actions, create a project outline, attempt quantification, and remodel risk.

Tolmay (2009), stated that the basic principles to be applied to any risk model could be determined by asking questions of what it is that we require from such modelling. This can be outlined within the following points:

- What are the factors that are the greatest contributors to deviations from the end product?
- What can be done about these factors?
- What is the effect on the risk profile if alternative scenarios are envisaged?; and
- If controls are emplaced what will this do to the risk profile?

He further outlined the necessary answers to the questions that one needs to follow:

- Identify principal components for analysis;
- Analyze variables and correlations;
- Use results for input into the risk model;
- Run simulation;
- Rank principal components in order of effect on output;
- Identify 80:20 principals;
- Determine actions to minimize effects;
- Quantify effects of actions;
- Re-run simulation; and
- Quantity final run, Tolmay (2009).

3.3.1 Example of Monte Carlo Simulation for project time estimation

Table V indicates the estimations of the total time it will take to complete the project. In this case, it is a construction project, with three parts (RiskAMP, n.d.). The parts have to be done one after the other so that the total number of months is the sum of all three parts. The times are in months, (RiskAMP, n.d.).

Table V: Basic forecasting model (RiskAMP, n.d.).

Task	**Time estimates**
Job 1	5 Months
Job 2	5 Months
Job 3	5 Months
Total	**14 Months**

For the creation of a model, the Monte Carlo simulation is used, to create three estimates for each part of the project. For each task, estimations are based on the minimum and maximum expected time to complete the project. This is the distribution of uncertainty that is sampled and put through a transfer function to derive outputs. Table VI indicates that there is a possibility that this project will be completed in 11 months, or takes long as 19 months. The simulation will run 500 times, and based on the results of the simulation, it will describe the characteristics of the risk in the model.

Table VI: Forecasting model using range estimates *(RiskAMP, n.d.).*

Task	**Minimum**	**Most Likely**	**Maximum**
Job 1	4 Months	5 Months	7 Months
Job 2	3 Months	4 Months	6 Months
Job 3	4 Months	5 Months	6 Months
Total	**11 Months**	**14 Months**	**19 Months**

The original estimate was expected to finish the project by 14 months. However, based on the Monte Carlo simulation results in Table VII, it is should be noted that there is, a 34% chance that the project could be completed in 14 months. There is a 79 % chance that the project could be completed in 15 months. Having more information about risk at the beginning of any project means that the plan execution can be planned better.

Table VII: Results of a Monte Carlo simulation (RiskAMP, n.d.)

Time (Months)	Number of Times (Out of 500)	Percentage (%)
12	1	0
13	31	6
14	171	34
15	394	79
16	482	96
17	499	100
18	500	100

3.3.2 Case Studies in mining projects

Heuberger (2004 pg 76), mentioned that *"a mining industry is considering to developing a small underground gold mine with an estimated reserve of million ounces of gold. Although a geological survey was done, there is still some uncertainty about the size of the orebody. The objective is to value the mining project on a discount cash flow basis, taking into account the impact of the geological and economic uncertainties".*

He further indicated that once the model has been tested and it calculates justifiable results, then the uncertainty can be entered into the Monte Carlo, and the following applies:

- Canvass estimates of uncertainties from experts in the company or economists;
- Select suitable probability density functions from the library of functions in the software;
- Apply the probabilities to the model; and
- Step test the model to see if anything looks wrong.

Figure 9 shows the proposed gold mine project, with the net cash flow, and the net profit profile.

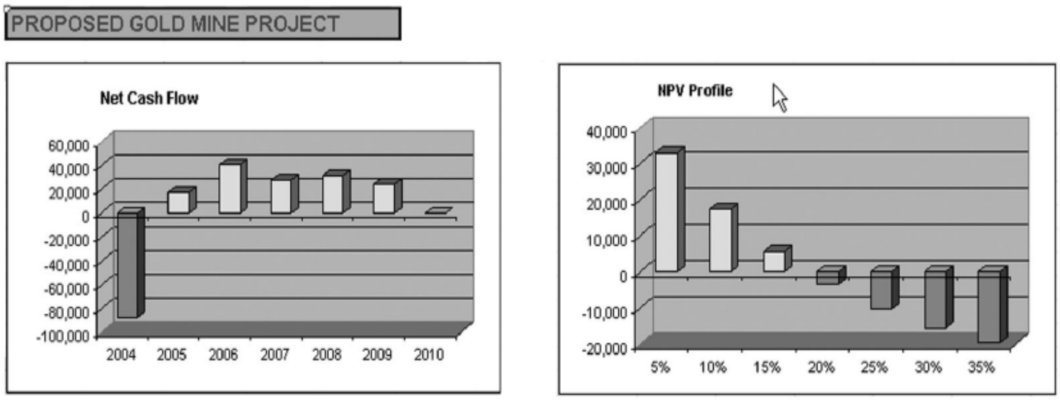
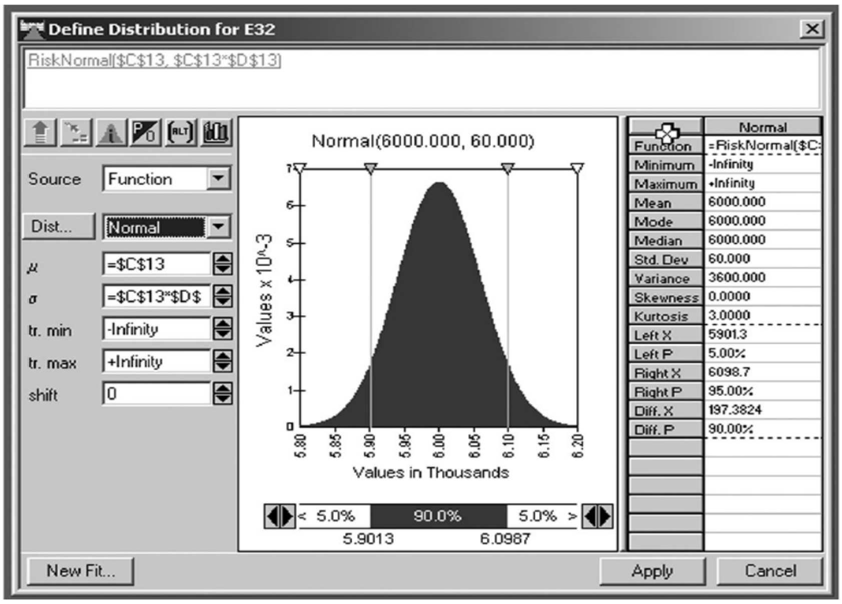


Figure 9: Proposed Gold Mine Project (Heuberger, 2004).

Figure 10 shows the simulated results of the normal distribution with the average of 6000 tons mined per day with the standard deviation of 1%, as a normal distribution.



RiskNormal($C$13, $C$13*$D$13)

Source: Function

Dist...: Normal

μ: =$C$13

σ: =$C$13*D

tr. min: -Infinity

tr. max: +Infinity

shift: 0

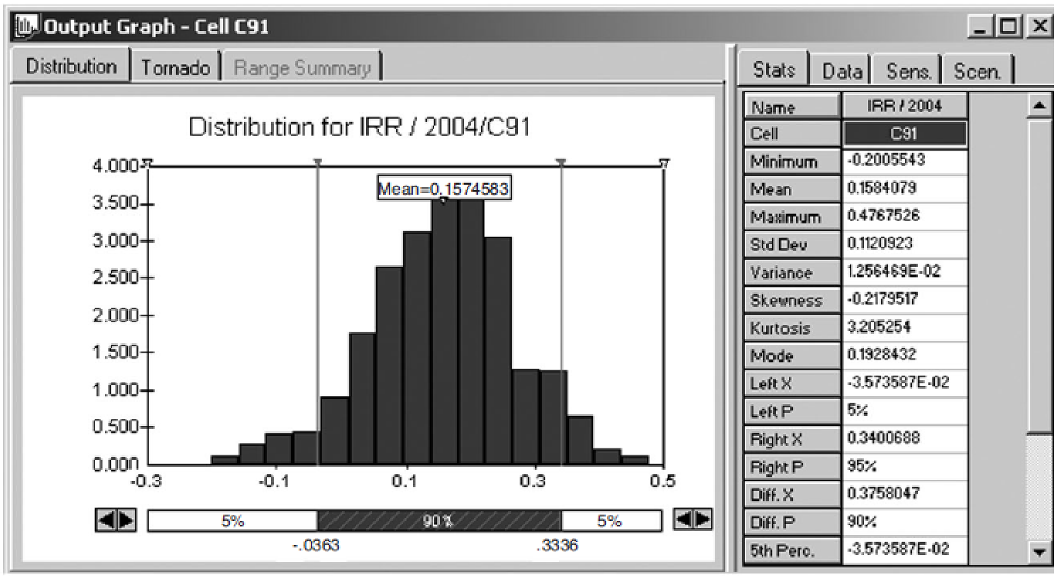
	Normal
Function	=RiskNormal($C:
Minimum	-Infinity
Maximum	+Infinity
Mean	6000.000
Mode	6000.000
Median	6000.000
Std. Dev	60.000
Variance	3600.000
Skewness	0.0000
Kurtosis	3.0000
Left X	5901.3
Left P	5.00%
Right X	6098.7
Right P	95.00%
Diff. X	197.3824
Diff. P	90.00%

Figure 10: Distribution of uncertainty for the tonnes *(Heuberger, 2004).*

Heuberger (2004), further indicated that to run the Monte Carlo simulation the following must apply:

- Select the number of iterations;
- Select the reports that you want to examine; and then
- Run the simulation.

Figure 11 shows the output of the simulation. Showing the internal rate of return of 15.8%, standard deviation of 11.2%, and the graphs also indicate that the internal rate of return lies between 3.5% and 3.4%.



Name	IRR / 2004
Cell	C91
Minimum	-0.2005543
Mean	0.1584079
Maximum	0.4767526
Std Dev	0.1120923
Variance	1.256469E-02
Skewness	-0.2179517
Kurtosis	3.205254
Mode	0.1928432
Left X	-3.573587E-02
Left P	5%
Right X	0.3400688
Right P	95%
Diff. X	0.3758047
Diff. P	90%
5th Perc.	-3.573587E-02

Figure 11: Results of the simulation for the IRR (Heuberger, 2004).

3.4 Chapter Summary

In this chapter, the introduction of the Monte Carlo simulation and the background of the Monte Carlo simulation was discussed. Case studies were discussed. The Fourth chapter introduces the research methodology of the report, qualitative, and quantitative research focusing on the introduction of the ore flow, as well as how Monte Carlo simulation will be used to estimate the uncertainty in volume as well as grade, and then the conclusion of the chapter. This project will use the Monte Carlo simulation software to quantify the apparent losses/gains and the real losses in a narrow tabular precious ore flow, at the Sibanye-Stillwater gold sector.

4 RESEARCH METHODOLOGY

4.1 Introduction

The ore flow balance sheet shows all the sources of metals in a mining operation (Tetteh & Cawood, 2014). 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 & Cawood, 2014). The mine surveyor measures the volume of the broken rock and applies the rock density to calculate the tonnages. Every working place is sampled to determine the grades, which are expressed in grams of metal per tonne of ore. From the ore flow balance sheet, the mine survey discrepancy (shortfall or excess), the mine call factor, and the plant recovery factor are calculated.

Quantitative approach the study will use the mine's data (already available), from Sibanye-Stillwater gold mines and build a distribution for each estimation to be able to use Monte Carlo simulation.

4.2 Quantitative Research

Stope mined area measurements by surveyors were observed and the stope widths by the samplers were observed. A visit was conducted in a working stope area underground with 10 mine surveyors and 10 samplers. The 10 surveyors took offsets in the panel using the survey instrument to determine the face length and face advance and the results were computed but there were different. The mine surveyors spent 2 hours so that they can all take the measurements. The same applied to the 10 samplers who measured the stope widths and the results were computed and the results were different.

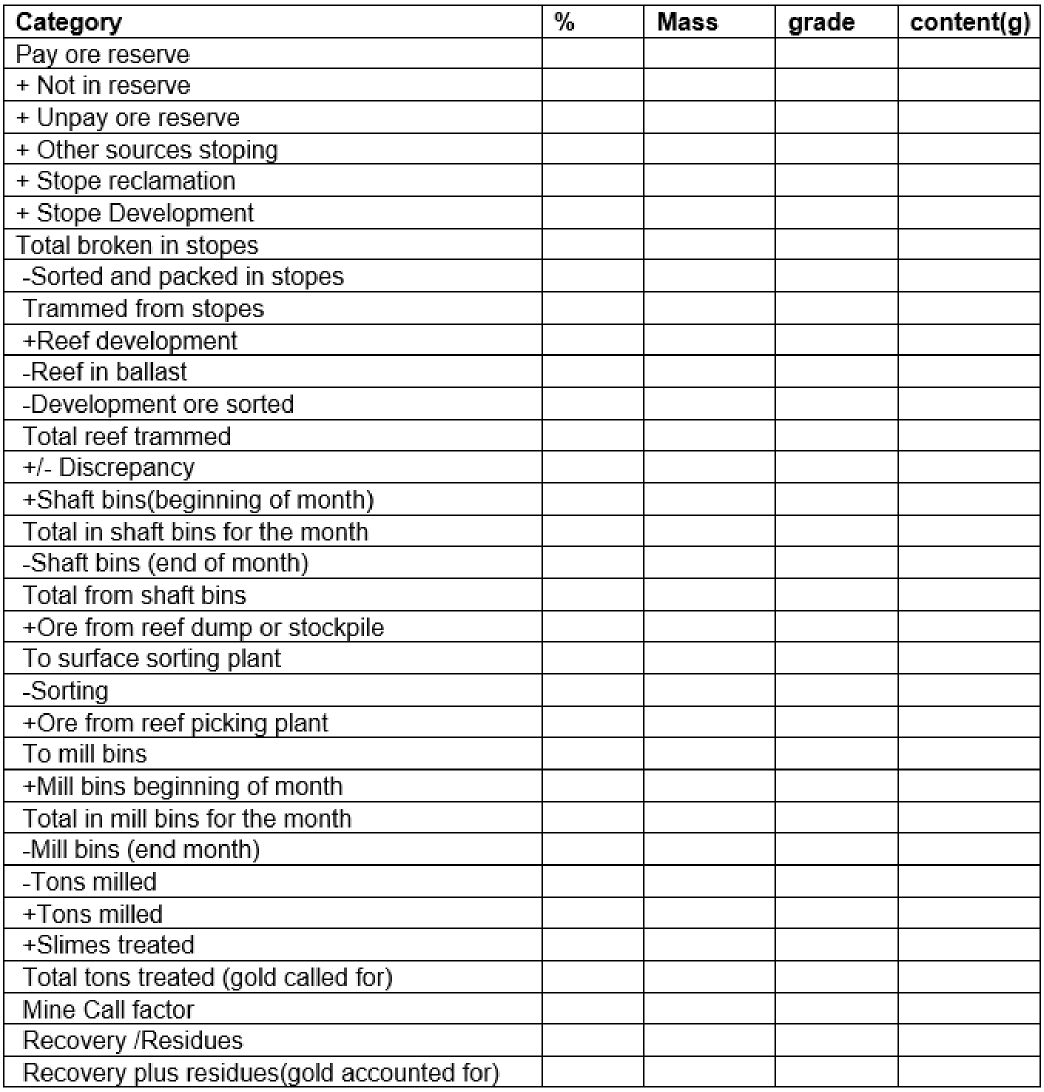
4.3 Qualitative Research

The literature review was conducted to get more understanding of the various components which are contributing to the low MCF. Data required is the ore flow balance sheet indicating the flow of ore from underground to the plant, which includes the stoping widths, the area measured in the working places, rock density, and the grade estimated to calculate the content. Tetteh (2014), has investigated that there are factors, which contribute to the mineral losses, including inaccurate grade control, and significant movements during the blast, poor mining supervision, complicated crushing cycle, inaccurate weight meter readings, and recoveries, poor assay strategy, and residue estimation.

4.3.1 Ore flow balance sheet

The ore flow balance sheet is the tool that is used by gold mining and companies to measure and analyse metal accounting. Ore reserves, ore that is accounted as not in reserves, development appears in the ore flow. The metal tonnes are obtained by multiplying the area measured by the survey department, and the weighted height. The evaluation department on a mine determines the weighted sampled grade, and then tonnes multiplied by grade to determine the metal content. Table VIII indicates the standard ore flow balance sheet for the gold mines operations with the various sources of ore. Recoveries and losses must be accurately recorded (Tetteh, 2014).

Table VIII: Ore Flow Balance Sheet (Cawood, 2012).

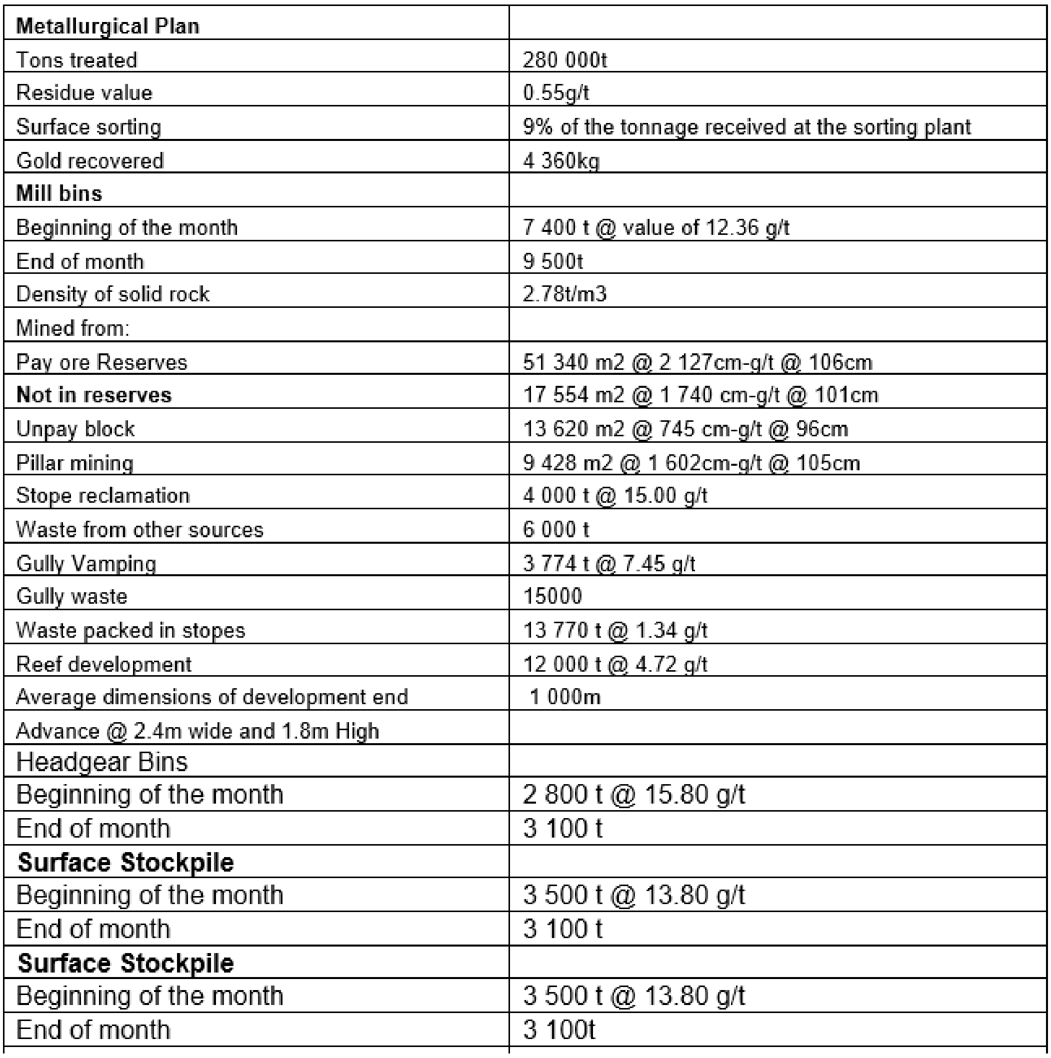


Category	**%**	**Mass**	**grade**	**content(g)**
Pay ore reserve				
+ Not in reserve				
+ Unpay ore reserve				
+ Other sources stoping				
+ Stope reclamation				
+ Stope Development				
Total broken in stopes				
-Sorted and packed in stopes				
Trammed from stopes				
+Reef development				
-Reef in ballast				
-Development ore sorted				
Total reef trammed				
+/- Discrepancy				
+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 month)				
-Tons milled				
+Tons milled				
+Slimes treated				
Total tons treated (gold called for)				
Mine Call factor				
Recovery /Residues				
Recovery plus residues(gold accounted for)				

Table VIII, indicates the standard gold mines ore flow with no information and Table IX indicates the mass and grade figures.

Table IX indicates the application of an ore flow sheet in underground gold mines, and calculation of tonnages, survey discrepancy (excess/shortfall), mine call factor, plant recovery factor.

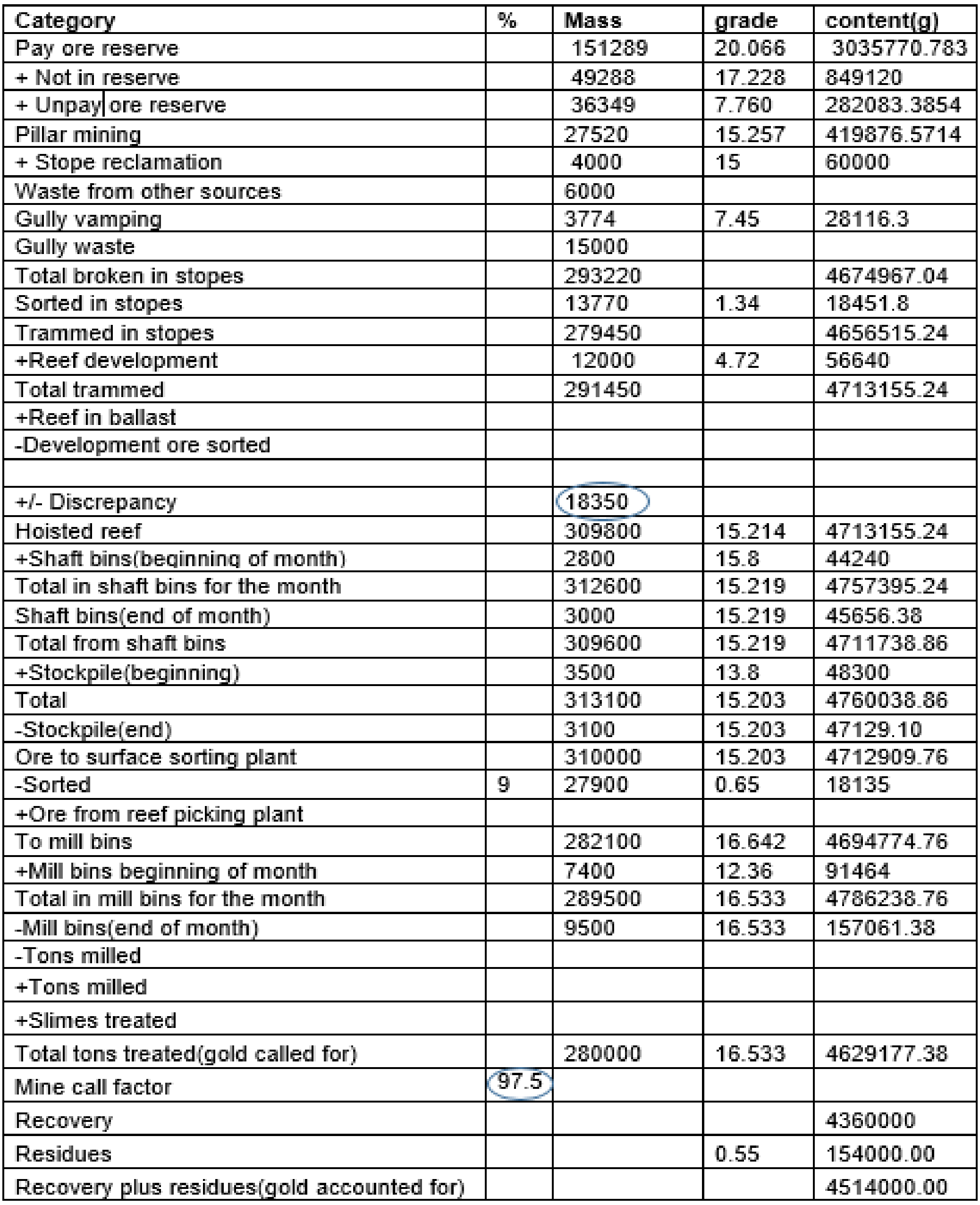
Table IX: Ore Flow Balance Sheet (Cawood, 2012).



Metallurgical Plan	
Tons treated	280 000t
Residue value	0.55g/t
Surface sorting	9% of the tonnage received at the sorting plant
Gold recovered	4 360kg
Mill bins	
Beginning of the month	7 400 t @ value of 12.36 g/t
End of month	9 500t
Density of solid rock	2.78t/m3
Mined from:	
Pay ore Reserves	51 340 m2 @ 2 127cm-g/t @ 106cm
Not in reserves	17 554 m2 @ 1 740 cm-g/t @ 101cm
Unpay block	13 620 m2 @ 745 cm-g/t @ 96cm
Pillar mining	9 428 m2 @ 1 602cm-g/t @ 105cm
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 development	12 000 t @ 4.72 g/t
Average dimensions of development end	1 000m
Advance @ 2.4m wide and 1.8m High	
Headgear 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 100t

Table X indicates that there is a survey shortfall of 18350t, MCF of 97.5% and plant recovery factor of 96.6% are calculated.

Table X: Ore Flow Balance Sheet Source (Cawood, 2012)



Category	%	Mass	grade	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 reclamation		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 in stopes		279450		4656515.24
+Reef development		12000	4.72	56640
Total trammed		291450		4713155.24
+Reef in ballast				
-Development ore sorted				
+/- Discrepancy		18350		
Hoisted 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

Table X shows that the grade for pay ore reserves in the stope is 20.066g/t but the recovered grade at the plant is 16.533g/t. This is due to the losses, either real or apparent losses.

Typically, an ore balance sheet shows the budget numbers and the actual numbers (Storrar, 1981). The survey department measures mined-out area and volume and multiplies the volume by the standard rock density to determine the tonnages excavated. The sampling department samples all the active mining areas to determine the weighted average grade, which is expressed in grams of metal per tonne of ore (Tetteh, 2014). The weighted grade is multiplied by the tonnage to convert the tonnages to the content of the metal mined. The tonnage trammed and hoisted in the mine is measured using the weightometer. The weightometer is a device underneath the conveyor belt, which is used to measure for continuous mass determination (Spangenberg, 2012). Figure 12, shows the weightometer

Figure 12: Weightometer (Sibanye-Stillwater, 2019).

Tonnage discrepancy can be classified as shortfall/excess. Excess is when the tonnages called for by the survey department are greater than the tonnages accounted for at the plant. Excess can be as a result of:

- Overmeasuring of stope areas and widths;
- Incorrect use of rock density;
- Sweepings not done to standard or ore left underground; and

- Incorrect readings of the weightometer.

Shortfalls are usually assigned to zero metal content (Storrar, 1981). Storrar (1981), stipulated the reasons for the survey shortfall during the investigation undertaken to understand the causes of low MCF:

- Under measuring of stope areas and widths;
- Using incorrect especially low rock densities for tonnages calculations;
- Allowances of sag and scaling of walls of excavations of headings;
- The tearing up of footwalls by scrapers;
- The measuring of cross-sectional areas of headings; and
- Estimation of waste packed under surface sorting spillage in drains.

Surface mines, survey shortfalls is as a result of:

- Underestimation of dilution; and
- Not recording losses at production areas, temporary stockpiles, and incorrect use of rock densities.

4.3.2 AMIRA P754 Code

The AMIRA P754 code was developed to enhance the transparency and audibility of the metal accounting process and for the promotion of good corporate governance (Gaylard et al 2009). Tetteh (2014), indicated that the AMIRA code was developed similar to the SAMREC Code (For reporting of exploration results, mineral resources, and mineral reserves) for metal accounting and reconciliation. The AMIRA code prescribes the best practices and standards for sampling, mass measurements, sample preparations and analysis, data management, and metal balancing (Tetteh, 2014). Figure 13 shows the structure with the ten guiding principles of the AMIRA code.

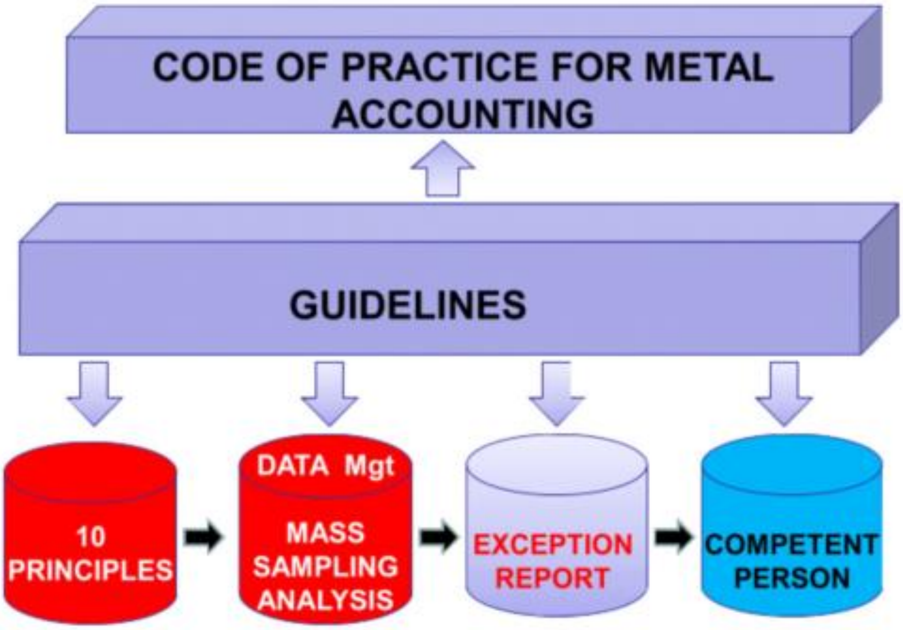


Figure 13: Structure of AMIRA Code, (Gaylard et al, 2009).

Tetteh (2014), discussed the 10 guiding principles for reporting as follows:

- The accounting system must be based on accurate and precise measurements of mass and metal content and the system must be a full "check in –check out" system using the best practice in the code;
- The source of all input into the system must be clear, transparent, and understood by all users of the system. The design of the system must incorporate the outcomes of a risk assessment of all aspects of the process of metal accounting;
- The procedure for an accounting must be well documented and user friendly for easy application by plant personnel and avoid the system from becoming one person dependent;
- "There should be regular internal and external audits and reviews of the system to ensure compliance with all aspects of laid down procedure;
- To meet operational needs, accounting result must be made in time to facilitate corrective action or investigation;

- When provisional data is used to meet reporting deadlines such as month ends, clear procedures and levels of authorization for replacement with provisional data should be laid down;
- There must be sufficient data generated to allow for data verification, handling of metal;
- The expected precision levels for metal recoveries, based on raw data, over a reporting period should be stated in the company's report to the audit committee; and
- In-process inventory figures should be verified by stock takes at defined intervals (Tetteh, 2014).

The research will apply the Monte Carlo simulation to identify whether it is an apparent gain/loss or real loss, hence after identifying the cause of low MCF then measures will be put in place to improve the company's MCF. The research will use the ore flow balance sheet available from the mine, for 12 month period and build the distribution for each estimation to be able to use Monte Carlo simulation. Monte Carlo simulation is a technique used to understand the impact of uncertainty and risk. This is done for Kloof, Driefontein and Beatrix mines.

The ore flow balance sheet shows all the sources of metals in mining operations (Tetteh & Cawood, 2014). 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 & Cawood 2014). The mine surveyor measures the volume of the broken rock and applies the rock density to calculate the tonnages. Every working place is sampled to determine the grades, which are expressed in grams of metal per tonne of ore. From the ore flow balance sheet, the mine survey discrepancy (shortfall or excess), the mine call factor, and the plant recovery factor are calculated.

4.4 Chapter Summary

In this chapter, the introduction of the ore balance sheet was discussed, the research methodology of the report, qualitative and quantitative research focusing on the introduction of the ore flow, as well as how Monte Carlo simulation will be applied in the ore flow to determine the uncertainty. The next chapter will be focusing on analysing ore flow to identify the % tonnage and % grade gain or loss. Sources of tonnages gains or loss, sources of grade gains or losses will be discussed.

5 TONNAGE OR GRADE GAIN/LOSS

5.1 Introduction

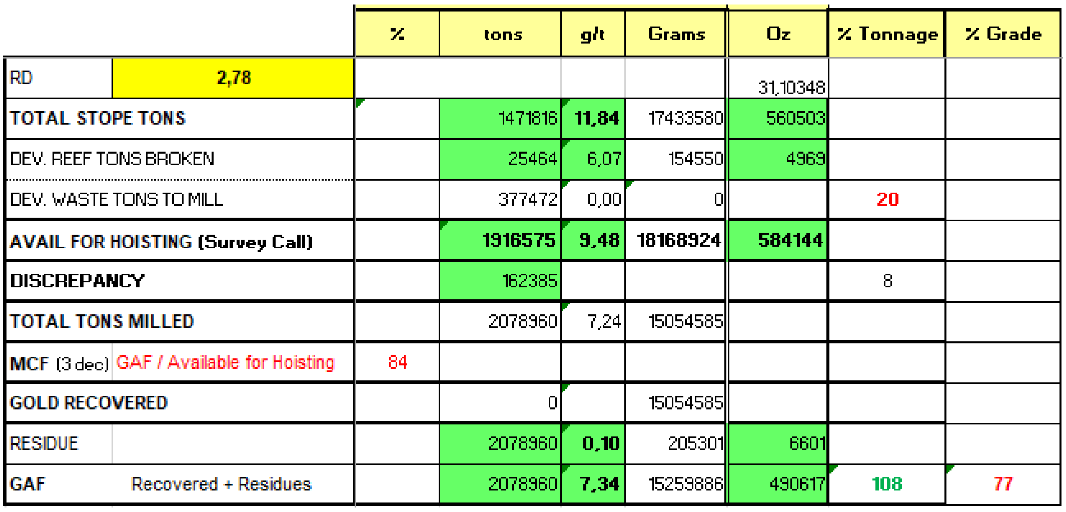
This chapter assesses the mining value chain at Sibanye-Stillwater, at the gold operations, to identify whether it is a tonnage, grade gain/loss that impacts the MCF. Possible causes of tonnage, grade gain/loss includes grade control, tonnage measurements, sampling, quality assurance and quality control, and evaluation. A summary of the analysis of the ore flow, to identify percentage grade gain/loss and percentage tonnage gain/loss is presented for all Sibanye-Stillwater gold operations.

5.2 Analysis of the Ore Flow Balance Sheet

5.2.1 Kloof Mine

The summary of the Kloof operations indicating the ore flow analysis for the 12 months, 2017, to determine percentage tonnage and grade losses is shown in Table XI**.**

Table XI: Kloof Mine 2017 Ore flow (Sibanye-Stillwater, 2017).



		%	tons	g/t	Grams	Oz	% Tonnage	% Grade
RD	2,78					31,10348		
TOTAL STOPE TONS			1471816	**11,84**	17433580	560503		
DEV. REEF TONS BROKEN			25464	6,07	154550	4969		
DEV. WASTE TONS TO MILL			377472	0,00	0		**20**	
AVAIL FOR HOISTING (Survey Call)			**1916575**	**9,48**	**18168924**	**584144**		
DISCREPANCY			162385				8	
TOTAL TONS MILLED			2078960	7,24	15054585			
MCF (3 dec)	GAF / Available for Hoisting	84						
GOLD RECOVERED			0		15054585			
RESIDUE			2078960	**0,10**	205301	6601		
GAF	Recovered + Residues		2078960	**7,34**	15259886	490617	**108**	**77**

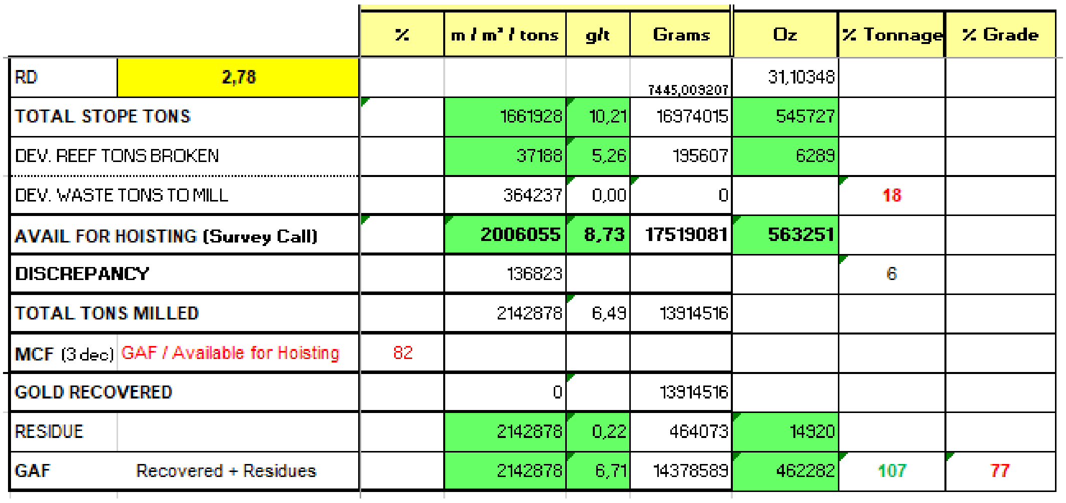
The following are the main points from the ore flow analysis:

- The tonnes broken from stopes is 1471816t @ 11.84 g/t Au (560503 ounces) and the on reef development for the period under review is 25464 t @ 6.07g/t Au (4969 ounces);
- Waste to mill amounts to 20% of the tonnage called for by the survey department;
- The gold called for is 1916575t @ 9.48 g/t Au (584144 ounces);
- Survey shortfall of 162385t, which is 8% of milled tonnes;
- The gold accounted for is 2078960 t @ 7.34g/t Au (490617 ounces);
- The percentage tonnage gain is 8%;
- The percentage grade loss 23%;
- Residue grade 0.10gt Au (6601 Ounces); and
- MCF is 84%.

5.2.2 Driefontein Mine

The summary of the Driefontein operations indicating the ore flow analysis for the 12 months, 2017, to determine percentage tonnage and grade losses is shown in Table XII**.**

Table XII: Driefontein Mine 2017 Ore Flow (Sibanye-Stillwater, 2017).



		%	m / m² / tons	g/t	Grams	Oz	% Tonnage	% Grade
RD	2,78				7445,003207	31,10348		
TOTAL STOPE TONS			1661928	10,21	16974015	545727		
DEV. REEF TONS BROKEN			37188	5,26	195607	6289		
DEV. WASTE TONS TO MILL			364237	0,00	0		18	
AVAIL FOR HOISTING (Survey Call)			**2006055**	**8,73**	**17519081**	**563251**		
DISCREPANCY			136823				6	
TOTAL TONS MILLED			2142878	6,49	13914516			
MCF (3 dec)	GAF / Available for Hoisting	82						
GOLD RECOVERED			0		13914516			
RESIDUE			2142878	0,22	464073	14920		
GAF	Recovered + Residues		2142878	6,71	14378589	462282	107	77

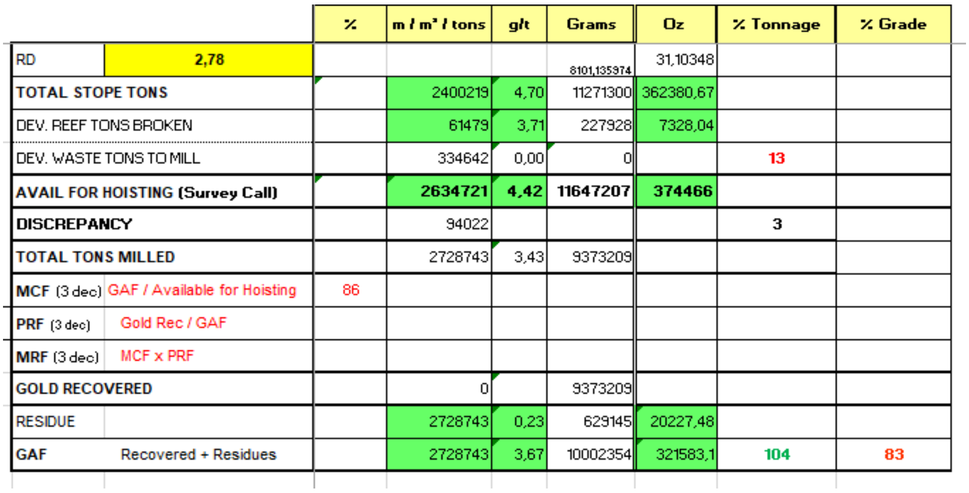
The following are the main points from the ore flow analysis:

- The tonnes broken from stopes is 1661928t @ 10.21 g/t Au (545727 ounces) and the on reef development for the period under review is 37188 t @ 5.26 g/t Au (6289 ounces);
- Waste to mill amounts to 18% of the tonnage called for by the survey department;
- The gold called for is 2006055t @ 8.73 g/t Au (563251 ounces);
- Survey shortfall of 136823t, which is 6% of milled tonnes;
- The gold accounted for is 2142878 t @ 6.71g/t Au (462283 ounces);
- The percentage tonnage gain is 7%;
- The percentage grade loss 23%;
- Residue grade 0.22gt Au (14920 Ounces); and
- MCF is 82%.

5.2.3 Beatrix Mine

The summary of the Beatrix operations indicating the ore flow analysis for the 12 months, 2017, to determine percentage tonnage and grade losses is shown in Table XIII.

Table XIII: Beatrix Mine 2017 Ore Flow (Sibanye-Stillwater, 2017).



		%	m / m^2 / tons	g/t	Grams	Oz	% Tonnage	% Grade
RD	**2,78**				8101,135974	31,10348		
TOTAL STOPE TONS			2400219	4,70	11271300	362380,67		
DEV. REEF TONS BROKEN			61479	3,71	227928	7328,04		
DEV. WASTE TONS TO MILL			334642	0,00	0		**13**	
AVAIL FOR HOISTING (Survey Call)			**2634721**	**4,42**	**11647207**	**374466**		
DISCREPANCY			94022				**3**	
TOTAL TONS MILLED			2728743	3,43	9373209			
MCF (3 dec)	GAF / Available for Hoisting	86						
PRF (3 dec)	Gold Rec / GAF							
MRF (3 dec)	MCF x PRF							
GOLD RECOVERED			0		9373209			
RESIDUE			2728743	0,23	629145	20227,48		
GAF	Recovered + Residues		2728743	3,67	10002354	321583,1	**104**	**83**

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

- The tonnes broken from stopes is 2400219t @ 4.7g/t Au (362381 ounces) and the on reef development for the period under review is 61479 t @ 3.71g/t Au (7328 ounces);
- Waste to mill amounts to 13% of the tonnage called for by the survey department;
- The gold called for is 2634721t @ 4.42 g/t Au (374466 ounces);
- Survey shortfall of 94022t, which is 3% of milled tonnes;
- The gold accounted for is 2728743 t @ 3.67g/t Au (321583 ounces);
- The percentage tonnage gain is 4 %;
- The percentage grade loss 17 %;
- Residue grade 0.23gt Au (6601 Ounces), and
- MCF is 86%.

5.3 Sources of Tonnage Gains/losses

5.3.1 Stoping width control

Higher stoping width than the business plan stoping widths increases the dilution and will result in more tonnage mined in the stopes. Anderson (1999), indicated that reduction in stope widths by reducing the dilution, could result in higher grade sent to the plant, and less tonnage sent, but maximizing the profits.

5.3.2 Gully tonnage determination

Anderson (1999), indicated that the gully tons at the gold mines are determined by the standard height and width, 2.0m x 1.8m, and standard density of 2.8 t/m^3, or 10 tons per advance. Several underground visits were conducted and it was found that the gully dimensions were found not to be on standard dimensions. He further recommended that physical measurements in gullies should be measured on measuring date. Overestimations of an area in the gullies will inflate the actual tons broken.

5.3.3 Underground tonnage lock-up

Current broken tons left underground influence the MCF negatively, as the broken ore is called for but not removed and send to the plant. Most of the current ore broken is left on the north sides and south sides of the panels. The clean mine concept is essential for the current broken ore to be removed from current panels to the plant. Sweepings are paramount and when continuously done will support the MCF in maintaining (Anderson, 1999).

5.3.4 Tramming

Anderson (1999), indicated that bottlenecks in the tramming operations are a result of rails conditions and excessive spillage. Derailments are a major issue in tonnage loss, as the ore blasted is split into the haulages and crosscuts due to the state of rails and tracks.

5.3.5 Cross tramming

Waste to reef and reef to waste is a major problem in most mines due to infrastructure and tramming discipline. It is important to tram the waste tons broken from haulages and cross cuts to the waste tip and hoist it to the waste dump. A sampling of waste dumps and hoisted tons is essential as this will indicate if there is any reef to waste, or waste to the reef during hoisting.

5.3.6 Blasting barricades

The use of the sweepings barrier on conventional breast mining stoping panels is important. The sweeping barrier is to be maintained at a position not exceeding 9.0m from the working face on the measuring date. The broken ore is spread over a wide area in open stopes if the sweepings barrier is not installed, which will lead to tonnage loss. In some areas, the blasted ore is lost in inaccessible to lashing.

5.3.7 Specific gravity

A standard specific gravity of $2.8t/m^3$ is currently accepted at the gold mines. Inaccurate estimation of specific gravity will results in inflating the estimated tons during estimation processes, ultimately gold can be overcalled and this contributes to the apparent gold loss.

5.3.8 Weightometer measurements

Incorrect weightometer measurements during tramming and hoisting will result in inflating the ore trammed and hoisted, which may either be survey shortfall or excess. Accuracy and precision in the tramming and hoisting processes are paramount, calibrations of the weightometer will help to reduce the inaccurate tons measured and improves the MCF.

5.4 Sources of Grade Gains/Loss

5.4.1 Waste to reef tipping

Waste to reef tipping leads to dilution, and this results in gold accounted for being less than the gold called for.

5.4.2 Drilling water

Drilling water in the gold operations is a major challenge because water sweeps away the fines in the stopes and the reef drives. The fines are deposited as mud in the drains. The fines consist of high gold values and turn into mud when they are watered (De Jager, 1997).

5.4.3 Shaft spillage

Shaft spillage is normally not recovered and it consists of high values of gold which results in gold loss, ultimately this will result in grade loss.

5.4.4 Footwall cracks

Footwall cracks in the gold mines can result in gold loss, ultimately grade loss, due to small particle size, the fines can easily enter the cracks in the footwall (De Jager, 1997).

5.4.5 Sweepings control

Sweepings in a stope refers to the removal of finely divided ore in which it is believed much of the richest portion of the ore is found (De Jager, 1997). Anderson (1999), indicated that sweepings play a role in a support of an MCF when they are continuously done. Sweepings left underground as fine particles, affect the grade negatively. Fines are likely to be lost during any part of the mining process and with a great chance of happening in the stopes (De Jager, 1997).

5.4.6 Sampling

Gold estimation contained in the ore mined affects the accuracy of grade loss in the mine. Individual samples are chipped from stopes and development working faces using a hammer and chisel (Sibanye-Stillwater, 2019). A detailed sampling record is kept indicating the reef geometry for each section sampled (Sibanye-Stillwater, 2019).

5.4.7 Unplanned dilution

Unplanned dilution leads to apparent gold loss. Geological structures, i.e. dykes and faults in the stopes contribute to a grade loss. Unplanned over-breaking of footwall and hanging wall also contributes to the loss of grade.

5.5 Chapter Summary

The ore flow analysis for the period 2017 indicates that Kloof mines have a grade loss of 23% and tonnage gain of 8%, with the survey shortfall of +8%.

Development waste to mill contributed 20% of the called for tonnes. The MCF averaged 84%. Driefontein mines, show the loss of grade of 23%, tonnage gain of 7%, with the survey shortfall of +6%. Development waste to mill contributed 18% of the called for tonnes. The MCF is averaged at 82%. Beatrix mines show a grade loss of 17%, tonnage gain of 4%, with a survey shortfall of 3%. Development waste to mill contributed 13% of the called for tonnes at zero grade. The MCF averaged 86% for the period under review.

Sibanye-Stillwater gold mines operations averaged the grade loss of 21%, tonnage gain of 6.3%, with a survey shortfall of +5.6%. Development waste to mill contributed 17% of the called for tonnes, and this contributed to the loss of grade. The MCF averaged 84%. The high gold values are lost due to the loss of fines. Some fines are lost in the footwall cracks. Unplanned dilution contributes to a loss of grade. In conclusion, the main loss at Sibanye-Stillwater is grade rather than tonnage. The next chapter will cover the introduction of apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss, and real grade loss. Overall there’s more confidence in how the mass measurements are done as compared to the grade however, there is still uncertainty. Both waste development to mill and survey shortfall which contributed 17% and +5.6%, respectively all contributed to the grade loss.

6 APPARENT GAIN/LOSS OR REAL LOSS

This chapter focuses on the apparent tonnage gain/loss, apparent grade gain/loss, real tonnage, and real grade loss along the mining value chain at Sibanye-Stillwater gold mines.

6.1 Apparent Tonnage Gain/Loss

During the month, the survey department measures underground excavations. Surveyors use theodolites to measure the mined-out areas, offsets are taken in the panels using the fixed survey pegs. Face lengths and face advances are determined during the measuring period by the surveyors, weighted stope widths measurements observed during the month are multiplied by the area measured to determine the volume. A standard rock density of 2.78 t/m³ is applied to the volume measured to determine the tonnages mined. The weighted sampled grade is multiplied by the tonnages mined to convert tonnages to metal contents. Metal contents are converted to ounces by dividing by a factor of 31.10348.

Kloof mine survey shortfall is +8%, Driefontein mine is +6%, and Beatrix mine averaged the survey shortfall of 3% for the year 2017. Sibanye-Stillwater gold mines operation averaged the tonnage gain of +6.3%. Tonnage discrepancies are a result of large parts of waste trammed as reefs (Tetteh, 2014). Ore left in the plant for long also increases the tonnages accounted for but reducing the metal content. Incorrect reading of weightometer also is a factor of apparent gain/loss. Apparent tonnage loss is attributed to overstated measurements.

6.2 Apparent Grade Loss

Kloof mine waste to mill amounts to 20% of the tonnages called for, Driefontein mine waste to mill amounts to 18% of the tonnages called for, and Beatrix mine waste to mill amounts to 13% of the tonnages called for.

This affects the metal content, hence the low MCF. Undetected dilution also plays a major role in affecting the MCF negatively.

6.2.1 Sampling

The main objective of sampling is to obtain unbiased results and be more representative of samples. Apparent grade loss can be a result of the overestimation method and the apparent grade loss is the major contributor to the low MCF. Sampling plays a role in the estimation of the gold contained in the ore mined. Sibanye-Stillwater gold mines' operations have drafted and employed a set of procedures and standards that need to be followed and maintained during the collection of underground data (Sibanye-Stillwater, 2019). The standards and procedures cover chip sampling, grade control, and metal accounting. Channels are perpendicular to the plane of the reef. Samples taken underground are in a region of 300g to 500g. Stoping and development channel samples are 5m and 3m respectively (Sibanye-Stillwater, 2019).

Channel samples are chipped by using a chisel and a hammer for evaluation purposes and bagged into the plastics and send to the laboratory for assay of the grade. Sample sections are captured into the mines database. Sibanye-Stillwater relies on in-house assay laboratories (Sibanye-Stillwater, 2019).

According to Rose & Fahey (2014, pg 680), it is important to establish a sampling method which "produces representation samples within the constraints of the mining schedule". They further indicated that there are two sorts of sampling, namely predictive and checking "predictive sampling is to confirm that areas of resource model before mining to ensure that the grade of the area is estimated to an acceptable level of confidence and checking sampling is used to confirm that the right mining decision has been made". Contamination poses a risk of overestimating the grade in the metal, which results in apparent grade loss. The current grade estimation is suitable for Sibanye-Stillwater gold operations.

6.2.2 Quality Assurance and quality control (QA/QC)

Tetteh (2014), indicated that quality assurance and quality controls involve inserting quality control samples in the batches of grade control samples. Tetteh (2014), outlined the quality assurance and quality control protocols implementation include:

- Duplicates to check the quality of sample splitting and the laboratory's precision;
- Standards to check the accuracy of the analytical laboratory;
- Retrieved pulps to check on the precision of the laboratory; and
- Blanks to check on how efficiently equipment is cleaned at the laboratory and also used to identify mixed sample numbers.

6.2.3 Interpolation of grade

Based on the structural and geological models, the resource is sub-divided into various geodomains (Sibanye-Stillwater, 2019). The main interpolation method employed at Sibanye-Stillwater is ordinary, simple kriging, and macro kriging. Checks are conducted for the comparison between kriged block estimates and domain declustered means and regularised data (Sibanye-Stillwater, 2019).

6.3 Real Tonnage Loss

Common contributing factors to real tonnage loss are derailments, lack of blasting barricades, spillages and leakages in the plant, and spillage in the shaft. Sibanye-Stillwater gold operations do not experience a real tonnage loss, the major challenge is the grade loss. In the year 2020, the survey shortfall was 8.0%. Sweepings must be done concurrently with the blasted faces to minimize the real tonnage loss.

6.4 Real Grade Loss

The major issue for the Sibanye-Stillwater gold operations is the grade loss. The major issues which result in the real grade loss are over fragmentation, drilling water, and handling of broken ore from the face to the processing plant. The high-grade gold values blasted in the stopes are not recovered and this gives rise to real grade loss. The water which is used to reduce the dust in the stopes washes away the fine particles and deposits them as mud in the drains. Fine particles are lost in the footwall cracks in the stoping and development areas. The loss of gold in the footwall cracks contributes to real grade loss.

6.5 Plant Process

This section will cover the Sibanye-Stillwater gold mines metallurgical and processing associated. Sibanye-Stillwater gold has seven plants in operation, (Sibanye-Stillwater, 2019). All the plants treat the underground ore, and comprise three-stage, crushing, and two-stage milling using the open circuit rod mills for primary milling and closed pebble mills for secondary milling (Sibanye-Stillwater, 2019). After milling the pulp is thickened and air agitated in cyanide leaching tanks (Sibanye-Stillwater, 2019). Milled tonnes are sampled in the plant to determine the build-up head grade. The average residue grade for the 2017 period averages at 0.19g/t. The plant recovery factor of 98.7%.

6.5.1 Gold accounted for

Gold accounted for is the function of the processing plant, for reporting mass measurements, sampling, sample preparation, and analysis. Gold accounted for is the recovery plus residue. Mass measurements are done to determine the mass of the particular material received at the plant at a specific time (Sibanye-Stillwater, 2018). Mass measurements at the processing plant are done by an electromechanical weightometer. A correct sampling of gold ore in a plant is done during the milling process using a mechanical sampler. A sampling of stockpiles is performed to determine the gold values.

Sibanye-Stillwater's gold operations created the code of practice for metal accounting. Gold accounting principles are summarised below:

- It provides an opportunity to ensure that all gold is accounted for as soon as the ore reaches the processing plant;
- The accounting system is transparent and consistent; and
- Accounting procedures to be well documented for auditing purposes. (Sibanye-Stillwater, 2018).

6.5.2 Sample Preparations

Moisture refers to water that can be removed from the sample, by drying the sample to temperatures of up to 105 degrees Celcius (Sibanye-Stillwater, 2018). Moisture determination must be carried out as soon as the sample has been taken (Sibanye-Stillwater, 2018). Stockpile sampling is a challenge because unless if the material in the stockpile is homogenous, there is uncertainty in how the stockpiles are sampled (Sibanye-Stillwatere, 2018). The run of mine ore sampling is done by the automatic cross-stream samplers, the sampler takes the ore from the belt. The storage of samples is stored in a suitable sealed container, and they are also labelled. Slurry sampling is determined after milling the ore, in a form of the pulp as a cyclone overflow (Sibanye-Stillwater, 2018).

Metal balancing is critical, in ensuring that the ore is measured, sampled, and analysed, using the check-in check-out system (Sibanye-Stillwater, 2018). The application of the check-in check-out system shows the difference between input and output, as a result of measurements, sampling, and analytical uncertainties (Sibanye-Stillwater, 2018). Residue grade represents the gold value of pulp leaving the gold extraction in the processing plant, the value is measured by regular sampling of the pulp stream before being pumped into the slimes dam (Sibanye-Stillwater, 2018). Gold recovered is the gold recovered in the extraction section of the plant over an accounting production month, minus residue. (Sibanye-Stillwater, 2018). Plant recovery factor is a ratio expressed as a percentage which is the product accounted for in-plant feed, to the specific product calculated from the belt sampling (Sibanye-Stillwater, 2018). The process of determining the gold called for is the same across the gold segment.

6.6 Chapter Summary

This chapter covered the apparent tonnage gain/loss, apparent grade gain/loss, real tonnage loss, and real grade loss. The apparent tonnage gain is 6.3% with the average survey shortfall of +5.6% for the year under review. The apparent tonnage loss is insignificant in this case. The main contributors to apparent tonnage loss are mainly, overstated specific gravity, and inaccurate weightometer. Real tonnage loss is insignificant, but the main contributors are lack of blasting barricades, spillage during tramming, and leaks in the plant.

The key driver for the low MCF is the apparent grade loss, with the main contributing factors such as estimation methods, and the mine plans are based on higher grades that are not even there in the first place. The real grade loss is due to real losses of fines during blasting. High-grade fines are lost in the footwall cracks in the stopes, drilling water washes away the fine particles into the drain, and as a result, they become mud. In conclusion, both apparent grade and real grade loss occur and they are significant as the MCF for the three mines combined is 84% for the year under review.

7 MONTE CARLO SIMULATION

7.1 Introduction

This chapter focuses on the introduction of Monte Carlo simulation, methodology for establishing distributions. Monte Carlo analysis of the ore flow, estimation of uncertainty in the Survey called for volume, and Survey called for grade, and also conclusion leading to the next chapter. The sequence of analysing the ore flow will be Kloof, Driefontein, and Beatrix mines. Due to the measurement uncertainties used to determine the metal called for in the MCF calculation, these uncertainties could then be used in a Monte Carlo simulation to estimate the range of the MCF and thus estimate the real and apparent loss split. The Monte Carlo simulation is preferable only if there are several sources of uncertainty.

7.2 Methodology for Establishing Distributions

7.2.1 Stoping area

Area mined is simply the face length (FL) worked multiplied by face advance (FA) (Anderson, 1999). The normal distribution is used when applying the Monte Carlo simulation. The formula for the grade and volume takes into account the standard deviation, the mean which is the start value before simulating, and the model was run 10 000 to get the best estimate of all the numbers in the ore flow balance sheet, as well as the probable ranges.

Table XIV: Area measured by surveyors.

Surveyor	Area Measured (m²)	Mean	Standard Deviation	Uncertanity
1	214	216	2,37	0,75
2	215			
3	217			
4	216			
5	219			
6	210			
7	215			
8	217			
9	215			
10	218			

The research used an excel spreadsheet to calculate the mean, standard deviation, and uncertainty. The following formulas were applied to calculate the mean, standard deviation, and uncertainty:

- =Average(214:218);
- =STDEV.P(214:218); and
- =2.37/SQRT(COUNT(214:218))

The following formula was applied in the ore flow using Monte Carlo simulation software for the Sibanye-Stillwater gold operations ore flows for 2017:

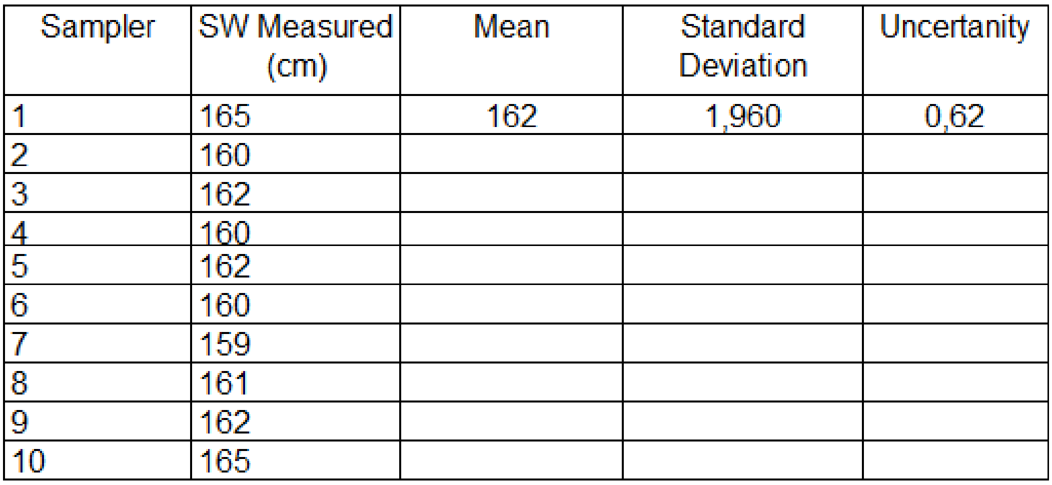
- Stoping Width (SW) =Risknormal () + (SW, SD*SW, Riskstatic (SW)),

Sibanye-Stillwater gold operations use the same methodology to calculate the area measured.

7.2.2 Stoping width

Stoping width refers to the final average actual weighted width of the excavation made during stoping operations. Table XV shows the results of the stoping widths measured in one panel by ten samplers and the mean stoping width is 162cm, with a standard deviation of 1.90cm and uncertainty of 0.62cm. Clinorulers and ten meters tape were used to measure the stoping width, at the interval of 3m apart on the dip of the reef. A clinoruler is put 90 degrees on the face of the panel to the dip of the reef.

Table XV: Stoping Width measured samplers.



Sampler	SW Measured (cm)	Mean	Standard Deviation	Uncertanity
1	165	162	1,960	0,62
2	160			
3	162			
4	160			
5	162			
6	160			
7	159			
8	161			
9	162			
10	165			

7.2.3 Tonnage measurements

The formula for the tonnage calculation is simply face length (FL) worked multiplied by face advance(FA), multiplied by the weighted stope width for the month over 100, and multiplied by the relative density t/m³. Relative density varies from one rock type to another, however, it is a result of many experiments done, Anderson (1999). Tonnages can either be off or on-reef.

Tonnages are off reef when the geological structure like potholes or dykes are intercepted in the area mined.

The following formula was applied in the ore flow using Monte Carlo simulation software:

- Tonnages=Risknormal () + (t, SD*t, Riskstatic (t)).

7.2.4 Stope reef tonnes

Stope reef tonnes refers to the total dry tonnes broken on the reef plane during stoping operations as measured by the survey department (Sibanye-Stillwater, 2018). Stope reef tonnes is the total of on reef tonnes and off-reef tonnes, the off-reef tonnes are also trammed to the mill.

7.2.5 Dykes, cubics and fault measurements

Dykes and faults square meters are determined by measuring the length and the throw of the geological features, by the survey department. The square meters and tonnes are recorded in the ore flow balance sheet.

7.2.6 Development tonnes

Development tonnes refers to the dry tonnes broken on the reef plane in reef development (Sibanye-Stillwater, 2018). The survey department measures the development, both on-reef or off-reef. Off-reef refers to totally off reef development done on the reef horizon. Mine surveyors use pegs and tapes underground to measure the linear meters blasted in the excavation. They also measure the width and the height of the excavation. Volume is determined by simply multiplying the linear meters measured, by the height and the width of the excavation. Tonnages are calculated by multiplying the volume by the rock density.

7.2.7 Total ore trammed

Total ore trammed from stopes is the sum of total stope tons and the reef development tonnes.

7.2.8 Vamping old gold

Vamping is the process of final clean-up of broken ore in the gullies and stopes. The vamping of old gold is measured by the evaluation department, estimates are done on the ore left underground. The area where there is ore is measured and the thickness.

7.2.9 Stope and development grades

Gold values generally follow a lognormal distribution. Sampling on regular grid spacing in the direction of mining is essential. Sampling is done in the working areas and samples are taken to the laboratory to determine the gold values, and the kriging software is used in the areas sampled. The kriged estimate is used for the evaluation of the working place to determine the best-estimated grade. The evaluation of working places is done using the latest kriged grid during the time of measuring.

7.2.10 Survey called for

Survey called for tonnes and grades are the measured figures from the survey department. Survey called for is the sum of all the reef sources underground. An ore balance sheet is done every month after measuring, applying the metal accounting standard of Sibanye-Stillwater.

7.2.11 Tonnage discrepancy

Tonnage discrepancy is the difference between the survey called for tonnes or the measured and the tonnes delivered to the concentrator. The survey discrepancy is either shortfall (+) or excess (-).

7.2.12 Total tonnes hoisted

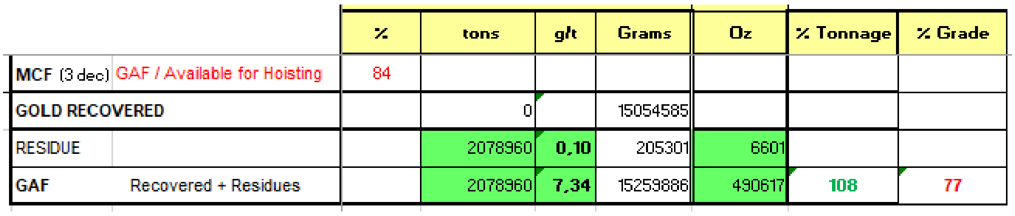
Total tonnes hoisted is the sum of the survey called for tonnes plus or minus survey discrepancy. The ore is hoisted by skips and the skip is automated, every time the skip loads the ore the control room is notified of the tonnages hoisted from the loading box.

7.3 Monte Carlo Analysis

7.3.1 Kloof Mine

The original ore flow indicated that the MCF is 84% as calculated and declared in Table XVI.

Table XVI: Kloof Mine MCF (Sibanye-Stillwater, 2018).

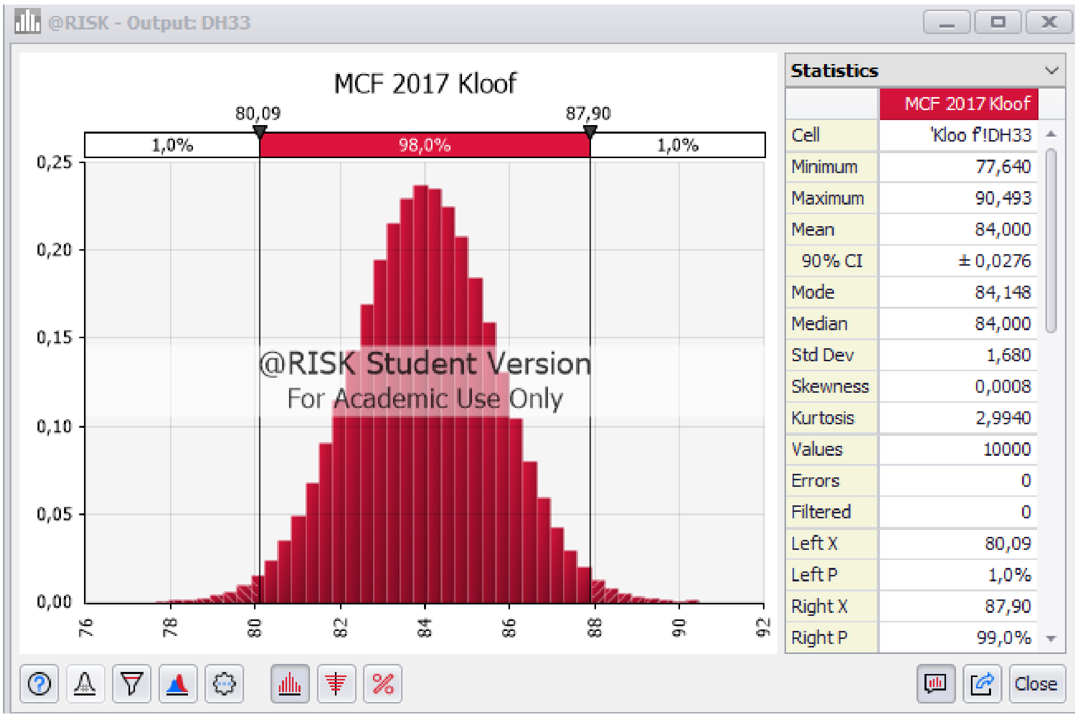


		%	tons	g/t	Grams	Oz	% Tonnage	% Grade
MCF (3 dec)	GAF / Available for Hoisting	84						
GOLD RECOVERED			0		15054585			
RESIDUE			2078960	**0,10**	205301	6601		
GAF	Recovered + Residues		2078960	**7,34**	15259886	490617	**108**	**77**

Figure 14 shows the results of the Monte Carlo simulation with 10000 iterations. The average MCF is 84%, with a standard deviation of 1.680%. The graph indicates that there’s a 98% certainty that MCF lies between 80% and 87.9%. It is clear that the MCF was under or overestimated due to uncertainties of the numbers measured to calculate the MCF. The distribution is the normal distribution with the following formula:

- =RiskNormal(MCF;SD;RiskStatic(MCF));
- MCF applied is the average MCF of 84%; and
- The estimated standard deviation applied is 1%, the uncertainty calculated in volume averaged 0.685 % and the grade uncertainty is assumed to be twice more than the volume estimation, because of the processes of sampling underground and at the plant.

The author also believes that due to more grade loss in all the Sibanye-Stillwater gold operations there is high uncertainty in the way grade is estimated.



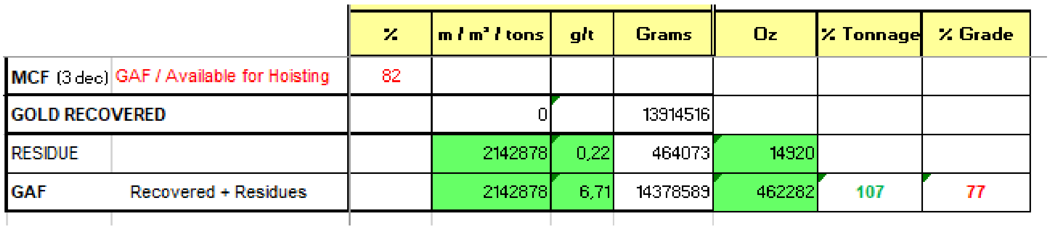
Statistics	MCF 2017 Kloof
Cell	'Kloo f'!DH33
Minimum	77,640
Maximum	90,493
Mean	84,000
90% CI	± 0,0276
Mode	84,148
Median	84,000
Std Dev	1,680
Skewness	0,0008
Kurtosis	2,9940
Values	10000
Errors	0
Filtered	0
Left X	80,09
Left P	1,0%
Right X	87,90
Right P	99,0%

Figure 14: Distribution of the MCF for Kloof operation from the Monte Carlo simulation, MCF of Kloof Mine 2017.

7.3.2 Driefontein Mine

The original ore flow indicated that the MCF is 82% as calculated and declared in Table XVII.

Table XVII: Driefontein Mine MCF (Sibanye-Stillwater, 2018).

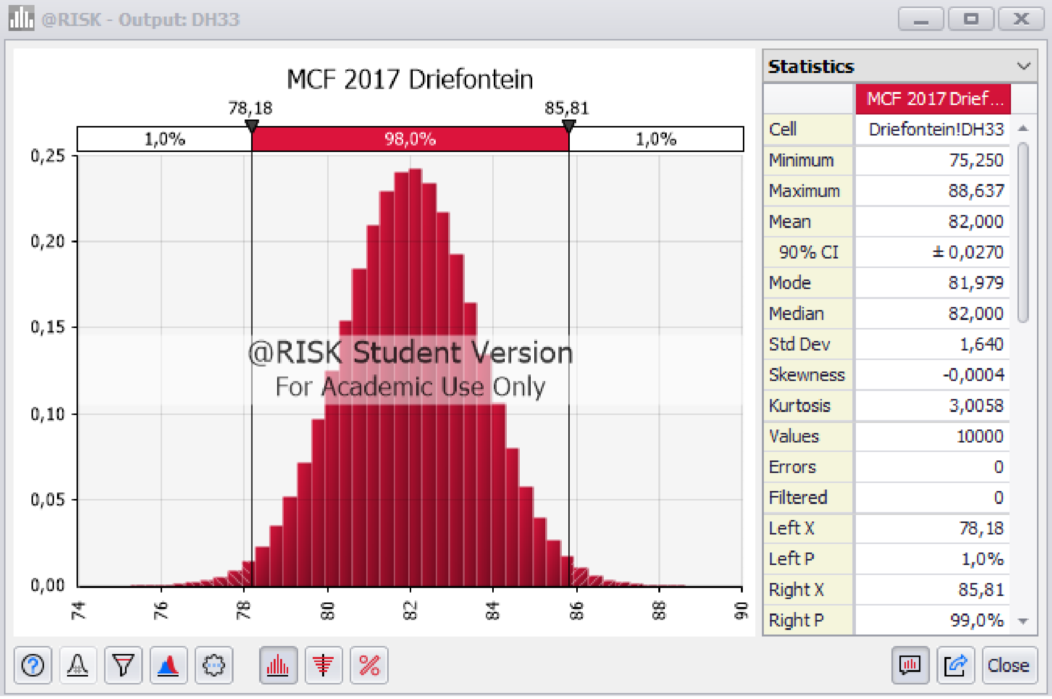


		%	m / m³ / tons	g/t	Grams	Oz	% Tonnage	% Grade
MCF (3 dec)	GAF / Available for Hoisting	82						
GOLD RECOVERED			0		13914516			
RESIDUE			2142878	0,22	464073	14920		
GAF	Recovered + Residues		2142878	6,71	14378589	462282	107	77

Figure 15 shows the results of the Monte Carlo simulation with 10000 iterations. The average MCF is 82%, with a standard deviation of 1.684%. The graph indicates that there's a 98% certainty that MCF lies between 78.1% and 85.8%. It is clear that the MCF was under or overestimated due to uncertainties of the numbers measured to calculate the MCF. The distribution is the normal distribution with the following formula:

- =RiskNormal(MCF;SD;RiskStatic(MCF));
- MCF applied is the average MCF of 82%; and
- The estimated standard deviation applied is 1%, the uncertainty calculated in volume averaged 0.685 % and the grade uncertainty is assumed to be twice more than the volume estimation, because of the processes of sampling underground and at the plant.

The author also believes that due to more grade loss in all the Sibanye-Stillwater gold operations there is high uncertainty in the way grade is estimated.



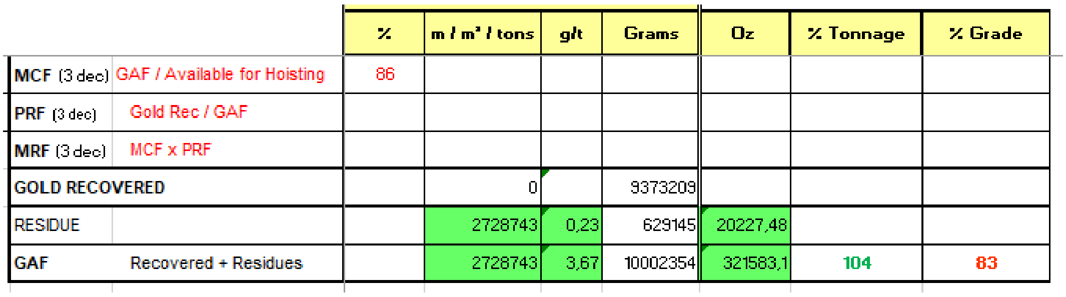
Statistics	MCF 2017 Drief...
Cell	Driefontein!DH33
Minimum	75,250
Maximum	88,637
Mean	82,000
90% CI	± 0,0270
Mode	81,979
Median	82,000
Std Dev	1,640
Skewness	-0,0004
Kurtosis	3,0058
Values	10000
Errors	0
Filtered	0
Left X	78,18
Left P	1,0%
Right X	85,81
Right P	99,0%

Figure 15: Distribution of the MCF for Driefontein operation from the Monte Carlo simulation, MCF of Driefontein Mine 2017.

7.3.3 Beatrix Mine

The original ore flow indicated that the MCF is 86% as calculated and declared in Table XVIII.

Table XVIII: Beatrix Mine MCF (Sibanye-Stillwater, 2018).

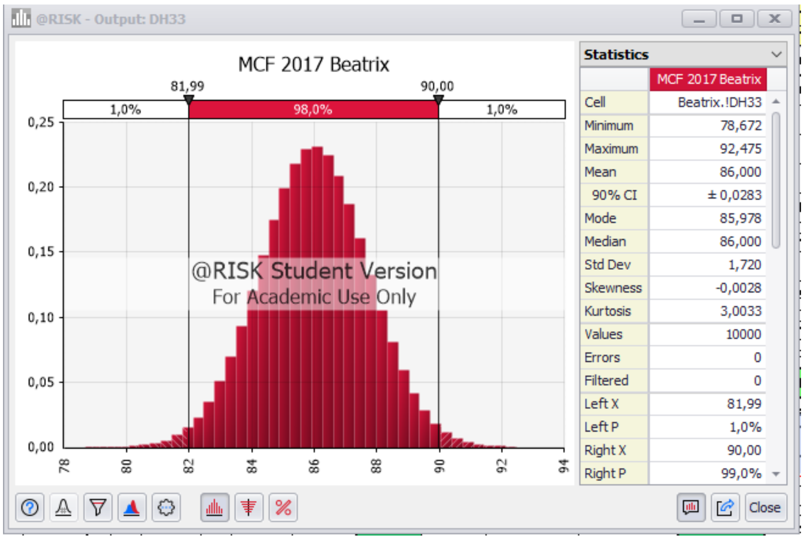


		%	m / m^3 / tons	g/t	Grams	Oz	% Tonnage	% Grade
MCF (3 dec)	GAF / Available for Hoisting	86						
PRF (3 dec)	Gold Rec / GAF							
MRF (3 dec)	MCF x PRF							
GOLD RECOVERED			0		9373209			
RESIDUE			2728743	0,23	629145	20227,48		
GAF	Recovered + Residues		2728743	3,67	10002354	321583,1	104	83

Figure 16 , shows the results of the Monte Carlo simulation with 10000 iterations. The average MCF is 86%, with a standard deviation of 1.720%. The graph indicates that there's a 98% certainty that MCF lies between 82% and 90%. It is clear that the MCF was under or overestimated due to uncertainties of the numbers measured to calculate the MCF. The distribution is the normal distribution with the following formula:

- =RiskNormal(MCF;SD;RiskStatic(MCF));
- MCF applied is the average MCF of 86%; and
- The estimated standard deviation applied is 1%, the uncertainty calculated in volume averaged 0.685 % and the grade uncertainty is assumed to be twice more than the volume estimation, because of the processes of sampling underground and at the plant.

The author also believes that due to more grade loss in all the Sibanye-Stillwater gold operations there is high uncertainty in the way grade is estimated.



Statistics	MCF 2017 Beatrix
Cell	Beatrix.!DH33
Minimum	78,672
Maximum	92,475
Mean	86,000
90% CI	± 0,0283
Mode	85,978
Median	86,000
Std Dev	1,720
Skewness	-0,0028
Kurtosis	3,0033
Values	10000
Errors	0
Filtered	0
Left X	81,99
Left P	1,0%
Right X	90,00
Right P	99,0%

Figure 16: Distribution of the MCF for Beatrix operation from the Monte Carlo simulation, MCF of Beatrix Mine 2017.

7.4 Chapter Summary

In this chapter, the methodology for establishing the distributions in the ore flow balance sheet was discussed. The initial MCF for the Kloof mine before applying the Monte Carlo simulation was 84%, however, after applying the Monte Carlo simulation with 10 000 iterations, the MCF ranges between 80 % and 88% with a standard deviation of 1.680. Driefontein mine MCF before applying the Monte Carlo Simulation was 82%, however, after the application of the Monte Carlo simulation, the MCF averaged between 78% and 86%, with the standard deviation of 1.640%. The initial MCF for Beatrix was 86% however, after applying the Monte Carlo simulation the results indicated that the MCF averages between 82% and 90%. It has been proven during the research that Kloof, Driefontein, and Beatrix mine there is at least 12%, 14%, and 10% of real losses respectively. Knowing that there is a 10-14% real loss means that any focus on reducing this is immediately rewarded with increased profits.

Estimation of the uncertainty in the survey called for volume and estimation of uncertainty of the survey called for grade was also discussed. The next chapter will conclude the key findings of Chapters Five and Six, summarize the key findings of Monte Carlo analysis. It will also identify if it is primarily an apparent gain/loss or real loss. Monte Carlo simulation is flexible and can take many sources of uncertainties of measurements in the ore flow.

8 CONCLUSION

8.1 Introduction

Chapter Eight presents the conclusion of the research study. The conclusion summarises the key findings from Chapters Five and Six. The chapter identifies whether it is primarily a tonnage gain/loss or grade gain/loss. Summarises the key findings of the Monte Carlo simulation analysis, as well as whether it is primarily an apparent gain/loss or real loss.

8.2 Summary of Key Findings

Generally, the MCF of Sibanye-Stillwater for the year 2017 was low, MCF is as follows, 84 % for Kloof, 82 % for Driefontein, and 86% for Beatrix. The study showed that there is a problem with Sibanye-Stillwater gold operations MCF as it averaged 84%.In the period under review, it is noted that the gold called for at Kloof mine was 584,144 ounces, and only 490,617 ounces were recovered from the plant. Theoretically, this simply means that 14% of ounces were lost and never recovered, and this means 14% of the revenue was not realized. Driefontein gold called for amounts to 563251 ounces, and only 462,282 ounces was recovered by the plant, 100,969 equates to a loss of 18% of the revenue which was lost during the period in review. Beatrix mine gold called for 374,466 ounces and only recovered 321,583 ounces, which implies that 15% of the revenue was not realized. The total ounces lost during 2017 amounts to 247,379 ounces. Assuming the gold price at $1300 per ounce, with the United States dollar (USD) average exchange rate of R13, meaning 1USD=R13.00, the total revenue lost equates to R4,18bn. It is imperative to investigate the low MCF at Sibanye-Stillwater to lower the loss of revenue.

Ore flow balance sheet for Kloof mine indicated that there is a larger percentage of 23% grade loss compared to 8% tonnage gain. Driefontein mine recorded a tonnage gain of 7% with a grade loss of 23%. Beatrix mine shows a tonnage gain of 4% with a grade loss of 17%.

For the period under review, the tonnage discrepancy was primarily a survey shortfall and was estimated at +5.6%. The sources of real tonnage gain are a result of vamping old gold tonnes and material left at the plant. The main loss at Sibanye-Stillwater gold operations is primarily grade loss. MCF is impacted by the grade, development waste to mill amounts to 107 6351t, which is 16% of the tonnes called for. Grade interpolation, unplanned dilution, gold locked in the footwall, lack of blasting barricades, sweepings not done to standard, derailments contribute to the loss of grade. Gold fines are lost in the stopes as a result of drilling and water, and they are trapped in the footwall cracks. There is a significant drop in grades, both apparent grade loss and real grade loss occur.

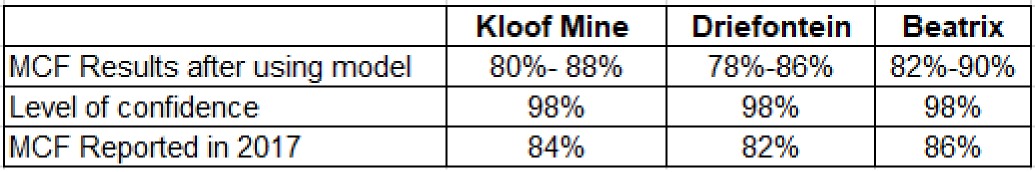
8.3 Grade Loss and Tonnage Gain

Sibanye-Stillwater gold's operations MCF is very low compared to the platinum operations, this is due to grade loss averaging 21 % for the period under review, and it is primarily a grade loss. Grade loss is a result of unplanned dilution, waste to reef averaging 16% of the tonnes called for. Fines lost during drilling and dewatering of dust, constitute a real grade loss, as small fines are trapped in the cracks of the stopes footwall (De Jager, 1997). During tramming and hoisting, gold fine particles are lost. Tonnage gain is due to waste to reef averaging 16%, and unplanned dilution. Survey shortfall for the period in review amounts to +5.6 %. Average tonnage gain amounts to 6.3% for the period under review, it is primarily tonnage gain.

8.4 Monte Carlo Analysis

Monte Carlo simulation is a useful tool because the tool provides quantifiable measures of the root causes (Tolmay, 2009). Table XIX below indicates the summary of the distribution of the MCF for the three mines.

Table XIX: Summary of the distribution, MCF (Sibanye-Stillwater, 2018).



	Kloof Mine	**Driefontein**	**Beatrix**
MCF Results after using model	80%- 88%	78%-86%	82%-90%
Level of confidence	98%	98%	98%
MCF Reported in 2017	84%	82%	86%

This clearly shows that the Monte Carlo simulation can be used to determine the distribution uncertainty in the MCF before doing the business plan on the mine. Uncertainty does exist in any number in the ore flow balance sheet, and this has been proven by applying the Monte Carlo simulation in the ore flow. Every number that is put in the ore flow balance sheet, does have uncertainty. Depending on the number of simulations, the standard deviation, kurtosis for each estimated number was calculated at the 98% level of confidence.

The following formulas were applied in the ore flow using Monte Carlo simulation software:

- Area=Risknormal () + (m^2, SD*m^2, Riskstatic (m^2));
- Tonnages=Risknormal () + (t, SD*t, Riskstatic (t)), and
- Grade= Risknormal () + (g/t, SD*g/t, Riskstatic (g/t)).

8.5 Apparent Gain/loss and Real Loss

Both apparent and real losses do exist in the Sibanye-Stillwater gold operations ore flow balance sheet. However, there is a tonnage gain of 6.3% and a major drop in grade of 21%. It is both apparent and real gain for the tonnages and apparent and real loss on the grade which affects the MCF, which ultimately affects the revenue, which equates to R4,18bn for the year under review. It has been shown that there are losses are between 10 and 14% on the Sibanye-Stillwater gold mines. This range includes the uncertainties in estimations. Monte Carlo simulation is been used to determine the range of the MCF due to estimation uncertainties. It can be concluded that the real losses are at least 10%.

9 RECOMMENDATIONS

9.1 Chapter Overview

This chapter presents the recommendation for this research. The main aim of the recommendation is to improve and minimize losses to improve the low MCF of Sibanye-Stillwater gold mine operations.

Actions to be taken to improve grade estimation techniques to minimize apparent loss:

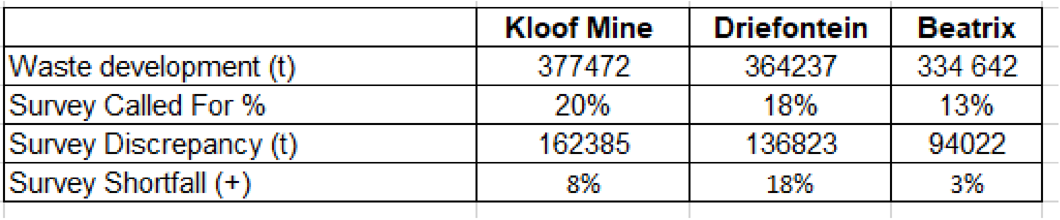
- Modelling of data should be done using the data mine software package, as all the data is validated in this software. This will be a group-wide standard;
- Resources must be validated by visual comparison of the drill hole data and related resource block estimates (Sibanye-Stillwater, 2019);
- Analysis of kriging efficiency and kriging variance values in the block, year on year (Sibanye-Stillwater, 2019);
- Regular underground sampling;
- Analysis of QA/QC for validation of sampling data;
- Monthly calibrations of weightometer;
- Using multiple assay laboratories, for comparison of grade estimate;
- Clear estimations of unplanned dilution; and
- More drilling to cover the bigger area on the surface, and underground.

While focussing on minimising the apparent losses, it doesn’t add any additional metal to the produced metal, and there is no additional revenue. However, it is important for the correct management decisions.

9.2 Actions to Minimize Real Losses

The following are the actions to minimize and eliminate the real losses along the mining value chain Sibanye-Stillwater gold mines. Table XX indicates the summary results of the ore balance sheet for the three mines.

Table XX: Summary of the ore balance sheet (Sibanye-Stillwater, 2018).



	Kloof Mine	Driefontein	Beatrix
Waste development (t)	377472	364237	334 642
Survey Called For %	20%	18%	13%
Survey Discrepancy (t)	162385	136823	94022
Survey Shortfall (+)	8%	18%	3%

- Reduction of development waste to the reef is required, to minimise the grade loss, 2017 development waste to reef amounted to 17%, which negatively affected the grade.
- Reduction of survey shortfall is required, 2017 Sibanye-Stillwater gold mines recorded a survey shortfall of +5.6%. Survey shortfall impacted the grade negatively because the ore mined monthly was not processed on time as a result, the fresh ore was mixed with old ore for processing and the ore was estimated with different grades.
- Continued processing of ore is required to avoid unnecessary stockpiling of ore, as this affects the grade called for.

Metal accounting indicates that both apparent grade and real grade loss occurred in the period under review. This research report indicated that the MCF has significant ranges after applying the Monte Carlo simulation in the ore flow balance sheet. Grade loss is a major concern. However, it is recommended that the use of Monte Carlo simulation be used to quantify the apparent losses/gains and the real losses in an ore flow balance sheet. Monte Carlo simulation is a good tool to use because it provides quantifiable measures of the major losses in the ore flow balance sheet. It also recommended that the resource estimations during grade and geological estimation have to be more accurate. The 10-14% real loss from the mines is a metal mined and paid for, which is lost. Any recovery of this is pure profit

REFERENCE LIST

AMIRA International (2005).Metal Accounting Code of Practice and Guidelines: Release 1, Published by AMIRA International, Australia.

Andersen, D.C, (1999), Criteria influencing the Mine Call Factor of a Gold Mine, Dissertation: MSc (Eng) University of Witwatersrand.

Cawood, F.T., 2003. Underground face sampling on narrow gold reefs: sampling practice and its impact on the mine call factor on Witwatersrand gold mines–lessons learned. *Journal of the Institute of Mine Surveyors of South Africa*, *31*(7), pp.202-224.

Cawood, F. T. (2012), Course notes on the role of the mineral evaluator in MRM, University of Witwatersrand.

Chieragati, A. C and Pitard, F. F. (2009), The challenge of sampling gold. Fourth World Conference on Sampling & Blending, The South African Institute of Mining Metallurgy, 2009.

De Jager, E.J, 1997, *The Analysis of the Mine Call Factor in the Gold Mining, with specific reference to western Holdings Mine.* Thesis: Ph.D. (Eng), University of the Witwatersrand, Johannesburg.

Donaldson, J., Ferguson, C., Murray-Haydon, E. (2014). Interpreting Long Term Mine to Mill Reconciliation at St Ives. Monograph 30, Mineral Resources and Reserves Estimation, The AusIMM Guide to Good Practice pp707-720.

Fourie, A. and Minnitt, R.C.A., 2016. Review of gold reef sampling and its impact on the mine call factor. *Journal of the Southern African Institute of Mining and Metallurgy*, *116*(11), pp.1001-1009.

Gaylard, P.G., Morrison, R.D., Randolph, N.G., Wortley, C.M.G. and Beck, R.D., 2009, July. Extending the application of the AMIRA P754 Code of Practice for Metal Accounting. In *Proceedings of the 5th Base*

Metals Conference (pp. 15-38). Johannesburg: Southern African Institute of Mining and Metallurgy.

Heuberger (2004), Risk analysis in the mining industry.The Journal of the South African Institute of Mining and Metallurgy, 105, 75-79.

Hills, V.W. (2000) Metal accounting, An integral part of Mineral Resource Management, Colloquium of the South African Institute Mining and Metallurgy, Johannesburg.

Kühn, C. and Visser, J.K. 2014. Managing uncertainty in typical mining project studies. *South African Journal of Industrial Engineering*. 25(2):105–120. DOI: 10.7166/25-2-800.

Mugwagwa, C. (2016), To examine whether the resource estimation method is a major contribution to the low Mine Call Factor at Mazowe Mine, Thesis MSc (GIS), University of Salisbury, Australia.

Palisade, n.d. [Monte Carlo simulation] online Available at: http//palisade.com/risk/monte carlo simulation.asp [Accessed: 01 August 2019].

Paulos, J. A. (2000). A mathematician plays the stock market, Basic Books, New York.

RiskAMP, n.d. [Monte Carlo simulation] online Available at: http://www.riskAMP.com [Accessed 02 June 2019].

Rose, S., Fahey, F., (2014) Effective Grade control systems. Monograph30, Mineral Resources and Reserve Estimation. The Australasian Institute of Mining and Metallurgy to Good Practice pp679-682.

Sibanye-Stillwater Company Limited, 2017. 2017 Annual Report, Johannesburg, Sibanye-Stillwater. Available at [https://www.sibanyestillwater.com/].

Sibanye-Stillwater Company Limited, 2018. 2018 Annual Report, Johannesburg: Sibanye-Stillwater, Available at [https://www.sibanyestillwater.com/].

Sibanye-Stillwater Company Limited, 2019. 2019 Annual Report, Johannesburg: Sibanye-Stillwater, Available at [https://www.sibanyestillwater.com/].

Storrar, 1981, *South African Mine Valuation*. In: 2nd ed. Johannesburg: published by Chamber of Mines of South Africa, pp.226, 265.

Springett, M., 1993, *Solving open pit grade control problems*. Innovative Mine Design for the 21st century, Bawden & Archibald (eds), USA, pp. 255-226.

Spangenberg, I., (2012), The status of Sampling Practice in the Gold Mining Industry in Africa, Dissertation: MSc. (Eng.) University of Witwatersrand, Johannesburg.

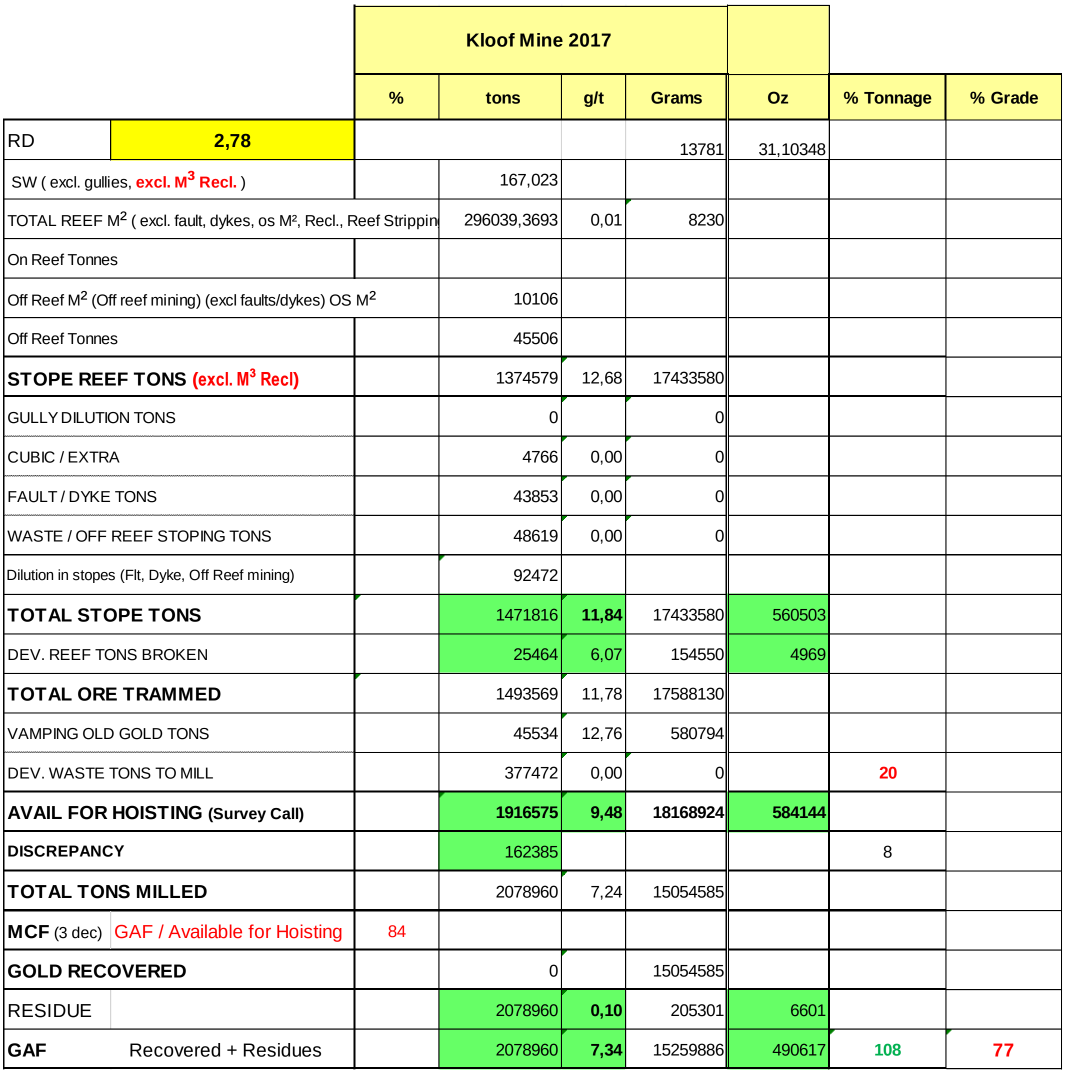
Tetteh, M.N.M, 2014. Mine Call Factor issues at Iduapriem Mine; Working towards a Mineral and Metal accounting protocol, Dissertation: MSc (Eng) University of Witwatersrand, Johannesburg.

Tetteh,M.N.M;Cawood,F.T,(2014), INTERNET http://africageoproceedings.org.za.content/uploads/2014/06/82-Tetteh-Cawood. Pdf[Accessed on 24 January 2018].

Tolmay, L. 2009, The use of Monte Carlo simulation for operations management decision criteria. World Gold *Conference* 2009, The Southern African Institute of Mining and Metallurgy, 2009.

APPENDIX

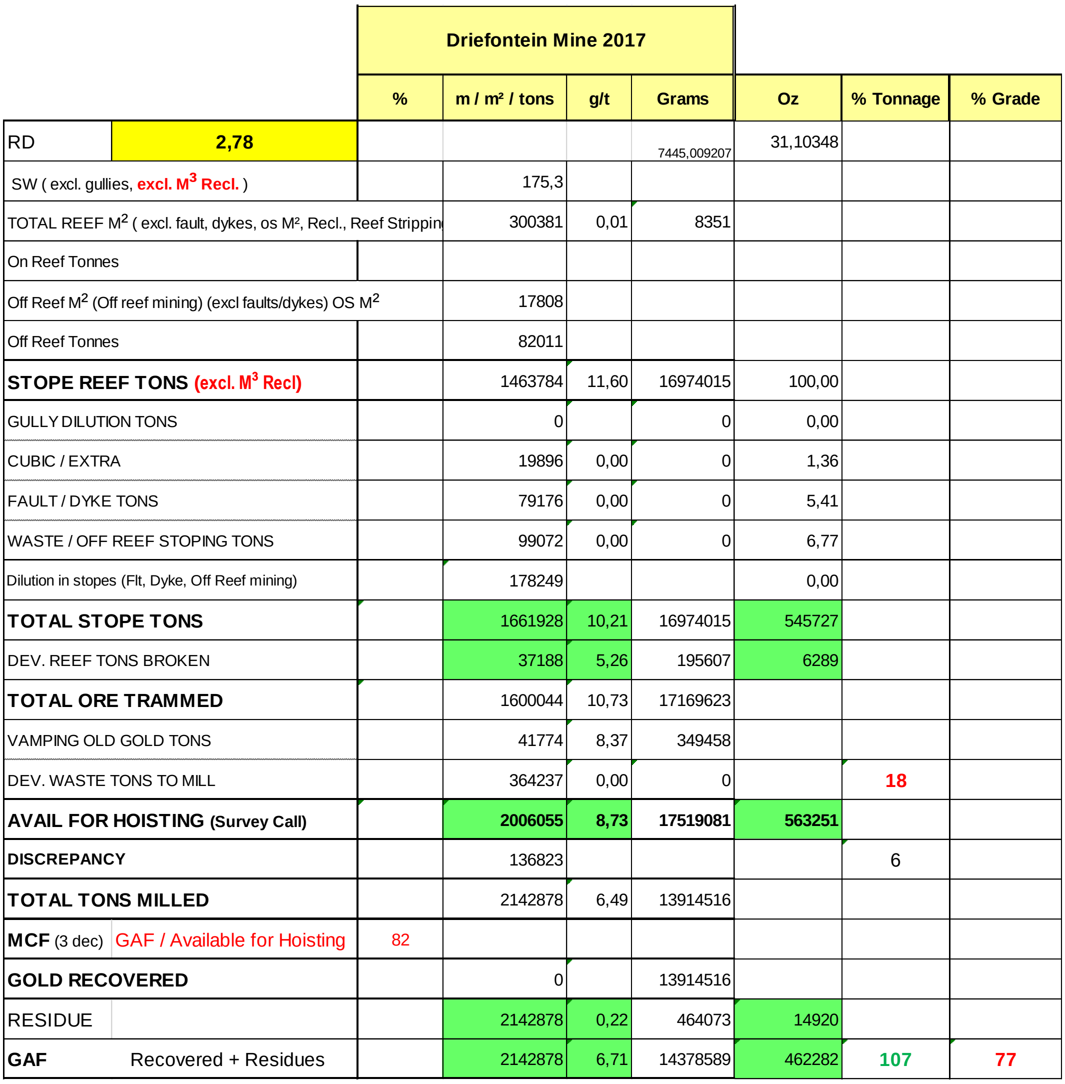
Kloof Mine Ore Flow



		Kloof Mine 2017						
		%	tons	g/t	Grams	Oz	% Tonnage	% Grade
RD	**2,78**				13781	31,10348		
SW (excl. gullies, **excl. M^3 Recl.**)			167,023					
TOTAL REEF M^2 (excl. fault, dykes, os M², Recl., Reef Strippin			296039,3693	0,01	8230			
On Reef Tonnes								
Off Reef M^2 (Off reef mining) (excl faults/dykes) OS M^2			10106					
Off Reef Tonnes			45506					
STOPE REEF TONS (excl. M^3 Recl)			1374579	12,68	17433580			
GULLY DILUTION TONS			0		0			
CUBIC / EXTRA			4766	0,00	0			
FAULT / DYKE TONS			43853	0,00	0			
WASTE / OFF REEF STOPING TONS			48619	0,00	0			
Dilution in stopes (Flt, Dyke, Off Reef mining)			92472					
TOTAL STOPE TONS			1471816	**11,84**	17433580	560503		
DEV. REEF TONS BROKEN			25464	6,07	154550	4969		
TOTAL ORE TRAMMED			1493569	11,78	17588130			
VAMPING OLD GOLD TONS			45534	12,76	580794			
DEV. WASTE TONS TO MILL			377472	0,00	0		**20**	
AVAIL FOR HOISTING (Survey Call)			**1916575**	**9,48**	**18168924**	**584144**		
DISCREPANCY			162385				8	
TOTAL TONS MILLED			2078960	7,24	15054585			
MCF (3 dec)	GAF / Available for Hoisting	84						
GOLD RECOVERED			0		15054585			
RESIDUE			2078960	**0,10**	205301	6601		
GAF	Recovered + Residues		2078960	**7,34**	15259886	490617	**108**	**77**

Source (Sibanye-Stillwater, 2020)

Driefontein Mine Ore Flow



		Driefontein Mine 2017						
		%	**m / m² / tons**	**g/t**	**Grams**	**Oz**	**% Tonnage**	**% Grade**
RD	**2,78**				7445,009207	31,10348		
SW (excl. gullies, **excl. M³ Recl.**)			175,3					
TOTAL REEF M² (excl. fault, dykes, os M², Recl., Reef Strippin			300381	0,01	8351			
On Reef Tonnes								
Off Reef M² (Off reef mining) (excl faults/dykes) OS M²			17808					
Off Reef Tonnes			82011					
STOPE REEF TONS (excl. M³ Recl)			1463784	11,60	16974015	100,00		
GULLY DILUTION TONS			0		0	0,00		
CUBIC / EXTRA			19896	0,00	0	1,36		
FAULT / DYKE TONS			79176	0,00	0	5,41		
WASTE / OFF REEF STOPING TONS			99072	0,00	0	6,77		
Dilution in stopes (Flt, Dyke, Off Reef mining)			178249			0,00		
TOTAL STOPE TONS			1661928	10,21	16974015	545727		
DEV. REEF TONS BROKEN			37188	5,26	195607	6289		
TOTAL ORE TRAMMED			1600044	10,73	17169623			
VAMPING OLD GOLD TONS			41774	8,37	349458			
DEV. WASTE TONS TO MILL			364237	0,00	0		**18**	
AVAIL FOR HOISTING (Survey Call)			**2006055**	**8,73**	**17519081**	**563251**		
DISCREPANCY			136823				6	
TOTAL TONS MILLED			2142878	6,49	13914516			
MCF (3 dec)	GAF / Available for Hoisting	82						
GOLD RECOVERED			0		13914516			
RESIDUE			2142878	0,22	464073	14920		
GAF	Recovered + Residues		2142878	6,71	14378589	462282	**107**	**77**

Source (Sibanye-Stillwater, 2020)

Beatrix Mine Ore Flow

		Beatrix Mine 2017						
		%	m / m² / tons	g/t	Grams	Oz	% Tonnage	% Grade
RD	**2,78**				8101,135974	31,10348		
SW (excl. gullies, **excl. M^3 Recl.**)			189,809					
TOTAL REEF M^2 (excl. fault, dykes, os M², Recl., Reef Strippin			383228	0,01	10654			
On Reef Tonnes								
Off Reef M^2 (Off reef mining) (excl faults/dykes) OS M^2			9742					
Off Reef Tonnes			50048					
STOPE REEF TONS (excl. M^3 Recl)			2022180	5,57	11271300			
GULLY DILUTION TONS			0		0			
CUBIC / EXTRA			131581	0,00	0			
FAULT / DYKE TONS			57438	0,00	0			
WASTE / OFF REEF STOPING TONS			189019	0,00	0			
Dilution in stopes (Flt, Dyke, Off Reef mining)			246458					
TOTAL STOPE TONS			2400219	4,70	11271300	362380,67		
DEV. REEF TONS BROKEN			61479	3,71	227928	7328,04		
TOTAL ORE TRAMMED			2272678	5,06	11499228			
VAMPING OLD GOLD TONS			27401	5,40	147980			
DEV. WASTE TONS TO MILL			334642	0,00	0		**13**	
AVAIL FOR HOISTING (Survey Call)			**2634721**	**4,42**	**11647207**	**374466,376**		
DISCREPANCY			94022				**3**	
TOTAL TONS HOISTED		**144,29**	2728743	4,27	11647207			
STOCKPILES AT # - BEGIN +		0,00	0		0			
STOCKPILES AT # - END -		0,00	0		0			
SUB TOTAL		0,00	0		0			
Waste dumps +			0					
Slimes dam +			0					
Reef ex sorting +			0					
Waste washings +			0					
Railway bins - begin +			0					
Railway bins - end -			0					
TOTAL TO PLANT		**0,00**	2728743	3,43	9373209			
TOTAL TONS MILLED			2728743	3,43	9373209			
MCF (3 dec)	GAF / Available for Hoisting	86						
PRF (3 dec)	Gold Rec / GAF							
MRF (3 dec)	MCF x PRF							
GOLD RECOVERED			0		9373209			
RESIDUE			2728743	0,23	629145	20227,4777		
GAF	Recovered + Residues		2728743	3,67	10002354	321583,128	**104**	**83**

Source (Sibanye-Stillwater, 2020)