CALIBRATION OF A MIXING MODEL FOR SUBLEVEL CAVING

by

Daniel Villa Salinas

B.A., University of Santiago of Chile, 2001

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

Master of Applied Science

(Mining Engineering)

in

The Faculty of Graduate Studies

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

December 2012

Abstract

Sublevel caving (SLC) is an underground mass mining method where the orebody is divided into a regular network of tunnels. The ore is extracted by level working downwards through the orebody. The caved waste from the overlying rock mass fills the void created by ore extraction generating a dynamic mixing situation between the broken ore and the waste (dilution) from upper levels. The dynamic process of mixing creates a significant challenge in the SLC project to estimate grades reliably.

PCSLC is an application developed by Gemcom Software specifically designed for the mine planning of Sub Level Caving projects and operations. It incorporates a rich set of tools to assist with the whole design and planning process including a sophisticated mixing models, it can simulates the material flow observed in caving mines using a technique known as Template Mixing, but due to the complexity that it represents, it is extremely necessary to calibrate its results against real data.

The main purpose of this study was to calibrate the mixing model implemented in PCSLC using real data from Newcrest Ridgeway Gold Mine to provide guidelines for SLC project to forecast grade reliably.

The methodology used was to collect historical information provided by Ridgeway to reproduce its design and result in PCSLC and then be capable to understand the complexity of gravity flow in SLC. Key information for this purpose was the utilization of the trial marker scale experiments applied at the mine, since it creates the concept of material recovery curve per level. This was fundamental to create a PCSLC model and be able to replicate the tonnage extracted and the grades reported at the mine.

One of the main results in this thesis is the understanding of the gravity flow in SLC method and the demonstration of the benefit to use a recovery curve per level as a main driver for mixing modeling. The calibration of the mixing model in PCSLC was successful and the most important part is the guideline created to use in PCSLC to get reliable results in the prediction of grades and dilution for production scheduling purposes.

Table of Contents

List of Tables

List of Figures

Acknowledgements

I would like to thank Gemcom Software International for the opportunity to work with PCSLC and be part of the research and development team, in particular Dr. Tony Diering whose expertise, continuous encouragement, patience and enthusiasm for this project, added considerably to my professional experience. Also I want to thank Newcrest Mining Limited for access to the Ridgeway SLC marker trial and historical data that has provided substantial contributions to the results presented.

This thesis would not have been possible without the help, support and patience of my principal supervisor, Dr. W. Scott Dunbar especially when I decided to move to Indonesia before finishing my thesis.

I would also like to thank my family for the support they offered me in each of our adventures and in particular, I must acknowledge my wife Romina, without whose love, encouragement and patience, I would not have finished this thesis.

Dedication

To my wife Romina

For her patience, understanding, and guidance

1. Introduction

The sublevel caving (SLC) mining method is a mass mining method in which all material to be mined needs to be blasted. In this sense, it differs from the block cave mining method which relies on gravity and stresses to fragment most of the rock to be mined. Because of the need to blast the rock, the orebody has to be divided into a regular network of tunnels. A good overall description of the method is given by(Bull and Page, 2000).

A significant challenge in the design and evaluation of any SLC project is the estimation of mineable grades resulting from the mixing and diluting process. This is strongly affected by tunnel spacing, draw strategy and rock mass characteristics. Conventional mine planning software tools are not well suited to use with this type of underground extraction method due to their inability to model the mixing behavior.

PCSLC is a new application developed by Gemcom Software Int. specifically designed for mine planning of Sub Level Caving projects and operations. It incorporates a set of tools to assist with the whole design and planning process and includes sophisticated mixing models, it can simulates the material flow observed in caving mines using a technique known as Template Mixing (TM) (Diering, 2007).

The main purpose of this study is to address the mixing technique used by PCLSC. Due to the complexity that it represents, it is extremely necessary to calibrate its results against real data. The calibration will be done replicating actual production schedule and grades from the Ridgeway Gold Mine. This information should be one of the most complete set of data ever collected so it will provide a strong support for this new simulation mixing method.

1.1. Objectives

This study aims to calibrate the mixing model implemented in PCSLC using actual data from Newcrest Ridgeway Gold Mine to provide guidelines for SLC project to forecast grade reliably using PCSLC as mining planning tool.

In summary the main objectives of this research are the following:

a) Understand the complexity of the flow behavior of a Sublevel Caving mine using the data collected in the Ridgeway mine from June 1999 to February 2009. An important role in this part of the study is the work done using markers and the analysis done in the flow mechanism of a SLC mine(Power, 2004).
b) Create a small scale model in PCSLC to replicate the extraction profile used at Ridgeway mine and to study the mixing model and its parameters understanding the impact of each one in the results.
c) Build a PCSLC model replicating Ridgeway mine design and using the knowledge obtained from the small scale model in PCSLC, calibrate the mixing model parameters in PCSLC utilizing the actual data collected at Ridgeway mine. The main items to calibrate will be the actual tonnage and grades (Gold and Copper).
d) Based on the calibrated model provide guideline to run PCSLC in other projects to achieve reliable results specifically to forecast tonnage, grade and dilution.

1.2. Description of the problem

Conventional mine planning software tools are not well suited to use with Sublevel or block caving method due to their inability to forecast grades reliably and model the dilution behavior. Otherwise much work has been done to try to understand the flow mechanisms at work in an active cave mine. A common problem encountered in this work is that of problem size and computation time. For example several flow models already developed such as Rebop (Itasca Consulting Group, 2000) and Cellular Automata (Alfaro and Saavedra, 2004) are good tools to model the dynamic conditions generated at cave mines, but the duration and complexity of a large mine layout (a real case could have more than 15 levels, 600 tunnels and more than 25,000 rings) leads to computer runs more than 5 days long or to situations where the program simply cannot handle this amount of variables required to get reliable results. This becomes problematic when the mine planner wants to evaluate several scenarios, sequences or different options for layout geometry. The complexity of the depletion and mixing is illustrated in Figure 1 showing a model created using REBOP (Itasca Consulting Group, 2000)where it is possible to see the extraction by level and the complexity of the material in mixing.

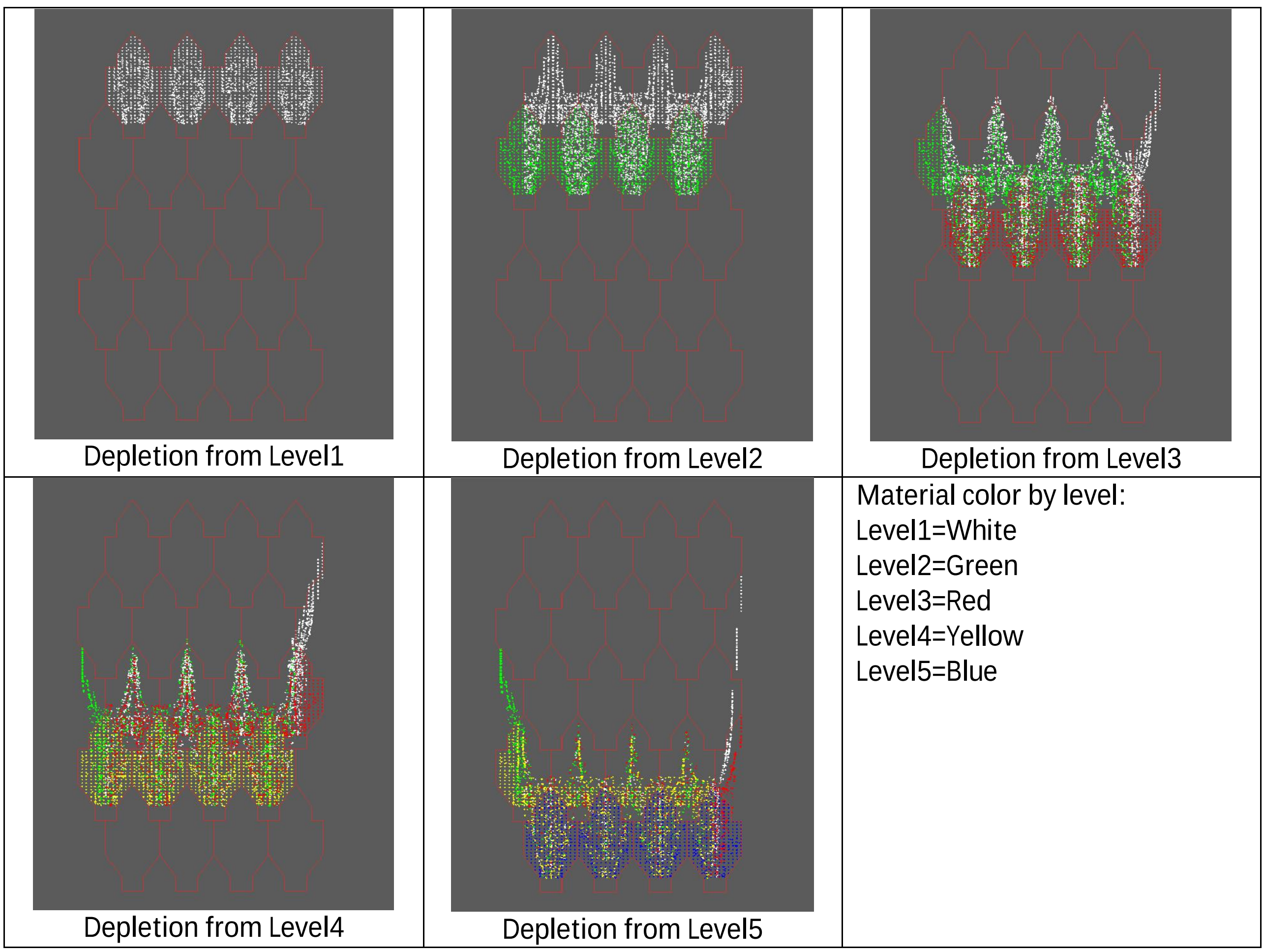


Figure 1: Extraction and mixing in Sublevel caving

When tonnage is extracted from Level5 only one portion of the material from the same level is depleted and residual material left behind from upper levels are mixed and depleted too, and therefore, the grade reported by Level5 is a combination of all the levels above combined in a dynamic manner that make of the prediction of a reliable grade a very difficult task.

PCSLC is a new mine planning and scheduling package for sublevel caving created by Gemcom Software International. The objective of this software is to provide a set of tools to take a project from the block modeling stage right through the process of generating tunnels and then rings along the tunnels, an example of a PCSLC model is shown in Figure 2.

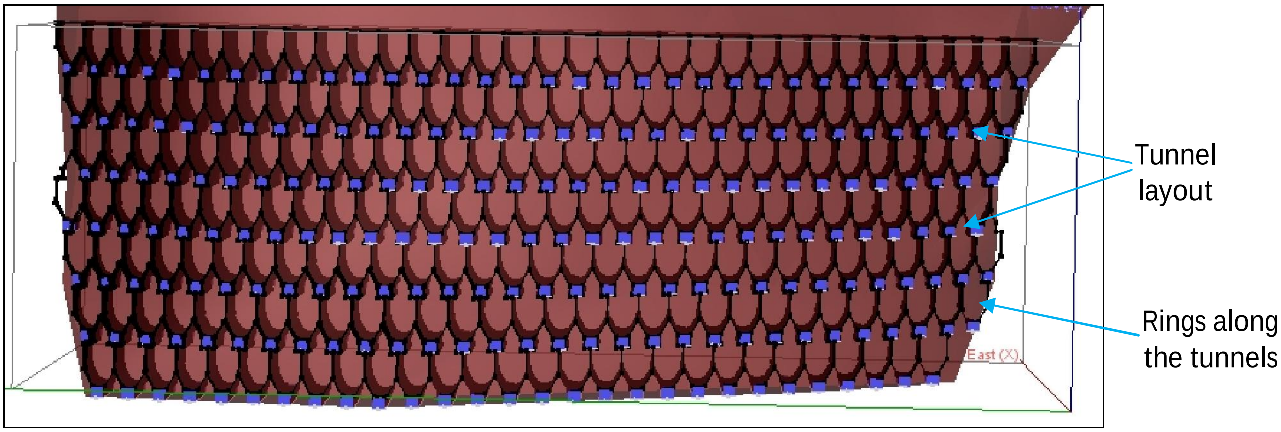


Figure 2: Example of a Sublevel caving model in PCSLC

Rings are populated with tons and grades from the block model from which an in-situ (or un-diluted) reserve can be estimated. Then a production schedule is set up including a detailed mining sequence, percentage of extraction by level and other production constraints. Figure 3 shows an example of the outcome of a production a schedule for a Sublevel Caving mine where the production is displayed by bars colored by each level (from top to bottom levels 550 to 400) and the black line represents the average copper grade reported in each period.

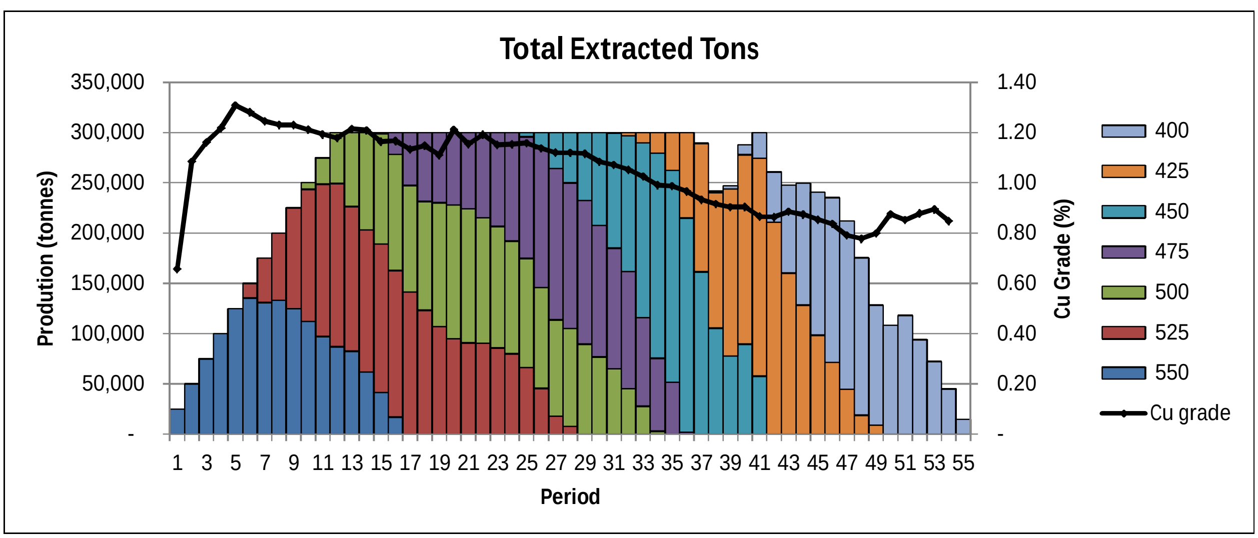


Figure 3: Production schedule from PCSLC

PCSLC uses a mixing model called Template Mixing to simulate the flow of material between the mined out rings and into the active mining areas. The mixing model has already been successfully calibrated against Itasca's REBOP program (Itasca Consulting Group, 2000), but it was never tested and validated against real information. Ridgeway Gold Mine provides an excellent record of actual data that can be used for calibration purposes. The information available is tonnage and grade reported by period, by level and even by ring. Additionally, several studies have been done in past using makers to understand the process of mixing and recovery per level.

1.3. Thesis structure

Chapter 2 describes a review of the Sublevel Caving method having an emphasis in the evolution and current practice using the result of a survey done in 2008 over the five most important Sublevel caving mine currently in operation. The results by describes the practice utilized in mine design, drill and blast, Production and draw control. Finally this chapter shows a description of the gravity flow of SLC highlighting the experimental work done in small and full scale.

Chapter 3 summarizes the information provided by Ridgeway to replicate its design and result in PCSLC. Key information for this study is described here with the trial marker scale experiments applied at the mine, describing the method used, design, installation and the analysis done in two PhD theses and the conclusion obtained in the mine.

Chapter4 shows the principles of the software Gems-PCSLC used in this study describing in detail how to model a Sublevel Caving mine with this tool and the components of the Mixing model implemented in PCSLC. The most important part of this chapter is the creation of small scale model in PCSLC to study the mixing model and its parameters.

Chapter5 describes the calibration of mixing model of PCSLC using Ridgeway data. This section includes all the work done to create a PCSLC model with Ridgeway design replicating the tonnages extracted in the mine and the work done to calibrate the PCSLC mixing model to get similar gold and copper grades reported by the mine based on the results of the trial marker experiments.

Chapter 6 presents a discussion and interpretation of the results, followed by the final conclusions and recommendations for future work.

1.4. Contribution made by this thesis

The main contributions made by this thesis are described as follow:

- This study gives a description of the evolution of the sublevel caving method and how the changes in the design have affected the flow mechanism and the recovery of the material by level.
- It also demonstrates that PCSLC is a reliable tool for mining planning purpose because it was able to replicate the tonnage extracted in the mine showing an excellent correlation with grade sampled by rings and reported by month.
- The data and information collected empirical and experimentally at the sublevel caving mine allowed to establish that using the material recovery profile by level is a valuable approach to understand the mixing behavior of a SLC mine.

- Finally this research provides a good understanding of the parameters to model in a SLC mine using PCSLC. Also a methodology to forecast grades and dilution reliably by adjusting TM inputs using the recovery curve by level.

2. Review of Sublevel Caving method

The SLC method functions on the principle that the ore is fragmented by blasting, while the overlying host rock fractures and caves in under the action of mining induced stresses and gravity. It is a "top down" method, with ore being extracted level by level working downwards through the orebody. The caved waste rock from the overlying rock mass fills the void created by ore extraction. Figure 4 shows a schematic view through a SLC mine. The orebody is divided into sublevels at regular vertical spacing. A network of production drifts are developed across the full width of the orebody footprint at a specified horizontal spacing. The volume of ore immediately above each sublevel production drift is drilled with long holes in a fan or ring pattern. The drilling is undertaken as a separate operation, and completed well before blasting and loading commence (Bull and Page, 2000).

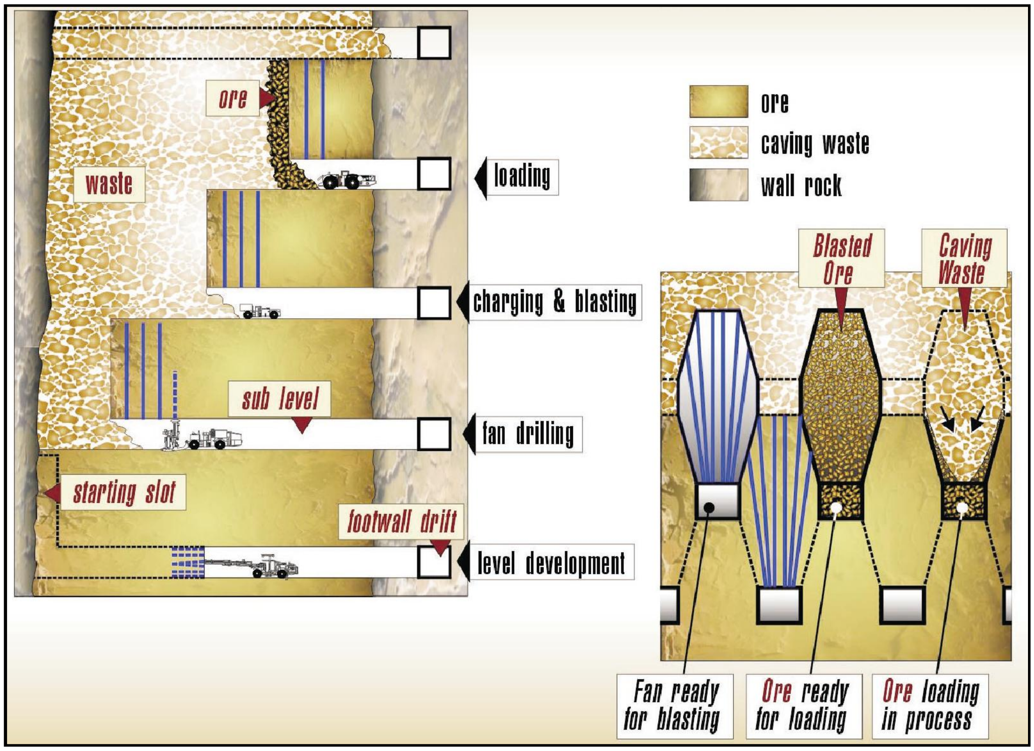


Figure 4: Schematic view of sublevel caving (Bull and Page, 2000)

In terms of extraction when one ring is blasted the first part is drawn clean and then waste from above and behind of the ring starts move towards into the draw point and a mixture of ore and waste is drawn. When the proportion of waste increases until a grade shut-off is reached the extraction from that ring stop and a new ring is blasted. Some ore will be left behind and it is mixed with the waste above creating "dilution" material, this increases when the cave is more mature. The main objective of this extraction method is being able to recover as much as ore is possible maintaining the waste material under control.

The following items provide a brief description of the essential features of the sublevel caving system. Sublevel caving can be applied successfully in the absence of some of these characteristics, but their absence can lead to increased operational complexity:

- Cavable overlying waste rock
- Relatively wide orebody footprint to promote caving
- Infrastructure placement to enable top down extraction sequence and delivery of ore to surface
- Location of infrastructure outside the subsidence zone
- Ability to drill blast holes of the required length and precision between sublevels
- Maintenance of development headings to permit continuous production
- Relatively uniform orebody dipping at 45° or greater
- Ideally visually different ore and waste properties
- No need to transport fill into the mined out area
- Lower cost of production blasting compared to development costs
- Low grade “halo” so that waste dilution effects are minimized
- Relatively strong orebody rock to minimize excavation support costs

Although the principal application of the method throughout time has been to the extraction of ironore, now, it is been implemented in other type of metal deposit as nickel, copper and gold. It create the option to implement this method in many deposit increasing its popularity, for example many large open pit mines are rapidly reaching their final economic depths and sublevel caving is a natural candidate for underground continuation.

2.1. Sublevel caving evolution

Sublevel caving has evolved through improvements in technology from the original caving methods of mining first introduced to extract ore from very low strength orebodies. The top slicing mining method is considered as the first caving method of mining that closely resembled what is known today as sublevel caving. This layer of ore was extracted from the development headings by allowing ore to cave into the development headings and be extracted during retreat. One of the first major applications of sublevel caving was in the early 1900’s in the underground extraction of the low strength iron ores in Minnesota and Michigan. Major changes were implemented in the mid 1900’s with advances in underground mine mechanization that enabled the method to be used in the high strength iron ores in Sweden. Improved drilling and blasting techniques allowed sublevel intervals to be increased and the relative amount of development to be further reduced to around 25% of the total ore extracted. The introduction of mechanized ore handling systems and trackless equipment allowed increased flexibility in extraction heading layouts. However these changes increased the potential for waste dilution and lower ore recoveries during ore production due to the reliance on gravity flow to move the ore, and some waste, to the drawpoints in the extraction headings. The most recent changes in drilling and blasting technology have resulted in a substantial increase in sublevel intervals such that in some cases less than 10% of all ore is now removed through development. LKAB has been a leader in this regard. Figure 5 provides a comparison of the sublevel caving mining geometries appropriate for the years 1963, 1983 and 2003 at the Kiruna mine.

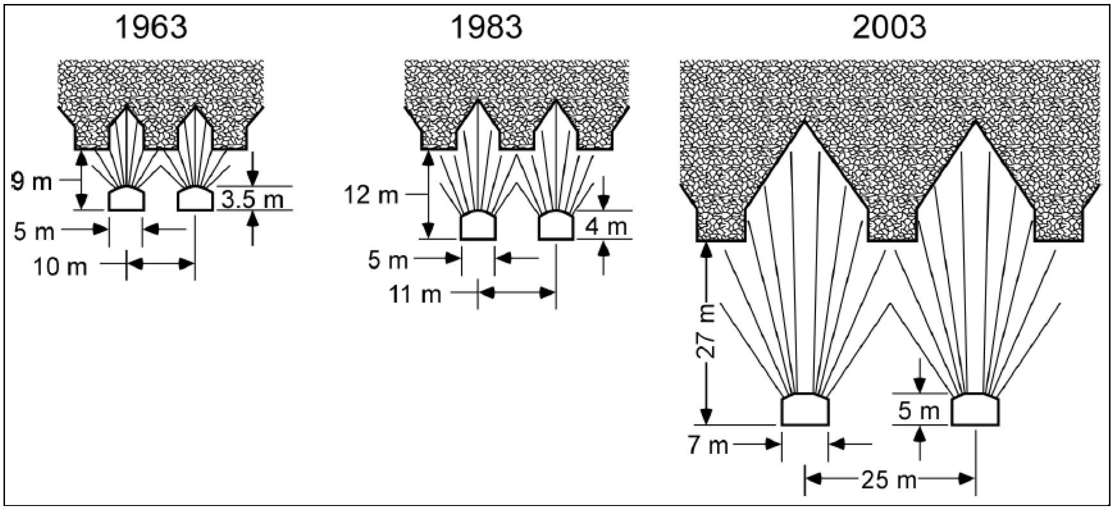


Figure 5: The sublevel caving geometry at the Kiruna mine at three different points in time

2.2. Sublevel caving current practice

In 2008 a review of practice in sublevel caving was done at five major sublevel caving mines (Stobie, Ridgeway, Perseverance, Miamberget and Kiruna) getting information about the current practice used at the present time. The items surveyed were Mine Design, Drill and Blast and Production and Draw Control. The following section described a summary of the information collected by(Power and Just, 2008).

2.2.1. Mine Design

The mine design tried to response the difficulties and risks associated to Sublevel caving layout and there are two approaches to selecting layout dimensions, the cost and recovery approaches(Power and Just, 2008). Figure 6 shows summary information on layout dimensions at the mines surveyed.

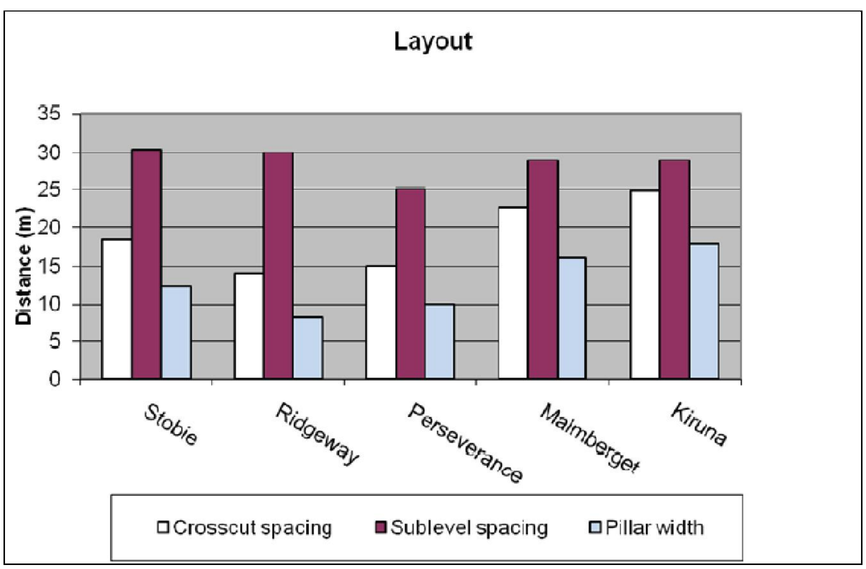


Figure 6: Mine layout summary

Figure 6 indicates that sublevel spacing is relatively consistent, ranging from 25m to 30m. The main layout variation is in production drive spacing, and most strongly influenced by underlying cost or recovery focus. Productions drive spacing range from 14m at Ridgeway to 24.75m at Kiruna. This results in pillar widths at Kiruna more than twice those at Ridgeway, with significant operational and cost advantages, due to increase production rate and geotechnical stability.

The main drivers for choice of development size are geotechnical stability, equipment size and ore recovery. To increase production rate, mines generally prefer larger equipment, which requires increased development size. Wider drawpoints also produce increased draw widths to improve recovery, and reduce hang-up frequency which helps improve production rate(Kvapil, 2008).

2.2.2. Drill and blast

This is one of the most important items for Sublevel Caving mines since it has big influence over fragmentation size, hang-up frequency, ore recovery, etc.

Drill and blast design factors with potential to significantly impact operational performance include:

- Drill hole diameter
- Maximum drill hole length
- Blast ring burden
- Number of holes per ring
- Inclination of lower holes in the ring
- Timing of ring drilling, loading and firing in relation to drawpoint production
- Drilling accuracy
- Ring charging and priming details e.g. powder factor
- Pre-charging of blast rings
- Pre-priming of blast rings and
- Brow stability

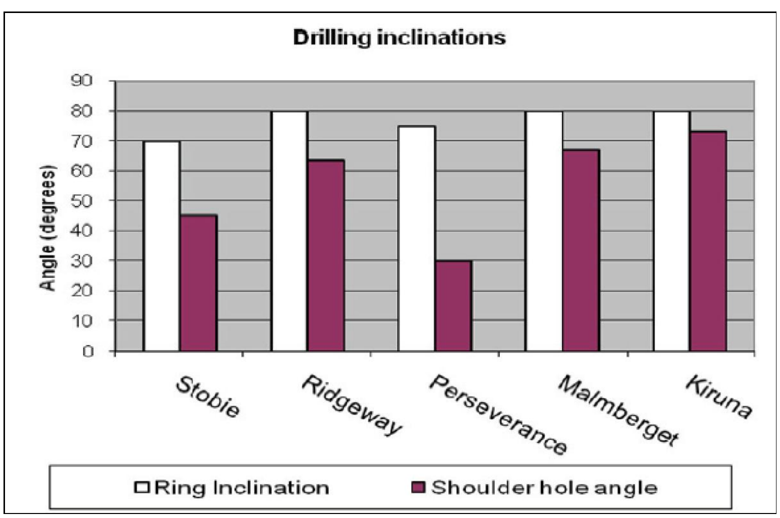


Figure 7: Drilling inclination data

Figure 7 shows a summary of drilling inclinations at the mines surveyed. Ring inclination is relatively uniform at between 70° and 80° forward to the horizontal. Shoulder hole angle is more variable, ranging from 30° from the horizontal at Perseverance to more than 70° from the horizontal at Kiruna. Generally the greater the inclination on the shoulder hole, the more the ring shape will conform to the natural granular flow tendency of the broken rock. However higher shoulder hole inclinations extend the length of the drill holes at the center of the ring, and in poor ground conditions, long holes can be difficult to keep open, resulting in excessive re-drills, and reduced blasting performance.

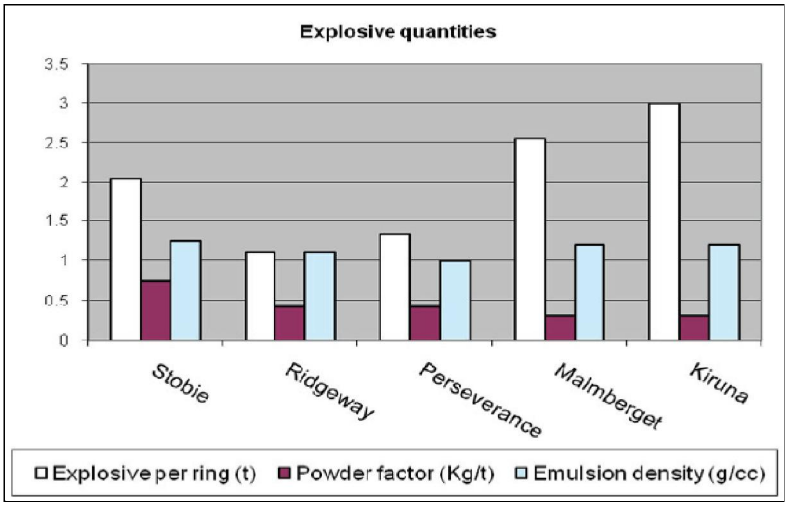


Figure 8: Explosive data

Figure 8 shows data on explosive use for different drilling patterns used at the mines surveyed. This indicates that the mines with larger layouts such as Kiruna and Malmberget use more explosives in each ring fired, but have lower average powder factors, due to the larger ring tonnages. This is keeping with the cost design focus at these mines.

2.2.3. Production and draw control

Draw strategy and production management are extremely important in SLC operations because of the difficulty in accurately predicting and controlling the flow of fragmented ore and waste rock. Effective draw control practice depends of fragmented material flow characteristics and the grade distribution within and around the orebody. The main objective of draw control planning is to maximize overall production rate and ore recovery with the minimum possible dilution. It is difficult due to the variability of material flow characteristics in individual drawpoints. Current draw control practices generally aim to ensure the achievement of specified major period production targets related to tonnes and grade.

Factors which influence the rate at which a mine can produce include:

- Orebody geometry
- Geotechnical conditions
- Ore handling system capacity
- Equipment unit size, fleet size and mechanical condition
- Fragmentation

Figure 9 shows comparisons of productivity at the mines surveyed in terms of tonnes per drawpoint per day. This indicates that the large scale tonnage focused operations allow for significant advantages in throughput, even factoring for orebody size. The scale and life of these mines acts to their advantage, as large scale ore transportation systems can be installed to service the mines over a period of many years, while smaller mines cannot always justify the installation of such large scale systems. Other factors, such as geotechnical conditions and fragmentation also impact the ability of some mines to produce at these scales.

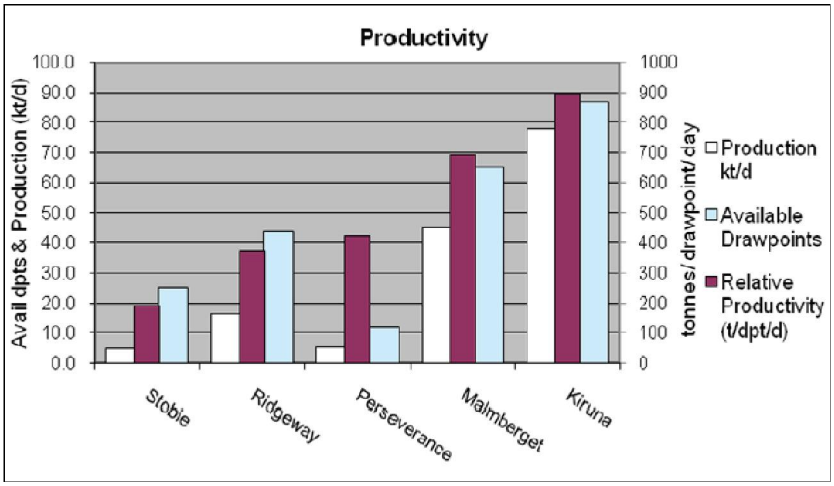


Figure 9: Key productivity parameters

Figure 10 shows a combination of productivity information collected in the survey. These attempts to balance the advantages some mines see in resource extraction against what other mines see in productivity and cost. It indicates that while the large scale, cost focused mines tend to recover less of the in-situ ore than the recovery focused mines, the rate and volume at which they produce allows them to produce relatively more metal over a given time period at a lower cost, giving them overall productivity advantages.

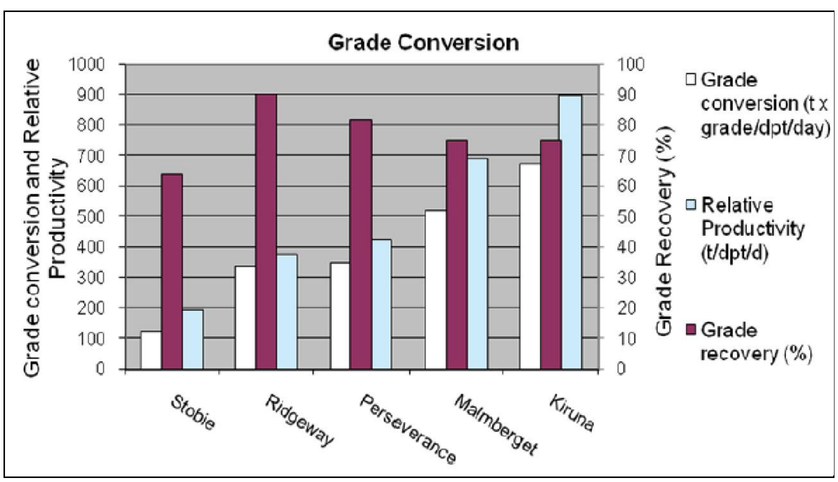


Figure 10: Calculation of grade conversion

2.3. Gravity Flow in Sublevel Caving

Sublevel Caving is a mass mining method based upon the utilization of gravity flow of blasted ore and caved waste rock (Hustrulid and Kvapil, 2008). The method functions on the principle that ore is fragmented by blasting, while the overlying host rock fractures and caves under the action of mine induced stresses and gravity (Bull and Page, 2000). The caved waste from the overlying rock mass fills the void created by ore extraction. The flow behavior is influenced by the geometry of the extraction layout and drives, sublevel height, blast ring design, characteristics of the blasted ore and waste material and draw control methodology. Due to the complex interaction of these parameters, the flow behavior has been studied and quantified through theoretical, small and full scale experimental programs for almost 50 years but it is still not fully comprehended.

2.3.1. Small Scale Experimental work

Small scale experimental work investigating SLC flow behavior has been ongoing for over 40 years, providing an extensive knowledge of gravity flow behavior and theoretical calculation for SLC design and mixing behavior. One of the most famous studies was done in Czechoslovakia in 1950. Rudolf Kvapil constructed the sand models to study the gravity flow principles in bins and silos. In 1965, Kvapil joined Janelid at Division of Mining, the Royal Institute of Technology (KTH) in Stockholm and began applying the gravity flow principles gained in the study of bins and silos to sublevel caving. Figure 11 shows one of the elaborate sand models constructed as part of the studies(Hustrulid and Kvapil, 2008). With draw, the ore contained within the black ellipsoid of extraction disappears through the drawpoint as the ellipsoid of loosening forms.

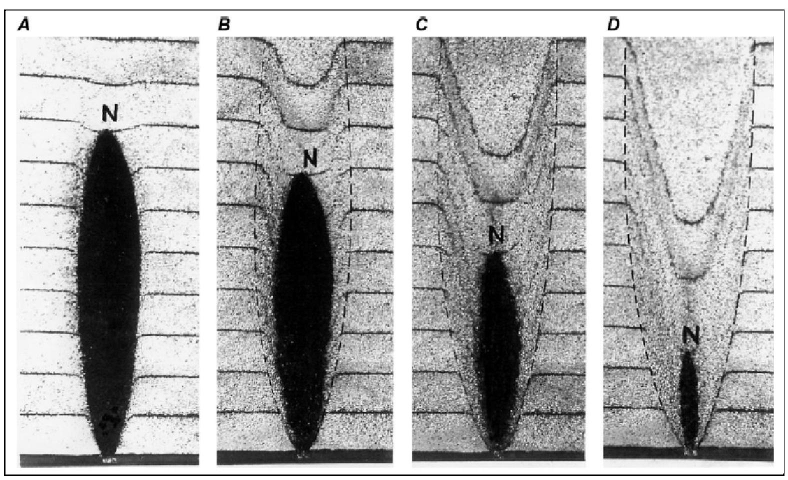


Figure 11: Typical sand model showing the draw ellipse(Hustrulid and Kvapil, 2008).

The fundamental concept of this theory was the flow ellipsoid illustrated in Figure 12 where the flow ellipsoid was divided into two distinct boundaries – the ellipsoid of motion and limit ellipsoid. It was one of the first attempts to describe material flow mathematically. The theory proposed that the shape of a given ellipsoid was described by its eccentricity which is related to the major and minor semi-axes of the ellipsoid. The eccentricity of the ellipsoid was dependent upon a number of parameters including the size, shape, and form of the particle, surface roughness of particles, angle of friction, density, extraction rate, and particle material properties such as strength and moisture(Hustrulid and Kvapil, 2008).

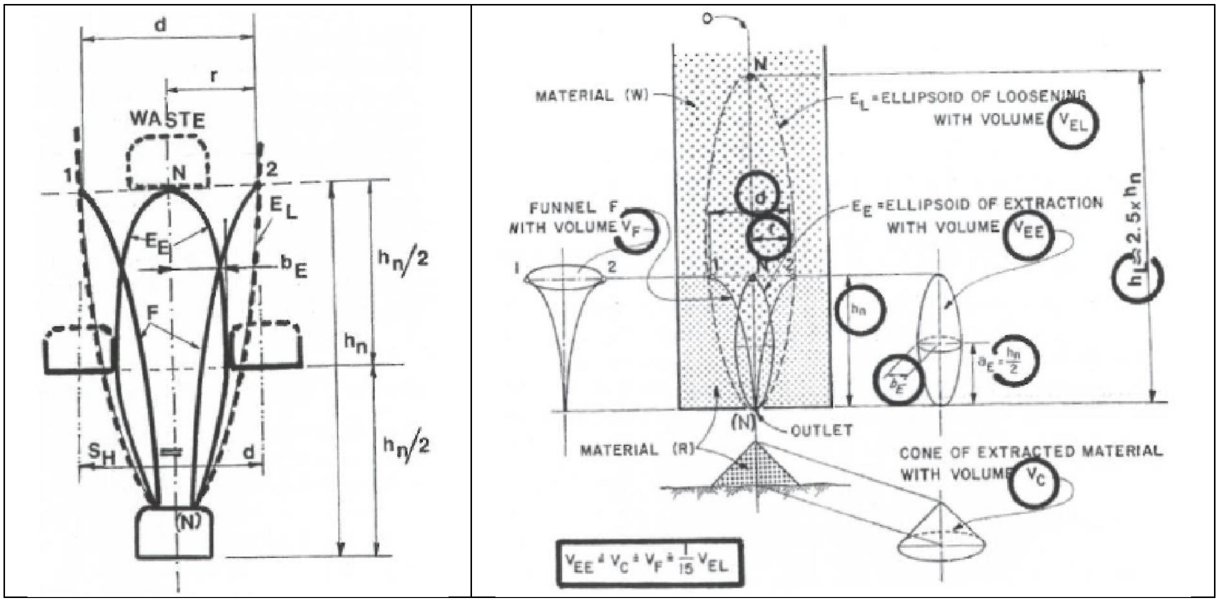


Figure 12: Flow ellipsoid concept proposed by Janelid and Kvapil

2.3.2. Full Scale Experimental Work

Full scale experiments have been undertaken at a number of SLC operations for over 40 years trying to validate numeric and small scale models and assess the SLC flow behavior for further development. These experiments have generally used markers (plastic or metal) installed in the ring and recovered visually at the drawpoint or within the material handling process. Results from these experiments have provided information and understanding about the development and final shape of the extraction zone, but no details relating to the movement zone.

2.3.2.1. The Grängesberg mine marker tests

The first important marker trials was done at the Grängesberg mine (Janelid, 1972), where over 15,000 plastic markers were used for these trials, with approximately 70 percent of markers recovered visually at the drawpoints. Marker density was high (five marker ring planes in a 1.5 m burden) but restricted to the top half of the blasted ring(markers installed in downholes from the level above). Sublevel geometry is shown in the Table 1 (approximately half the size of current SLC mines).

Table 1: Grängesberg SLC mine geometry

Parameter	Value
Sublevel drift spacing (m)	7
Sublevel spacing (m)	13
Hole diameter (mm)	41
Burden (m)	1.5
Sublevel drift width (m)	3.0 slashed to 3.5
Sublevel drift height (m)	3
Front inclination (degrees)	90

Figure 13 shows the average volumes of motion as determined using the markers positioned 15 cm in front ofthe mining front for loaded ore quantities of 400 tons and 600 tons.

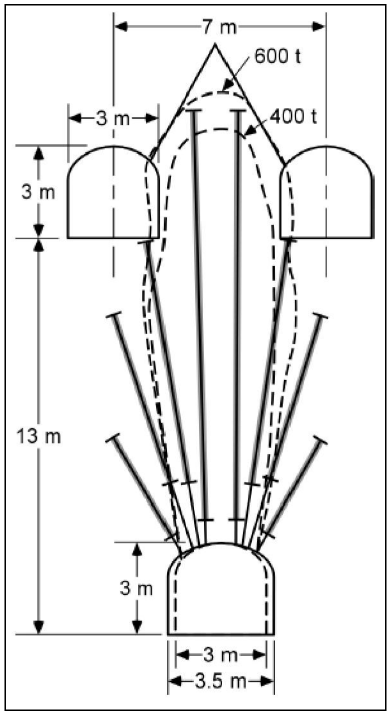


Figure 13: Results of the Grängesberg marker tests

2.3.2.2. The Kiruna mine marker tests

The SLC design implemented at LKAB's Kiruna mine at 2000 exceeded the dimension of the guideline used at that time and therefore a detailed marker study was carried out with the purpose of verify the gravity flow pattern for this very large sublevel caving area (Quinteiro, 2001). Table 2 summarizes some of the important parameters. The length of the longest holes was of the order of 40m.

Table 2: Kiruna SLC mine geometry

Parameter	Value
Sublevel drift spacing (m)	25
Sublevel spacing (m)	27
Hole diameter (mm)	114
Burden (m)	3
Sublevel drift width (m)	7
Sublevel drift height (m)	5
Front inclination (degrees)	80

Figure 14 (left) shows a vertical section the 15 marker located in a fan. The markers were installed in special holes drilled half way between the production rings. A total of 908 markers were installed in 24 and only 272 were recovered. Figure 14 (right) displays the results of the recovered markers as a percentage of the total number of markers installed at each particular location.

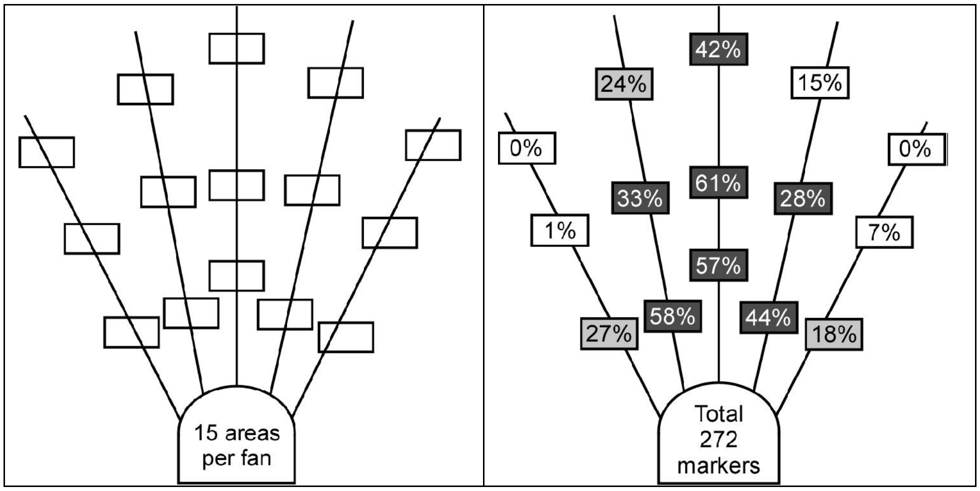


Figure 14: Marker install and recovered at the Kiruna mine

A large number of markers were recovered from the central part of the fan and only a small number from the sides of the fan. It indicates a low interaction between rings in the same level and it describes a predominant ore flow pattern in the center. Figure 15 shows the recovery in the form of a contour plot.

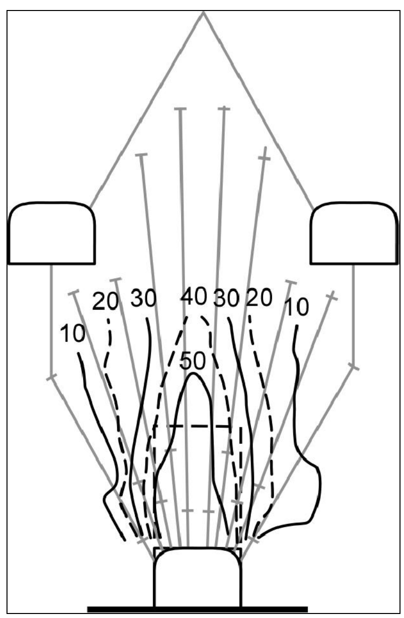


Figure 15: Contour plots showing the percent recoveries at the different marker positions

2.3.2.3. The Perseverance mine marker studies

The Perseverance mine in 2000 reduced the sublevel drift spacing from 17.5m to 14.5m with the idea to facilitate interactive draw(Hollins and Tucker, 2004).It motivates to implement a marker study where a total of1762 markers were installed at one-meter intervals in five separate crosscuts on three different levels of the mine. The geometry used in Perseverance mine is shown in the Table 3.

Table 3: Perseverance SLC mine geometry

Parameter	Value
Sublevel drift spacing (m)	14.5
Sublevel spacing (m)	25
Hole diameter (mm)	102
Burden (m)	3
Sublevel drift width (m)	5.1
Sublevel drift height (m)	4.8
Front inclination (degrees)	75

Based on the marker recovered was no evidence of interaction between rings at the same level, where the maximum width of draw measured was 11.5m (+/- 1m).The overall flow as determined from the markers is shown in Figure 16.

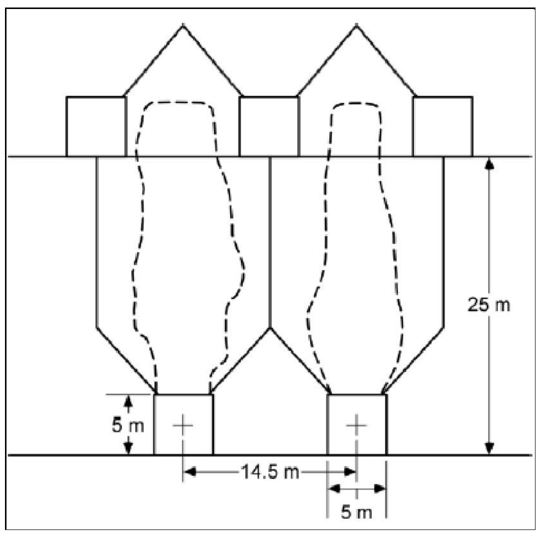


Figure 16: Ring geometry and overall flow determined from the markersat Perseverance mine

More than 100% of design tones were depleted from the marker trial rings and material from the side of the ring was not reported and therefore the material is been traveling to the drawpoint from outside the blast envelope. The trials indicate that markers located at the level above can flow into the drawpoint with 20% of drawn. Finally this study classified the material based on the place where the maker was recovered showing the following numbers:

- Primary recovery: 60-70% (markers were recovered on the level on which they were installed)
- Secondary recovery: 20 - 25% (marker recovered on the subsequent level)
- Tertiary recovery: 10 - 15% (marker recovered on the third level)
- Quaternary recovery: Up to 8% (marker recovered on the fourth level)

3. Ridgeway Gold Mine

Ridgeway Gold Mine is located approximately 250km west of Sydney, Australia, near the city of Orange in N.S.W. see figure 17. The Ridgeway and Cadia Hill gold mines form Cadia Valley Operations, which are owned and operated by Newcrest Mining Limited. The Ridgeway gold-copper orebody was discovered in November1996, with mine construction and commissioning completed in March 2002. The expected mine life of the Ridgeway operation is ten years based on current reserves. Average annual metal production from the mine at full production will be 280,000 ounces of gold and 28,000tonnes of copper. Production for 2004-2005 was 382,000 ounces of gold and 42,900 tonnes of copper from the treatment of 5.59 million tonnes of ore grading 2.55 g/t gold and 0.86 percent copper (Brunton, 2010).

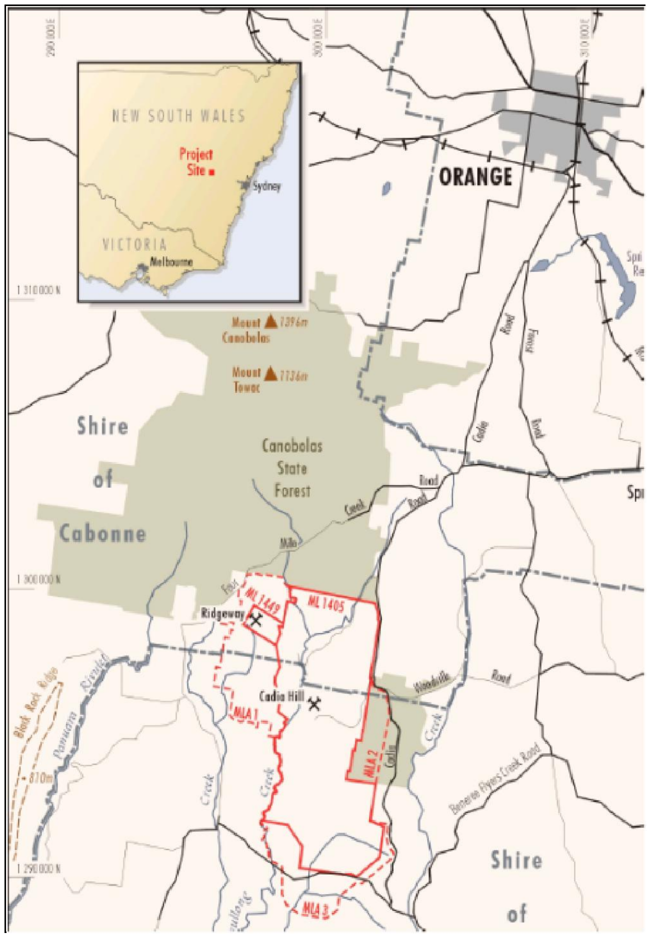


Figure 17: Ridgeway Gold Mine location

The orebody is a stockwork and sheeted quartzite centered on a monzonite intrusion, and is accessed via decline development. The ore handling system at the mine comprises a series of sub-vertical ore passes which feed a gyro crusher located approximately 900m below surface. Crushed ore is transported to the surface via 4km conveyor decline. The SLC production beginning in 2000 and the mine layout consist of 13 sublevels of 25 and 30 meters, an isometric view of the mine is shown in the Figure 18.

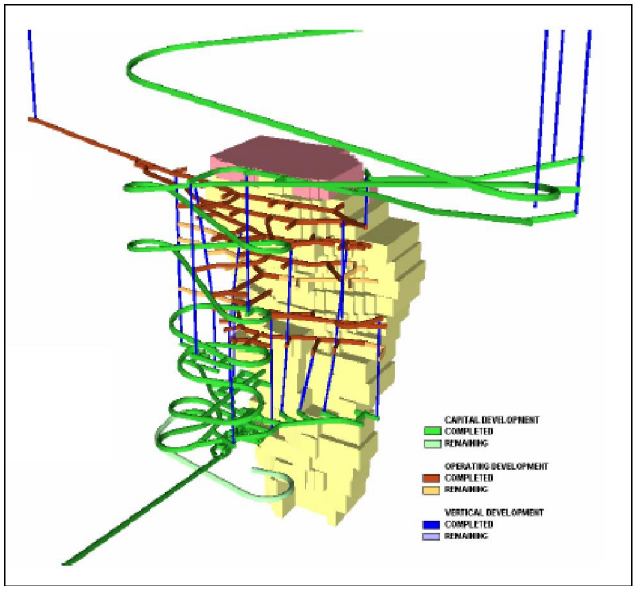


Figure 18: Isometric view of the Ridgeway mine layout

A vertical section (looking west) of the mine with the lithological composition and the distribution of the mine by level is shown in the Figure 19. The dates describes the time to the Ridgeway cave to breakthrough to the surface.

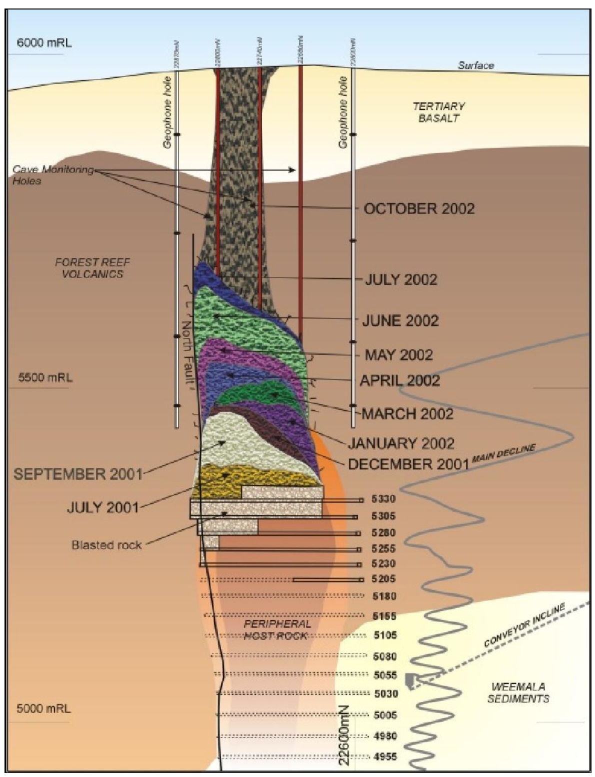


Figure 19: Vertical section looking west of Ridgeway Mine

3.1. Data and information provided

A complete set of information was provided by Ridgeway mine for this study:

- SLC Design
- Block Model
- Monthly Production Records
- Ring Summary data
- Geology Assay Results

3.1.1. SLC Design

The actual SLC design was provided in Surpac string file with the following details:

- Sublevel interval 25m between the 5330 (top level) to 5130 level. Sublevel interval then increased to 30m from the 5100 to 5010 (bottom level) levels.
- Drive spacing is 14 m center to center.
- Cross cut geometry is 6.0 x 4.7m (Figure 20).
- Ring burden is generally 2.6 m (although variations to this exist, refer to drill and blast).
- Ring inclination is 10 degree dump towards the cave.

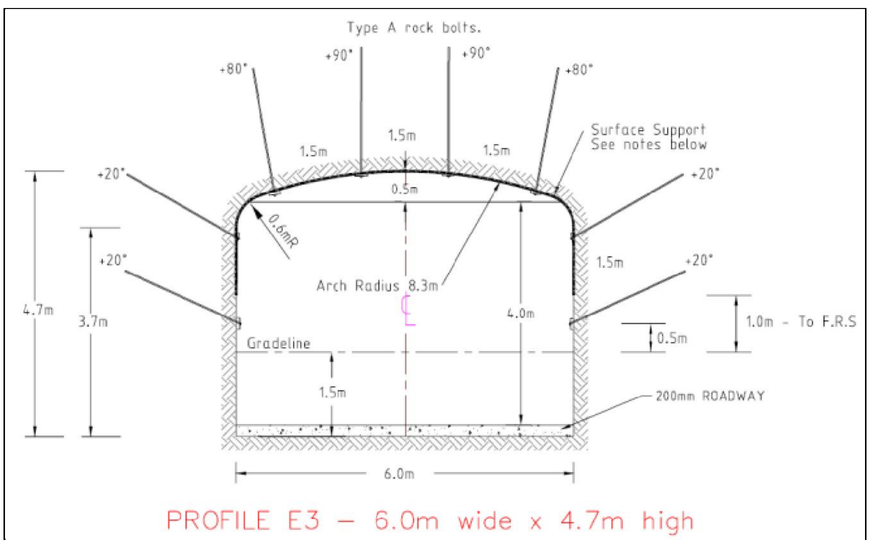


Figure 20: Typical cross cut geometry

The standard blast pattern is shown in Figure 21, where it is possible to see the distribution of the blasthole and the typical geometry of an actual ring.

The design lines were imported in Gems to get the real location of the production drift and then be able to create rings using their real location (Figure 22). Level 5010 was not used in this study since the detail of tonnage and grade weren't provided.

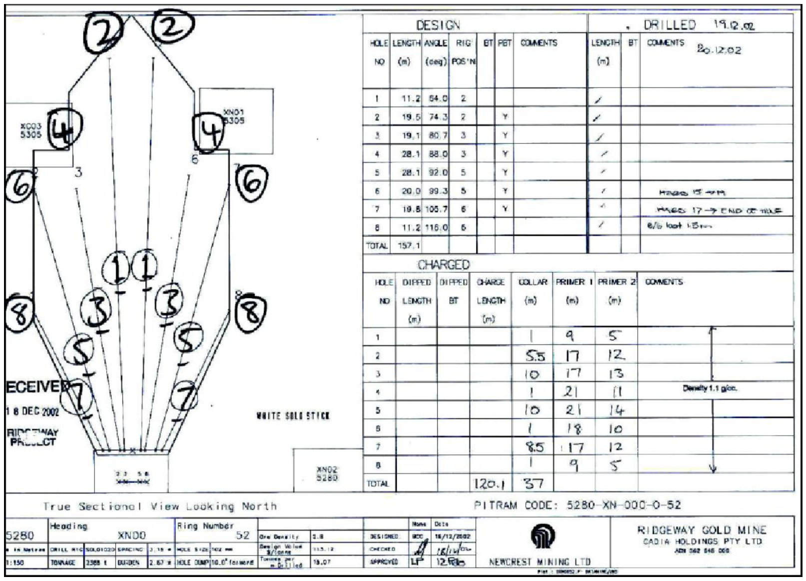


Figure 21: Standard blast patter for a typical ring

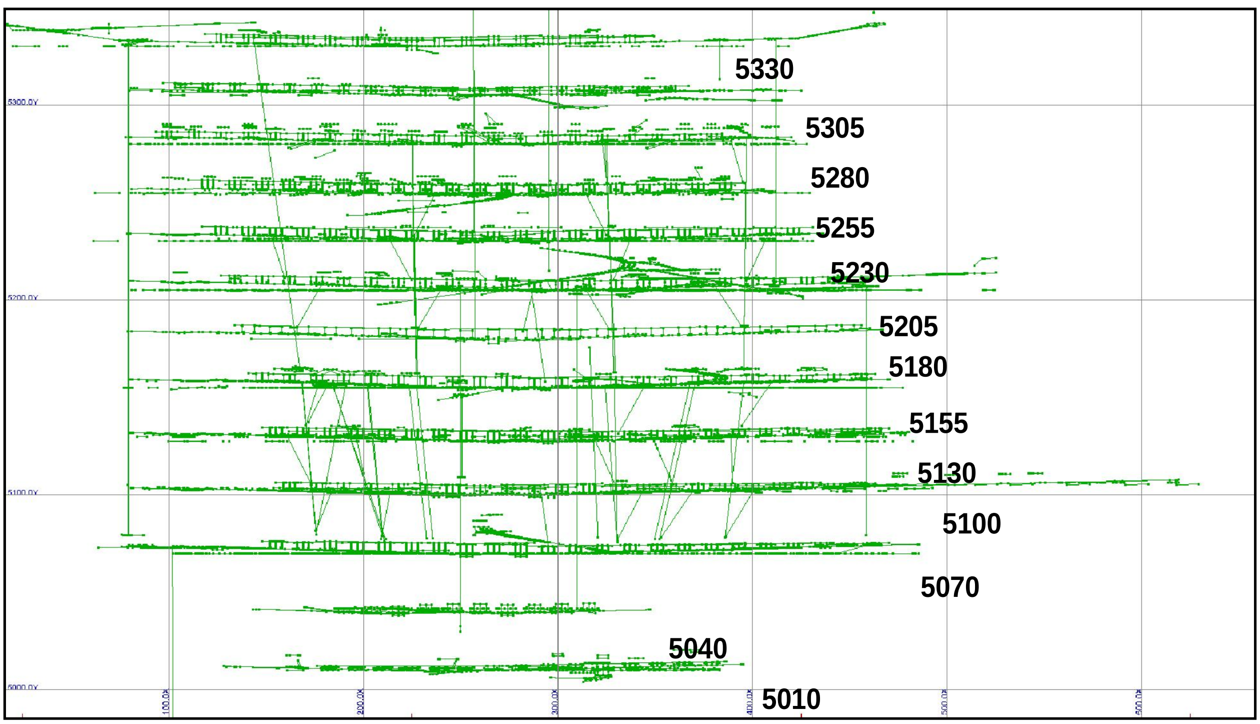


Figure 22: Monthly production record

3.1.2. Block model

The block model is one of the most important components in the calibration work since it provides the grade information to use during the simulation of the production and then be able to compare grades reported by PCSLC versus actual grades. Figure 23 shows the gold and copper grade in the block model at vertical section at 22750N, it is located at the middle of the layout so it gives a good representation of the grade distribution in the deposit.

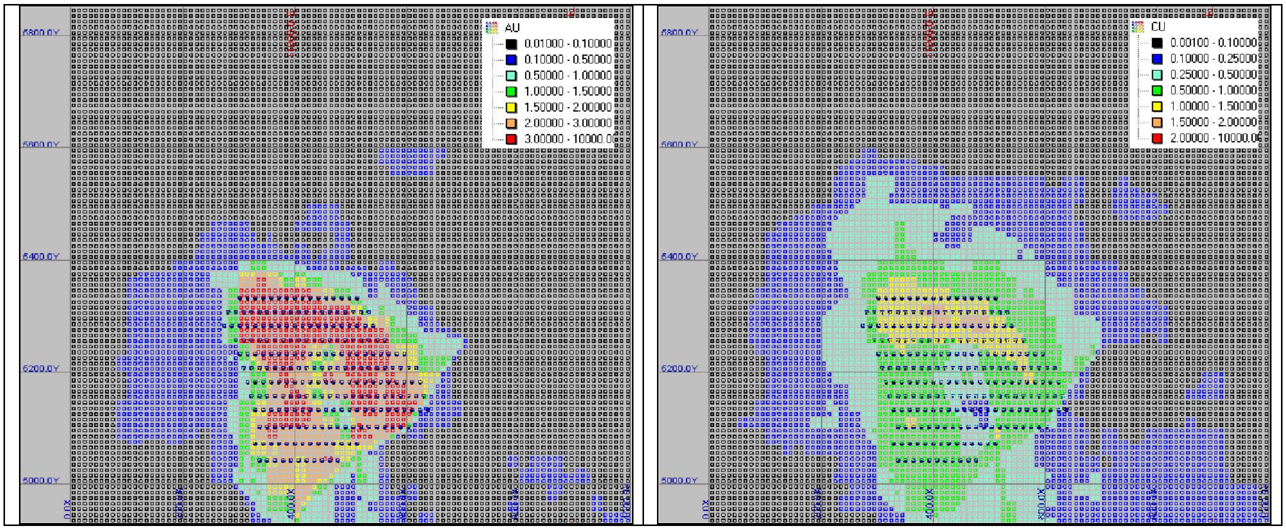


Figure 23: Block model gold (left) and copper (right) grade

3.1.2.1. Statistical analysis

A brief statistical analysis was done to get a better understanding of the grade and density distribution. Table 4 shows a summary of the block model in restricted to the layout area only.

Table 4: Statistical information of the Block Model

Field	Min value	Max value	Min Row	Max Row	Min Col	Max Col	Min Level	Max Level	Ave(non-zero)	Num(non-zero)
Rock Type	99	120	1	45	1	100	1	160	112.77	720,000
Density	2.72	2.77	1	45	1	100	1	160	2.75	720,000
AU	0.00	9.28	1	45	1	100	1	160	0.16	720,000
CU	0.00	1.83	1	45	1	100	1	160	0.11	720,000
AG	0.01	4.97	1	45	1	100	1	160	0.24	720,000
S	0.03	2.47	1	45	1	100	1	160	0.38	719,928
VALUE	0.50	259.61	1	45	1	100	1	160	6.73	719,928

Figure 24 shows the distribution of the grades per level. It shows a clear increment from Level 5395 where the average is 0.40% and 0.25 g/t for Cu & Au respectively. Considering that the first extraction level is located at 5330 it provided a layer of good grade before get mainly dilution.

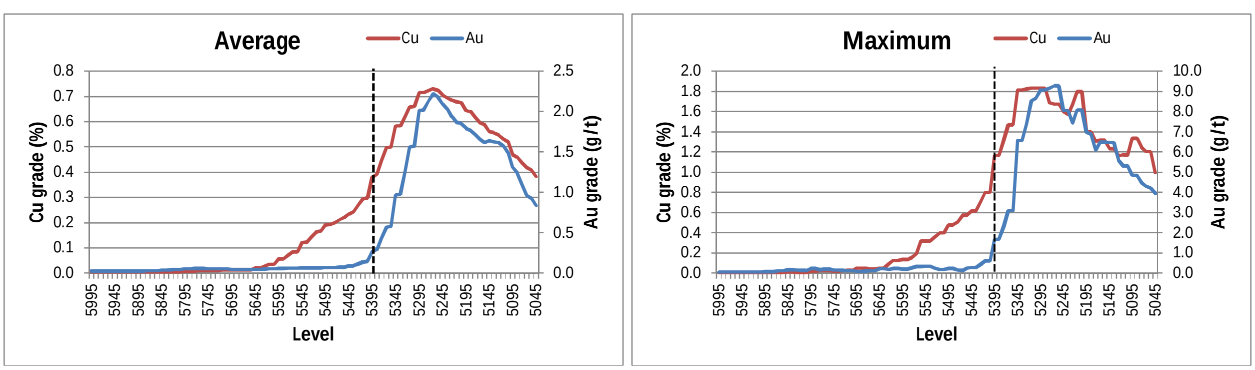


Figure 24: Average and Maximum values for Au and Cu grade per level

3.1.3. Ring Summary

Summary information was provided per ring in the file "Ridgeway SLC DP & DS All Data.xlsx". Table 5 shows an example of the ring data.

Table 5: Ring summary information

Easting	Northing	R.L.	DPID	Actual Mined Tonnes	Design Tonnes	%Drawn	Start	Finish	Level	Tunnel
10,881	22,726	5,305	5305XN025O37	1,734	1,970	88%	16-May-02	17-Jun-02	5305	XN025
10,881	22,729	5,305	5305XN025O36	1,735	1,972	88%	20-Mar-02	16-May-02	5305	XN025
10,881	22,732	5,305	5305XN025O35	1,735	1,972	88%	5-Mar-02	20-Mar-02	5305	XN025
10,881	22,734	5,305	5305XN025O34	793	1,982	40%	23-Jan-02	28-Feb-02	5305	XN025
10,881	22,737	5,305	5305XN025O33	795	1,988	40%	16-Jan-02	20-Jan-02	5305	XN025
10,881	22,739	5,305	5305XN025O32	796	1,991	40%	5-Jan-02	14-Jan-02	5305	XN025
10,881	22,742	5,305	5305XN025O31	797	1,991	40%	23-Dec-01	5-Jan-02	5305	XN025
10,881	22,745	5,305	5305XN025O30	798	1,996	40%	14-Dec-01	21-Dec-01	5305	XN025
10,881	22,747	5,305	5305XN025O29	799	1,998	40%	1-Dec-01	12-Dec-01	5305	XN025
10,881	22,750	5,305	5305XN025O28	800	2,000	40%	19-Nov-01	24-Nov-01	5305	XN025
10,881	22,752	5,305	5305XN025O27	801	2,001	40%	7-Nov-01	10-Nov-01	5305	XN025
10,881	22,755	5,305	5305XN025O26	801	2,002	40%	1-Nov-01	6-Nov-01	5305	XN025
10,881	22,758	5,305	5305XN025O25	800	2,000	40%	28-Oct-01	31-Oct-01	5305	XN025
10,881	22,760	5,305	5305XN025O24	801	2,002	40%	22-Oct-01	25-Oct-01	5305	XN025
10,881	22,763	5,305	5305XN025O23	804	2,010	40%	10-Oct-01	21-Oct-01	5305	XN025
10,881	22,765	5,305	5305XN025O22	800	2,000	40%	3-Oct-01	9-Oct-01	5305	XN025
10,881	22,768	5,305	5305XN025O21	800	2,000	40%	30-Sep-01	2-Oct-01	5305	XN025
10,881	22,771	5,305	5305XN025O20	800	2,000	40%	23-Sep-01	28-Sep-01	5305	XN025

This information was very useful to get key data to replicate the extraction done in Ridgeway:

- Real location of the rings. This provides the exact location of each ring to be able to replicate the real position and burden used during the operation.
- Actual and design tonnage. This is key information to extract the same tonnage depleted in each ring so it will be the percent of draw per each ring, tunnel and level. A detail of tonnage designed and extracted is shown in Table 6. It described the strategy used for the mine to mitigate the contamination by dilution above of Level 5330.
- Date start and finish. The dates will provide valuable information to define the blast sequence and the time spent to work in each specific ring.

Table 6: Percent extraction per level

Level	Design Tons	Extracted Tons	%Extraction
5330	783,520	411,465	53%
5305	2,415,503	1,567,533	65%
5280	2,619,320	2,279,549	87%
5255	2,826,836	2,921,361	104%
5230	2,947,129	3,548,220	121%
5205	3,056,328	3,496,568	115%
5180	3,026,981	3,436,195	114%
5155	2,686,947	3,548,731	132%
5130	2,998,515	3,939,907	132%
5100	2,968,202	4,531,597	153%
5070	2,906,371	3,949,471	136%
5040	1,571,047	1,896,716	121%
Total	**30,806,698**	**35,527,314**	**116%**

3.1.4. Monthly production data

The monthly SLC Production data contained the tonnage, gold and copper grade information after Mill reconciled per level. Figure 25 and 26 show the production record of the mine by level in 10 years. This information was substantial for the calibration process.

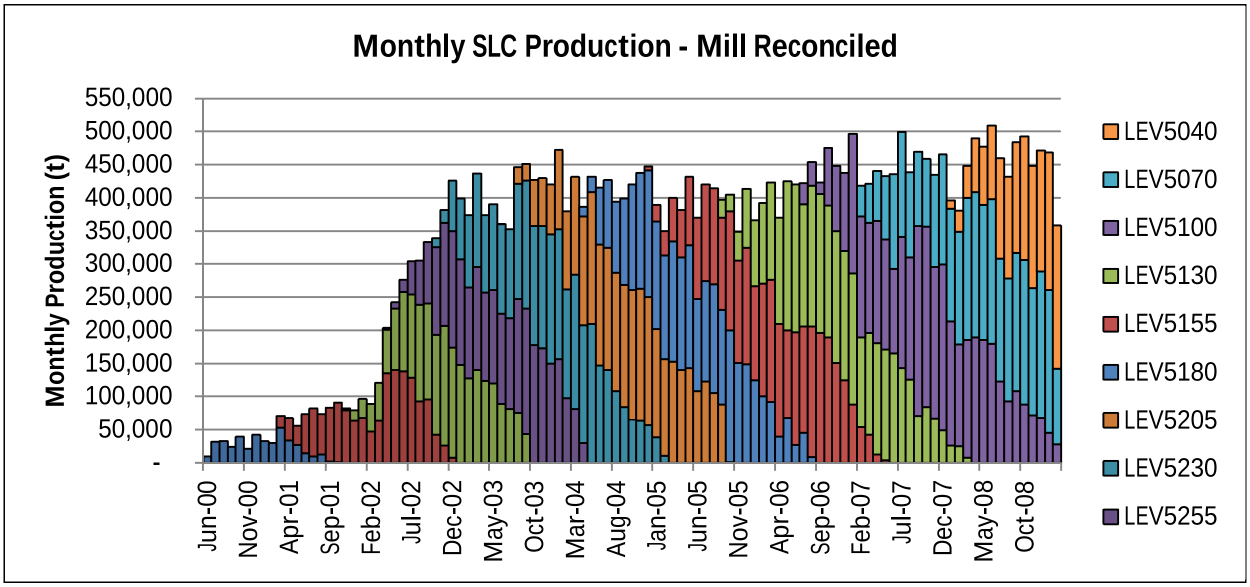


Figure 25: Monthly production per level

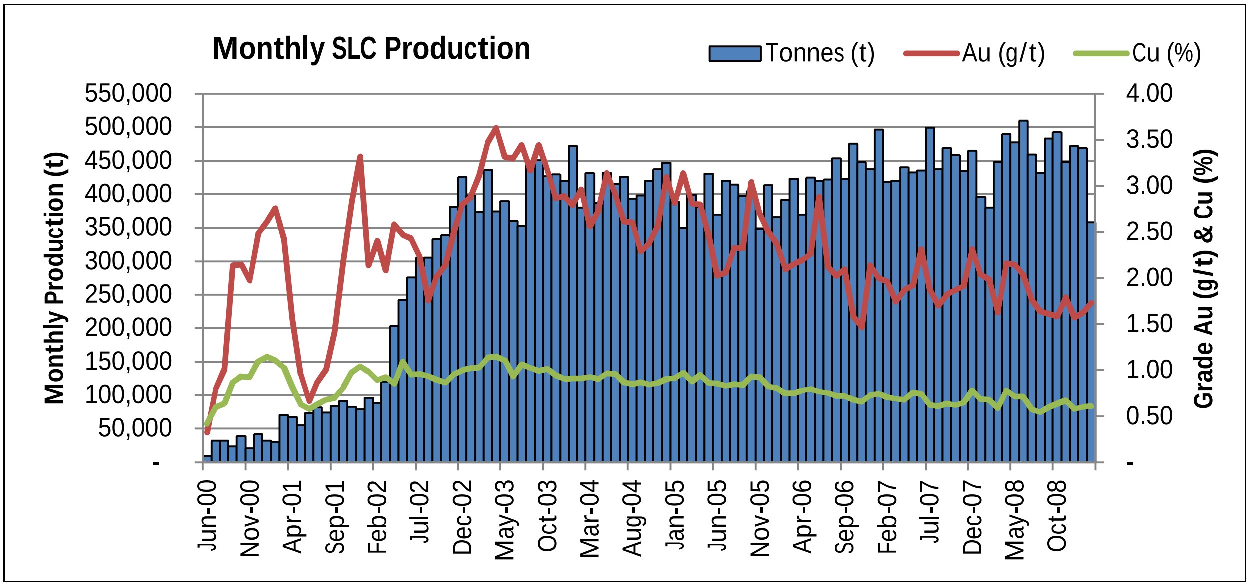


Figure 26: Monthly production (Tonnage, gold and copper grade)

Full detail of the Monthly SLC Production - Mill Reconciled is shown in the Appendix A.

3.1.5. Geology Assay Results

This information provide the result of the sample taken from several rings in many levels therefore this information can be used to compare with the grade reported by PCSLC as another option for calibration. Table 7 shows an example of the set of information from the geological assay data.

Table 7: Geology Assay data (Gold and Copper)

SAMPLEID	LEVEL	PROJECTCODE	SAMPLETYPE	Au_ppm	Cu_ppm	RingID	SampleDate	Sampler	Shift	Technicians	BucketsBogged	Sampled
5330XN025O35X0000	5330	RW	RING			5330XN025O35	11-Mar-02		n	LD	0	N
5330XN019O07X2040	5330	RW	RING	0.72	6640	5330XN019O07	31-Dec-02		d	Jco	2040	Y
5330XN019O07X1840	5330	RW	RING	0.42	5250	5330XN019O07	31-Dec-02		d	Jco	1840	Y
5330XN002O36X0060	5330	RW	RING			5330XN002O36	11-Mar-02		n	LD	60	N
5305XN025O38X0000	5305	RW	RING			5305XN025O38	19-Jun-02		n	MH	0	N
5305XN025O37X0060	5305	RW	RING			5305XN025O37	17-Jun-02		d	MK	60	Y
5305XN025O37X0020	5305	RW	RING			5305XN025O37	16-Jun-02		n	MH	20	N
5305XN025O37X0000	5305	RW	RING			5305XN025O37	16-May-02		n	LD	0	Y
5305XN025O36X0090	5305	RW	RING			5305XN025O36	16-May-02		d	MK	90	N
5305XN025O36X0085	5305	RW	RING			5305XN025O36	11-Apr-02		n	MK	85	Y
5305XN025O36X0045	5305	RW	RING			5305XN025O36	9-Apr-02		n	MK	45	N
5305XN025O36X0030	5305	RW	RING			5305XN025O36	7-Apr-02		n	MK	30	N
5305XN025O36X0010	5305	RW	RING			5305XN025O36	7-Apr-02		d	MH	10	N
5305XN025O36X0000	5305	RW	RING			5305XN025O36	20-Mar-02		n	JC	0	Y
5305XN025O35X0060	5305	RW	RING			5305XN025O35	20-Mar-02		d	LD	60	N
5305XN025O35X0020	5305	RW	RING			5305XN025O35	9-Mar-02		d	MK	20	N
5305XN025O35X0000	5305	RW	RING			5305XN025O35	5-Mar-02		d	MK	0	N

3.2. Trial marker scale experiments applied at Ridgeway Mine

Several studies were done at Ridgeway mine from 2001 trying to understand the gravity flow behavior of the SLC system. The implementation of full scale SLC marker trials has been noted to be crucial for the ongoing success of the mining method. Such trials provide detailed information concerning the development and shape of the extraction zone, identify possible sources of waste ingress into the ring, and determine the degree of flow behavior variability.

The marker trials undertaken at the Ridgeway SLC gold mine provide a unique opportunity to assess these factors. These trials are considered to be the most comprehensive to date, with 69 individual ring trials completed from July 2002 to April 2005. The Ridgeway marker dataset was used in this thesis to assess and quantify factors influencing material flow behavior and extraction zone recovery.

3.2.1. Marker Trial Experimental Method

The marker trial experimental method adopted by the Ridgeway operation was developed over a period of time and summarized by Power (Power, 2004). The marker trial design was based the following requirements:

- Recovery of 75 percent or more of markers which report to the drawpoint.
- Minimal disruption to operations.
- Cost effectiveness.
- Minimization of the effect of the experimental procedure on trial results.
- Data redundancy, to allow for some markers to be lost without affecting the trial result.

The experimental method can be divided into three components, marker design and installation, marker ring location and density, and marker recovery. The following sections briefly describe each of these components.

3.2.2. Marker Design and Installation

Markers were designed to monitor flow behavior of rock in the mine within the limitations of the installation techniques available. They had to be individually identifiable, robust enough to survive the initial blasting process and subsequent cave flow, and be recovered in a relatively easy and reliable fashion to ensure sufficient data for further analysis (Power, 2004). Based upon these requirements, markers were constructed from 42 mm diameter hollow steel pipe (inside diameter 38 mm) cut to 250 mm lengths (Figure 27). The pipe was filled with cement in an attempt to match the density of the marker to that of the rock within the cave. A four letter code was welded on the pipe to uniquely identify each marker (Power, 2004).

Figure 27: Metal marker used at the Ridgeway SLC operation

Installation of the marker up a drill hole required the installation of a 'redcap' and 'spider' at the base and top of the marker respectively. The redcap was designed to hold the weight of the marker in the hole, while the spider was used to centralize the marker during installation (Figure 27). Markers were loaded into holes by the use of an explosive truck, which allowed the distance of the marker up the hole to be accurately measured. Once installation was completed, markers were grouted in place to ensure no movement before blasting (Power, 2004).

3.2.3. Marker Ring Location and Density

Marker ring location and density of markers placed within the ring are important in defining the geometry of the extraction zone. The first trial undertaken at the Ridgeway operation used241 markers in one ring plane consisting of 13 holes (located 1.3 m from the blast ring plane)and an in hole marker spacing of 1 m (Power, 2004). The results of this trial indicated that the experimental procedure was sound. It did however highlight that the distribution of markers in the burden was not adequate to quantify the extraction zone, in particular the depth of draw (Power, 2004). Based upon this finding, further trials were designed with three marker ring planes located at 0.65 m (Ring 3), 1.3 m (Ring 2), and

1.95 m (Ring 1) from the blast ring plane. A two and three dimensional representation of marker location for a typical three ring marker trial can be referred to in Figure 28 (left) and (right) respectively.

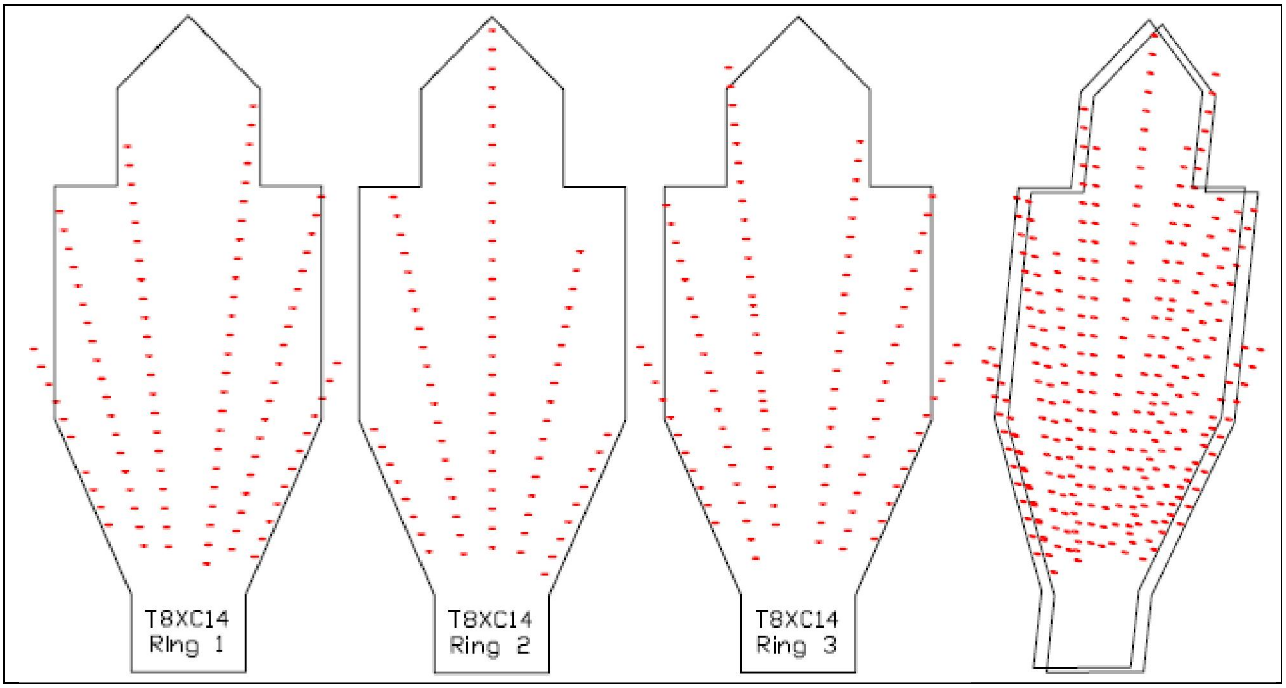


Figure 28: Typical two and three dimensional distribution of markers in a three ring marker trial

Three ring marker trials usually consisted of 17 marker holes, with approximately 320 markers installed per trial. Further refinement of marker ring locations were made after the eighth trial, with Ring 3 (located 0.65 m from the blast hole ring) being removed from the experiment. This resulted in a total of 11 marker holes being drilled, with approximately 190 markers installed per trial. A total of 15 and 53 individual rings were monitored with two and three ring marker planes respectively.

3.2.4. Marker Recovery

The recovery of an adequate number of markers is critical to the success of any full scale flow trial. Traditionally, marker recovery has been undertaken visually at the drawpoint with mixed success. A three stage approach for marker recovery was designed for the initial marker trials reported by (Power, 2004):

1. The first stage involved the visual identification and collection of markers at the drawpoint and LHD bucket (Figure 29). This approach was discontinued after the first trial due to marker detection rates being extremely low (the only markers detected were between 100 percent and 120 percent draw).

Figure 29: Collection of markers at the drawpoint

2. The second stage involved the visual identification and manual collection of markers from a conveyor belt after primary crushing (Figure 30). Approximately 50 percent of markers were recovered with this method of detection.

Figure 30: Marker recovery from the collection conveyor belt

3. The third stage involved the use of two magnets on the conveyor belt system after primary crushing to recover the markers. A trial of 100 'calibration' markers placed within the ore pass system indicated 100 percent recovery of markers with this method.

Based upon these results, the use of magnetic separation of markers within the material handling process was adopted. This method provides a relatively simple method of ensuring high recovery rates for markers extracted at the drawpoint. The main disadvantage of magnetic separation is that it does not provide detailed information concerning the development of the extraction zone over time (i.e. recovery of markers with respect to percentage draw).

3.2.5. Delineation of Extraction Zones

Delineation of extraction zones within a trial ring were made with information obtained from the recovered markers. These zones are divided into five categories defining primary, secondary, tertiary, quaternary, and backbreak respectively (the level of recovery for any given trial dependent upon the initial location of markers).

Three major assumptions are made for zone delineation:

1. The extraction zone is delineated as a series of polygons in two dimensions.
2. 100 percent of markers are recovered by magnetic separation within the material handling process.
3. Installed marker locations represent the location of markers after the blasting process (i.e. markers do not move from their original location during blasting).

Instead of a general ellipsoid shape being fitted to the data, the extraction zone is defined by a number of polygons based upon actual markers recovered. Delineation of these polygons is based upon a number of criteria or 'rules' consisting of:

- Polygon boundary defined by the half-way point between two markers (x and y directions).
- Polygon boundary bound by the blast ring outline.
- At least two markers adjacent to one another and having the same recovery level (primary, secondary, tertiary, quaternary, or backbreak) are required to define an extraction polygon (i.e. single markers do not define an extraction zone).
- Single markers of a different recovery level to those surrounding it may be contained in the polygon defining the dominant marker recovered.
- Markers not recovered in the material handling process are assumed to represent material not extracted from the cave to date.
- Areas within the blast ring that do not contain markers are treated as not being monitored; with extraction polygons terminating at these regions (i.e. polygons do not extend into areas with no marker coverage).

These criteria are considered important as they provide a systematic and consistent approach in defining extraction zones (Power, 2004).

While these polygons do not represent the true shape of the extraction zone, they do provide an insight into the non-uniform nature of full scale material flow. An example of delineated extraction zones for a single marker ring plane can be referred to in Figure 31.

Figure 31 described a relatively dense marker pattern with complete ring coverage is required to achieve an acceptable level of confidence for the delineation of extraction zones. Without this level of marker coverage the delineation and interpretation of these zones would be difficult if not impossible.

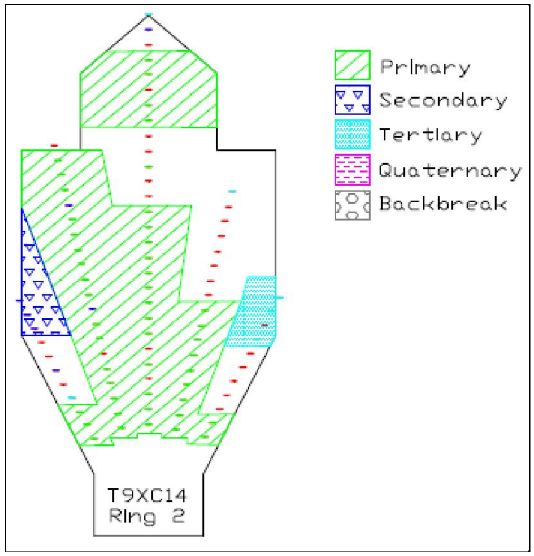


Figure 31: Delineation of extraction zone based upon recovered markers

3.2.6. Analysis of Extraction Zone Polygons

The percentage of material recovered from the extraction zone is used to quantify flow behavior. The percentage of material recovered from any given extraction zone is represented as two and three dimensional calculation. This analysis provides detailed information concerning the development of the extraction zone within the blast burden and an appreciation of the overall material recovered within the ring. For the two dimensional case, the percentage of material recovered for any given extraction level is simply the area of the extracted polygon divided by the total area of the blast ring. The three dimensional calculation relies on the assumption that each marker ring plane represents a volume of material bounded in the third dimension by either the half-way point between marker ring planes or the boundary of the blast volume (Power, 2004). The volume of any given extraction zone is therefore represented by Equation 1 and Equation 2 for two and three marker ring trials respectively (with equation terms defined in Figure 32).

Equation 1:

$$= \frac{(\ 1 + 0.5\ \ 2)\ \ 1 + (0.5\ \ 2 + \ \ 4)\ \ 2}{}$$

Equation 2:

$$= \frac{(\ 1 + 0.5\ \ 2)\ \ 1 + 0.5(\ \ 2 + \ \ 3)\ \ 2 + (0.5\ \ 3 + \ \ 4)\ \ 3}{}$$

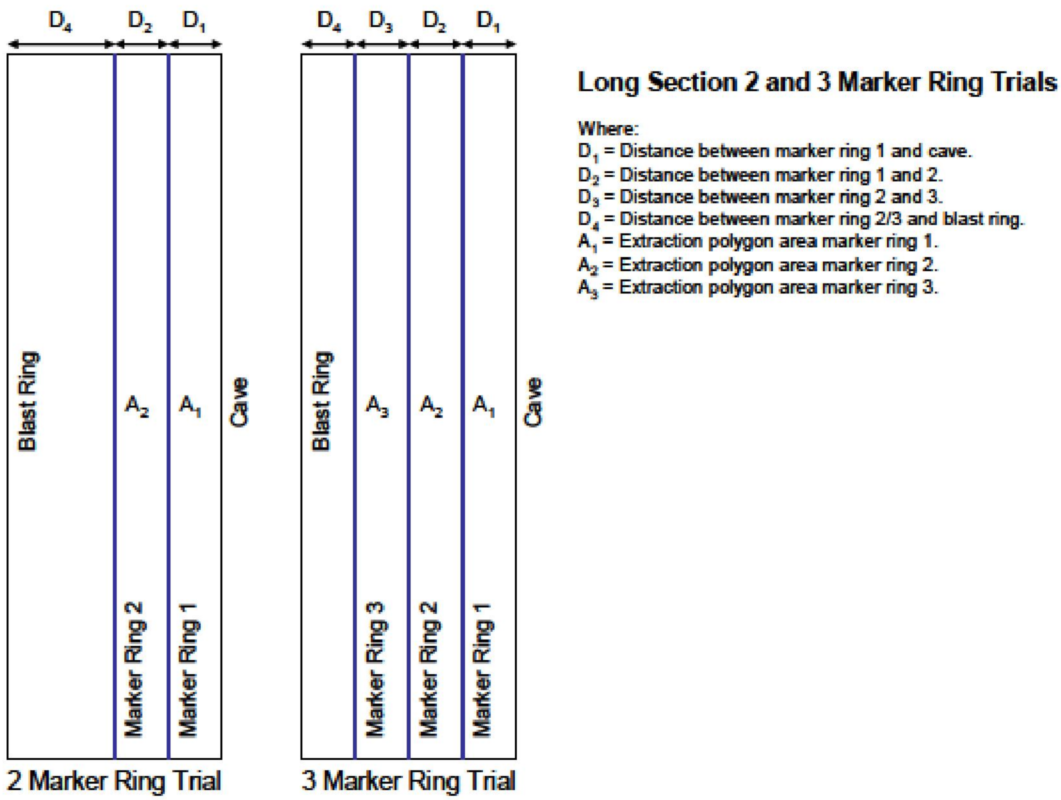


Figure 32: Definition of terms used to calculate extraction zone volume

For the standard distribution of marker rings within the blast burden (rings located at 0.65m, 1.3m, and 1.95m), the volumetric calculation for extraction zone recovery highlights three major limitations:

1. For two marker ring planes, the volumetric calculation for the extraction zone is biased towards marker Ring 2 (0.5D2 + D4 > D1 + 0.5D2).
2. For three marker ring planes, the volumetric calculation for the extraction zone is biased towards marker Rings 1 and 3 (D1 + 0.5D2, 0.5D3 + D4 > 0.5(D2 + D3)).
3. It is difficult to compare volumetric extraction zone recoveries between two and three ring marker trials. This can be primarily attributed to marker Ring 3 being absent for the two marker ring trials, thus biasing volumetric recovery results.

Based upon these limitations, emphasis has been placed on the results from two dimensional extraction zone polygons for further recovery analysis.

3.2.7. Result of full scale experiments

This section describes the data recovered from eighteen SLC rings fired for the seven full scale experiments. This information was intensively used in the calibration of PCSLC.

The experiment location and characteristics are described as follow:

- Experiment 1- 5255L, XC9, R11 (5255 mine level, cross cut 9, ring 11). Isolated draw methodology, standard Ridgeway 10 holes blast pattern was used.

- Experiment 2 - 5255L, XC0, R15 (5255 mine level, cross cut 0, ring 15). Isolated draw methodology, standard Ridgeway 10 holes blast pattern was used.
- Experiment 3 - 5255L, XC2&4, R17 (5255 mine level, cross cut 2 and 4, ring 15). Interactive draw Baseline, standard Ridgeway 10 holes blast pattern was used.
- Experiment 4 - 5255L, XC9&11, R21 (5255 mine level, cross cut 9 and 11, ring 21). Interactive draw with modified blast pattern 8 holes instead of 10.
- Experiment 5 - 5255L, XC4&6, R27&28 (5255 mine level, cross cut 4 and 6, rings27 and 28). Double Interactive draw. Designed to quantify better the effect of back break by firing two consecutive rings in adjacent crosscuts. A blast pattern 8 holes was used in all rings.
- Experiment 6 - 5280L, XC0&2, R51&52 (5280 mine level, cross cut 0 and 2, rings51 and 52). Double Ring Interactive draw in 5m drives. Designed to test the impact of drawing from a 5m wide drive as opposed to a 6m wide drive. A blast pattern 8 holes was used in all rings.
- Experiment 7 - 5230L, XC7&9, R18&19 (5230 mine level, cross cut 7 and 9, rings 18 and 19). Double Ring Interactive modified blast pattern 7 holes instead of 8.

Figures 33, 34 and 35 show the position of the rings used in the experiments described above.

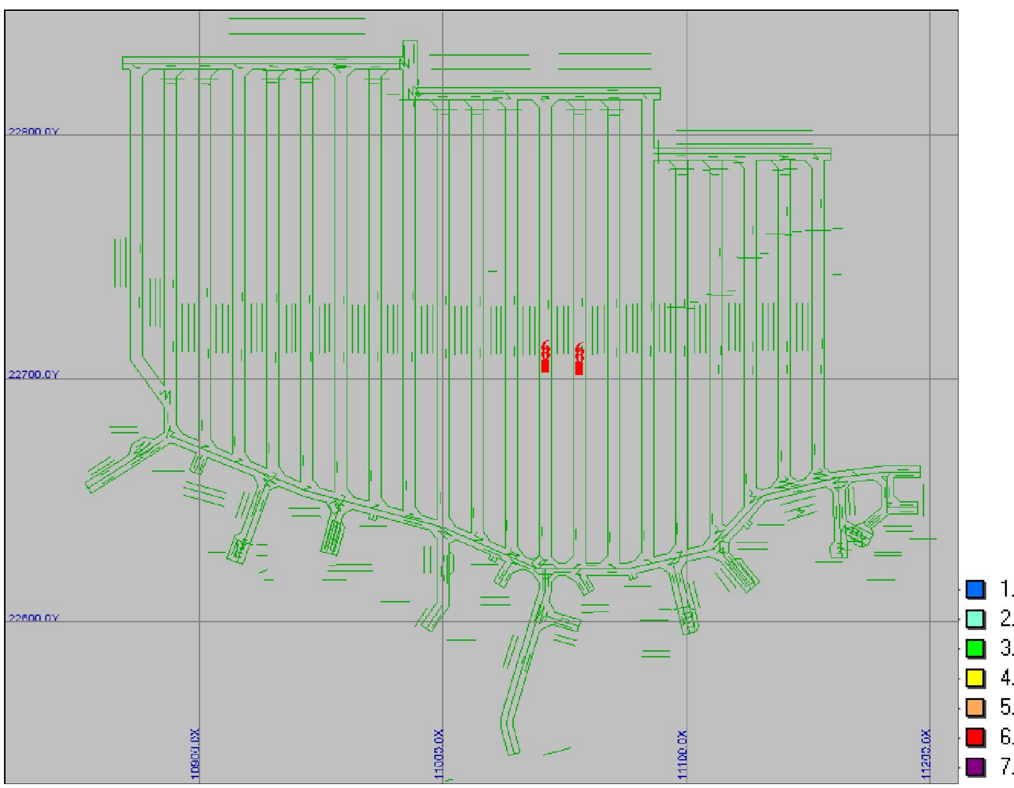


Figure 33: Experiments located at Level 5280

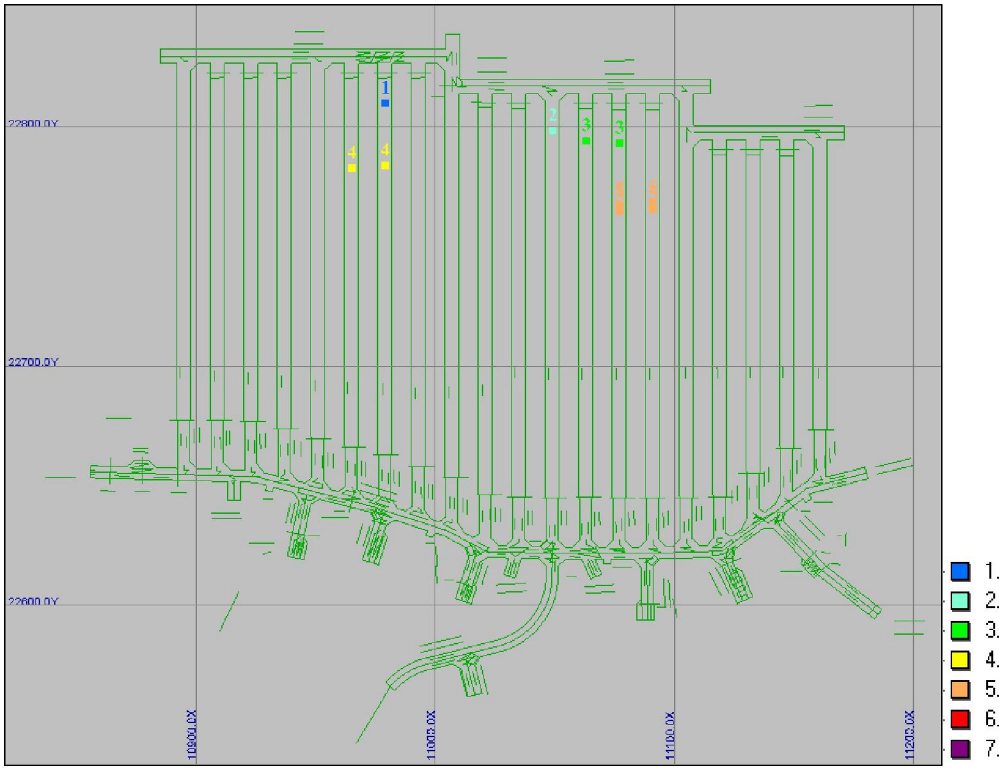


Figure 34: Experiments located at Level 5255

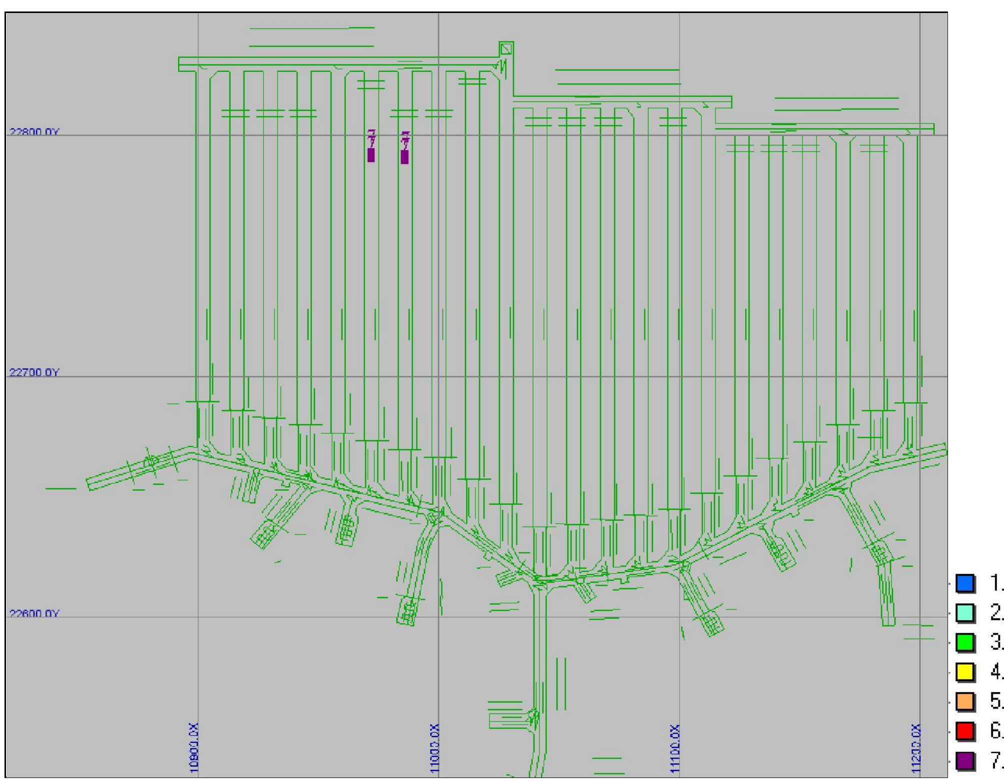


Figure 35: Experiments located at Level 5230

3.2.7.1. *Primary recovery and dilution entry*

The first trial, using a single marker ring, indicated that material was flowing to the drawpoint through a narrower and shallower zone than had been expected. After 120% draw, the draw envelope was 11.9m at its widest point, and approximately1.8m at its deepest (shallower than the 2.6m fired burden).This first experiment indicated 'dilution' was arriving at the drawpoint after less than 20% draw of the design ring tonnage. Interpretations indicated that volume of the draw envelope was too small to have delivered the tonnages drawn from the drawpoint without dilution being present. The origin of the dilution was identified as from the depleted drawpoint above. This interpretation was also supported by the evidence of recovered shotcrete encased mesh and bell wire used in the level above.

While early dilution entry had been recorded previously (Kvapil W. H., 2008), it was hypothesized that this 'diluting' material originated from the front of the fired ring rather than above it. The trial results stimulated interest in further experiments. Additional marker rings were installed and a number of drill and blast parameters were varied in these trials, with the aims of reducing drill and blast costs and increasing recovery. These trials were successfully validated reducing drill and blast costs by 20%; they provided limited leverage on improving recovery and dilution. Primary recovery (the percentage of the fired ring recovered from the level on which it was fired) continued at 60% (Power, 2004).Figure 36 shows typical primary recovery results from a draw marker trial. For this trial (as for the majority), two marker rings were monitored side by side, and drawn interactively as part of a panel of four adjacent rings. Adjacent rings are staggered and this section at 2.25m forward of XC2.

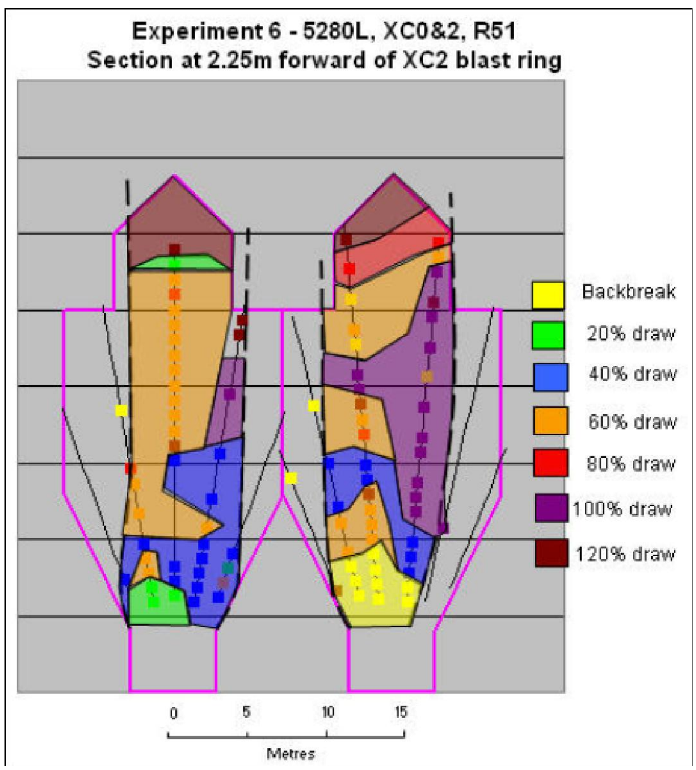


Figure 36: Typical results from a marker trial (section looking north)

The experimental findings show the widths of the draw envelopes to be narrower than the width of the fired rings. No evidence of interaction between two adjacent draw envelopes has been found (Power, 2004). Comparisons from isolated experiments also indicate interactive draw procedures do not significantly widen draw envelopes at Ridgeway.

3.2.7.2. Secondary recovery

While primary recovery results are of value, it is un realistic to expect that all material is recovered on the level from which it is fired. Ore which is recovered on the level immediately below is classified at Ridgeway as secondary recovery (Power, 2004). Because each marker was uniquely coded, all recovered markers were associated with the ring from which they were fired, even though production from that ring may have long since ceased. Figure 37 shows that in addition to the material recovered as primary recovery, a significant portion of the fired ring is also regularly recovered as secondary recovery.

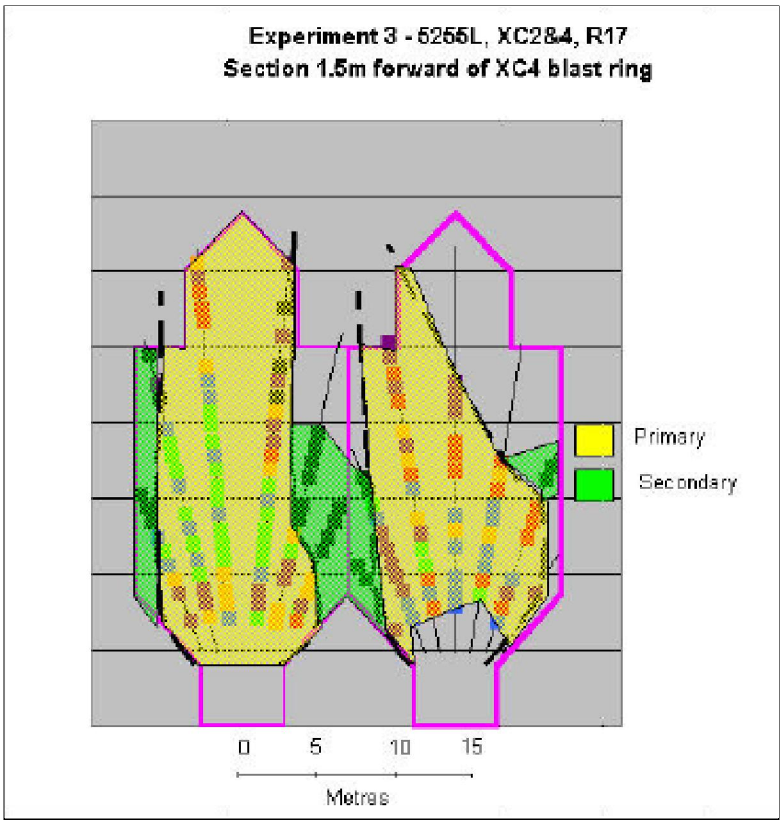


Figure 37: Typical secondary results

As the primary draw envelopes reach the top of the fired ring at less than 20% draw, they have the opportunity to draw up into previously unrecovered material from the sides of the rings above, increasing total recovery for these rings. While the behavior of primary recovery draw envelopes can be predicted to some degree, secondary recovery behavior is more variable.

3.2.7.3. Tertiary and Quaternary recovery

Material recovered from two or more levels below that from which it was fired is classified as tertiary and quaternary recovery at Ridgeway(Power, 2004). Production below the Ridgeway marker trials progressed to the extent that conclusive tertiary and quaternary recovery results was recorded and based on reconciliation and modeling work indicate that a value of approximately 85% at 100% draw the maker was recovered.

3.2.8. Marker experimental summary results

The data collected was analyzed in different period of time according to the amount of marker collected, consequently different conclusions were established.

In 2004 Power described results obtained as follow:"While individual experiments show the draw process to be a rather chaotic, analysis of the collected results shows a system that can be characterized relatively accurately. Both primary and secondary recovery show a 95% confidence interval of little more than 5% This is to some degree a function of the favorable sample size. Table 8summarizes the primary and secondary results of the Ridgeway marker trials to date." (Power, 2004)

Table 8: Summary of experimental results (Power, 2004)

	Primary recovery (%)	Primary + Secondary recovery (%)
Average	59.1	75.0
Standard deviation	10.2	10.0
95% confidence interval	5.4	5.6
Upper limit	53.7	69.4
Lower limit	64.5	80.6

Based on analysis of copper and gold grades recovered from the upper levels of the mine with respect to concentration of these metals in the sub-economic mineralized halo above the orebody Power was able to define a recovery curve adding the Tertiary component (see Table 9).

Table 9: Summary of experimental results based on boundary condition (Power, 2004)

Recovery Class	Known recovery (%)	Known stage of draw (%)	Dilution entry point (%)
Primary	60	120	20
Secondary	75	120	20
Tertiary	85.3	100	20

The Mine Planning Engineer group continues working with the trial marker after 2004 and they established the relationships between primary ring recovery and drill and blast performance so that designs can be prepared with consideration of primary recovery. Also they create a new recovery curve (see Figure 38) using more markers recovered extending the level of knowledge to Quaternary and Quinternary class (Mine Planning Engineer, 2008).

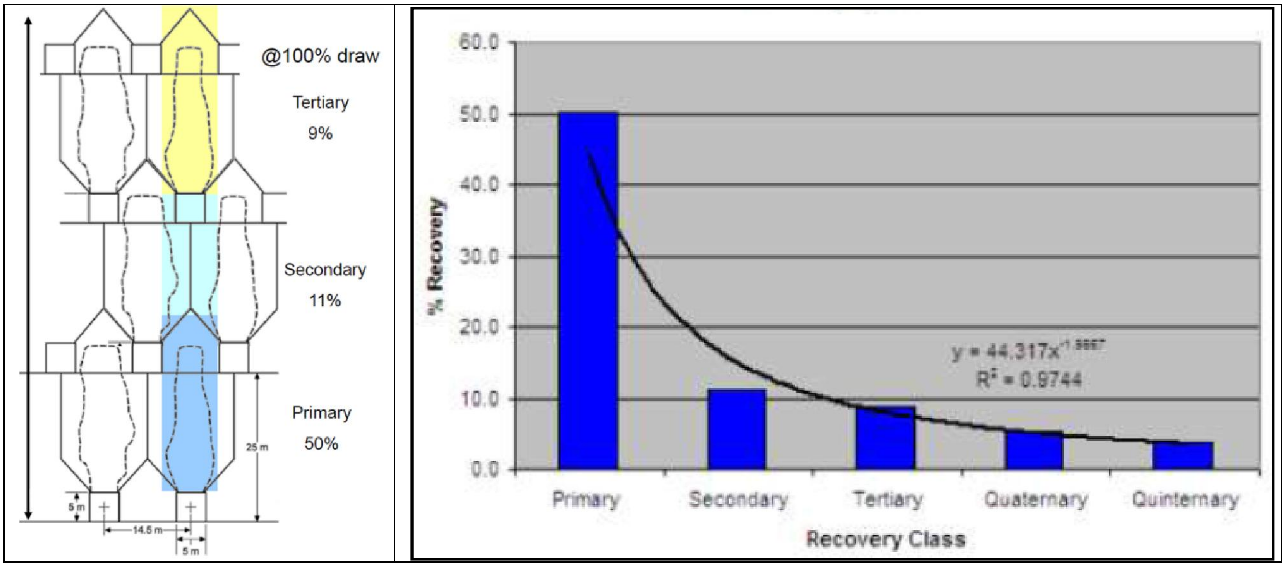


Figure 38: Recovery curve and description by level

Finally in 2010Brutron reanalyzed the Trial maker data collected from July 2002 to April 2005.The dataset was filtered by a two stage process in an attempt to remove some of the sampling bias from the results. The first stage involved the removal marker trials due to a number of issues related to significant variations in experimental setup and procedure, resulting in discrepancies in extraction zone recovery results. The second stage of filtering involved the removal of marker ring planes that did not have marker coverage of at least 80 percent (by area) of the design blast ring outline. The 80% was arbitrarily chosen by visual inspection of marker coverage for all trials (Brunton, 2010). A basic statistical analysis was undertaken for extraction zone recoveries calculated by area and volume. The mean extraction zone recovery by volume (Figure 39) is highest for primary recovery(36.2 %) and in turn decreases through secondary (9.7 %), tertiary (5.4 %), and quaternary(1.2%) recoveries. Backbreak recovery is relatively high with a mean recovery of 8.7 percent(Brunton, 2010).

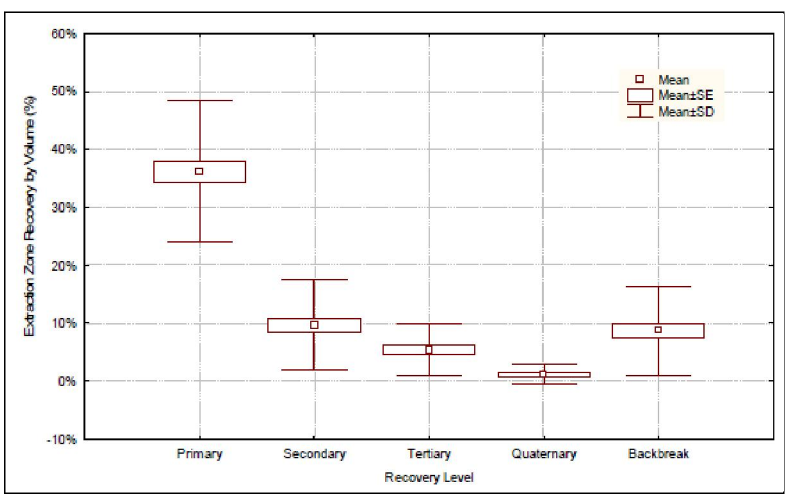


Figure 39: Box and whisker plot of recovery by volume for primary to quaternary recovery

3.2.9. Conclusions

The full scale marker trials done at the Ridgeway SLC gold operation are considered to be the most comprehensive experiments of their type conducted in the world to date(Brunton, 2010). The use of maker has made easier to measure ore body flow in Sublevel Caving mines. Improve fundamental understanding of material flow behavior and capability to predict behavior and production performance.

The main observations and conclusions from the general statistical analysis are:

- The recovery numbers presented are based upon the method employed to delineate the extraction zone polygons. The method adopted provides a systematic process for extraction zone delineation.
- The shape of the extraction zones are irregular in nature (not described by an ellipsoid shape), with primary recovery consisting of an area of 'continuous flow' near the blast ring plane.
- The backbreak extraction zone is relatively common, with highest recoveries occurring in markers in the ring plane closest to previously fired blast burden.
- Secondary, tertiary, and quaternary recoveries occur as relatively small discrete zones within the blasted material.
- Finally if we consider that the back break should be part of the primary recovery the mean of total primary recovery is almost 50% and similar value was registered by Engineer group in 2008 and Power in 2004. A new recovery curve is proposed in this thesis to use during the calibration work (see figure 40) based on the experience registered from these three groups and previous experience of the author with numerical models.

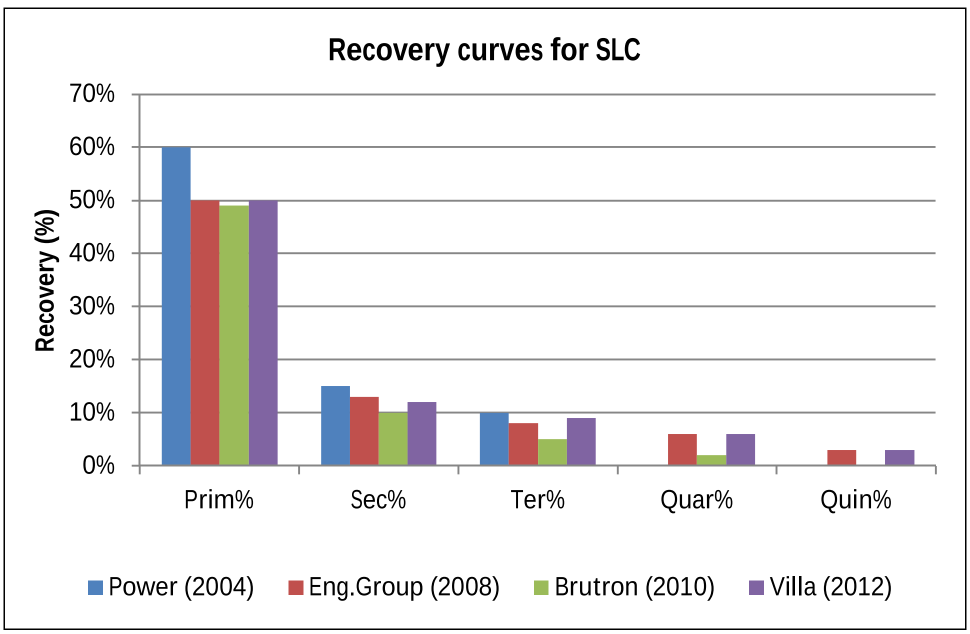


Figure 40: Summary of recovery curves and a new proposal for Calibration of PCSLC

4. Principles of Software Gems-PCSLC®

The PCSLC development tool was done in conjunction with SRK Consulting enabling Gemcom® to take advantage of the considerable Sublevel Caving experience gained by SRK over the years. In essence, the PCSLC modeling process is as follows:

- Identifying the ore zone to be modeled as a Sublevel Cave.
- Generation of a set of tunnels based on the tunnels spacing and orientation required.
- Generation of rings from tunnels. This will use one (or more) ring geometries; based on the distribution of the levels or specific requirements for example slot tunnels.
- Generation of Cells from Rings. These are the lowest building blocks for the TM flow modeling.
- Insertion of grades and other attributes from block models into cells.
- Reporting of Ring tons and grades. (This is an In Situ report of reserves contained in the layout).
- Preparation of dilution modeling strategy, which can be based on different sources, quality and amount of dilution tonnage.
- Set up of production scheduling information for development rates, sequence, extraction percentages, etc.
- The production scheduler has some specific input as follow:
    - Classification of tunnels into levels and rings into tunnels.
    - Maximum mining rate per tunnel
    - Maximum % extraction from each ring
    - Flow fractions (e.g. the "Template" for the TM algorithm)
    - Basis for closing each ring. Grade based or tonnage based.

4.1. Getting started

Basically this tool will enable users to create a realistic model to assess a Sublevel Caving project dividing the ore zone into a set of tunnels and rings using a specific geometry for each level and assigning the information to each ring directly from the block model. The basic information necessary to start work with PCSLC is the shape of the ore zone. This leads into setup of tunnels and block model data, which is the main source of information of grades (e.g. Cu, Au, and Ag), density (In situ) and rock types (used to distinguish ore material from dilution material and in some cases, previously caved material).

PCSLC is fully integrated into Geology and Mine Planning Software (Gemcom GEMS™) so that it can effectively use all the information available for a project such as drill holes, surfaces, geological models, tunnels, etc.)

4.2. Tunnel layout construction

The tunnel layout construction process is a very simple yet flexible step allowing creating several alternatives in few minutes. The main input for this step is the geometric definition of the area to be modeled; basically it requires the following definitions:

- Tunnel cross section.
- Layout definition (vertical distance between levels and tunnel spacing).

- Orientation of the tunnels.
- Number of the tunnels and levels to be created.
- The length of the tunnel could be the same for all of them or each tunnel could be trimmed automatically following the shape of the orebody after the creation. This option allows quick approximation of the real length of the tunnels. Figure 41shows an example of the creation of the tunnel layout and the trimming results after(Diering and Villa, 2010). This example has two areas each with different geometry and orientation.

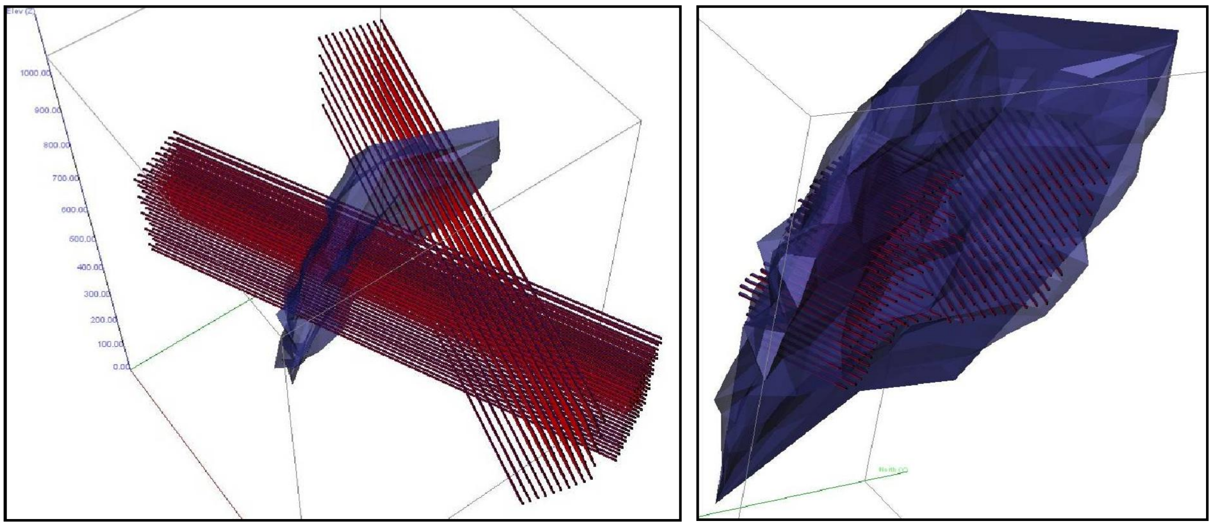


Figure41:Tunnel creation and trimming example

4.3. Generation of rings

After the tunnels are created the next step is to generate the rings associated with each tunnel. This option allows creation of all of the rings in one step even if they have different cross sectional geometry. This tool enables creation of rings using parameters such as ring burden and inclination to get a correct volume of the ring in 3D and to report the tonnage and grade correctly.

The ring burden defines the distance between each ring in the tunnel and ring inclination allows inclining the polygon ring toward the cave. The ring creation process includes these steps: a) define the ring geometry for each level and b) identify for each tunnel the ring geometry to use in the creation process. Figure 42 shows an example of ring generation where the top level has different geometry than the rest of the levels.

Figure 43 shows a few examples in 3D of the rings created for three different projects where the geometry of the orebody and the tunnel orientation were very important for a correct representation and evaluation for these projects. In some projects the number of rings could exceed 50,000 distributed in more than 1,000 tunnels.

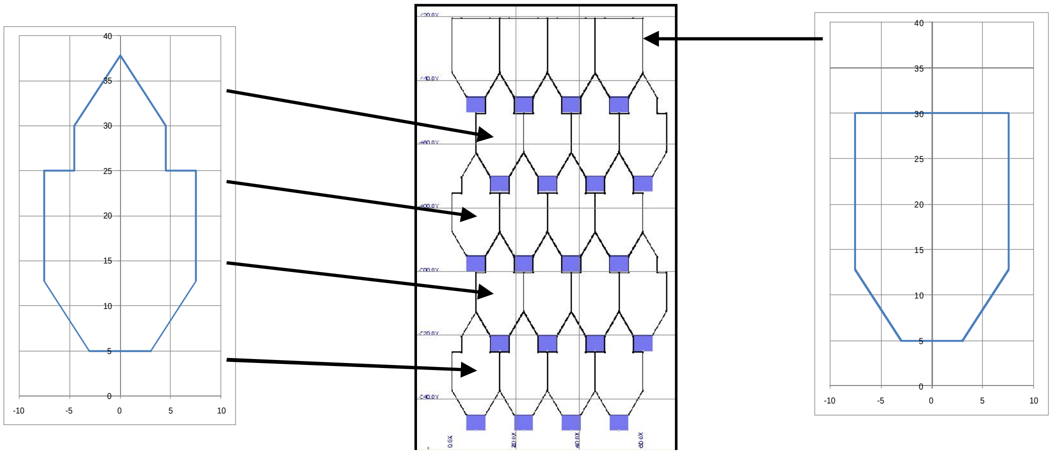


Figure 42: Ring generation example

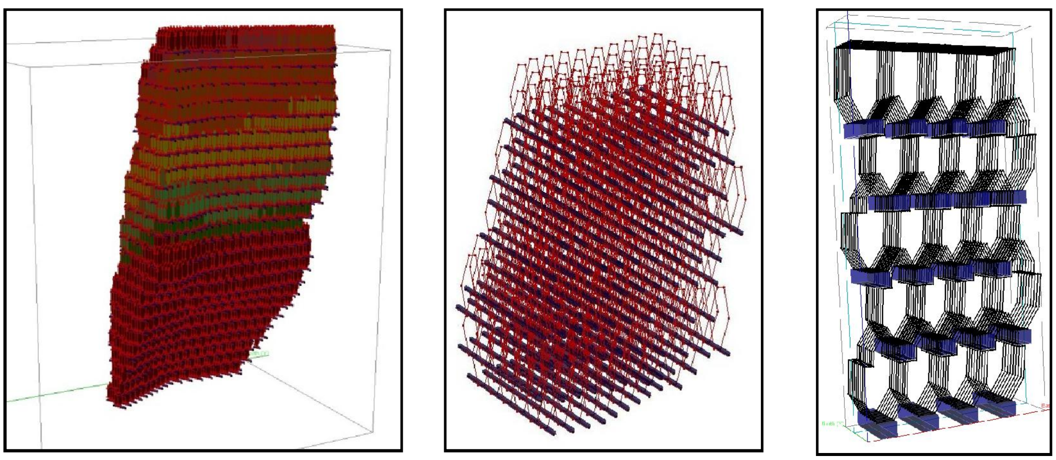


Figure 43: 3D Examples of ring creation process

4.4. Material mixing

Material mixing is fundamental in the evaluation of a SLC project since when a ring is blasted the first part of the ring is drawn cleanly but then waste from above and behind the ring then starts to come into the draw point and a mixture of ore and waste is drawn. The proportion of waste increases until shut-off or ring extraction percentage is reached. When draw from each ring is stopped, some ore will be left behind. When material is extracted from the next level ore from Level2 is mixed with the previous ore/waste (from Level1) in the cave and these "dilution" material increases in grade as the cave matures (see Figure 44).

The material mixing is a key element that any mine planning tool for SLC mine must incorporate to generate reliable results. Much work has been done to try to understand the material mixing process in an active SLC mine and a common problem encountered is the amount of the data to model and computation time to process (Diering, 2007). The mixing model applied in this tool is called "Template mixing" and it is a modification of the original mixing algorithm developed for Block Caving mines within the software system called Gemcom-PCBC developed by Gemcom Software International (Diering, 2000). This new algorithm has been developed specifically for use within a production scheduler. This differentiates it from some of the other flow models already as REBOP (Itasca Consulting Group, 2000)and Cellular Automata(Alfaro and Saavedra, 2004).The objective of Template mixing also differs from some other approaches. There are two mode of use: A) to try to understand the nature of the gravity flow, draw cones, draw radius, draw cone interaction etc. B) For a given set of flow conditions, to try to predict the material which will be extracted at draw points for use in a production schedule. The Template Mixing focuses on the latter approach (Diering, 2007).

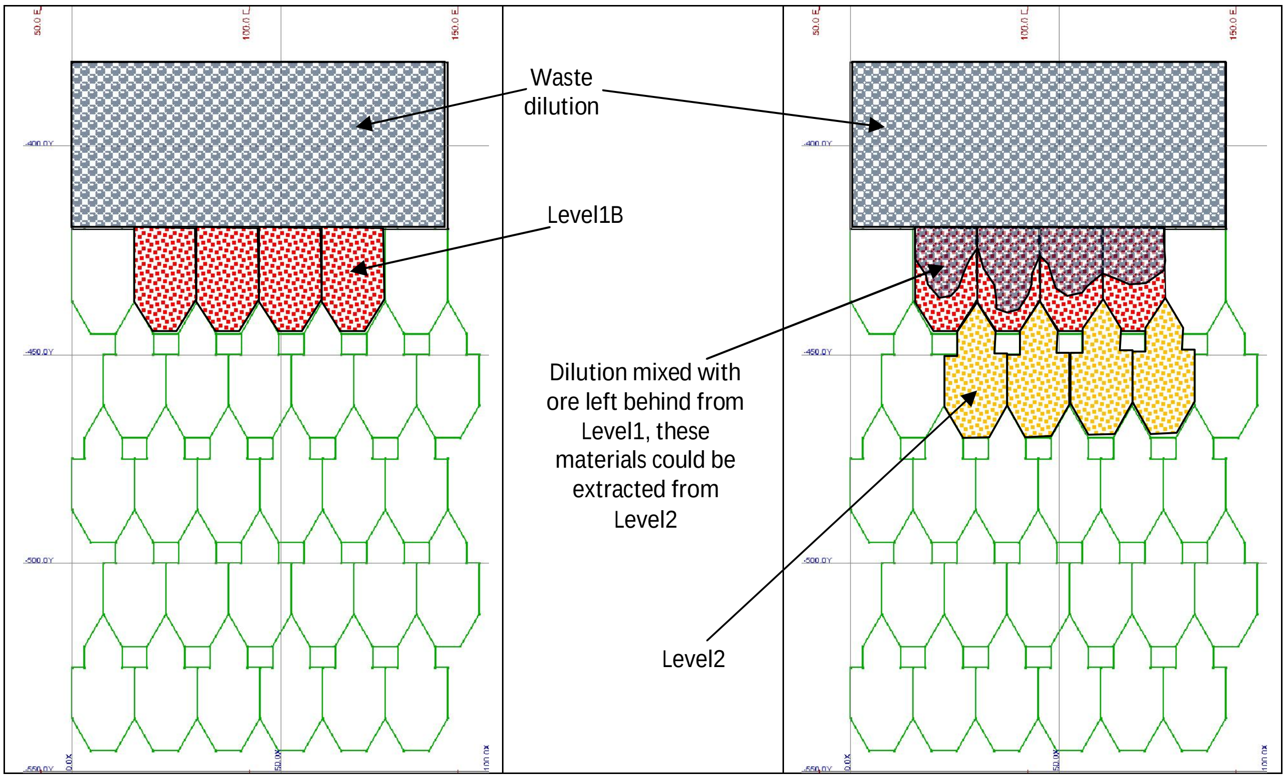


Figure 44: Example of extraction and mixing process in Sublevel Caving

4.4.1. Methodology

In setting up the Template Mixing algorithm, the underlying rules for material flow in a sublevel cave needed to be identified and clarified. This can either be extremely complex if one goes into the detailed flow mechanisms or it can be quite simple if we take an overview of the whole process. We have used the latter approach. Some of the key rules and drivers are as follows:

- Gravity is the main driving force. Gravity acts vertically downwards.
- Material can only move into a gap left by other material. (e.g. we cannot have the overlap of material)
- Broken material is generally less dense than intact material this is referred to as the swell factor.
- Solid or intact material does not move.
- The material from the rings is only available to be moved after it is been blasted.

- The waste material outside of the rings needs to be analyzed specifically based on the host rock properties.

The hard part is to decide how the material "moves into the gap". The Template Mixing routine defines a number of rules in the form of a template linking each material element with its neighbors. Each element can be depleted and when sufficiently depleted, it needs to be replenished. The template is used for this process combines spatial, geotechnical and some randomization considerations. The algorithm is applied in a recursive manner throughout the whole model (Diering, 2007).

4.4.2. Internal cells definition

The movement of the material inside the rings is controlled by a regular element called "Internal Cell". The internal cells can have different sizes and depending of the level of detail and the amount of the rings to be modeled it could be one cell per ring or multiple cells per ring, but working with more number of cells implies an increase in the process time. Previous calibration work again result from Rebop (Itasca Consulting Group, 2000) shows that in some cases one cell should be enough to get reliable results for Pre-Feasibility or Feasibility study, but it was never tested against real data and then this calibration work should be really useful to evaluate the impact of the number of cells in the final results, not only in terms of the grade predicted also the time spent during the run. Figure 45 shows an example of multiple cells per ring.

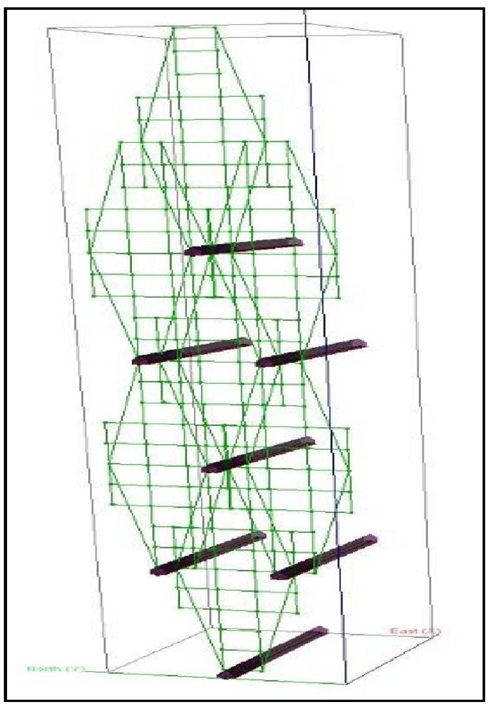


Figure 45: Example of multiple cells per ring

4.4.3. Strategy for boundary waste model

There are various ways to treat waste material in PCSLC depending of the location of the orebody and the geotechnical condition of the ore and the host rock. This material can be allocated dynamically when production schedule simulates the depletion, using what is called sequential mixing based on the amount of the waste material available. The system has several options to create complex model to replicate the best manner real scenarios of dilution. Some examples are described below:

a) If the ore zone is located close to the surface or below an open pit, only a limited amount of waste material can fail gradually over time from the old pit/cave sides. The best way to model this effect is enabling certain amount of material to move per period during the schedule run trying to simulate the toppling effect.
b) When the ore zone is located very deep an infinite amount of the waste material can cave and move down. In this case is necessary to have waste material available to mix with ore all the time.
c) Another option is to leave a buffer of ore between the waste material and the first level, with the intent to reduce the effect of the waste ingress. In this case the dilution from the top has grade so it is necessary to model this material precisely, to allocate the correct information directly from the block model to be used in the mixing process.

Figure 46 shows an example of a solid on top of some rings to enable block selection to allocate certain amount of waste material. Blocks in the block model which overly rings which can receive this boundary waste material are flagged. Then as rings which are close to these blocks are mined, the boundary waste material is able to flow into the rings. A cap on the amount of boundary material is set. In addition, it is possible to add a fixed amount of additional boundary material for each period in a schedule(Diering and Villa, 2010).

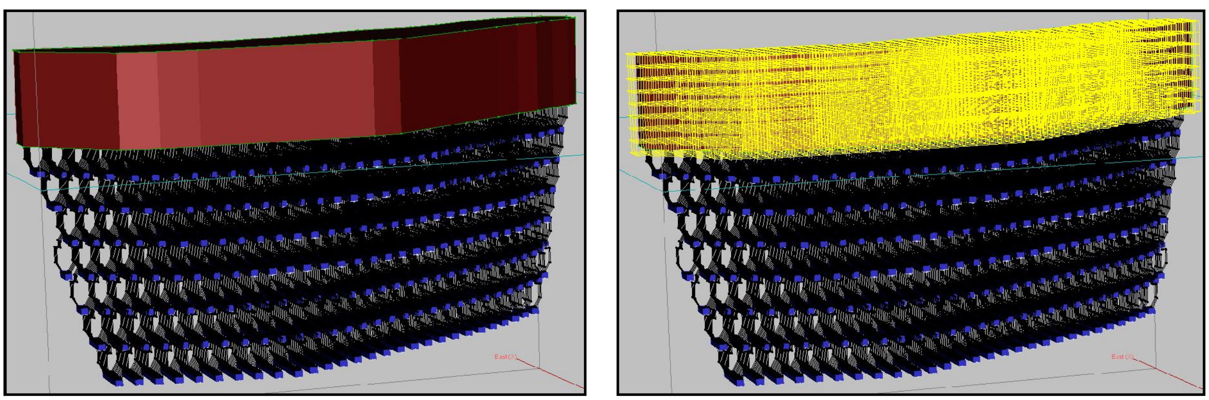


Figure 46: The selected blocks are shown in yellow for waste material modeling purposes

4.4.4. Neighbor calculations

This is an internal process as preparation for the Template mixing (Production schedule run). The program computes a linkage between all the cells of all the rings so that as material in each cell is depleted, it can get replenished from connecting or neighboring cells. Weights for neighboring cells are such that movement will be mostly vertically downwards with less horizontal movement. The adjustment of the neighbor parameters is one of the key parameters to calibrate in this research, for this purpose the trail marker results should be really useful to understand the connection and recovery reported by level (primary, secondary, tertiary, etc.).

The method to calculate the neighbors uses a three dimensional cone to select cells or blocks within the cone that are used to build weights. These weights are calculated using sampling points within the cone. Then each sampling point is matched to the closest ring or block and its weight contribution is added to that ring or block(Figure 47).

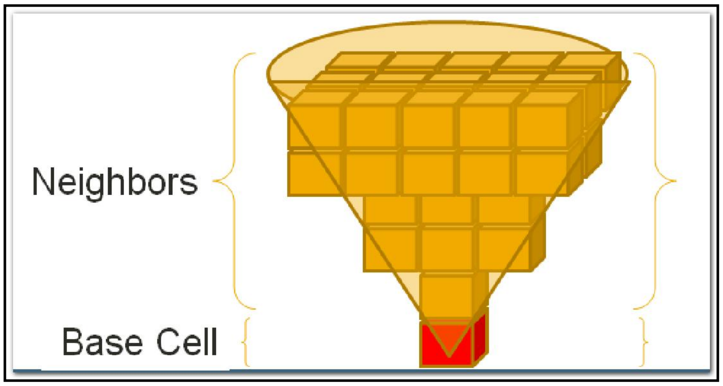


Figure 47: Example of the neighbor calculations

The linkage between the cells and weights for selected rings are shown in Figure 48 (left). The links of the ring from the lower level are shown in Figure 48 (right), the weights are distributed based on the distance.

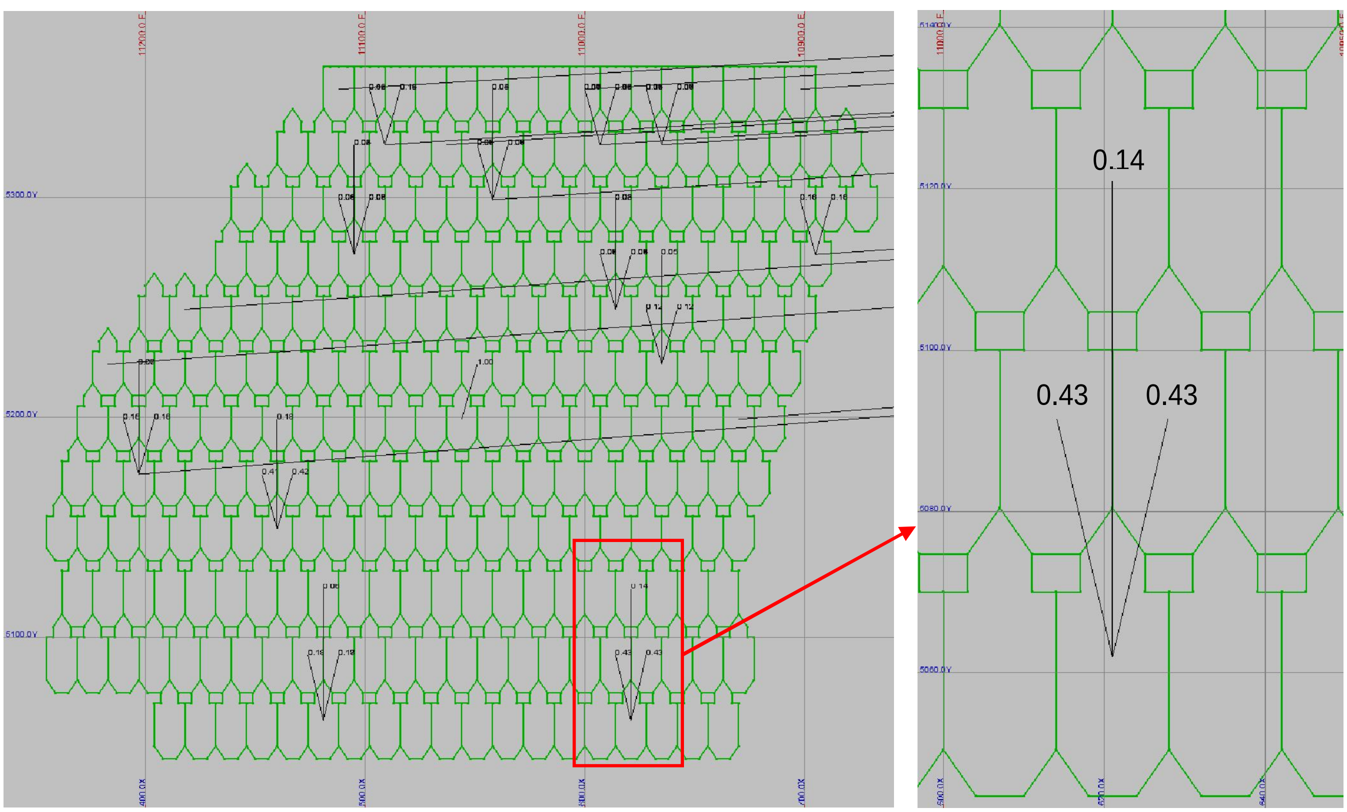


Figure 48: Example of linkage between the cells and weights

4.4.5. Template mixing inputs

The mixing algorithm in PCSLC is controlled by a list of inputs as follow:

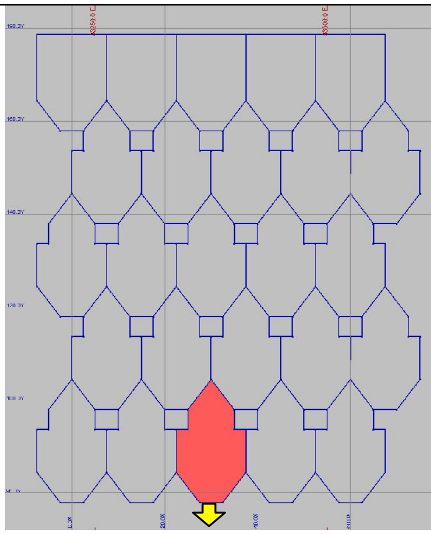
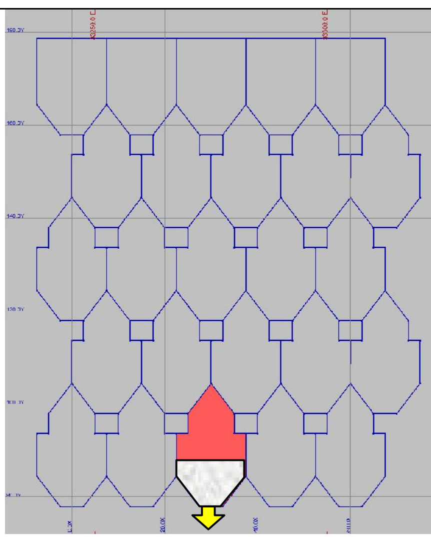
Input item	Description
TONNAGE_LIMIT	Maximum percentage to be depleted from one ring (1 for 100%)
MIN_TONS_TO_ASK	Minimum amount allowed to be depleted from a cell
SWELL_FACTOR	Factor used to determine maximum caved density
REPLENISH_THRESHOLD	A cell has to be less than 90% full for replenishing
CELL_LUMP_DIST	Determines how far away cells are lumped
RING_LUMP_DIST	Determines how far away rings are lumped
MAX_INCREMENT	Maximum amount to deplete per increment from all tunnels
SHOW_GRAPHICS	Determines whether or not graphics will be shown
LUMP	Determines whether or not rings and cells are lumped
BOUNDARY_DENSITY	Density of material outside the rings
BOUNDARY_TONNAGE	Initial total tons available to depletion from outside the rings
BOUNDARY_WEIGHT	Default weight if this has not been computed
PERCENT_FROZEN	Percentage of material to leave frozen when a ring is blasted
RING_LUMP_NUMBER	The number of adjacent rings to lump
SHUT_OFF_GRADE	Grade element name for ring shut off
SHUT_OFF_VALUE	Grade value for ring shut off
BOUNDARY_TONNAGE_TIME_PERIOD	Boundary tons to include each time period
MAX_RINGS_TIME_PERIOD	Max number of rings to open in 1 time period
USE_EXCEL_BOUNDARY	If 'yes', then boundary material from excel is used
REPORT_HANGUPS	Tons are hanging when all cells pointing to them are empty
DISABLE_PLAYBACK	If 'yes', playback files are not recorded
EROSION_RATE	Rate at which frozen material is depleted (0..1)
NEIGHBOUR_LINK_TYPE_SCALE	Rate at which disabled neighbours are depleted (0..1)
MIN_REMAIN_TONS_IN_RING	Min tons to remain in a ring
QUICK_TONS	Quick depletion. Always returns what was asked.
REPORT_FIELD	Used for level reports. Must be a string.
REPORT_FIELD2	Used for level reports. Must be a string.
RINGS_TUNNEL_PER_TIME_PERIOD	Max rings to open per tunnel per period.
BOTTOM_REFILL	If bottom is below this value, mix top and bottom
DETAIL	If yes, use Detail worksheet

The numbers of items are 31 but only 5 of them are important for mixing purpose calibration purpose the rest is to generate report or control the inputs for production schedule. The following list was analyzed in detail during the calibration work:

- REPLENISH_THRESHOLD
- PERCENT_FROZEN
- EROSION_RATE

- BOTTOM_REFILL

This section will describe the process of depletion and mixing used in PCSLC with the main purpose to clarify the participation of each input described above. In this example the mixing model was created using one cell per ring; it means each ring was divided by one internal cell and then the movement of material between rings will be controlled by one unique source of tonnage and grade per ring. It has the benefit to reduce the compute time for mixing purpose. Figures 49 to 53 represent the depletion and mixing process:

 Figure 49: Step 1 in Template mixing (TM)	a. Material is extracted from one ring (red ring)
 Figure 50: Step 2 in TM	b. The extraction generates a void inside the ring and this void needs to be filled from other material.

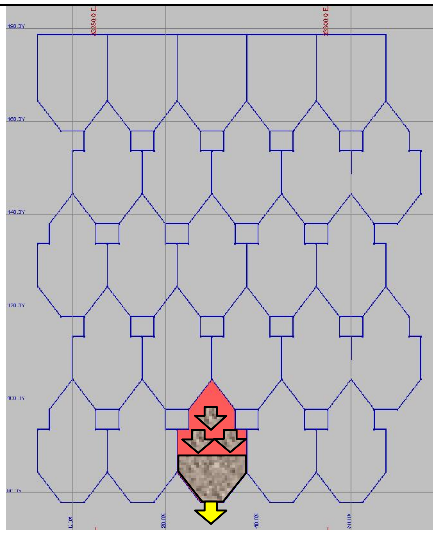


Figure 51: Step 3 in TM

c. The first option to fill the gap is with material from the same ring.

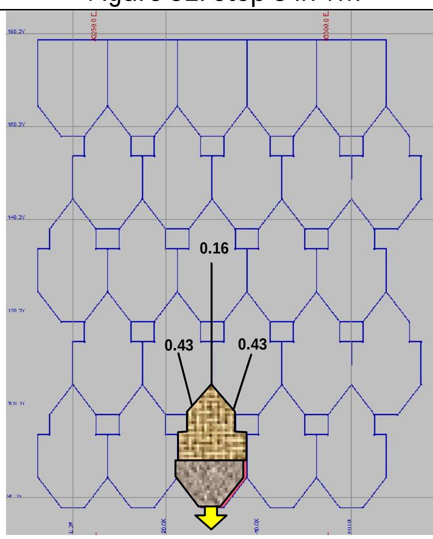


Figure 52: Step 4 in TM

d. When material from the same ring is not enough to fill the void, material from rings in the levels above start moving into the gap. The portion of the material moved from one ring to other depends of the links and weight created previously in the neighbor definition. For example in this case 64% of the material can flow from one level above and only 14% can migrate from two levels above to fill the empty space in the lower level.

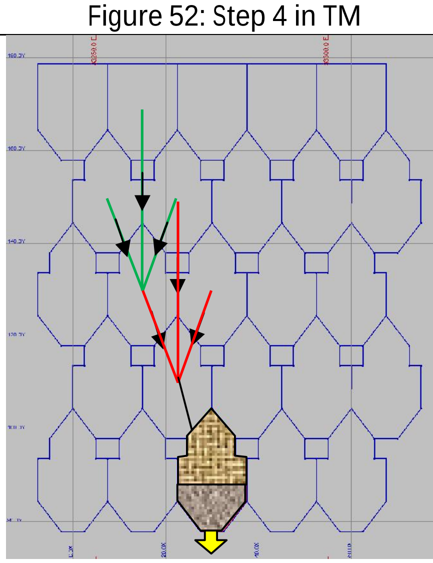


Figure 53: Step 5 in TM

e. If material is depleted from one ring it generates a movement in the entire area close to the zone extracted, since there are links created for all rings and then material from upper levels are replenished originating mixing for the whole layout.

It is very clear from the sequence of steps above that the links (neighbor definition) are very important for mixing purpose, since these control the way to fill the void generated in lower levels due to the extraction. The amount of material available to move from one ring into other is controlled in PCSLC using the four main inputs (REPLENISH_THRESHOLD, PERCENT_FROZEN, EROSION_RATE & BOTTOM_REFILL). Figure 54 shows the process of mixing and the participation of these in the internal mixing process between cells (Diering, 2012).

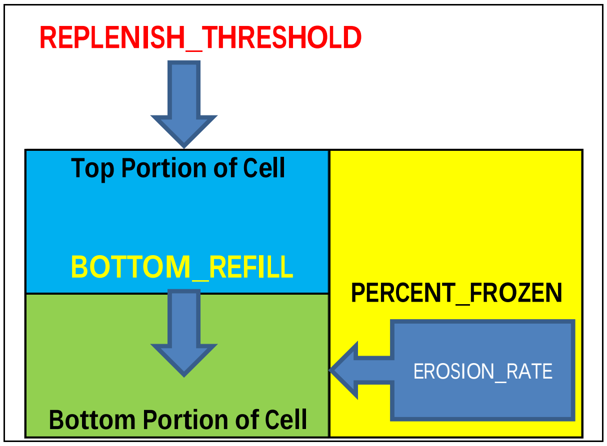


Figure 54: Cells division for mixing purpose

Each cell is divided in three parts (top, bottom and frozen). When the depletion take place the bottom part is depleted and then depending of the 'Bottom refill' value it will be filled also the amount of tonnage moved from outside of the cell will depend of the 'Replenish factor' used. Finally it is possible to freeze part of the material from the cell to represent low interaction (when only 1 cell per ring is used).This option allows leaving a percentage of frozen material when a ring is blasted and part of this material can be depleted using an 'Erosion Rate'. For example if a ring has 2,000 tonnes and 50% is frozen, then if we mine 1,000 tonnes from that ring with an erosion rate of 5%, the additional 50 tonnes would be eroded from the frozen part of the ring.

Template Mixing provides a huge amount of combination and then it is able to model any type of mixing, but also it create a confusion in the user to utilize the correct parameters to get reliable grade forecast therefore this calibration work will provide an understanding of these parameters and values to get feasible results based on the experience of Ridgeway.

4.4.6. Testing model of Template mixing results

This section describes the runs done using PCSLC to illustrate the effect of the changes in the mixing parameters in the schedule results, specifically in the grade, dilution and recovery profile reported as result of the schedule. The objective of this model is to replicate the geometry used in Ridgeway Gold Mine in small scale and then be able to run several scenarios of setup to evaluate the impact in the results changing the main parameters described previously.

The geometry used in Ridgeway Gold Mine is summarized as follow:

- Sublevel interval 25m.

- Drive spacing is 14 m center to center.
- Cross cut geometry is generally 6.0x4.7m.
- Ring burden is generally 2.
- Ring inclination is 10 degree dump towards the cave.

The block model was setup to have high grade on the top levels trying to replicate the distribution observed at Ridgeway mine (Figure 55).

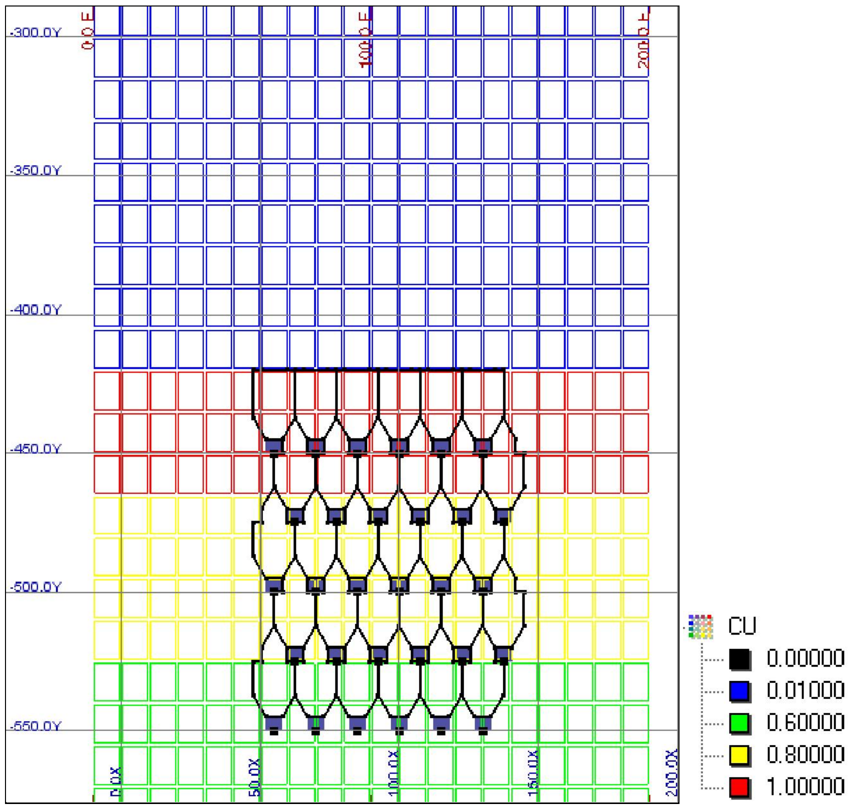


Figure 55: Block model with grade distribution

To track the material by level and then be able to quantify the material recovered in each level every ring was assigned based on the position in the layout using the following table:

Table 10: Level name assignation

Location	Grade element name
Top level	LEV1
Second level	LEV2
Third level	LEV3
Fourth level	LEV4
Bottom level	LEV5

For this exercise material reported at the Level four (see Figure 56) will be track to quantify the recovery by level based on portion of the material originally located in each level (from Level1 to Level4).

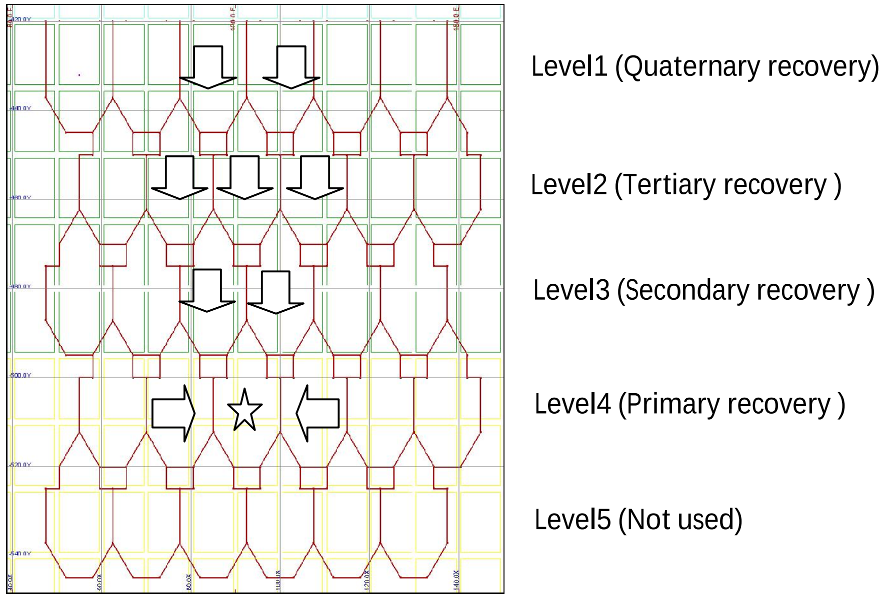


Figure 56: Description of the recovery by level

The main items of the mixing model of PCSLC were evaluated:

- Numbers of cells per rings
- Template Mixing main inputs:
    - Percent Frozen
    - Erosion rate
    - Replenish factor
    - Bottom refill

The purpose of these runs is to replicate a similar extraction profile used in Ridgeway but working with a small project to be able to use different configuration and assess what is the impact in the results and the recovery curves. Figure 57 shows the tonnage profile used in these runs. It is important to note that the tonnage profile is an input so every run has the same extraction profile.

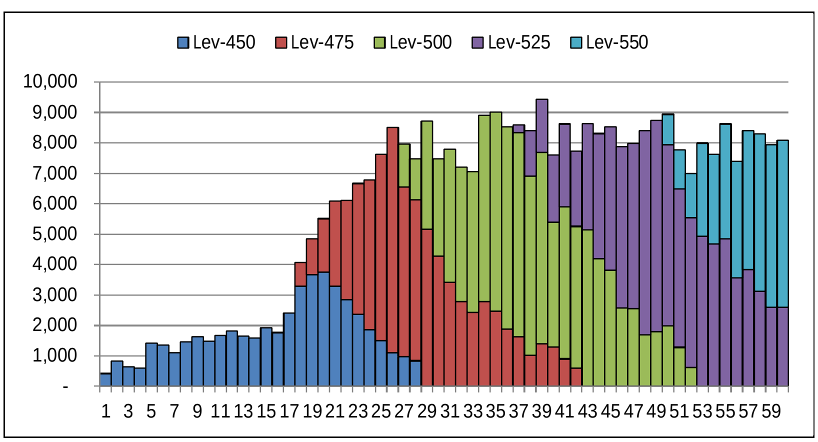


Figure 57: Description of the tonnage reported by level

4.4.6.1. *Working with one cell per ring*

The following exercises were done using only one cell per ring minimizing the computer's memory utilization since only one element per ring will be used for depletion and mixing purpose. Figure 58 shows the PCSLC model created using only one cell per ring (left) and the neighbors links created (right).

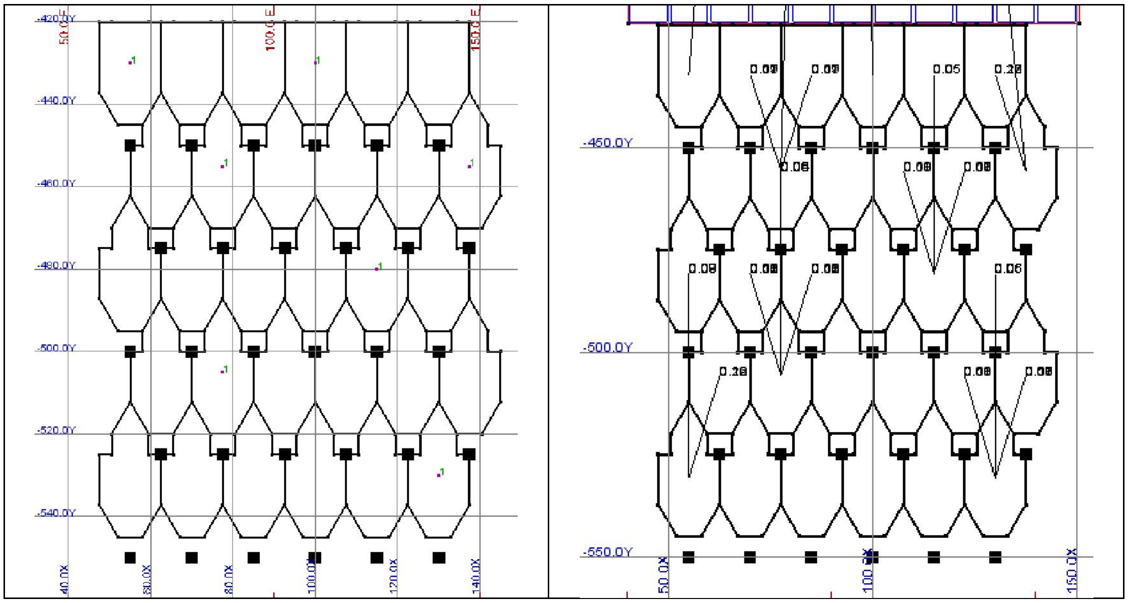


Figure 58: PCSLC model with one cell per ring

4.4.6.2. *Summary results*

More than 50 runs were done using a combination of the mixing parameters described above to assess the impact of changing parameters in the result. In each run the results were evaluated in terms of the tonnage, grade and recovery by level. Figure 59 shows an example of the tonnage depleted with the Cu grade and dilution, where the profile is quite irregular in the first 20 month due to the irregular ingress of the dilution.

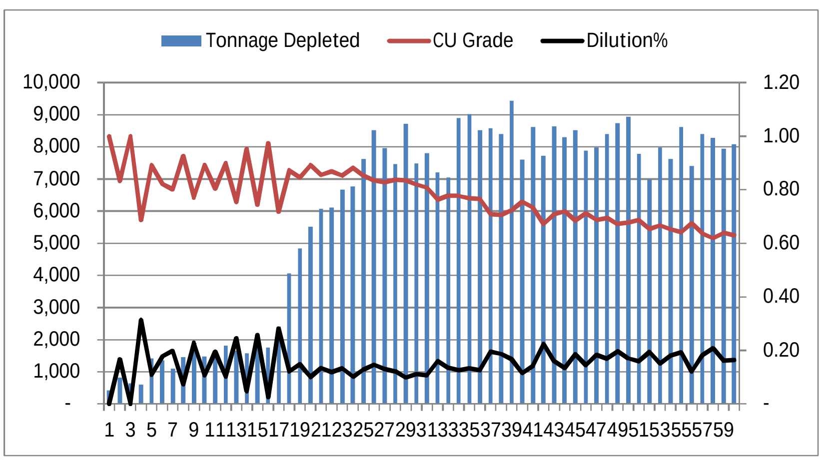


Figure 59: Tonnage, grade and dilution reported

Figure 60 display the material composition based on the origin by level, for example in period# 49, 7% of the material comes from Level1, 11% from Level2, 23% from Level3, 40% from Level4 and finally 19% of dilution. This analysis is very important to quantify the level of mixing and recovery by level.

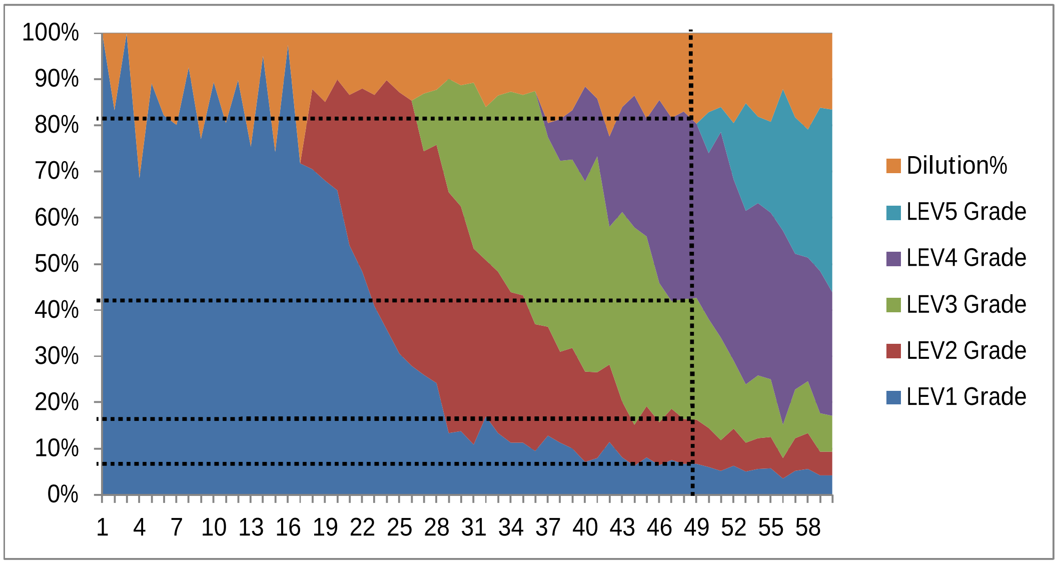


Figure 60: Material composition per level and dilution

In this model the material was tracked following the logic used in the experiment done in the Ridgeway mine therefore was possible to create a recovery curve to obtain the material extracted as primary, secondary, and tertiary, etc. Figure 61 described the recovery profile achieved in this model.

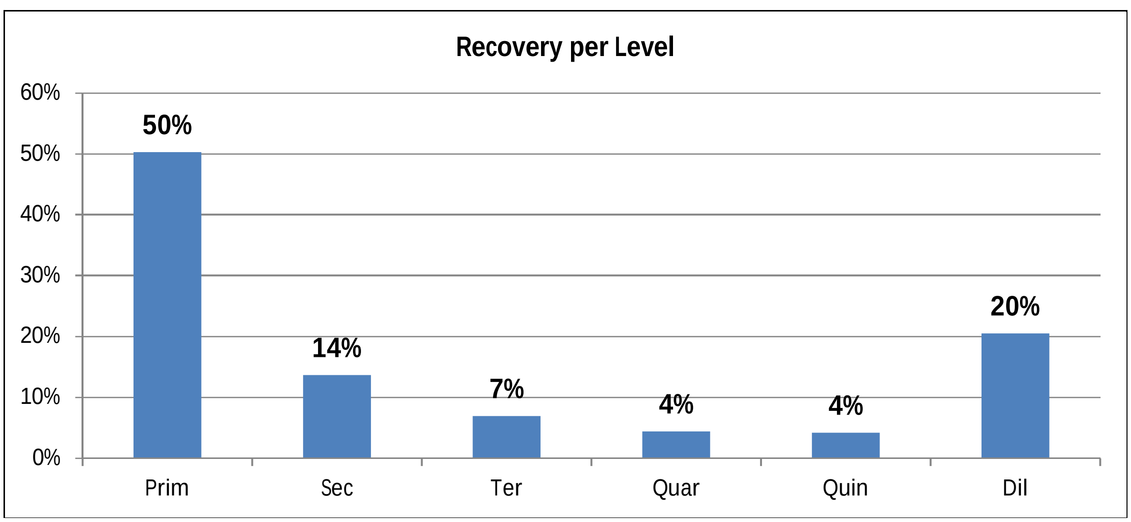


Figure 61: Recovery profile

4.4.6.3. Summary of the run done and the effect in the mixing and recovery results

This section described a summary of the run done and the effect in the mixing and recovery results based on the modification done over each mixing parameter. The results are summarized in the figures62-65 and tables 11-14.

Percent Frozen

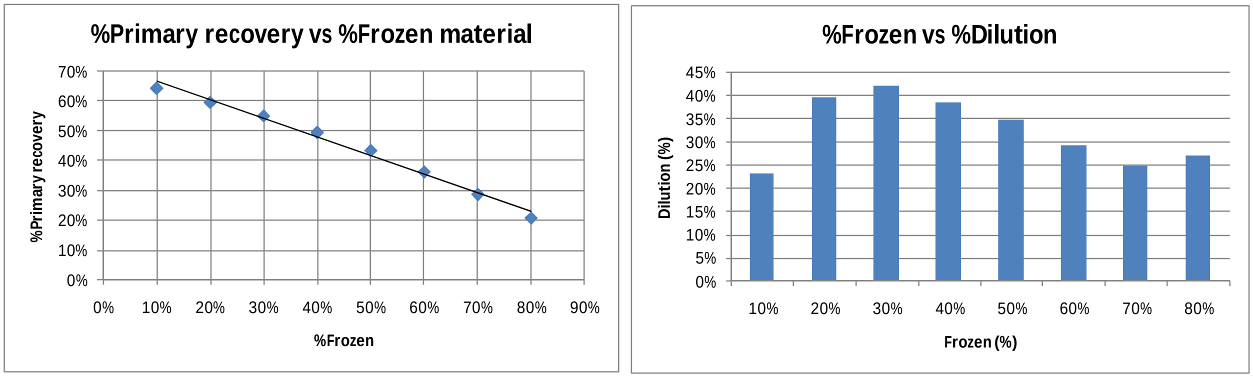


Figure 62: Primary recovery and %Dilution based on Percent Frozen

Table 11: Percent frozen runs

Erosion rate

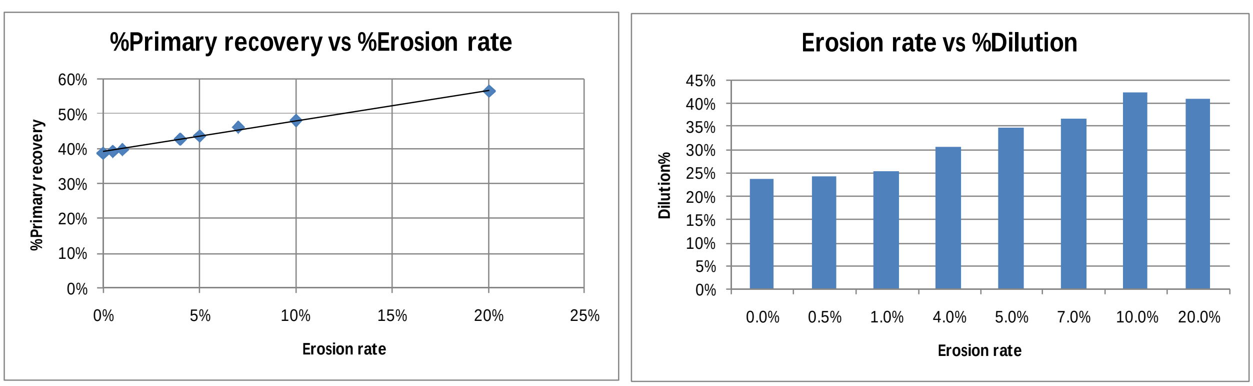
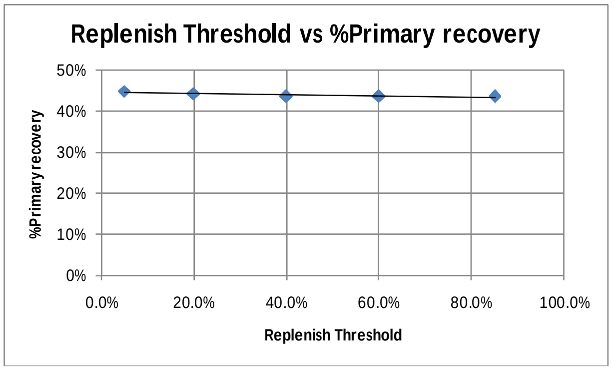


Figure 63: Primary recovery and %Dilution based on Erosion rate

Table 12: Erosion rate runs

Run	Real	B08	B09	B10	B12	C08	C14	B13	B14
Numbers of cells per rings		1	1	1	1	1	1	1	1
Neighbors and neighbor weights.		3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels
Replenish Threshold		0.85	0.85	0.85	0.85	0.85	0.50	0.85	0.85
Bottom refill		0.8	0.8	0.8	0.8	0.80	0.50	0.8	0.8
%Frozen		50%	50%	50%	50%	50%	50%	50%	50%
Erosion rate		0%	0.5%	1%	4%	5%	7%	10%	20%
Shut off value (Cu%)		-	-	-	-	-	-	-	-
Prim%	50%	39%	39%	40%	43%	44%	46%	48%	56%
Sec%	12%	21%	21%	20%	17%	16%	15%	8%	2%
Ter%	9%	9%	8%	8%	6%	4%	2%	1%	0%
Quar%	6%	4%	4%	4%	2%	1%	0%	0%	0%
Quin%	3%	3%	3%	3%	2%	1%	0%	0%	0%
Dil%	20%	24%	24%	25%	31%	35%	37%	43%	41%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
Tonnage	kt	445.33	445.33	445.33	445.33	445.33	445.33	445.33	445.33
Cu	%	0.68	0.68	0.68	0.64	0.63	0.64	0.58	0.56
Dil%	%	22%	22%	22%	25%	27%	25%	32%	33%

Replenish Threshold



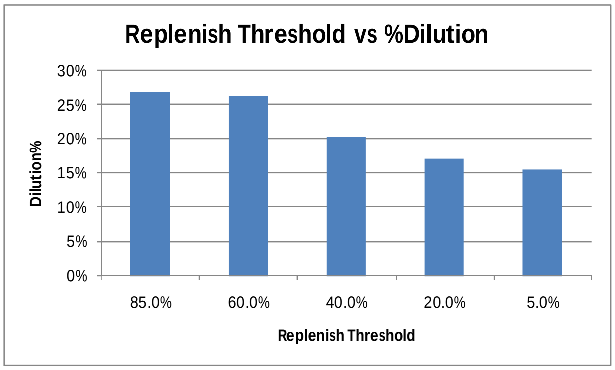


Figure 64: Primary recovery and %Dilution based on Replenish Threshold

Table 13: Replenish Threshold runs

Run	Real	C08	C09	C10	C11	C12
Numbers of cells per rings		1	1	1	1	1
Neighbors and neighbor weights.		3 levels	3 levels	3 levels	3 levels	3 levels
Replenish Threshold		0.85	0.60	0.40	0.20	0.05
Bottom refill		0.80	0.80	0.80	0.80	0.80
%Frozen		50%	50%	50%	50%	50%
Erosion rate		5%	5%	5%	5%	5%
Shut off value (Cu%)		-	-	-	-	-
Prim%	50%	44%	44%	44%	44%	45%
Sec%	12%	16%	16%	18%	19%	19%
Ter%	9%	4%	4%	7%	8%	8%
Quar%	6%	1%	1%	4%	4%	4%
Quin%	3%	1%	1%	3%	4%	4%
Dil%	20%	35%	34%	24%	20%	20%
Total	100%	100%	100%	100%	100%	100%
Tonnage	kt	445.33	445.33	445.33	445.33	445.33
Cu	%	0.63	0.63	0.69	0.71	0.73
Dil%	%	27%	26%	20%	17%	15%

Bottom refill

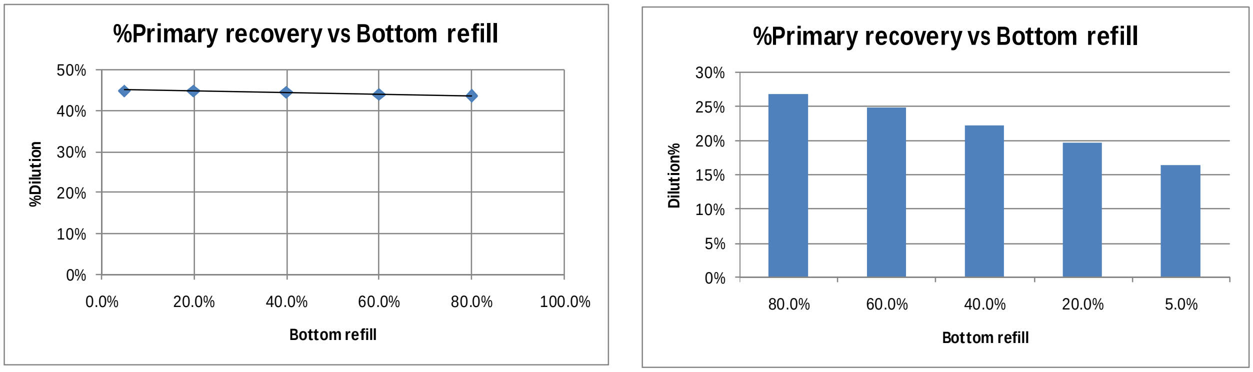


Figure 65: Primary recovery and %Dilution based on Bottom refill

Table 14: Bottom refill runs

Run	Real	C08	D01	D02	D03	D04
Numbers of cells per rings		1	1	1	1	1
Neighbors and neighbor weights.		3 levels	3 levels	3 levels	3 levels	3 levels
Replenish Threshold		0.85	0.85	0.85	0.85	0.85
Bottom refill		0.80	0.60	0.40	0.20	0.05
%Frozen		50%	50%	50%	50%	50%
Erosion rate		5%	5%	5%	5%	5%
Shut off value (Cu%)		-	-	-	-	-
Prim%	50%	44%	44%	45%	45%	45%
Sec%	12%	16%	17%	19%	22%	24%
Ter%	9%	4%	4%	4%	4%	5%
Quar%	6%	1%	1%	1%	1%	1%
Quin%	3%	1%	1%	1%	1%	1%
Dil%	20%	35%	34%	30%	28%	24%
Total	100%	100%	100%	100%	100%	100%
Tonnage	kt	445.33	445.33	445.33	445.33	445.33
Cu	%	0.63	0.64	0.66	0.69	0.72
Dil%	%	27%	25%	22%	20%	16%

Conclusion about the parameters used

- Percent Frozen has a major impact over the primary recovery. If %Frozen is bigger than 70% the result of the primary recovery is lower than secondary recovery creating a not very realistic profile, so depending the actual primary and secondary recovery this is one of the most important input to modify.
- Erosion rate has a bigger impact in the secondary recovery than the primary, allowing to change the overall recovery profile.
- Replenish Threshold has minimum impact in the primary and secondary recovery profile, but change the distribution of the tertiary and the quaternary recovery creating a profile similar than expected. The dilution increase when this value is higher so it should means that more material outside of the cell is allow to move in and then it should means more level of mixing.
- Bottom refill has an impact only in the secondary recovery, increasing this when the bottom refill is lower. The dilution shows different results as well increasing with bigger values so it should have similar effect than Replenish Threshold since higher value could mean more mixing allowing the dilution material moving faster.

Table 15 below summarizes the effect of the changes of the parameters in the recovery and dilution profile.

Table 15: Effect of the changes of the parameters in the recovery and dilution

Parameter	Action	Prim Rec	Sec Rec	Ter Rec	Qua Rec	Dil
Percent Frozen	5	6 6 6	5 5	5	5	6 6
Erosion rate	5	5 5	6 6	6	6	5 5
Replenish Threshold	6	=	5	5	5	6
Bottom refill	6	=	5	=	=	6

4.4.6.4. Working with three cells per ring

An additional work was done using three cells per rings to assess this effect in the recovery result, since the main portion of the flow is on the center of the rings and less at the border therefore having three cells should provide a good representation of the real flow. Figure 66 shows the location of the three cells per rings (left) and the neighbors links calculated (right).

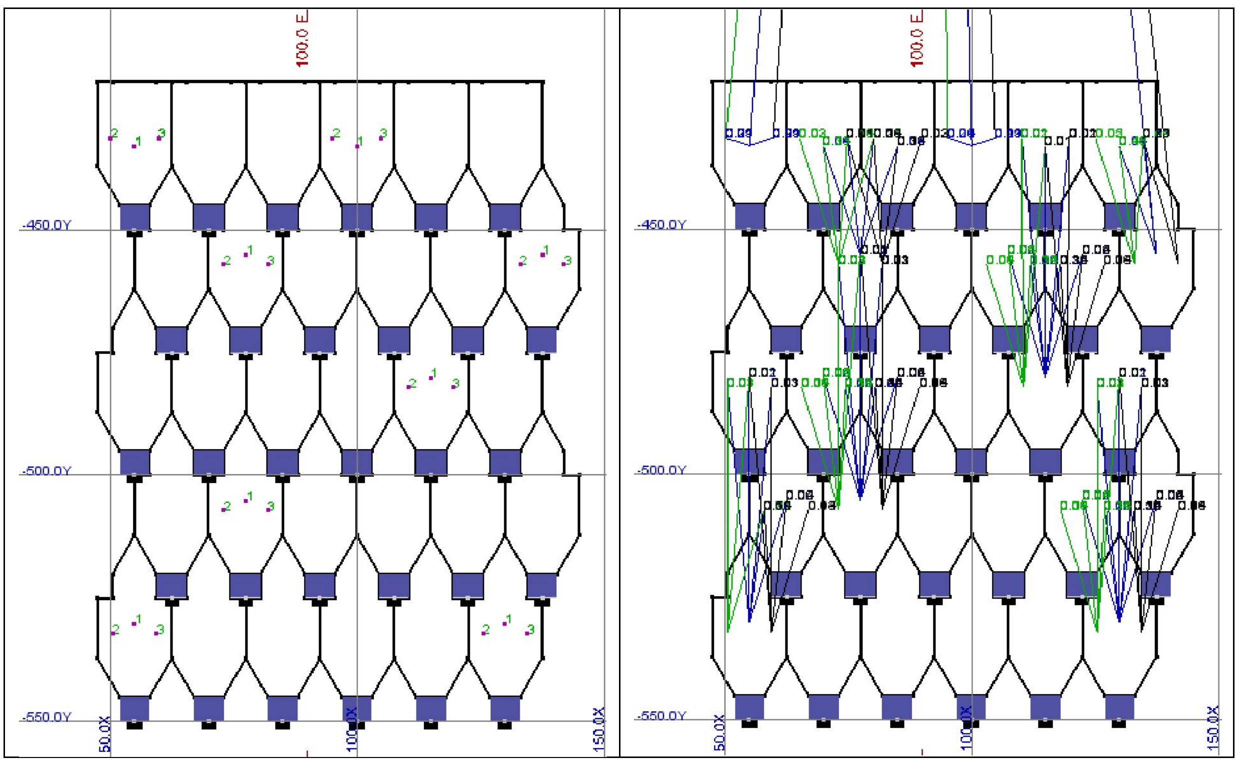


Figure 66: PCSLC model with three cells per ring

The same type of analysis was done with the runs done using three cells per ring, trying to identify if using these new model the result are more realistic than the model created with only one cell per ring. Figure 67 display the tonnage, grade and dilution profile. In this case the grade is lower and the dilution is higher compare with the run described using only one cell per ring (Figure 59).

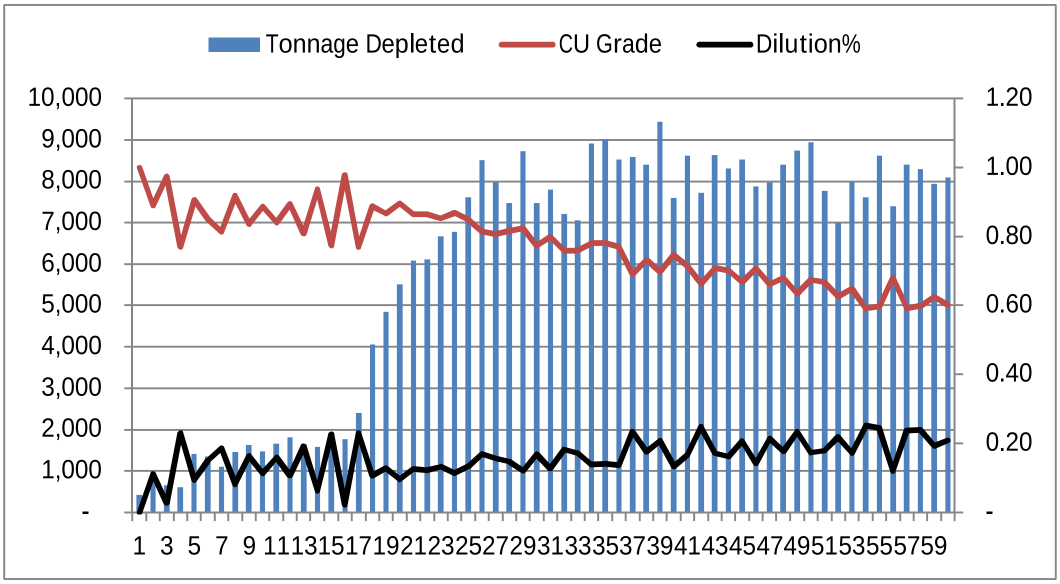


Figure 67: Tonnage, grade and dilution reported

This model shows a different material composition than the model using only one cell per ring (Figure 60). In this case Figure 68 displays the results for period #49 as4% of the material comes from Level1, 7% from Level2, 40% from Level3, 29% from Level4 and finally 20% of dilution.

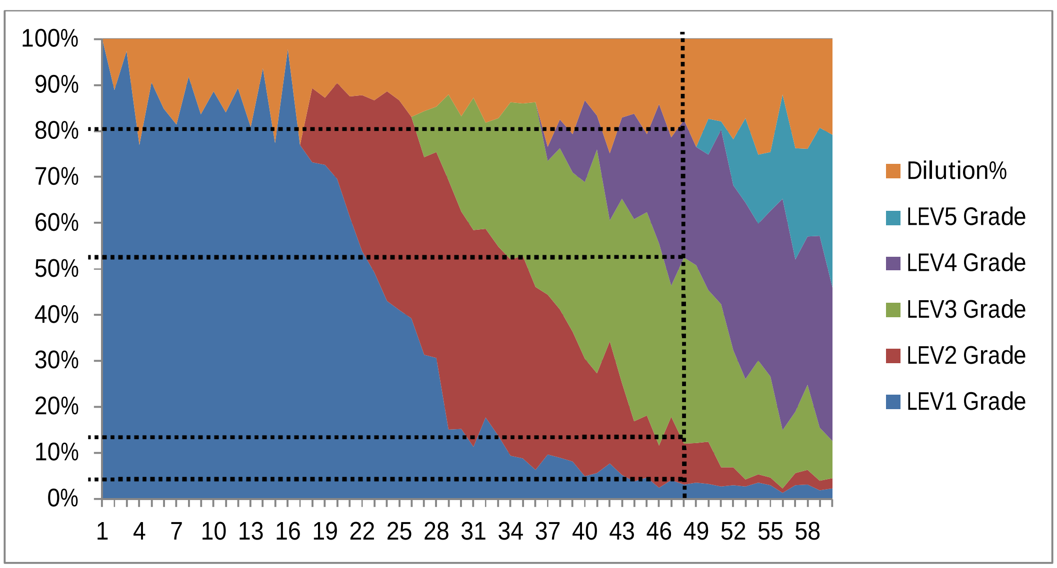


Figure 68: Material composition per level and dilution

Finally the recovery profile is shown in Figure 69. This model doesn't represent a real profile for SLC extraction since the primary and secondary recoveries are high and very similar also tertiary, quaternary and quinternary are very low. The dilution seems to be quite high as well.

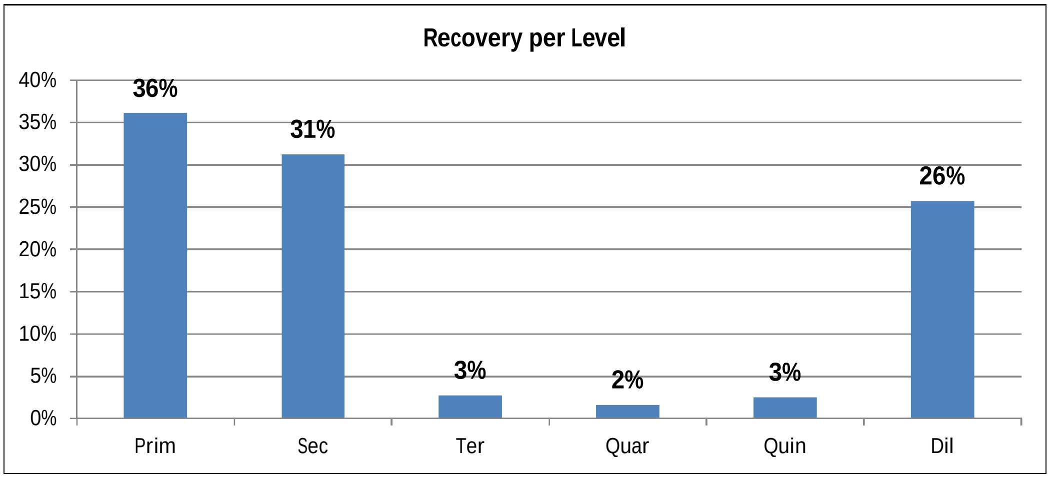


Figure 69: Recovery profile

4.4.7. Conclusion

Comparing the recovery results shown in Figure 69 with the data provided by the experiment done in Ridgeway (see Figure 40: Summary of recovery curves and a new proposal for Calibration of PCSLC) sing three cells per ring doesn't provide a realistic scenario and then using only one cell per ring is enough to have a good PCSLC model.

Finally the best set of Template mixing parameters selected to get similar profile of the recovery by level compare with Ridgeway data is shown in Figure 70:

Run	Run#C15
Numbers of cells per rings	1
Neighbors and neighbor weights.	3 levels
Replenish Threshold	0.40
Bottom refill	0.80
%Frozen	40%
Erosion rate	5%
Shut off value (Cu%)	-
Prim%	50%
Sec%	14%
Ter%	7%
Quar%	4%
Quin%	4%
Dil%	20%
Total	100%
Tonnage	445.33
Cu	0.71
Dil%	17%

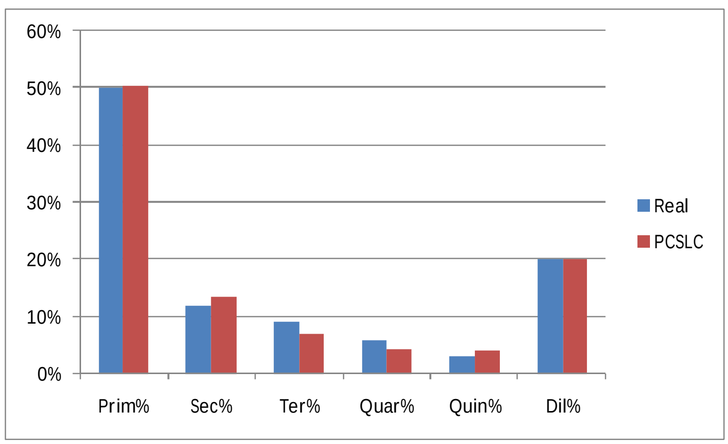


Figure 70: Run selected to replicate similar profile that real data

5. Calibration of mixing model using Ridgeway database

This section described the PCSLC calibration work done using Ridgeway database. The following steps were used to replicate Ridgeway mine at PCSLC:

1. Create tunnels and ring using the real coordinates
2. Import block model to Gems
3. Define cell size for mixing purpose
4. Assign grades to cells and rings
5. Define the dilution strategy
6. Identify the material to track to replicate the experiment done using trial marker
7. Production schedule run at PCSLC using Ridgeway data
    a. Define the sequence of extraction per level and tunnel
    b. Define extraction percentage per ring
    c. Replicate the tonnage extracted by level
    d. Compare the grade and recovery profile

5.1. Creation of tunnels and ring using the real coordinates

The first was creating a PSCLS model to replicate the Ridgeway mine using the real tunnel and ring location. Figure 71 shows Real mine layout (left) and the tunnels created at PCSLC (right), the main purpose is create the tunnels for each level at the real location to allocate tonnage and grade in the same place where the mine report originally.

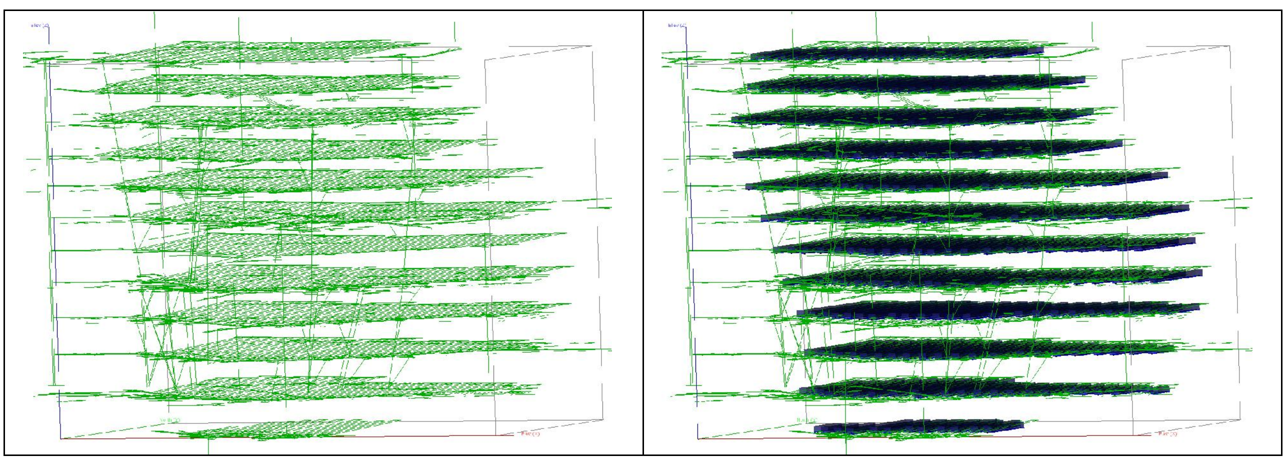


Figure 71: Real mine layout (left) and the tunnels created at PCSLC (right)

Also the rings were created based on the real coordinated so the burden was not regular specifically at the begging of the tunnels, it create different volume for each ring. PCSLC respond very well allowing importing the rings from and ASCII file and then the volume and tonnage match correctly with the actual data. Figure 72 shows an example of the ring location at level 5070 and Figure 73 describes the distance between rings to define the volume used at the mine.

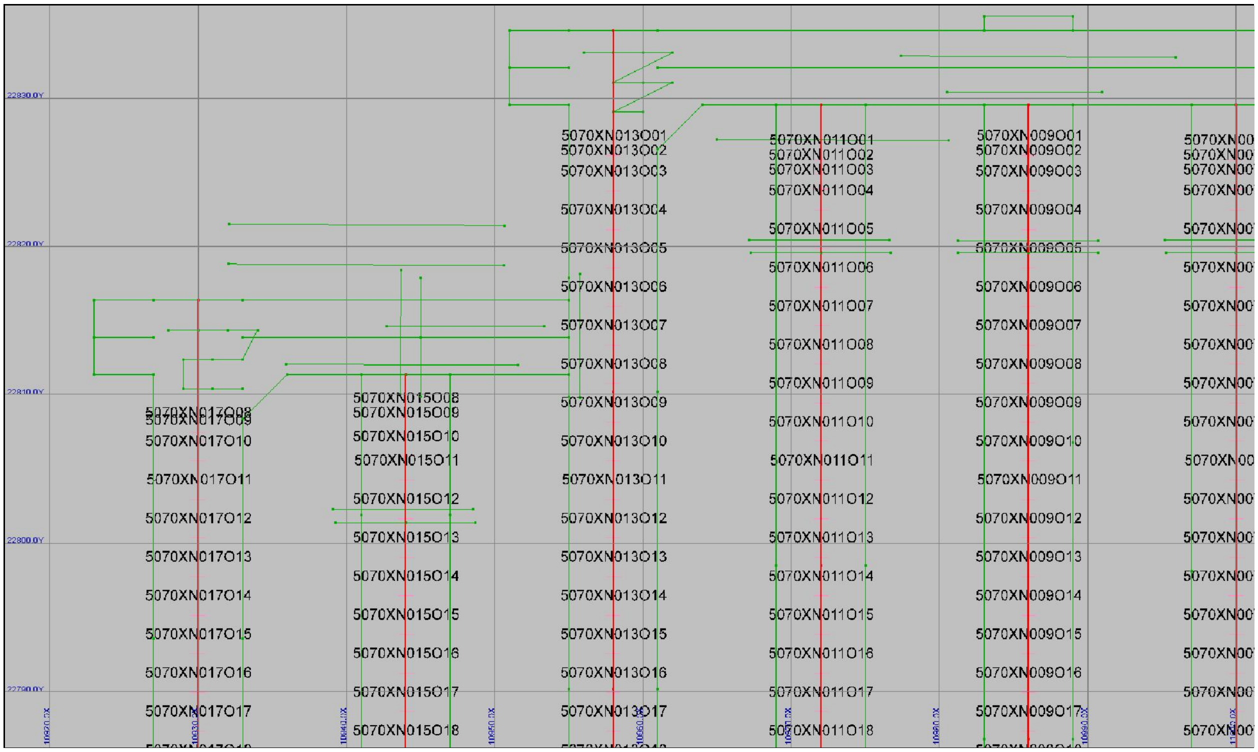


Figure 72: Example of the ring location at level 5070

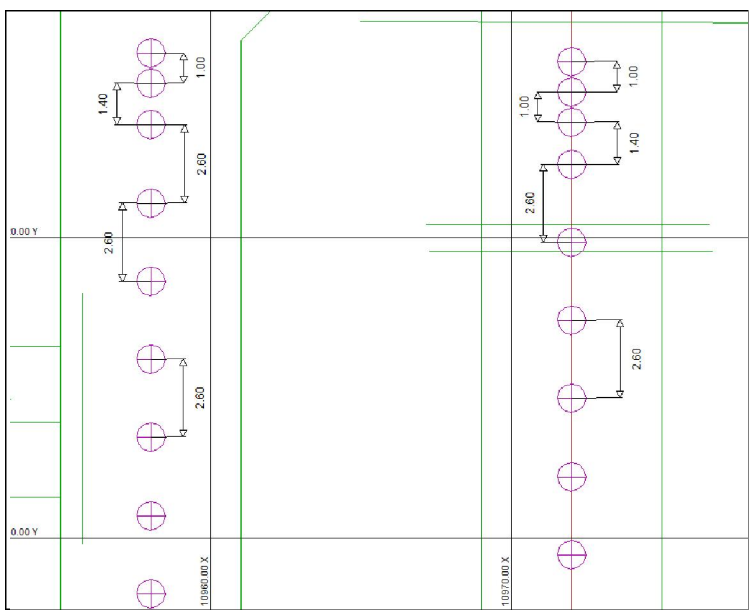


Figure 73: Example of the burden used between rings

Finally more than 14,096 rings were created using the combination of 12levels and 254 tunnels. Figure 74 shows the final PCSLC model having tunnel in blue and rings in green.

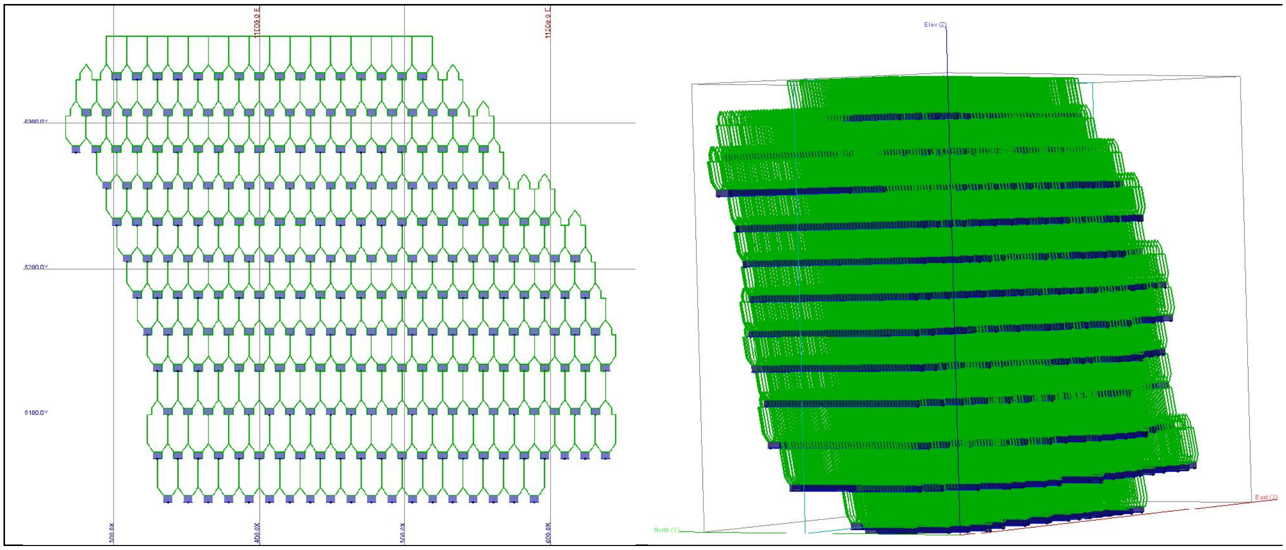


Figure 74: Example of the burden used between rings

5.2. Import block model to Gems

The block model provided by Ridgeway was imported and used in this work. A total of 720,000 blocks cover the entire area of study and also provide enough information above of the layout are to define the dilution from the top correctly. Also the size of the block was 10x10x10m providing a good level of discretization to use in the calibration process. Figure 75 describes the definition of the block model created in Gems.

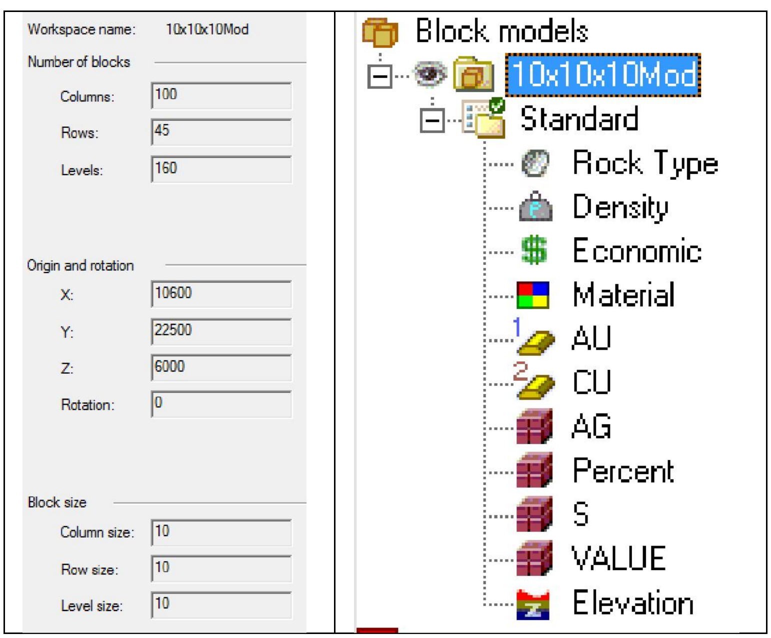


Figure 75: Definition of the block model created in Gems

A vertical section (22710N) with the distribution of gold and the rings created is shown in Figure 76.

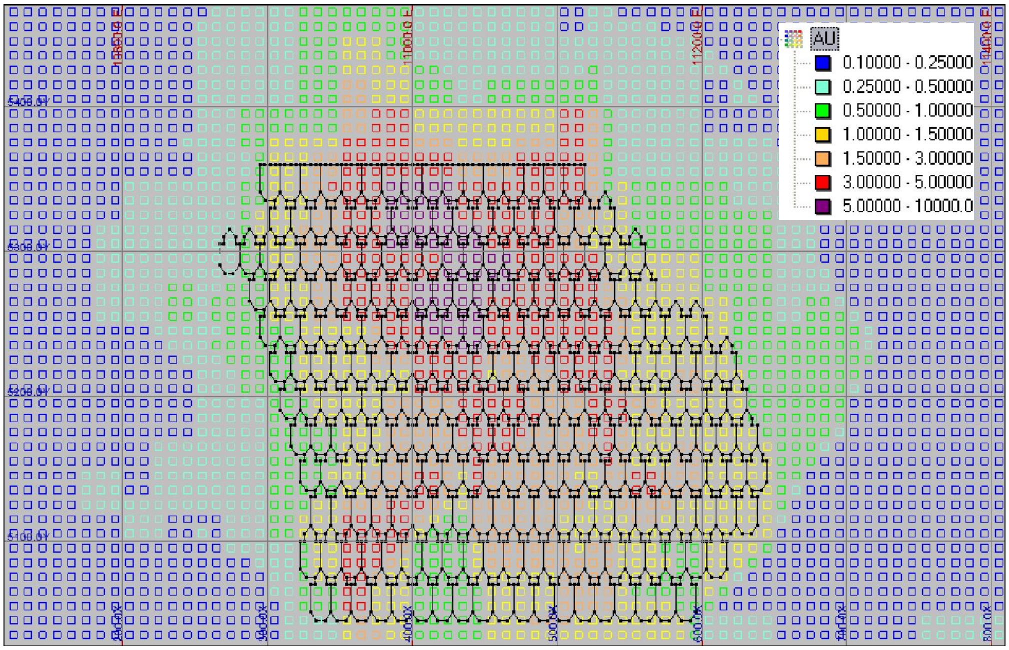


Figure 76: Distribution of gold and the rings created

5.3. Cell definition for mixing purpose

Based on the description done at the section4.4.2 (Internal cells definition),the cell definition is really important since it allows defining a center point in each ring to move material during the depletion. Also it was demonstrated that only one cell per ring is enough to get good recovery results and then Ridgeway model was created using only one cell per ring. Figure 77 shows the cells defined for this model, it is possible to see that each cells is located in the middle to provide a good representation of each ring.

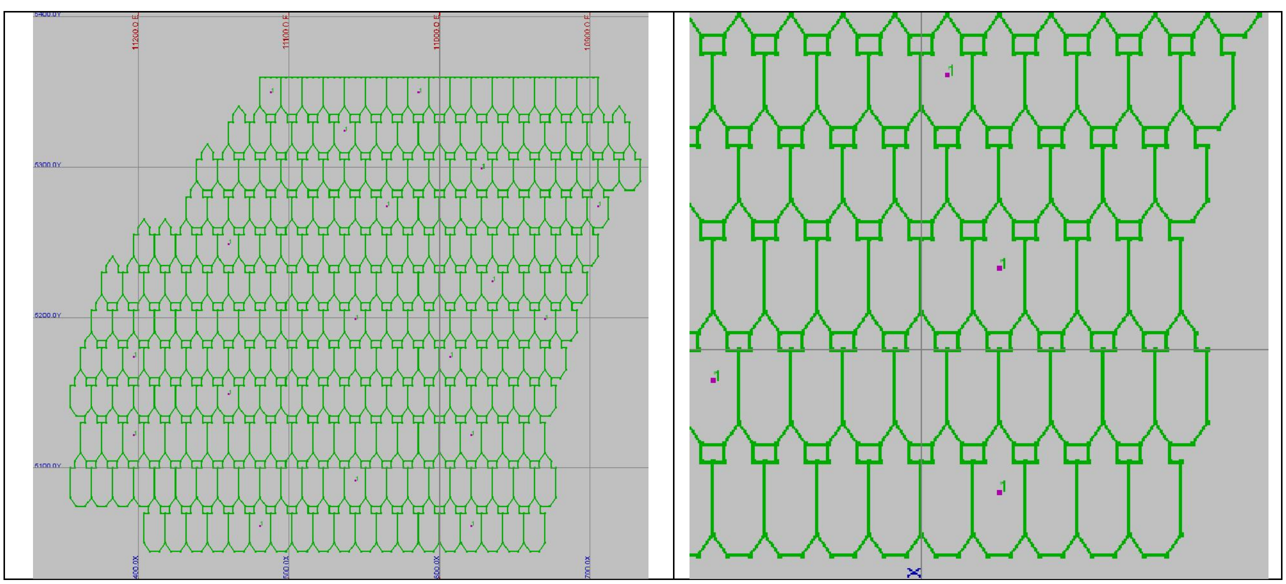


Figure 77: Definition of one cell per ring

5.4. Assign grades to cells and rings

Having the cells and ring defined the next step is to assigned Au and Cu grade from the block model. Table 16 shows the in situ report of tonnage and grade by level. It is important to note that the Cu grade is decreasing in the lower levels. Based on the production records from June 2000 to February 2009, 35.527 Mt were extracted reporting Au 2.34 g/t and Cu 0.81% in average and then at least 2.5Mt were extracted from above as "dilution".

Table 16: In situ tonnage and grade distribution per level

LEVEL	#RINGS	TONNAGE	Average t/ring	CU (%)	AU (g/t)
5330	550	1,322,216	2,404	0.943	2.104
5305	1,083	2,503,402	2,312	0.871	2.386
5280	1,291	2,911,283	2,255	0.898	2.928
5255	1,371	3,052,872	2,227	0.908	3.195
5230	1,419	3,173,313	2,236	0.888	3.097
5205	1,447	3,241,835	2,240	0.844	2.764
5180	1,403	3,146,275	2,243	0.825	2.671
5155	1,347	3,028,971	2,249	0.781	2.556
5130	1,295	2,897,381	2,237	0.737	2.537
5100	1,235	3,356,805	2,718	0.704	2.501
5070	1,072	2,885,463	2,692	0.649	2.155
5040	583	1,530,437	2,625	0.669	2.188
Grand Total	**14,096**	**33,050,254**	**2,345**	**0.809**	**2.641**

5.5. Define the dilution strategy

PCSLC offers several options to model the dilution such as described in the section4.4.3. (Strategy for boundary waste model). In this case two options were used as follow:

- The dilution was modeled using only material boundary.
- The dilution was modeled using material boundary and block rings.

5.5.1. Dilution model with only boundary material

This model was created with all the material above the mine layout considered pure dilution with no grade, it means all the rings in the border of the layout and the top levels were connected with an infinite source of dilution with no grade. Figure 78displays the neighbor link used in this case, the line going to the left side represent the connection with boundary material consequently when these rings were depleted dilution with no grade took this space.

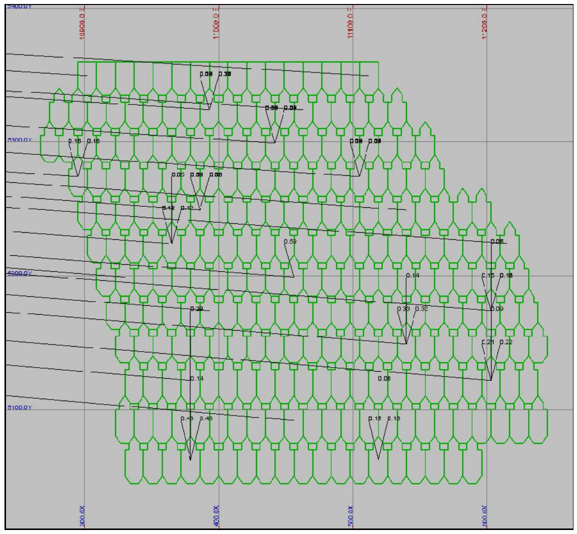


Figure 78: PCSLC model using only boundary material as dilution

5.5.2. Dilution model with only boundary material and block rings

In this case using “Block rings” allow having a layer of material above of the rings created as fictitious rings to track ore material more accurately since these ring take information directly from the block model and on top of this material boundary. Figure79 described the PCSLC model using block ring and boundary material on top allocating dilution material in a combination of data from the block model and pure dilution with no grade, also the link created are shown at the right side.

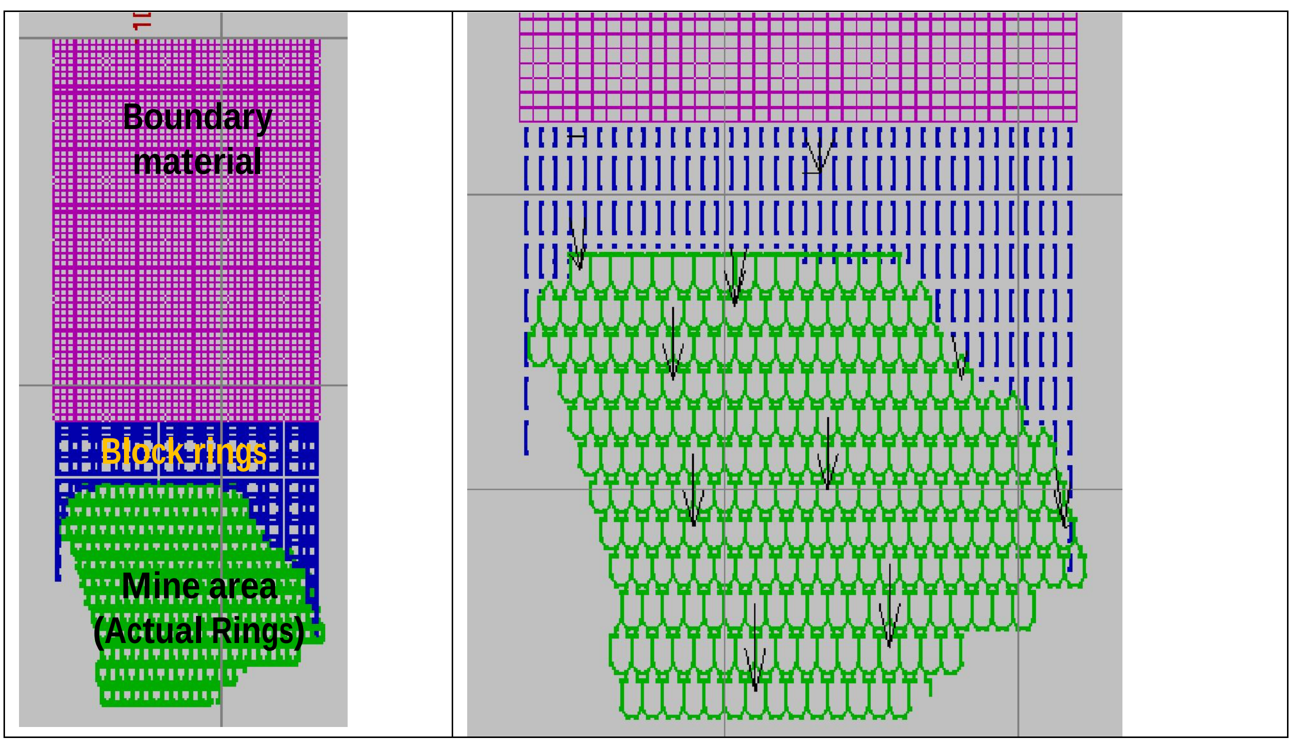


Figure 79: PCSLC model using block ring and boundary material on top

5.6. Identify the material to track to replicate the experiment done using trial marker

The trial marker done at Ridgeway is key information to calibrate the mixing model, consequently these experiments needs to be replicated in the PCSLC model. For this purpose every experiment was located in their real coordinates based on the ring used at the mine and assigned at the PCSLC model independently to track this material in the lower levels. Figure 80displays the experiment located at the level 5255 and for each experiment a surrounded area was identified to track and report this material later. Figure 81 describes the method used to track the material to quantify the amount of primary, secondary, tertiary, quaternary and quinternary recovery.

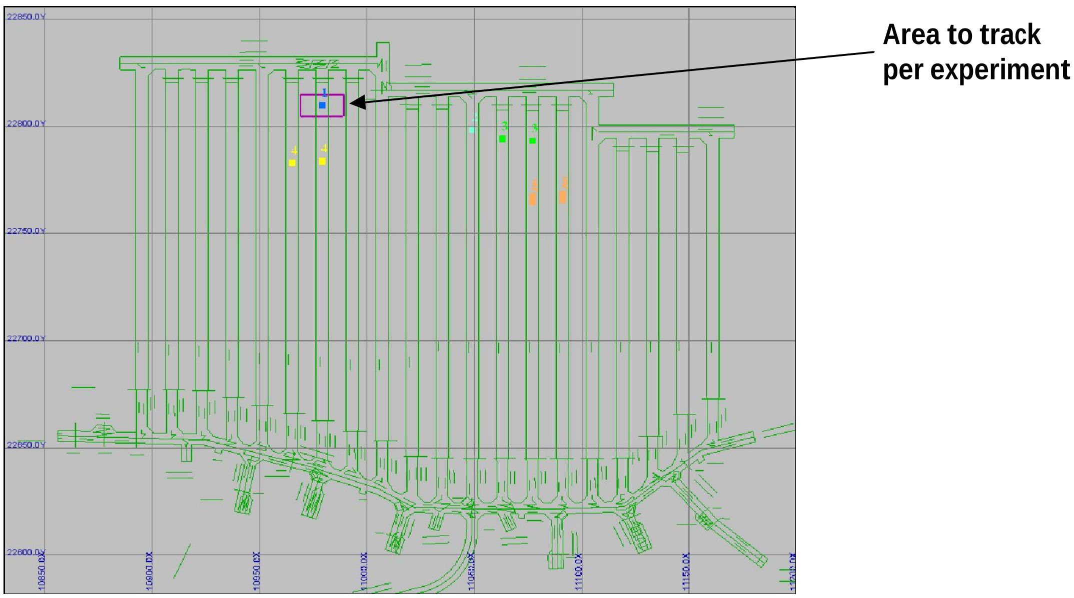


Figure 80:PCSLC manner to replicate the marker used at Ridgeway at level 5255

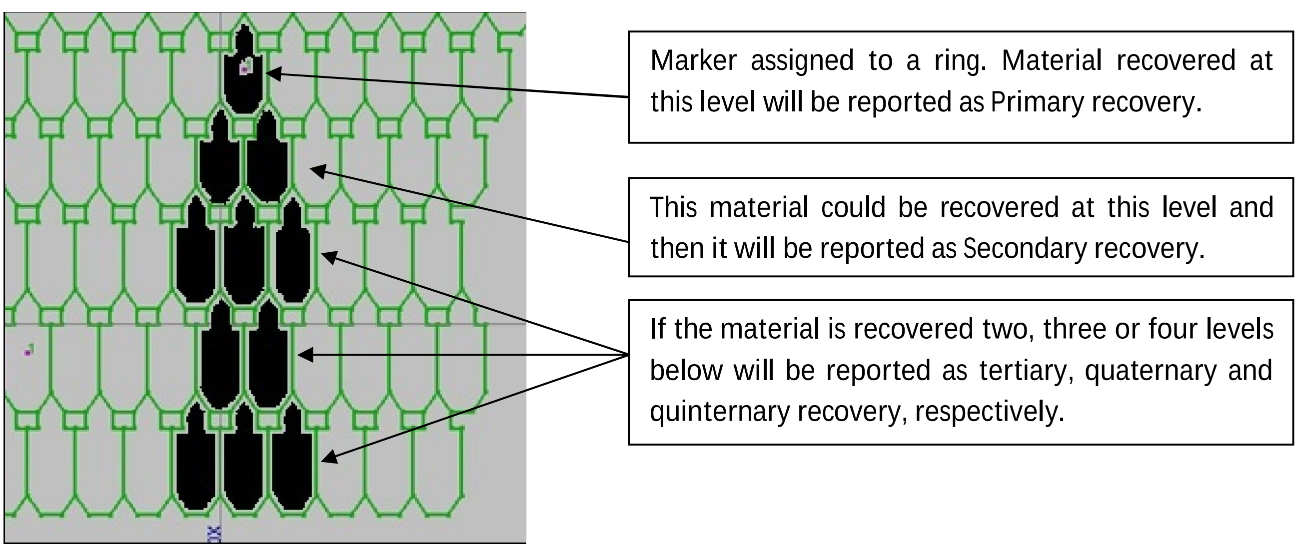


Figure 81: Method to track material by level

5.7. Production schedule run at PCSLC using Ridgeway data

This section describes the work done at PCSLC in terms of production schedule trying to get similar results than Ridgeway mine and then be able to calibrate the PCSLC with actual grade and recovery results. Figure 82 described the elements used to create a production schedule run at PCSLC.

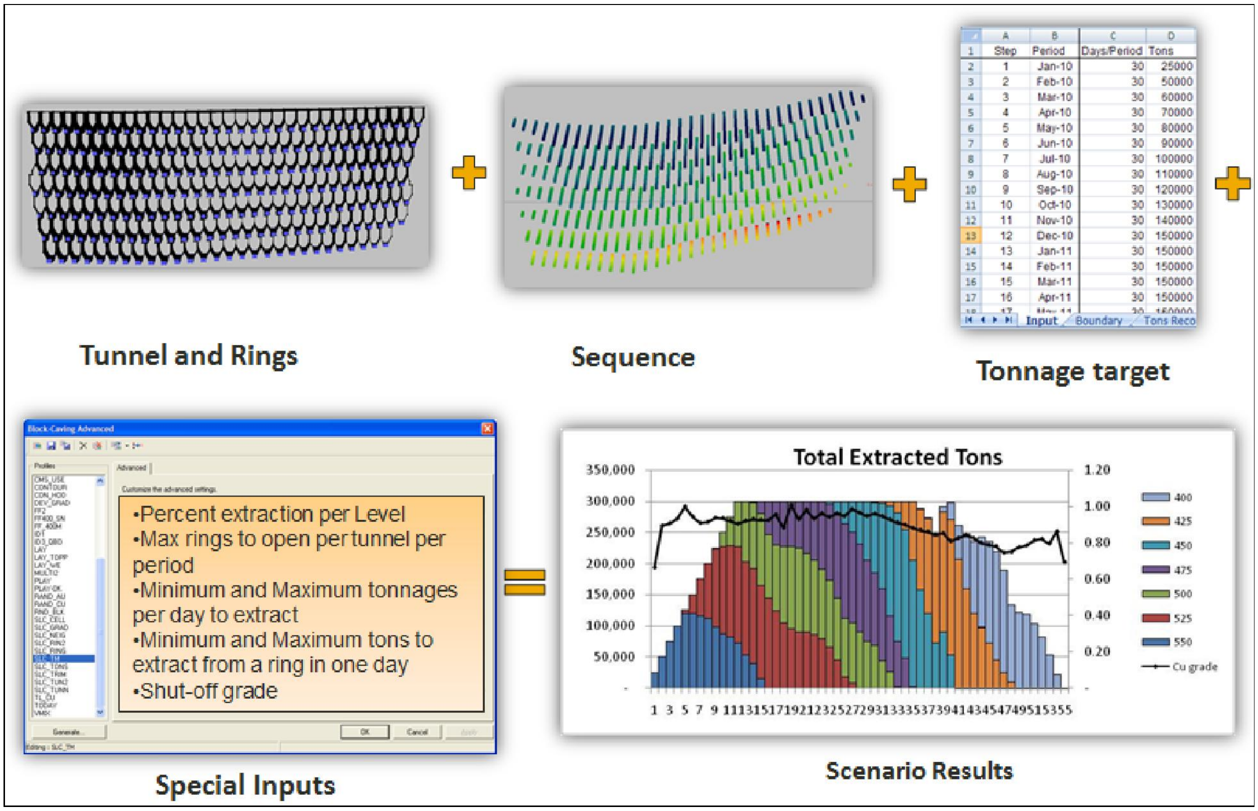


Figure 82: Elements used to create a production schedule run at PCSLC

The following steps were used to create a PCSLC production schedule run for calibration purpose reference:

1. Define the sequence of extraction per level and tunnel
2. Define extraction percentage per ring
3. Replicate the tonnage extracted by level
4. Compare the grade and recovery profile

5.7.1. Define the sequence of extraction per level and tunnel

The sequence is really important since allow to replicate the way that the rings were blasted giving the mine direction for levels and tunnels. This data was obtained using the information provided by Ridgeway. Figure 83 described the record of data by Ring where the start and finish date give the production period and also the day of blast. Using the start date was possible to define the sequence order to use in PCSLC.

Easting	Northing	R.L.	DPID	Actual Mined Tonnes	Design Tonnes	%Drawn	Start	Finish	Period_Start	Duration
11,049	22,795	5,305	5305XN001O11	817	2,043	40%	15-Jul-01	19-Jul-01	2001-07	4.00
11,035	22,791	5,305	5305XN003O12	812	2,029	40%	17-Jul-01	18-Jul-01	2001-07	1.00
10,965	22,794	5,305	5305XN013O11	824	2,059	40%	17-Jul-01	19-Jul-01	2001-07	2.00
10,979	22,791	5,305	5305XN011O12	824	2,061	40%	17-Jul-01	19-Jul-01	2001-07	2.00
10,881	22,797	5,305	5305XN025O10	880	2,200	40%	17-Jul-01	20-Jul-01	2001-07	3.00
11,007	22,791	5,305	5305XN007O12	823	2,058	40%	17-Jul-01	21-Jul-01	2001-07	4.00
10,993	22,791	5,305	5305XN009O12	817	2,044	40%	17-Jul-01	28-Jul-01	2001-07	11.00
11,063	22,791	5,305	5305XN002O12	818	2,045	40%	18-Jul-01	18-Jul-01	2001-07	1.00
10,937	22,794	5,305	5305XN017O11	838	2,094	40%	18-Jul-01	19-Jul-01	2001-07	1.00
10,951	22,794	5,305	5305XN015O11	759	1,897	40%	18-Jul-01	19-Jul-01	2001-07	1.00
11,091	22,789	5,305	5305XN006O13	813	2,033	40%	18-Jul-01	20-Jul-01	2001-07	2.00
11,077	22,793	5,305	5305XN004O12	818	2,045	40%	18-Jul-01	20-Jul-01	2001-07	2.00
11,119	22,785	5,305	5305XN010O13	133	334	40%	18-Jul-01	23-Jul-01	2001-07	5.00
10,923	22,794	5,305	5305XN019O11	835	2,087	40%	18-Jul-01	24-Jul-01	2001-07	6.00
11,063	22,789	5,305	5305XN002O13	762	1,904	40%	19-Jul-01	23-Jul-01	2001-07	4.00
11,035	22,789	5,305	5305XN003O13	749	1,873	40%	19-Jul-01	24-Jul-01	2001-07	5.00
11,049	22,793	5,305	5305XN001O12	818	2,045	40%	20-Jul-01	20-Jul-01	2001-07	1.00
10,937	22,791	5,305	5305XN017O12	819	2,047	40%	20-Jul-01	23-Jul-01	2001-07	3.00
10,951	22,791	5,305	5305XN015O12	771	1,928	40%	20-Jul-01	25-Jul-01	2001-07	5.00
10,965	22,791	5,305	5305XN013O12	833	2,082	40%	20-Jul-01	25-Jul-01	2001-07	5.00
11,077	22,790	5,305	5305XN004O13	748	1,870	40%	21-Jul-01	21-Jul-01	2001-07	1.00
11,049	22,790	5,305	5305XN001O13	765	1,913	40%	21-Jul-01	26-Jul-01	2001-07	5.00
11,091	22,786	5,305	5305XN006O14	809	2,022	40%	22-Jul-01	26-Jul-01	2001-07	4.00
11,077	22,788	5,305	5305XN004O14	776	1,940	40%	22-Jul-01	26-Jul-01	2001-07	4.00
11,007	22,789	5,305	5305XN007O13	763	1,908	40%	23-Jul-01	26-Jul-01	2001-07	3.00
11,021	22,791	5,305	5305XN005O12	820	2,051	40%	23-Jul-01	26-Jul-01	2001-07	3.00
10,881	22,794	5,305	5305XN025O11	880	2,200	40%	24-Jul-01	26-Jul-01	2001-07	2.00
10,895	22,794	5,305	5305XN023O11	825	2,062	40%	24-Jul-01	26-Jul-01	2001-07	2.00
11,105	22,786	5,305	5305XN008O12	49	123	40%	24-Jul-01	27-Jul-01	2001-07	3.00
11,035	22,786	5,305	5305XN003O14	764	1,910	40%	26-Jul-01	29-Jul-01	2001-07	3.00
11,119	22,785	5,305	5305XN010O14	388	969	40%	26-Jul-01	31-Jul-01	2001-07	5.00
10,979	22,789	5,305	5305XN011O13	767	1,918	40%	26-Jul-01	3-Aug-01	2001-07	8.00
11,049	22,788	5,305	5305XN001O14	752	1,880	40%	26-Jul-01	4-Aug-01	2001-07	9.00
10,965	22,789	5,305	5305XN013O13	754	1,885	40%	26-Jul-01	7-Aug-01	2001-07	12.00

Figure 83: Detailed record of data by Ring

The graph shown in Figure 84 describes how the sequence works by level. Most of the time 4 levels were blasted at the same time having good interaction between the level finishing at the top and the level starting at the bottom.

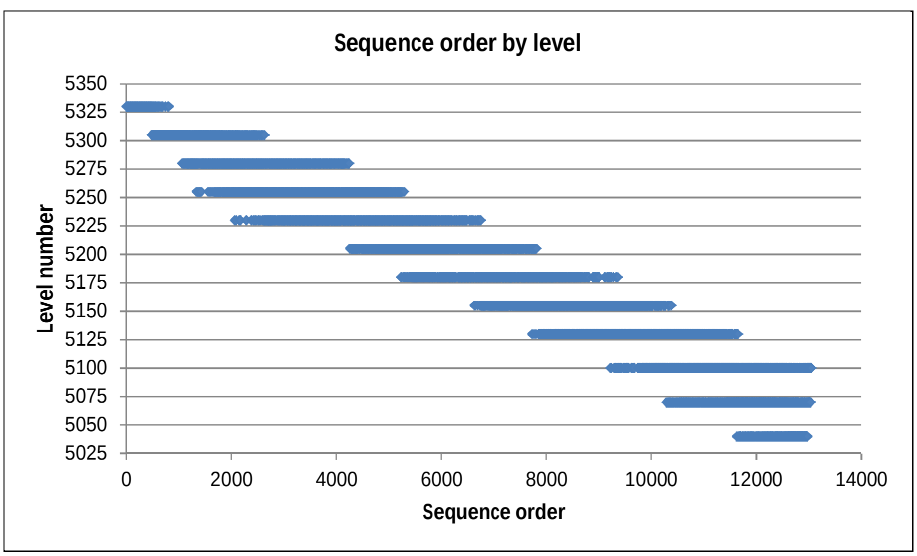


Figure 84: Sequence order by level

Figure 85displays the rings colored by sequence order in isometric view. The sequence shows mine advanced by level using a straight line as a front cave moving from north to south, Figure 86 shows this situation clearly in planview using Level 5255 as an example.

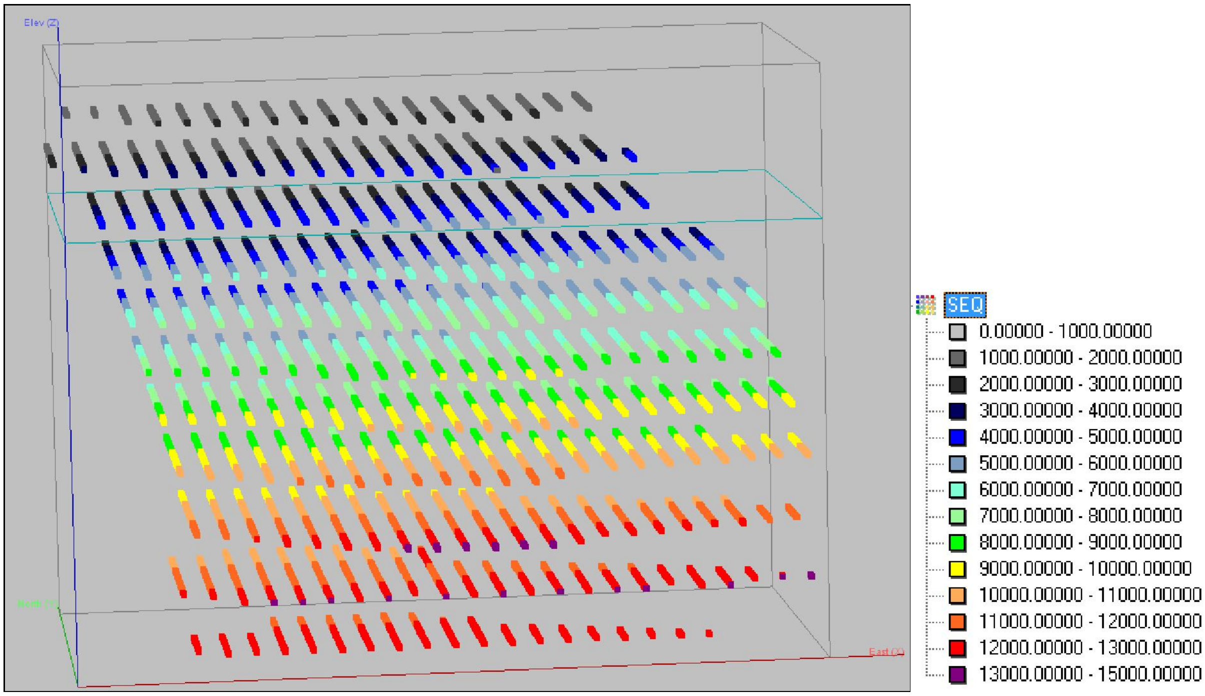


Figure 85: Rings colored by sequence order in isometric view

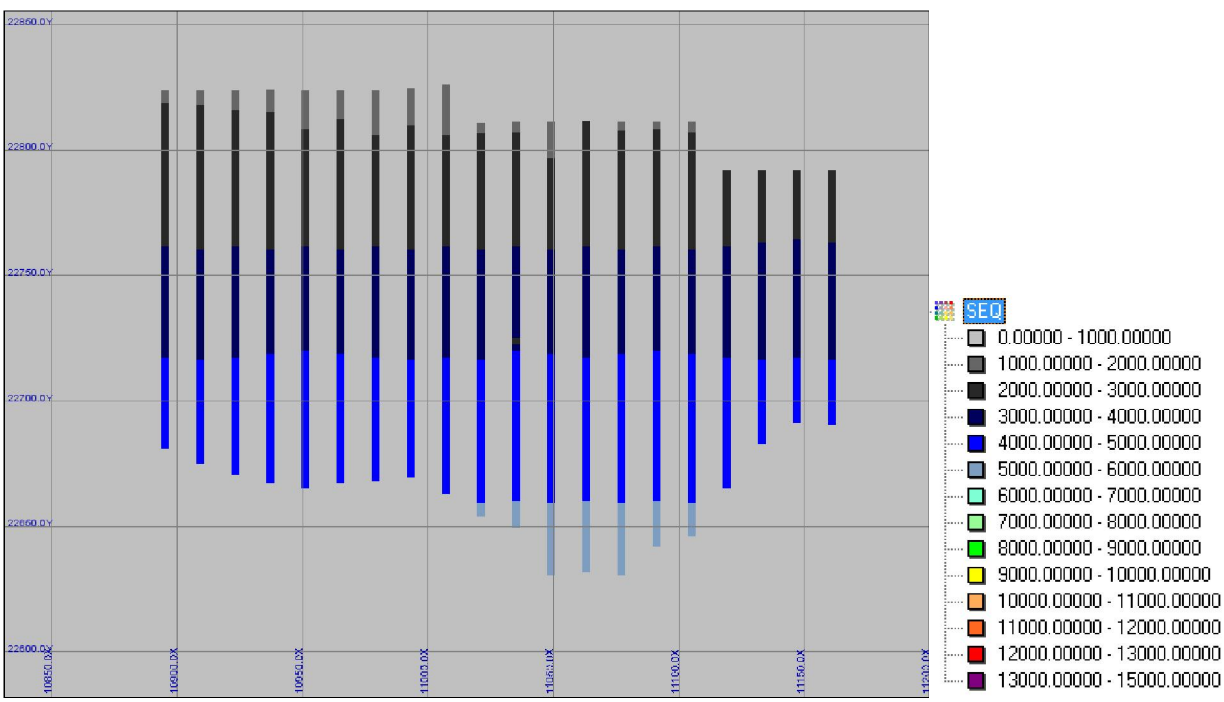


Figure 86: Rings colored by sequence order in 2D (Level 5255)

5.7.2. Define extraction percentage per ring

This input was very important to be able to replicate the tonnage extracted by Ridgeway since the production data provided only has total numbers by level in monthly basis, but not detailed by rings consequently having the amount of tonnage designed and mined per ring (see Figure 82) it was possible to estimate an extraction percentage per ring. Table 17 described the extraction percentage used by level. Top level has lower extraction attempting to mitigate the effect of the ingress of the dilution from the top and then ore left behind will try to be recovered at the bottom level extracting more than 100%.

Table 17: Average extraction percentage by level

Level	Desing Tons	Extracted Tons	%Extraction
5330	783,520	411,465	53%
5305	2,415,503	1,567,533	65%
5280	2,619,320	2,279,549	87%
5255	2,826,836	2,921,361	103%
5230	2,947,129	3,548,220	120%
5205	3,056,328	3,496,568	114%
5180	3,026,981	3,436,195	114%
5155	2,686,947	3,548,731	132%
5130	2,998,515	3,939,907	131%
5100	2,968,202	4,531,597	153%
5070	2,906,371	3,949,471	136%
5040	1,571,047	1,896,716	121%
Total	**30,806,698**	**35,527,314**	**115%**

Figure 87shows the rings colored by extraction percentage in isometric view, it is possible to see the strategy used by Ridgeway extracting less from the top levels and the border of the layout and having high extraction from lower levels.

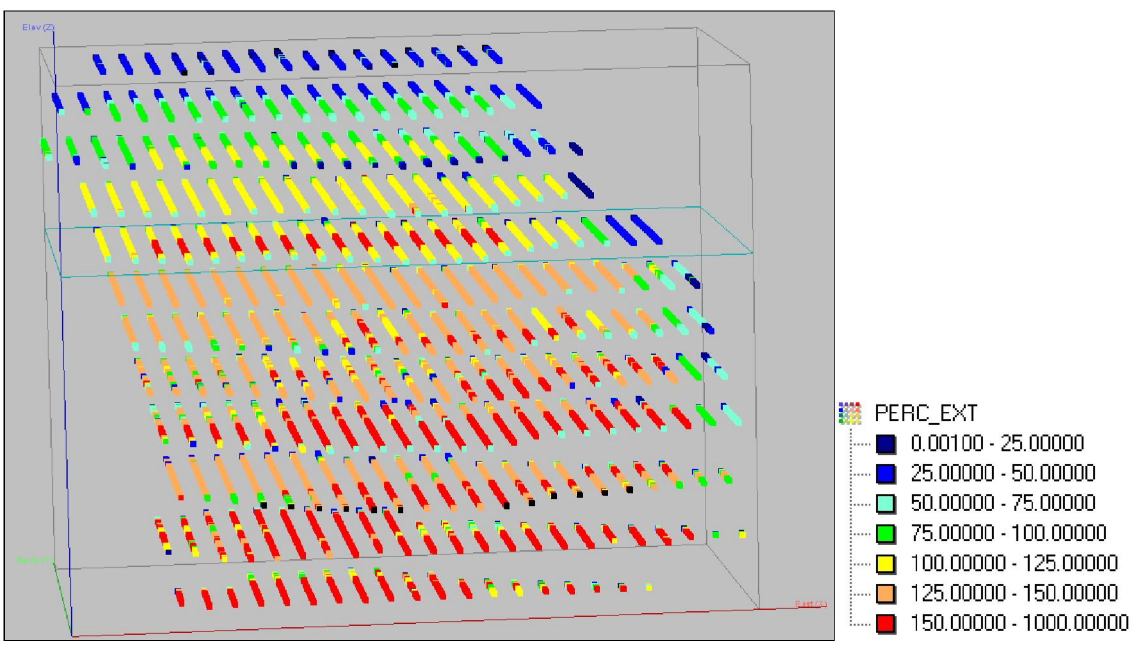


Figure 87: Rings colored by extraction percentage order in isometric view

5.7.3. Replicate the tonnage extracted by level

More than 30 production schedule runs were done in PCSLC to replicate the tonnage extraction and trying to get good results in terms of Au and Cu grades for calibration purpose.

One of the most important aspects was to reproduce the tonnage extracted by period and level, but unfortunately the information provided by Ridgeway was not detailed by rings so several runs were necessary to replicate the same tonnage profile. Figure 88 shows the first run done in PCSLC where was not possible to get the tonnage extracted since the first sequence used was incorrect having issues between levels and tunnels.

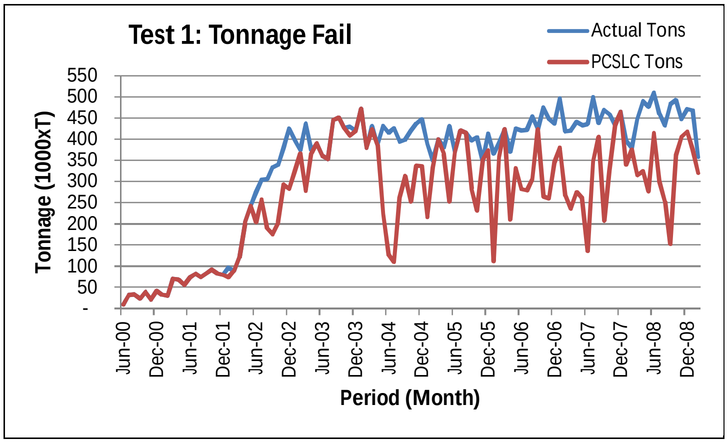


Figure 88: First PCSLC run trying to replicate the tonnage extracted

A second run was done having a new sequence fixing problems of overlap between levels and the tonnage profile was very similar than the real, but still some periods shows differences (see Figure 89). These issues were relative to a specific problem in the percentage extraction used for some rings and tunnels, for example at March 2004 the real extraction was 431K tonnes and PCSLC was able to get only 247K tonnes.

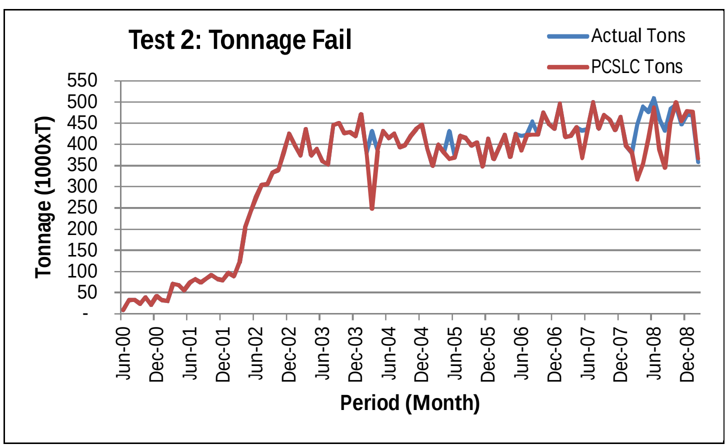


Figure 89: Second PCSLC run trying to replicate the tonnage extracted

Finally the percentage of extraction per ring was fixed matching with the tonnage reported by tunnels and by month therefore it was possible to replicate the tonnage reported by Ridgeway (see Figure 90).

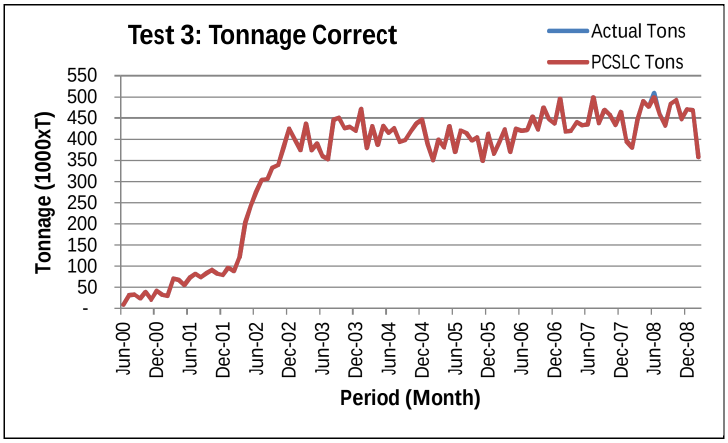


Figure 90: Final PCSLC run replicating the tonnage extracted

Additionally Figure 91 shows the tonnage profile per level where it is possible to see a very good match between the real and PCSLC extraction. The graphs shows minor differences but the overall profile is enough for calibration purpose.

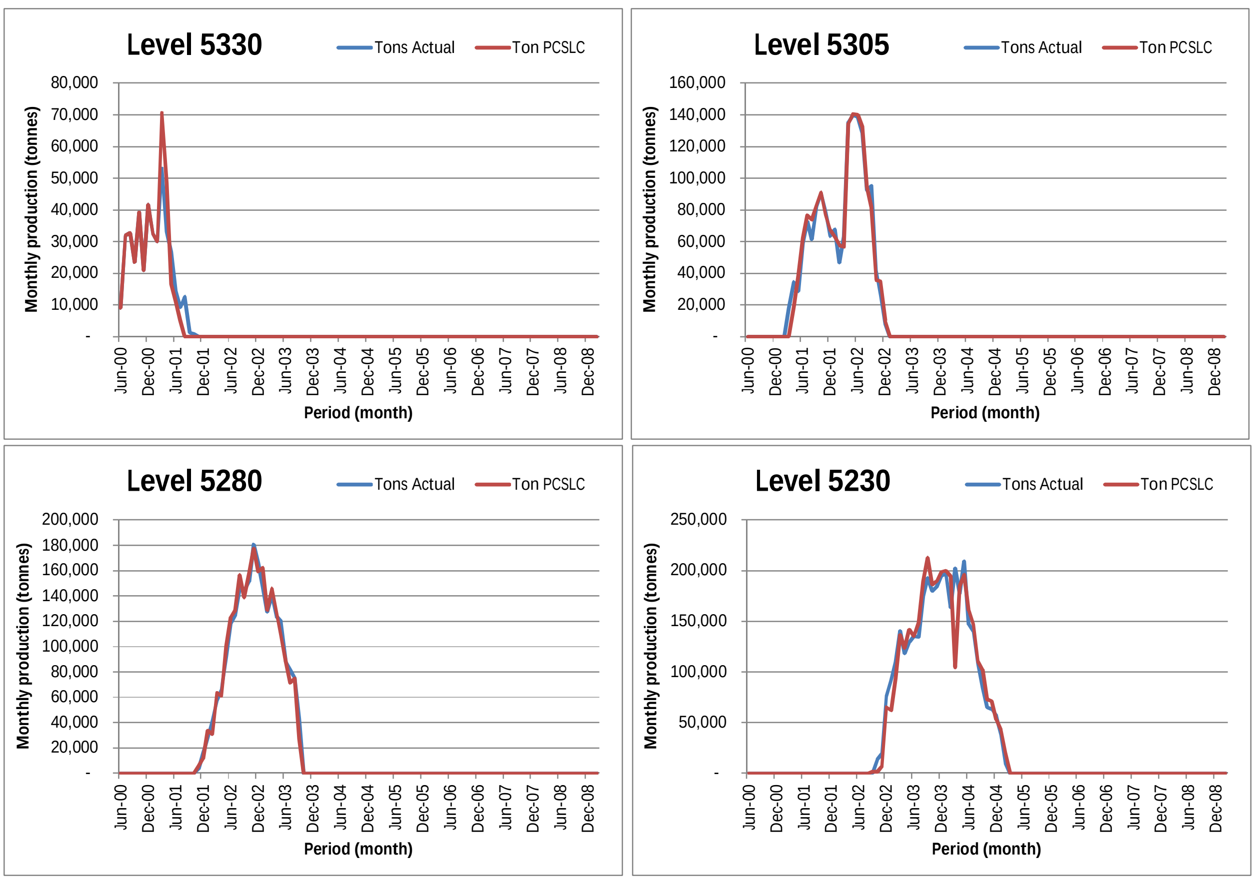


Figure 91: Final PCSLC run replicating the tonnage extracted by level

The complete sets of graphs per level are shown in the Appendix B.

5.7.4. Compare the grade and recovery profile

Once the tonnage was extracted replicating similar profile used in the mine the next step was start doing several runs to calibrate the Au & Cu grade. The main tool used was the recovery by level obtained from the experiment done in Ridgeway combined with the knowledge of the TM parameters.

Figure 92 shows the actual tonnage per level and gold and copper grade profile.

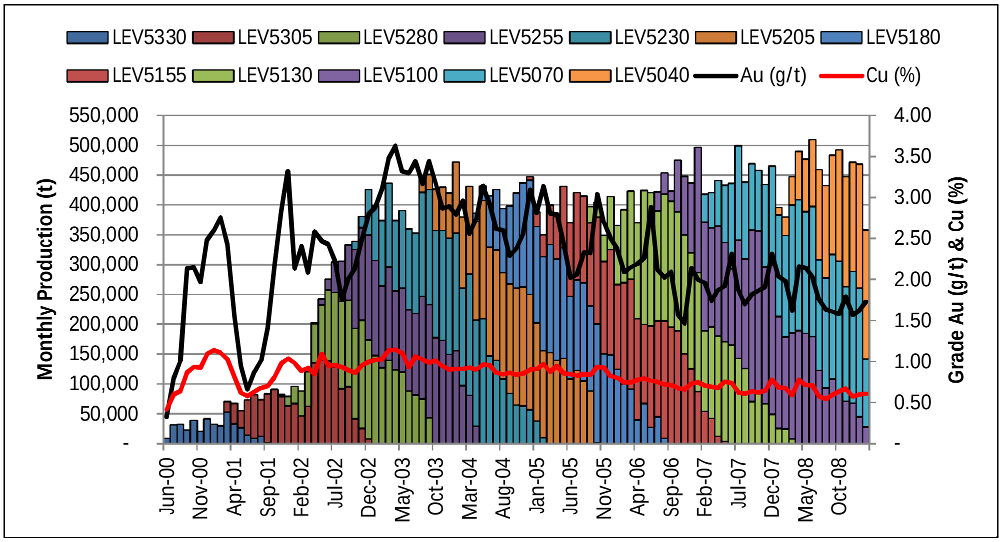


Figure 92: Actual tonnage per level and grade profile

Table 18 shows summary of some of the runs done in PCSLC using different TM parameters. In general all the runs were able to deplete the tonnage and the grade reported by the mine. The best results are highlighted in yellow color since it reproduces a very similar recovery profile.

Table 18: Summary of run done to calibrate the grade and recovery profile

Item\Run	Real	A03	A04	A07	A01	A08	A09	A02	A10	A06	A05	B01	C01	D01
Neighbors		3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	3 levels	2 levels
Boundary dilution?		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Block rings (m)		90m	90m	90m	90m	90m	90m	90m	90m	90m	90m	No	150m	No
# Total Rings		15,736	15,736	15,736	15,736	15,736	15,736	15,736	15,736	15,736	15,736	14,096	21,375	14,096
Replenish Threshold		0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Bottom refill		0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
%Frozen		10%	20%	30%	40%	45%	47.5%	50%	50%	60%	70%	50%	50%	50%
Erosion rate		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	7.5%	5.0%	5.0%	5.0%	5.0%	5.0%
Shut off value		-	-	-	-	-	-	-	-	-	-	-	-	-
Prim%	50%	74%	70%	65%	58%	53%	51%	49%	51%	40%	32%	48%	49%	49%
Sec%	12%	2%	5%	7%	12%	15%	16%	18%	16%	25%	33%	16%	18%	16%
Ter%	9%	0%	3%	5%	6%	7%	7%	8%	7%	9%	10%	7%	7%	3%
Quar%	5%	0%	2%	3%	3%	4%	4%	4%	4%	4%	4%	3%	4%	3%
Quin%	4%	0%	1%	1%	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%
Dil%	20%	24%	18%	19%	19%	20%	20%	20%	20%	20%	20%	25%	20%	28%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Tonnage (Mt)	35.53	4.29	35.49	35.52	35.52	35.52	35.52	35.52	35.52	35.52	35.52	35.52	35.52	35.52
Au (g/t)	2.34	2.69	2.29	2.26	2.23	2.21	2.20	2.19	2.20	2.17	2.14	2.14	2.20	2.17
Cu (%)	0.81	0.93	0.71	0.71	0.70	0.69	0.69	0.69	0.69	0.68	0.67	0.63	0.69	0.64
Dil (%)		1%	11%	12%	13%	14%	15%	15%	15%	16%	18%	26%	10%	25%
Time to run (hh:mm)		0:34					2:25					1:47	4:40	0:48

Here is a description of the TM parameters used in this calibration work:

- Neighbors: it described the large of linked used to connect levels. In most of the run the connection was done using three levels and only in one case two levels, but with no good results.
- Boundary dilution: All the runs done were done using boundary material as a source of infinite dilution, to replicate the real condition of the mine were the top level 5330 has more than 500m of caved material from previous mine.
- Block rings: This item was tested using three options (no block rings, 90 and 150 meters). The results showed that block rings provides a better representation of the reality having dilution with grades but it increases the amount of rings to model making every run much slower and requiring a computer with better hardware. In summary 90m gave a good balance between level of resolution (for dilution modeling) and the time process one PCSLC run.
- Replenish Threshold: This value was constant (0.4) based on the result obtained in the section 4.4.7
- Bottom refill: This value was also kept constant (0.8) based on the result from section 4.4.7
- %Frozen: This item was recognized as one of the most critical for calibration purpose. Several runs were done to evaluate the impact in the grade and recovery profile. This showed similar trend observed in section 4.4.6.3 where the primary recovery decrease and the secondary recovery increase when the percent of frozen material increase (see Figure 93). The best %Frozen value was 50% since it was able to reproduce the recovery registered by the trial marker at Ridgeway getting values very similar not only for primary and secondary, also it shows a good match with tertiary, quaternary and quinternary.

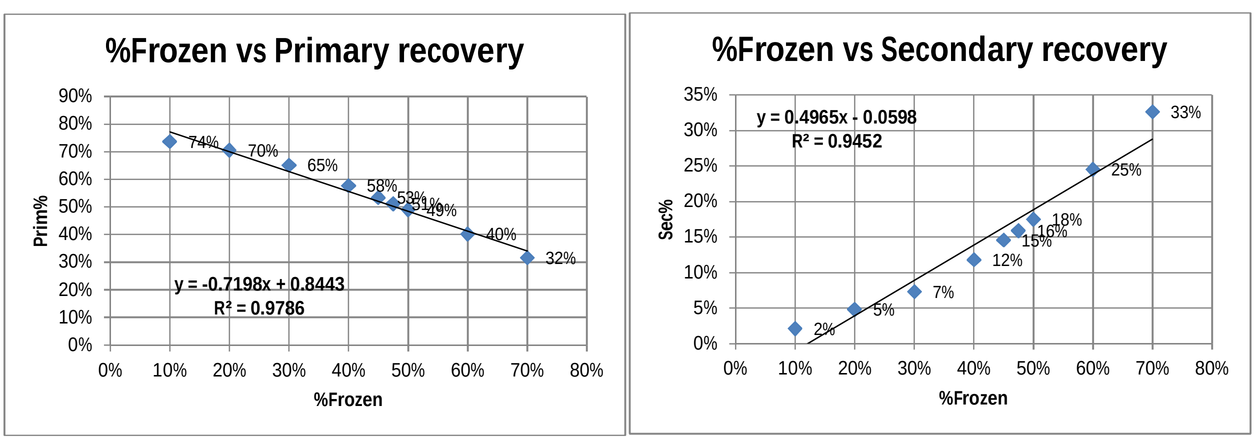


Figure 93: Primary and secondary recovery versus percent frozen

- Erosion rate: This value was constant (5%) based on the result obtained in the section 4.4.7. Only one extra run was done using 7.5% with no significant impact in the overall results.
- Shut off value: This option was not used since the rings were closed when they reached their extraction percentage, it means when they were able to deplete the tonnage reported by the mine and then the grade reported by PCSLC is function only of the TM parameters used.

One of the main objectives of this calibration is to replicate the grade reported by the mine and therefore the following graphs show example of the runs done to get a good match with the real data.

Figure 94 shows one of the first run done where grade from PCSLC (Green line) described a good match in the first year, but after the grade is very low compare with the actual data. This is due to a problem with the links created between rings so too much dilution was pulled too fast. The recovery profile is shown in Figure 95, it is possible to observe the PCSLC recovery profile has very low after the tertiary recovery and the dilution reported was almost twice bigger. This explains the results obtained for Au grade.

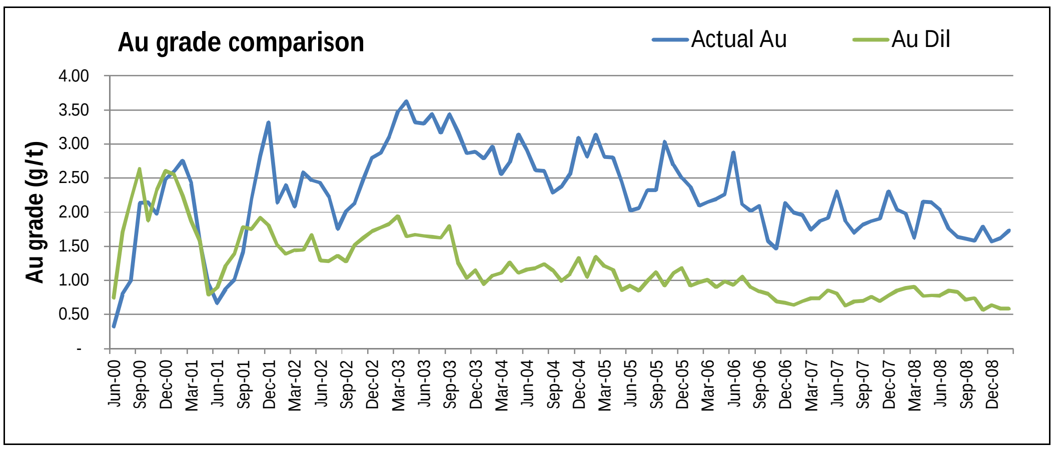


Figure 94: Gold grade curve Ridgeway vs PCSLC run (high dilution)

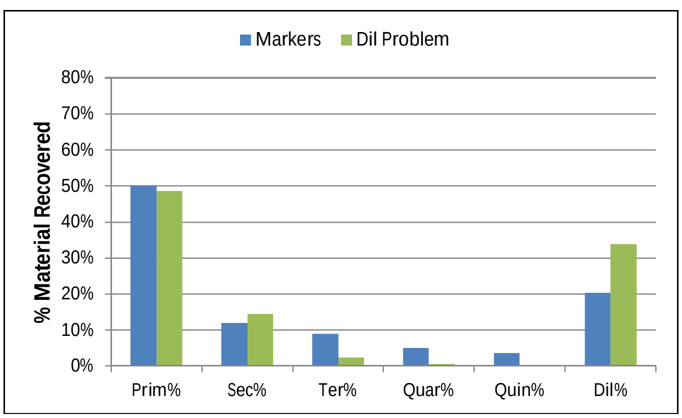


Figure 95: Ridgeway recovery curves compare with PCSLC run (high dilution)

A second example is shown in Figure 96 in which PCSLC result has a better match but, it is still higher than actual grade specifically at the beginning. Also the recovery profile shown Figure 97 presents a very high primary recovery describing a much higher extraction from the level where the ring was blasted. This is a better result but not realistic.

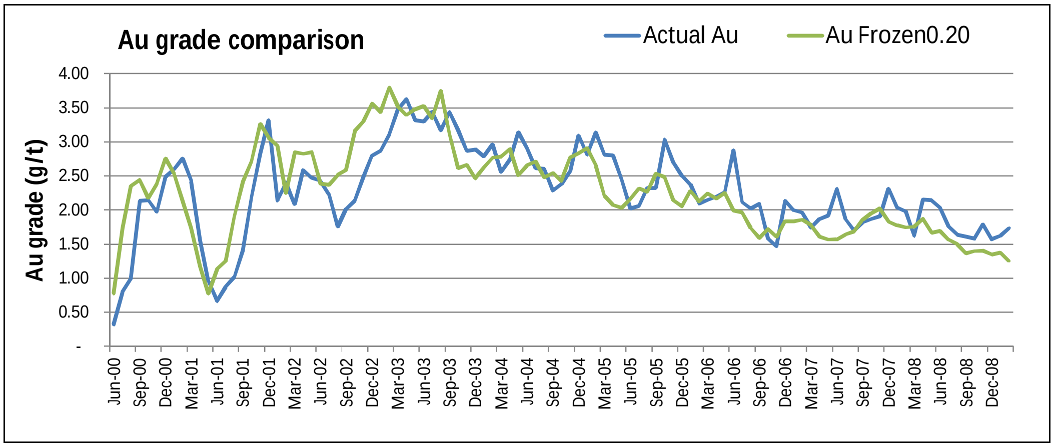


Figure 96: Gold grade curve Ridgeway vs PCSLC run (higher grades)

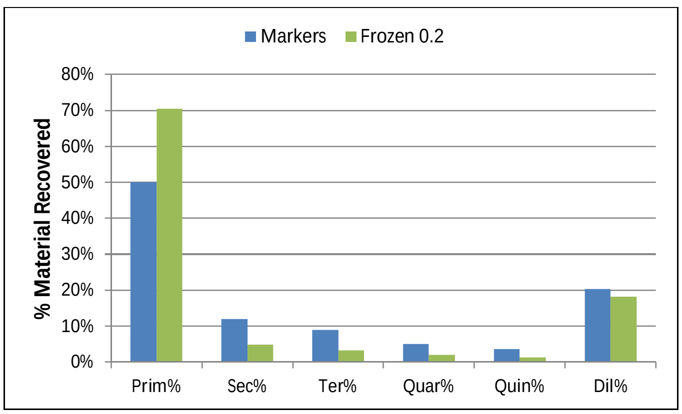


Figure 97: Ridgeway recovery curves compare with PCSLC run (higher grades)

5.7.5. PCSLC run finally calibrated

This section describes the results and details of the best PCSLC run in term of the calibration. PCSLC run called A02 was identify as the best run and Table 19shows the TM parameters and results.

The main target for calibration purpose was the recovery curve since being able to replicate the recovery observed at the mine will provide the correct mixing profile and then getting good correlation with the grades reported at the mine. Figure 98 shows the summary of the recovery curves used at Ridgeway and the curve obtain by PCSLC in this run. It shows a very similar profile matching perfectly with the primary, tertiary, quaternary and quinternary recovery, only the secondary was a bit higher but still in a correct range therefore we can conclude that the run A02 was able to replicate the recovery profile observed at the mine using markers.

Table 19: Run done to calibrate the grade and recovery profile

Item\Run	Real	A02
Neighbors		3 levels
Boundary dilution?		Yes
Block rings (m)		90m
# Total Rings		15,736
Replenish Threshold		0.40
Bottom refill		0.80
%Frozen		50%
Erosion rate		5.0%
Shut off value		-
Prim%	50%	49%
Sec%	12%	18%
Ter%	9%	8%
Quar%	5%	4%
Quin%	4%	2%
Dil%	20%	20%
Total	100%	100%
Tonnage (Mt)	35.53	35.52
Au (g/t)	2.34	2.19
Cu (%)	0.81	0.69
Dil (%)		15%

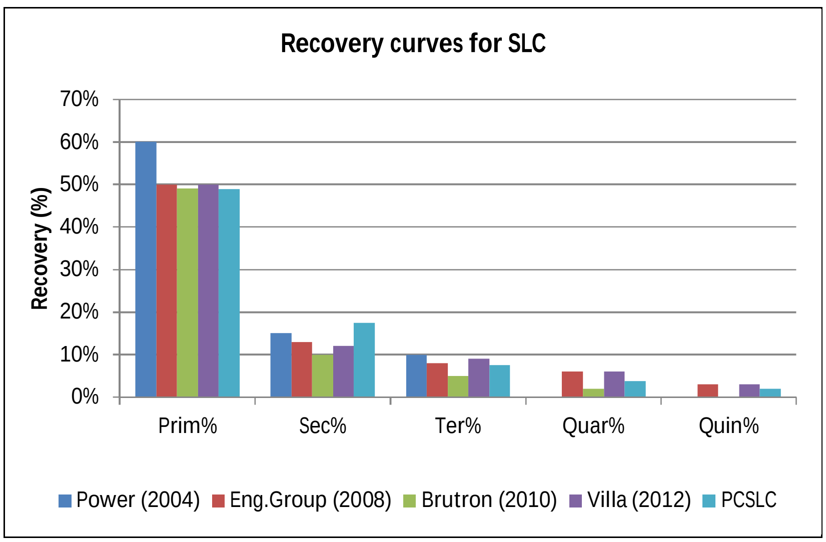


Figure 98: Ridgeway recovery curves compare with PCSLC run

For calibration purpose the main focus was to obtain a good match with the recovery curve but also the grade profile was really important. Figure 99 and 100 shows the gold and copper grade both describe a very good match with the actual data and showing a very good match with the actual trend, going up and down as the actual grade describe, it is very important since a forecast prepared with PCSLC will be able to predict a grade with a high level of confidence.

Gold grade calibration shown in Figure 99 is excellent since PCSLC was able to generate the same trend than the actual grade.

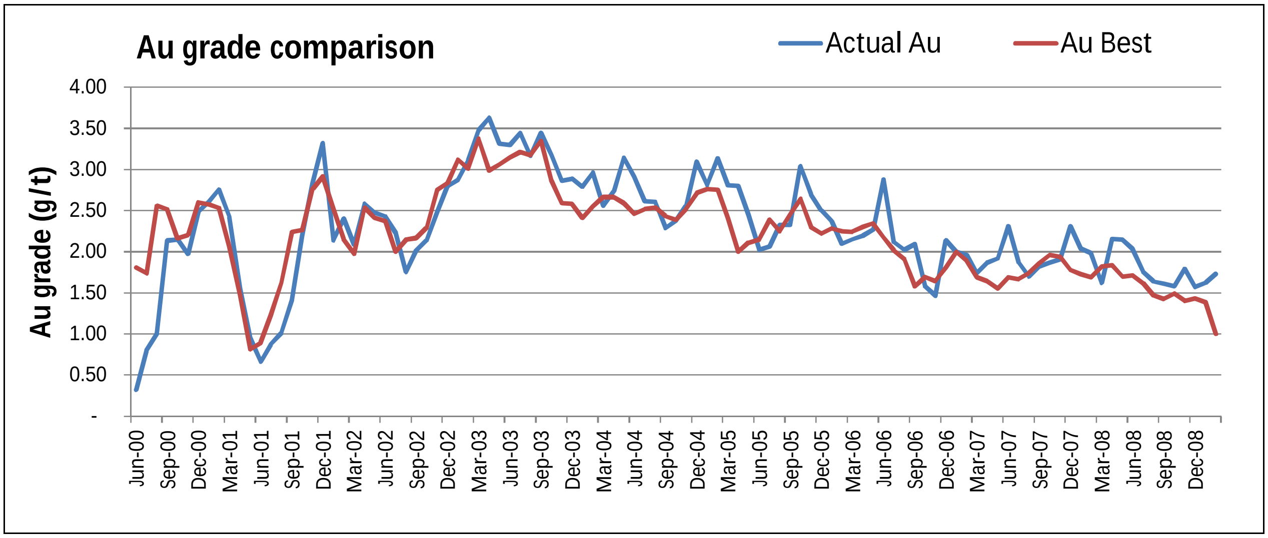


Figure 99: Gold grade curve Ridgeway vs PCSLC run

Copper grade shown in Figure 100 is also good since PCSLC was able to generate a similar trend than the actual grade, but PCSLC shows a constant difference (lower in average of 0.15%) starting in February 2002 when the production jump from 4,000 to 10,000 tonnes per day.

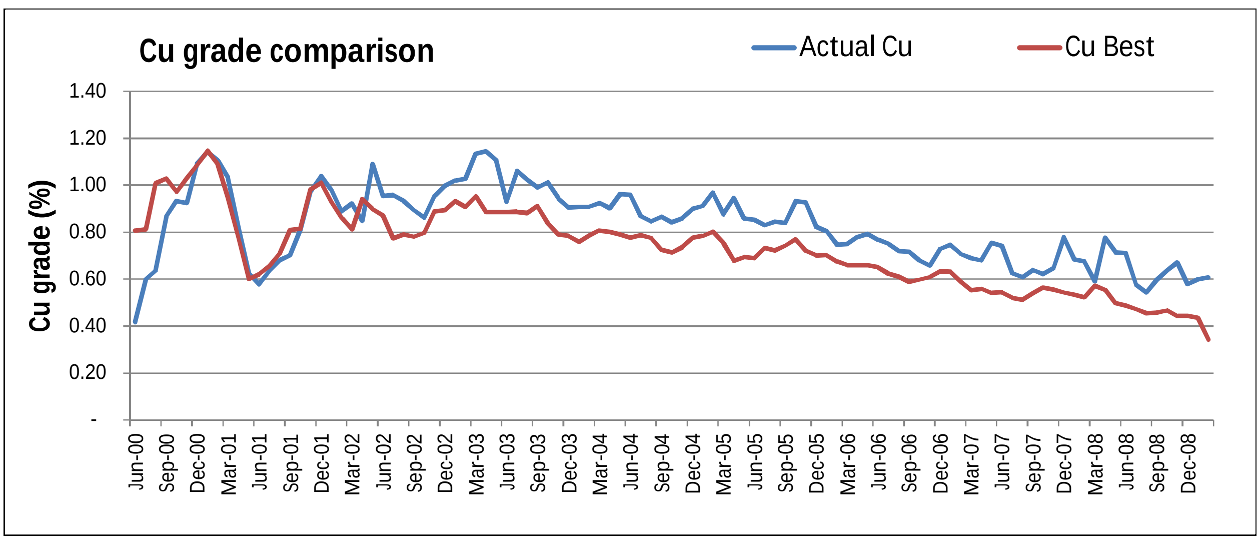


Figure 100: Copper grade curve Ridgeway vs. PCSLC run

Other tool used to quantify the result of the calibration was the correlation between actual monthly grade and PCSLC run. Figure 101 and 102 show good correlations of gold and copper reporting values of 67.6% and 61.4% respectively.

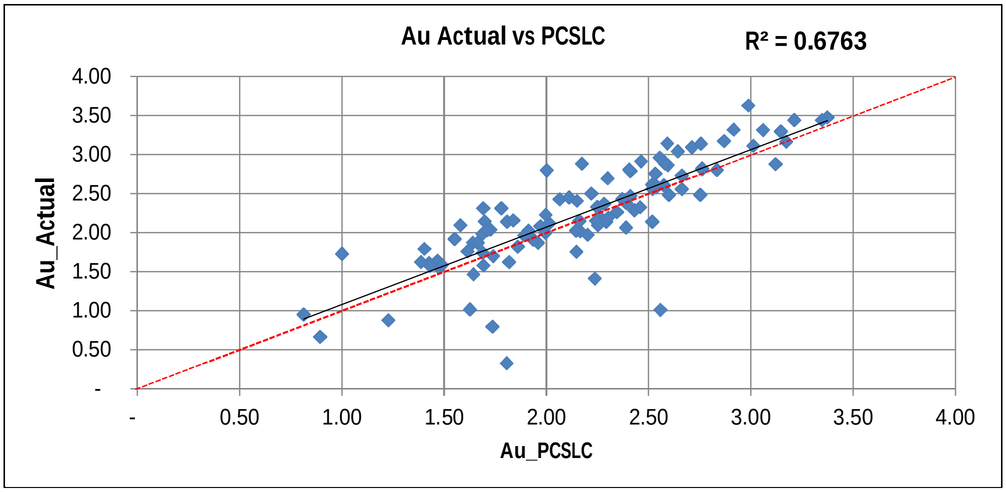


Figure 101: Gold correlation between Actual grade vs. PCSLC monthly data

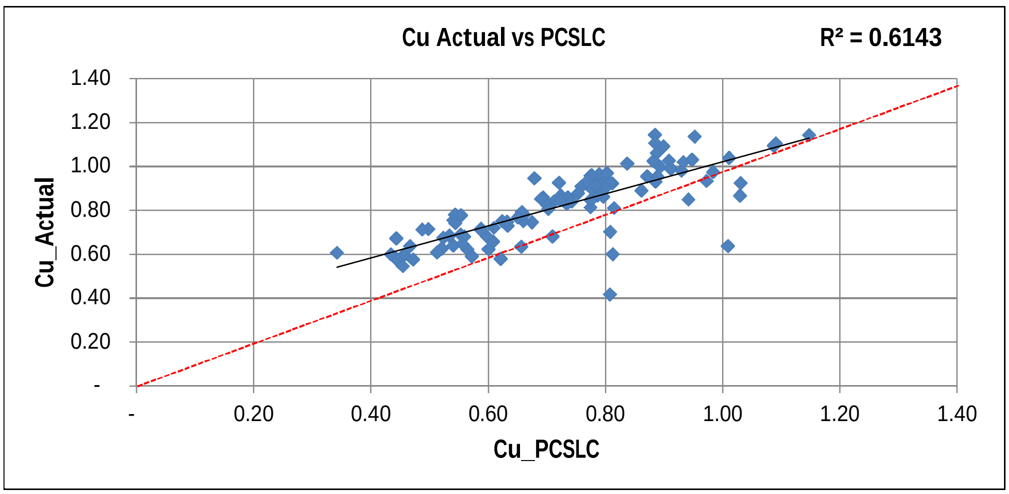


Figure 102: Copper correlation between Actual grade vs. PCSLC monthly data

Ridgeway provided assay data collected for 9,487 rings and these was compare with the grades reported by PCSLC. Both cases show a good correlation between assay data and PCLSC results. Figure 103 shows the dispersion of the gold grade where the assay data is much higher than the PCSLC values for example there are some rings reporting grade bigger than 10 g/t and PCSLC showed maximum grades of 6.5 g/t. The values reported by PCSLC come from the block model and it suggests the block model was created using a capping value that prevents to have grades bigger than 7 g/t.

Figure 104 described the correlation of copper grade and the profile is very similar than the case observed with gold grade, but in the copper case the capping value used in the block model avoid to have value reported by PCSLC bigger than 1.5% and this could explain the big difference detected in the grade value reported by month (See Figure 96).

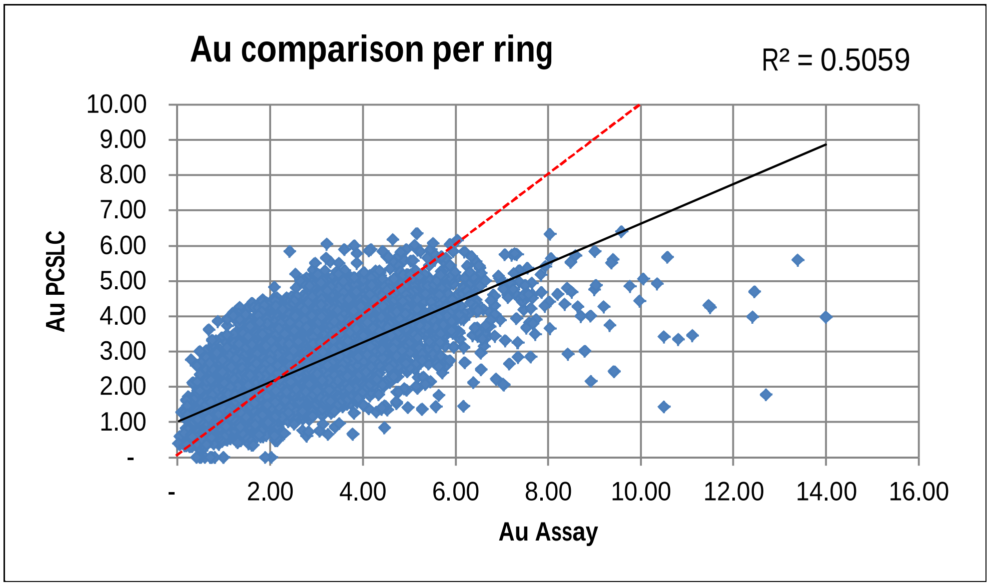


Figure 103: Gold correlation between Actual grade vs. PCSLC ring data

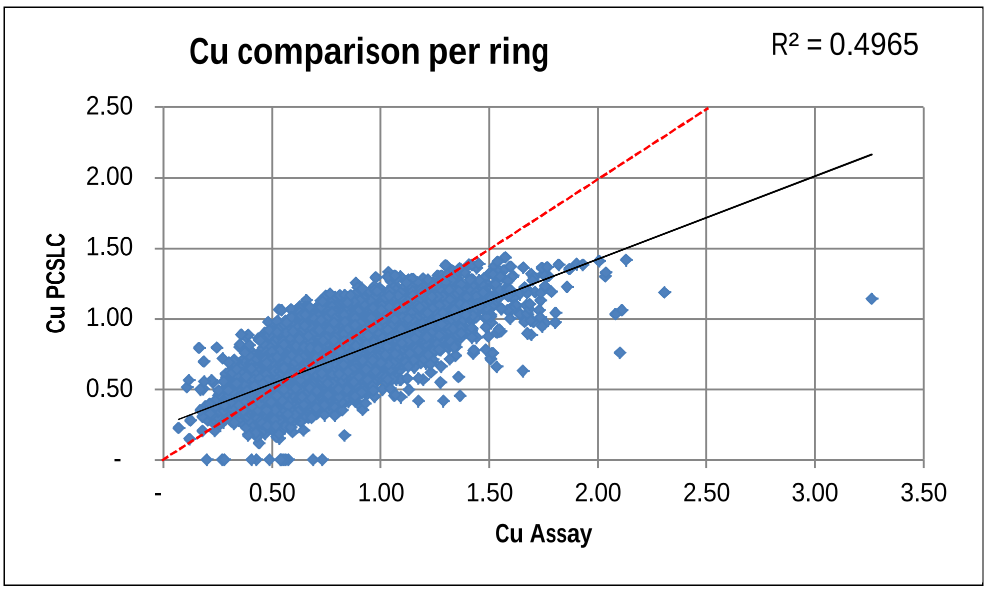


Figure 104: Copper correlation between Actual grade vs. PCSLC ring data

5.8. Conclusion

All results shown above validate the calibration work done since PCSLSC was able to replicate the grade reported by the mine using a similar recovery profile. Specifically gold grade shows an excellent curve where PCSLC shows very similar grade and having an excellent correlation with the real values provided by the mine. Also copper grade described a very good trend but in terms of grade it shows some differences due to a possible capping value used to create the block model. In summary the calibration of the mixing model was very success because gold grade showed an excellent match between PCSLSC and actual data and this grade was the main focus at Ridgeway mine since copper was treated as sub-product only and then some difference could be accepted in copper grade.

6. Conclusions and recommendations

The main conclusions of this study are summarized as follows:

- This research met the goals set at the beginning, providing an overview for SLC method, describing its evolution and the work done in small and large scale to understand the flow mechanism for a Sublevel Caving mine. Modifications done in the size of the sublevel spacing over the last 10 years have affected the dynamic of the SLC flow behavior creating a low interaction between rings in contiguous production drives, see Figure 105 where the areas recovered are highlighted in blue, orange and green. Studies of large scale done in SLC mine using markers installed directly inside of the ring have provided valuable information to understand the comportment of the SLC flow material at the mine. These studies have confirmed that the material blasted is not recovered completely in the level blasted due the no interaction and the ore left behind could be recovered in the lower levels and therefore the material mixing would be predicted based on a recovery curve identifying material extracted as primary (recovered in the same level on which the marker were installed), secondary (marker recovered on the subsequent level), tertiary (marker recovered on the third level), etc.

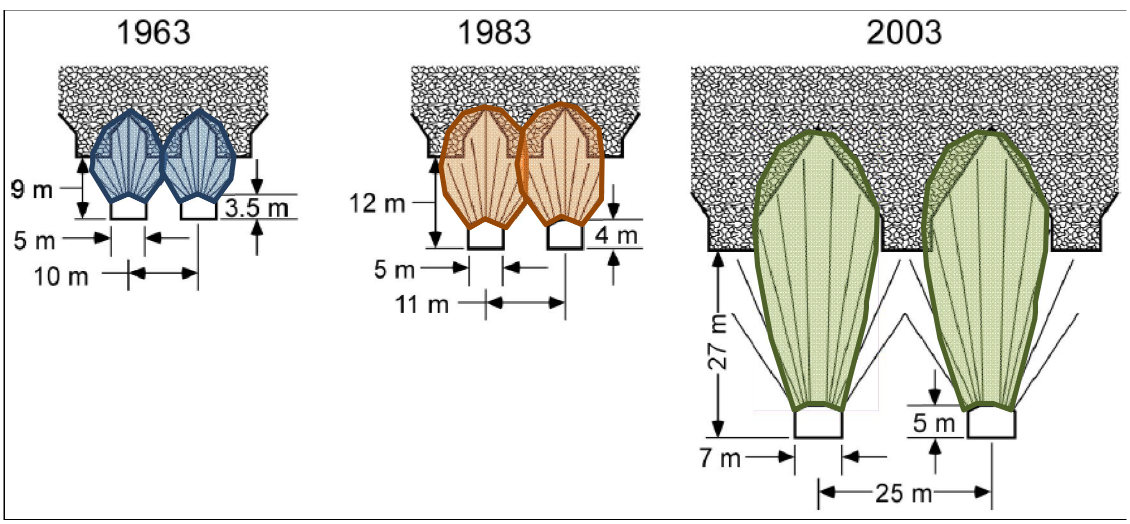


Figure 105: Changes in sublevel caving geometry and its impact in the recovery and interaction

- The full scale marker trials done at the Ridgeway SLC gold operation is considered to be the most comprehensive experiments of their type conducted in the world to date. The results obtained shows the shape of the extraction zones are irregular in nature (not described by an ellipsoid shape), with primary recovery consisting of an area of continuous flow near the blast ring plane. Secondary, tertiary, and quaternary recoveries occur as relatively small discrete zones within the blasted material.
- Based on the analysis of marker recovered by several authors in the last 10 years a recovery curve was proposed in this study to use for calibration purpose. This indicated that having 100% of draw a recovery profile by level expected should be as follow (see Figure 106):

- o Primary recovery around 50%.
- o Secondary recovery between 15% to 10%
- o Tertiary recovery between 10% to 5%
- o Quaternary recovery between 3% to 6%
- o Quinternary recovery between 1% to 3%

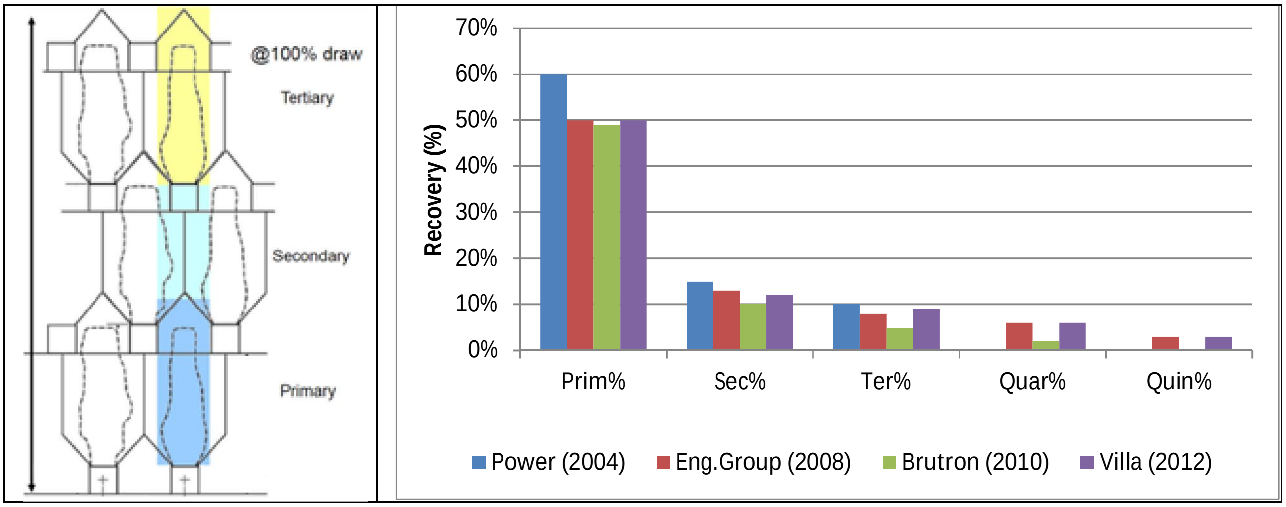


Figure 106: Recovery curves derived from marker experiment in Ridgeway

- An intensive work was done using the software Gems-PCSLC. The first step was creating a small SLC model to study the mixing model and its parameters since the originally it has more than 31 inputs but only 5 of them were identified has important for mixing purpose. These parameters are the following:
  - o Numbers of cells per rings. This parameter represents the division of the ring to generate the connections between rings which lead the depletion and mixing. The runs done shows only one cell per ring will be necessary to get good results, since more than one increase the size of the data to manage for the memory exponentially and doesn't provide a realistic result according to the recovery profile described by Ridgeway experiment results.
  - o Percent Frozen. This parameter is one of the most important and physically could represent the low interaction between rings'; in the contiguous production drives. This input has a direct impact over the primary recovery. The recommended values are 55% to 40% to generate a primary recovery similar to 50% depending of the geometry of the SLC design.
  - o Erosion rate. This input is also very important since combined with "Percent Frozen" has a big impact in the primary and secondary recovery, but having a bigger sensitivity over the secondary. It allows changing the overall recovery profile by adjusting the secondary recovery. Based on the runs done the recommended value in this case is 3% to 6%.
  - o Replenish Threshold. It has minimum impact in the primary and secondary recovery profile, but change the distribution of the tertiary and the quaternary. The dilution increase when this value is higher, it means that more material outside of the cell is allowed to move in and then it indicates more level of mixing. The value recommended for this input is 0.40.

- <u>Bottom refill</u>. This input has an impact only in the secondary recovery, increasing this when the bottom refill is lower. The dilution shows different results as well increasing with bigger values so it should have similar effect than Replenish Threshold since higher value mean more mixing allowing the dilution material moving faster. The value recommended for this input is 0.80.

- A PCSLC model was created using Ridgeway database and following the understanding of the Template mixing inputs was possible to replicate the tonnage extracted at the mine (Figure 107).

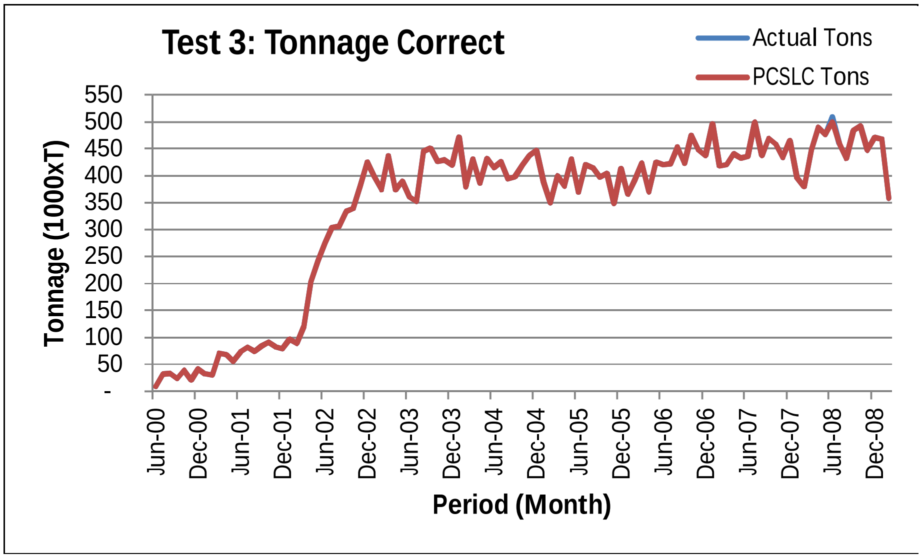


Figure 107: PCSLC run replicating the tonnage extracted

By reproducing the recovery profile obtained by the trial maker at Ridgeway (Figure 106), it was possible to get an excellent agreement with grade samples reported by month (see Figure 108).

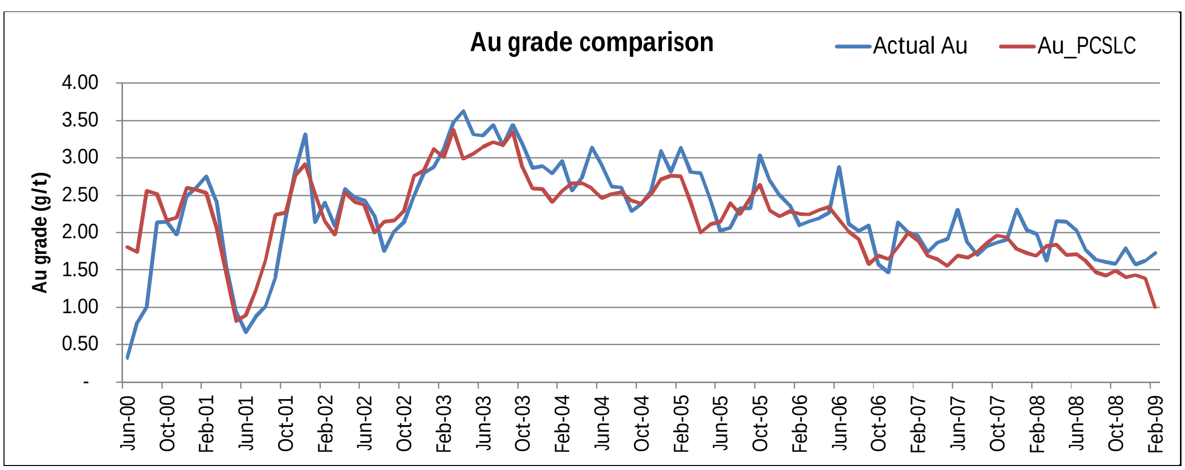


Figure 108: Good agreement in gold grade curve Ridgeway vs. PCSLC run

- Finally all the conclusions described above demonstrated that PCSLC is an appropriate tool for mining planning purpose able to forecast grade and dilution reliably, using a recovery profile has described in Figure 106. Obviously this depends of the SLC design, sublevel drift spacing and height mainly. In the case of Ridgeway SLC mine these values represent very well the current practice and therefore the TM inputs suggested in this study can be used to assess similar SLC project. For a different SLC geometry the TM parameters needs to be fine-tuned to obtain a similar recovery profile.

6.1. Recommendations

Based on the results obtained from this study the recommendation and future work are divided in two topics suggestion for improvement for PCSLC and new technology applied in marker experiments.

6.1.1. PCSLC

PCSLC is a reliable mining planning tool for SLC mines, but it needs to add some feature to be more user-friendly and be able to support the requirement generated by a mine in operation the following list provide some idea to improve this tool in the future:

- Having an option to incorporate the past tonnes extracted by ring and period using easy format for entry data like Excel. This alternative will allow depleting the right information for each specific ring to replicate the same extraction profile used in the mine and then it will be easier to do back analysis and deplete the material from the top level to create a mine plan for the lower levels.
- Incorporate an option to differentiate fine and coarse fragmentation for flow modeling purposes. This option is been used successfully by Gems-PCBC where is possible to have different velocity for material fine and coarse creating a mixing profile more realistic. In the past this input was calibrated again real data for Block Caving mines (for PCBC) showing excellent results in the dilution modeling. In SLC method the ore will be broken by a blast and the dilution located in the top will cave naturally so it will be possible to control the fragmentation and having a better profile for dilution control and then adding the option to model different fragmentation sizes into PCSLC will generate a better dilution model.
- Simplify the amount of inputs and phases to create a PCSLC model since some of them can be reduced, the following items are examples how PCSLC could be utilized easily:
  - Assigning grades and density from the block model to the rings require two steps, since in the first the information is transfer from the block model to the rings and it calculates an approximated volume so after the first step a second step needs to be used to re-estimate the volume based on the real shape of the ring and then get the real volume and tonnage. These can be done in one step avoiding confusion and the mistake of using the wrong tonnage by ring.
  - The neighbor creation is difficult to do it correctly, since it requires creating a specific selection of block on the top and the side of the mine layout to allow those ring enough volume to connect with "boundary material" and then allocate dilution correctly.
  - Also this study demonstrates the "Block rings" are very useful to model the dilution correctly, but it generates more rings to model increasing the memory usage and making every run slower and in some case the system simply crash. The current version of Gems-PCSLC is running in 32 bit so there is an opportunity to move to 64 but improving the performance of the memory increase the capacity of PCLSC

- Finally this study was done with a version of PCSLC where every ring is modeled with a polygon consuming lot of hardware resources mainly for displaying purpose and creating slow access to the data since all information was store in a database, so the process to run a schedule was quite slow an limited to model no more than 20,000 rings. A new version of PCSLC recently released replaces the polygons by a dot and all the information is saved in binary file allowing to PCLSC to increase its capacity to model more rings (more than 50,000 rings has been tested by Gemcom) and it creates an efficient manner to handle the memory speeding all the internal depletion and mixing process reducing the time for each run of production schedule. It is highly recommended to update the Ridgeway database to the new version and compare the results of the run obtained in this study.

6.1.2. Smart marker

The experiment done in SLC mine using marker have been demonstrated to be very useful providing very valuable information about the SLC flow; primary, secondary and tertiary recovery; development of the extraction zone over time; Dilution entry; etc. The recovery of the marker is a difficult task since it is associated with manually process that affect the production draw rates and also force to install a big number of steel maker to get a good number of marker recovered.

New technology was developed in Australia by Elexon Electronics. This new system called ‘Smart Marker’ uses hardened Radio Frequency Identification (RFID) technology to automate the marker detection process. The operation of the system is shown in Figure 109.

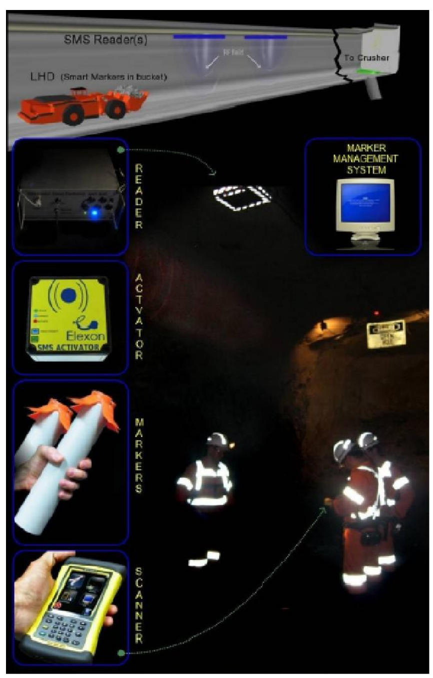


Figure 109: Smart marker system

Markers are wirelessly activated prior to installation and have an operational life of 10 years. Smart Markers in the LHD bucket are electronically detected (while still in the LHD bucket) by readers as ore is extracted (Whiteman, 2012).

The Smart marker system operation and installation is shown in the Figure 110. Where (a) The handheld scanner; (b) and (c) markers are loaded into SLC installation holes drilled between the blast holes (d) Standard equipment is used to push the marker up into installation holes.

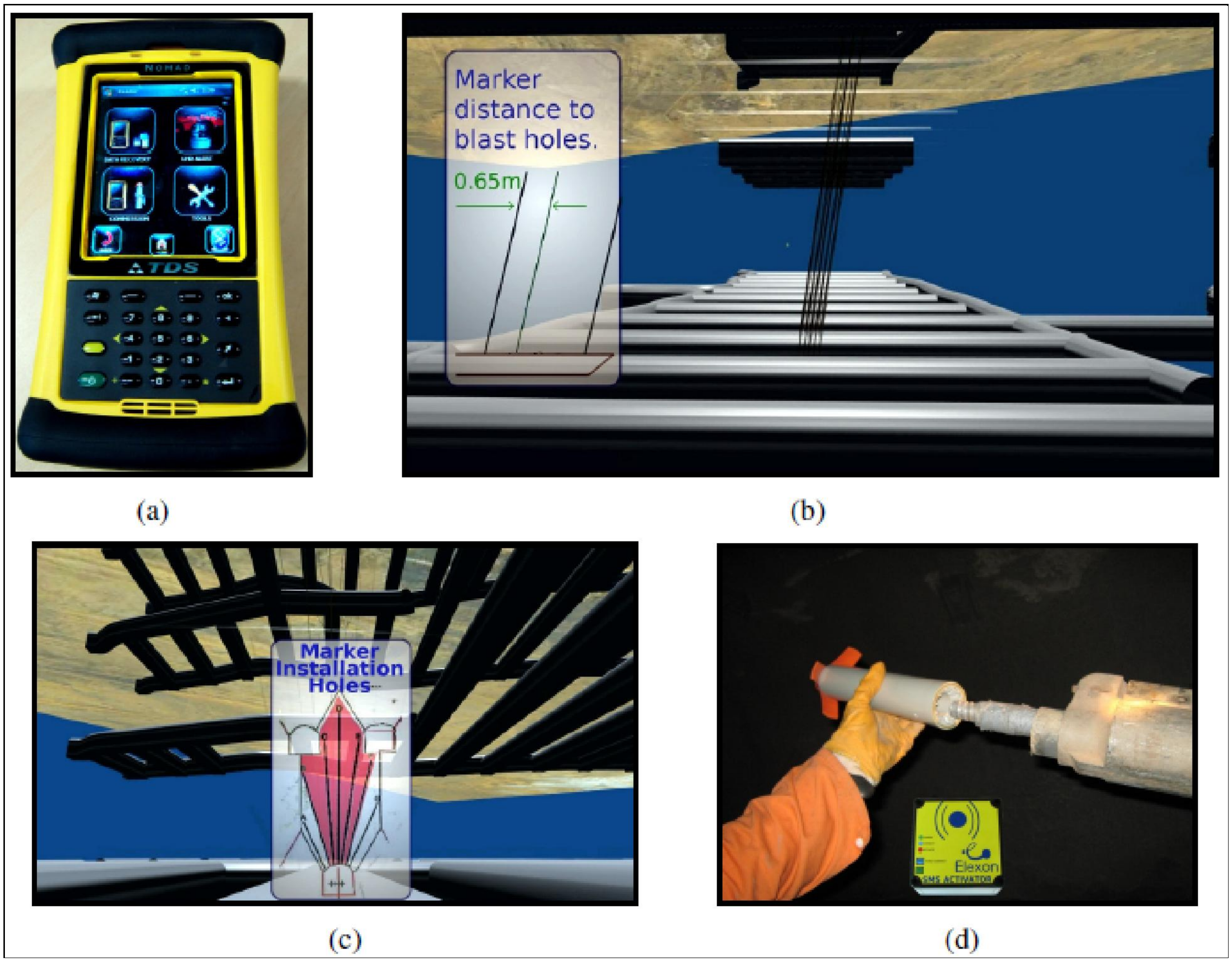


Figure 110: Smart marker system operation and installation

This system is been implemented in some SLC mine already. It will provide a new set of data with more reliable information to use for future SLC flow studies and calibrations. Appendix C shows more information about Smart Marker system.

References

Alfaro, M. and Saavedra, J. 2004.*Predictive models for gravitational flow*, Proceedings;4th International Conference & Exhibition on Mass Mining. Santiago, Chile (pp 179-184)

Brunton, I. 2010. *The impact of blasting on sublevel caving material flow behaviour and recovery.*Ph.D. Thesis, University of Queensland, W H Bryan Mining and Geology Research Centre.

Bull, G. and Page, C.H. 2000. *Sublevel Caving - Today's Dependable Low-Cost 'Ore Factory'*. Proceedings; 3rd International Conference & Exhibition on Mass Mining. Brisbane, Australia (pp537-556)

Diering, T. 2000. *PC-BC: A block cave design and draw control system*. MassMin 2000, Proceedings; 3rdInternational Conference & Exhibition on Mass Mining. Brisbane, Australia (pp469-484)

Diering, T. 2007. *Template Mixing: A Depletion Engine for Block Cave Scheduling*, Proceedings; APCOM 2007 – 33rd International Symposium on Application of Computers and Operations Research in the Mineral Industry. Santiago, Chile (pp 313-320)

Diering, T. 2012. *Personal correspondence*. Vancouver, Canada.

Diering, T. and Villa, D. 2010. *A new mine planning tool for sub level caving mines*, Proceedings; 2ndInternational Symposium on Block and Sublevel Caving. Perth, Australia (pp 237-252)

Hollins, B. and Tucker, J. 2004. *Drawpoint analysis using a marker trial at the Perseverance nickel mine*. Proceedings; 4th International Conference & Exhibition on Mass Mining. Santiago, Chile (pp 498-502)

Hustrulid, W. and Kvapil, R. 2008. *Sublevel caving – past and future*. Proceedings; 5th International Conference & Exhibition on Mass Mining. Luleå, Sweden (pp. 107-132)

Itasca Consulting Group, 2000. REBOP (Rapid Emulator Based On PFC3D) Formulation and User's Guide, Version 1.0. Minneapolis, USA.

Janelid, I. 1972. *Study of the gravity flow process in sublevel caving*. International Sublevel Caving Symposium. Stockholm, Sweden.

Kvapil, R. 2008. *Gravity flow in sublevel and panel caving*. Lulea, Sweden.

Mine Planning Engineer Ridgeway Mine. 2008. Personal correspondence. Orange, Australia.

Power, G. 2004. *Full scale SLC draw trials at Ridgeway Gold Mine*. Proceedings; 4th International Conference & Exhibition on Mass Mining. Santiago, Chile (pp 225- 230)

Power, G. 2004. *Modelling Granular Flow in Caving Mines: Large scale physical modeling and full scale experiments*. Ph.D. Thesis, University of Queensland, W H Bryan Mining and Geology Research Centre.

Power, G. and Just, G. D.2008. *A review of sublevel caving current practice*. Proceedings; 5th International Conference & Exhibition on Mass Mining. Luleå, Sweden (pp. 155-164)

Quinteiro, C. 2001. *Theory and practice of very large scale sublevel caving*. Underground Mining methods – Engineering Fundamentals and International Case Studies, SME. Colorado, USA (pp381-384)

Whiteman, D. 2012. *The Smart Marker system — A new tool for measuring underground ore body flow in block and sub-level mines*. Proceedings; 2ndInternational Symposium on Block and Sublevel Caving. Perth, Australia (pp 603-622)

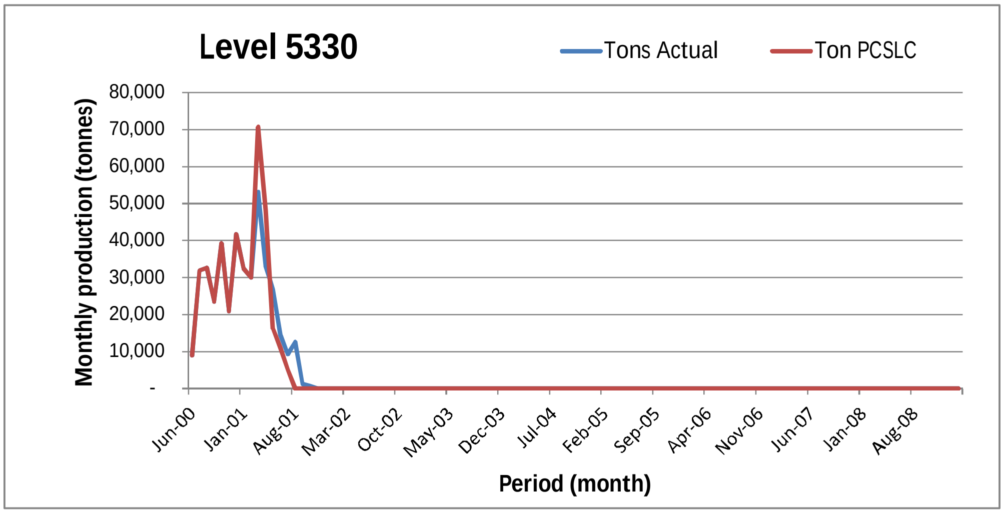
Appendix

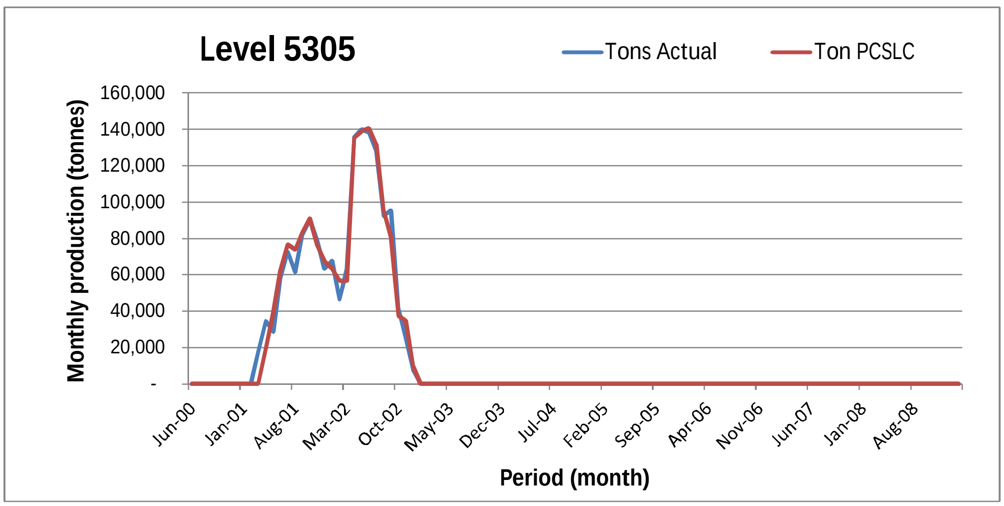
Appendix A. Ridgeway monthly SLC Production - Mill Reconciled

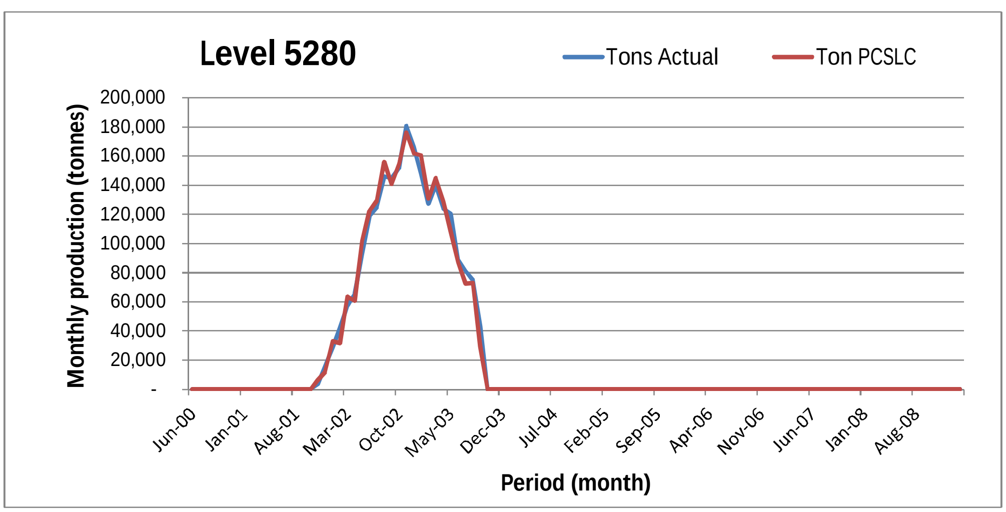
Month	5330			5305			5280			5255			5230			5205		
	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)
Jun-00	9,007	0.32	0.42															
Jul-00	31,895	0.80	0.60															
Aug-00	32,631	1.01	0.64															
Sep-00	23,462	2.14	0.87															
Oct-00	39,225	2.15	0.93															
Nov-00	20,912	1.97	0.92															
Dec-00	41,665	2.49	1.09															
Jan-01	32,439	2.61	1.14															
Feb-01	29,954	2.76	1.11															
Mar-01	53,111	3.01	1.18	17,600	0.67	0.59												
Apr-01	33,123	2.74	1.07	34,496	0.42	0.56												
May-01	26,710	1.72	0.86	28,530	0.23	0.40												
Jun-01	14,401	1.48	0.84	58,825	0.46	0.52												
Jul-01	9,279	1.45	0.80	72,642	0.80	0.61												
Aug-01	12,611	1.24	0.80	61,268	0.97	0.66												
Sep-01	1,254	2.43	1.06	82,121	1.40	0.70												
Oct-01	702	2.53	1.08	90,468	2.19	0.81												
Nov-01				78,986	2.93	0.99	3,540	0.46	0.65									
Dec-01				63,308	3.93	1.13	15,765	0.86	0.69									
Jan-02				67,801	2.71	1.09	28,493	0.78	0.71									
Feb-02				46,595	3.86	1.14	41,818	0.78	0.61									
Mar-02				62,943	3.13	1.16	57,339	0.94	0.67									
Apr-02				135,482	3.21	0.96	65,590	1.31	0.62	2,061	1.82	0.77						
May-02				139,982	3.32	1.29	92,448	1.36	0.82	9,668	0.86	0.82						
Jun-02				138,464	3.30	1.15	118,658	1.67	0.78	18,349	0.77	0.61						
Jul-02				128,463	2.79	1.11	125,033	1.99	0.86	50,608	1.38	0.81						
Aug-02				92,268	1.99	1.07	145,994	1.85	0.91	67,437	1.22	0.81						
Sep-02				95,395	1.62	0.89	144,643	2.60	0.95	93,307	1.51	0.81						
Oct-02				41,722	1.19	0.79	151,614	2.81	0.93	131,951	1.80	0.82	13,717	0.88	0.66			
Nov-02				25,788	0.98	0.77	180,810	3.08	1.06	155,364	2.21	0.88	19,011	1.12	0.83			
Dec-02				7,867	0.77	0.65	165,925	3.43	1.09	175,797	2.66	0.95	76,081	1.96	0.96			
Jan-03							147,668	3.43	1.09	159,681	2.97	1.02	91,212	1.83	0.90			
Feb-03							127,333	3.45	1.08	137,159	3.35	1.03	109,423	2.43	0.95			
Mar-03							139,849	3.67	1.17	156,003	3.99	1.20	140,589	2.71	1.03			
Apr-03							123,956	3.64	1.16	132,178	4.35	1.25	117,962	2.82	1.01			
May-03							120,110	2.90	1.07	140,549	3.95	1.20	129,452	3.01	1.04			
Jun-03							88,623	2.17	0.82	135,707	3.99	1.02	135,423	3.35	0.91	582	1.27	0.99
Jul-03							81,252	2.00	0.88	136,820	3.92	1.13	134,472	3.83	1.10	-		
Aug-03							75,025	1.54	0.78	171,435	3.63	1.10	174,342	3.64	1.07	24,745	1.55	0.88
Sep-03							43,126	1.16	0.67	189,681	3.78	1.05	193,024	3.92	1.04	25,010	1.18	0.75
Oct-03										177,828	3.58	1.04	179,856	3.44	1.06	68,761	1.43	0.81
Nov-03										172,848	3.00	0.93	184,254	3.09	0.97	72,241	1.96	0.90
Dec-03										149,474	2.35	0.85	194,878	3.47	0.93	75,651	2.47	0.94
Jan-04										155,910	1.77	0.80	196,918	3.64	0.97	118,949	2.72	0.95
Feb-04										97,263	1.75	0.75	163,709	3.61	0.97	118,965	3.06	0.95
Mar-04										81,003	1.11	0.71	202,588	3.16	1.02	147,612	2.53	0.92
Apr-04										29,769	0.87	0.63	177,249	3.04	0.96	165,207	2.89	0.90
May-04													209,398	3.20	0.99	198,509	3.28	0.94
Jun-04													146,985	2.84	0.95	182,507	3.66	1.01
Jul-04													140,200	1.94	0.76	184,541	3.48	0.94
Aug-04													108,066	1.63	0.75	178,501	3.25	0.86
Sep-04													84,280	1.42	0.76	183,473	2.43	0.83
Oct-04													64,983	1.51	0.77	195,919	2.11	0.75
Nov-04													63,394	1.30	0.73	198,936	2.42	0.81
Dec-04													56,860	1.21	0.66	193,113	2.99	0.87
Jan-05													37,858	0.95	0.61	164,253	2.71	0.91
Feb-05													9,915	0.80	0.57	145,977	2.98	0.97
Mar-05																152,905	2.95	0.95
Apr-05																139,858	2.88	1.02
May-05																143,004	2.37	0.89
Jun-05																108,134	1.65	0.83
Jul-05																122,759	1.62	0.83
Aug-05																105,039	1.39	0.77
Sep-05																88,209	0.88	0.62
Oct-05																976	0.78	0.55
Nov-05																		
Dec-05																		
Jan-06																		
Feb-06																		
Mar-06																		
Apr-06																		
May-06																		
Jun-06																		
Jul-06																		
Aug-06																		
Sep-06																		
Oct-06																		
Nov-06																		
Dec-06																		
Jan-07																		
Feb-07																		
Mar-07																		
Apr-07																		
May-07																		
Jun-07																		
Jul-07																		
Aug-07																		
Sep-07																		
Oct-07																		
Nov-07																		
Dec-07																		
Jan-08																		
Feb-08																		
Mar-08																		
Apr-08																		
May-08																		
Jun-08																		
Jul-08																		
Aug-08																		
Sep-08																		
Oct-08																		
Nov-08																		
Dec-08																		
Jan-09																		
Feb-09																		
Total	412,379	2.08	0.94	1,571,015	2.33	0.95	2,284,611	2.52	0.95	2,927,849	2.92	0.98	3,556,101	2.92	0.95	3,504,334	2.62	0.89

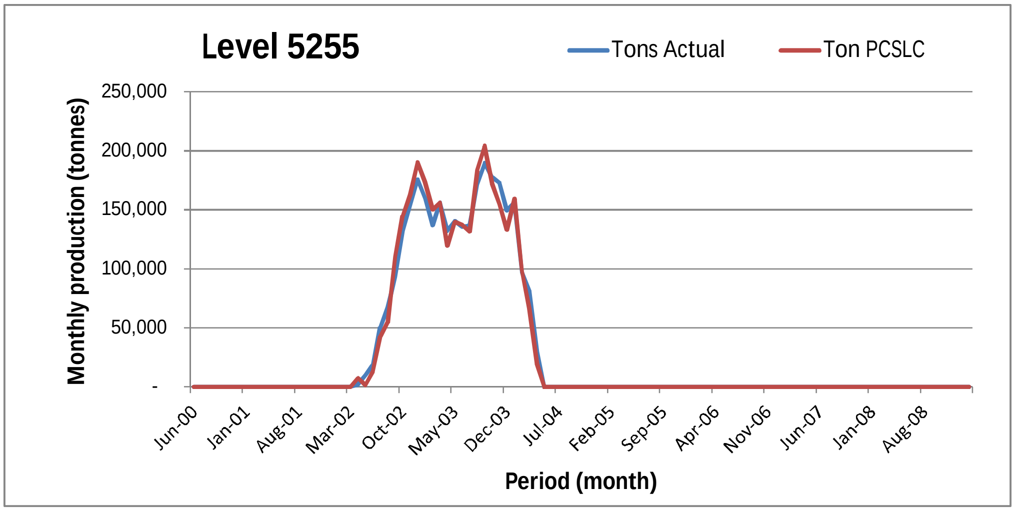
Month	5180			5155			5130			5100			5070			5040			Total		
	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)	Tonnes (t)	Au (g/t)	Cu (%)
Jun-00																			9,007	0.32	0.42
Jul-00																			31,895	0.80	0.60
Aug-00																			32,631	1.01	0.64
Sep-00																			23,462	2.14	0.87
Oct-00																			39,225	2.15	0.93
Nov-00																			20,912	1.97	0.92
Dec-00																			41,665	2.49	1.09
Jan-01																			32,439	2.61	1.14
Feb-01																			29,954	2.76	1.11
Mar-01																			70,712	2.42	1.03
Apr-01																			67,619	1.56	0.81
May-01																			55,240	0.95	0.62
Jun-01																			73,226	0.66	0.58
Jul-01																			81,921	0.88	0.64
Aug-01																			73,879	1.01	0.68
Sep-01																			83,374	1.41	0.70
Oct-01																			91,170	2.20	0.81
Nov-01																			82,526	2.83	0.97
Dec-01																			79,074	3.32	1.04
Jan-02																			96,293	2.14	0.98
Feb-02																			88,413	2.40	0.89
Mar-02																			120,282	2.08	0.92
Apr-02																			203,133	2.58	0.85
May-02																			242,098	2.47	1.09
Jun-02																			275,471	2.43	0.95
Jul-02																			304,105	2.23	0.96
Aug-02																			305,699	1.75	0.93
Sep-02																			333,345	2.02	0.89
Oct-02																			339,004	2.14	0.86
Nov-02																			380,973	2.49	0.95
Dec-02																			425,671	2.80	1.00
Jan-03																			398,561	2.88	1.02
Feb-03																			373,915	3.11	1.03
Mar-03																			436,441	3.48	1.14
Apr-03																			374,096	3.63	1.14
May-03																			390,111	3.32	1.11
Jun-03																			360,334	3.30	0.93
Jul-03																			352,544	3.44	1.06
Aug-03																			445,547	3.17	1.02
Sep-03																			450,841	3.44	0.99
Oct-03																			426,445	3.18	1.01
Nov-03																			429,343	2.87	0.94
Dec-03																			420,002	2.89	0.90
Jan-04																			471,776	2.79	0.91
Feb-04																			379,936	2.96	0.91
Mar-04																			431,203	2.56	0.93
Apr-04	14,166	1.06	0.79																386,391	2.73	0.90
May-04	23,822	1.53	0.91																431,729	3.14	0.96
Jun-04	85,935	1.44	0.87																415,428	2.91	0.96
Jul-04	101,526	1.97	0.87																426,267	2.62	0.87
Aug-04	107,071	2.52	0.91																393,638	2.60	0.85
Sep-04	130,853	2.64	0.99																398,607	2.29	0.87
Oct-04	159,078	3.06	0.98																419,980	2.38	0.84
Nov-04	174,900	3.18	0.97																437,230	2.56	0.86
Dec-04	191,343	3.81	1.00	5,716	1.37	0.80													447,034	3.09	0.90
Jan-05	161,815	3.60	1.01	24,867	1.17	0.76													388,793	2.81	0.91
Feb-05	157,327	3.84	1.04	36,765	1.37	0.79													349,985	3.14	0.97
Mar-05	180,946	3.41	0.87	65,791	0.82	0.71													399,642	2.81	0.88
Apr-05	169,968	3.34	0.93	71,140	1.35	0.84													380,966	2.80	0.95
May-05	185,202	2.64	0.82	102,984	2.22	0.87													431,190	2.45	0.86
Jun-05	138,452	2.17	0.81	123,246	2.19	0.92													369,832	2.02	0.85
Jul-05	151,429	2.33	0.80	146,210	2.16	0.86													420,398	2.06	0.83
Aug-05	164,523	2.58	0.86	144,934	2.71	0.88													414,495	2.33	0.85
Sep-05	142,669	2.90	0.94	138,874	2.98	0.90	27,469	0.67	0.67										397,220	2.32	0.84
Oct-05	199,073	2.95	0.98	179,248	3.44	0.92	25,277	1.01	0.66										404,573	3.04	0.93
Nov-05	150,273	2.55	1.00	155,375	3.30	0.93	43,224	1.04	0.67										348,873	2.70	0.93
Dec-05	149,086	2.44	0.90	175,886	3.13	0.82	88,690	1.36	0.71										413,662	2.50	0.82
Jan-06	124,739	2.30	0.88	141,768	2.76	0.76	99,281	1.91	0.77										365,787	2.37	0.80
Feb-06	100,124	1.84	0.80	170,102	2.19	0.68	121,639	2.18	0.79										391,865	2.10	0.75
Mar-06	91,745	1.61	0.77	183,878	2.00	0.68	147,471	2.67	0.83										423,094	2.15	0.75
Apr-06	39,428	1.41	0.79	169,547	1.90	0.73	161,123	2.69	0.82										370,098	2.19	0.78
May-06	67,443	1.11	0.72	132,217	2.06	0.78	224,938	2.73	0.82										424,598	2.27	0.79
Jun-06	27,040	1.00	0.40	169,990	2.83	0.85	223,374	3.15	0.75										420,404	2.88	0.77
Jul-06	45,170	0.75	0.53	160,504	2.52	0.91	184,182	2.39	0.70	32,231	0.50	0.58							422,087	2.12	0.75
Aug-06	8,680	0.53	0.42	197,109	2.09	0.82	212,454	2.22	0.66	35,494	0.82	0.61							453,737	2.02	0.72
Sep-06				195,551	2.22	0.81	210,333	2.08	0.64	17,353	0.84	0.60							423,237	2.09	0.72
Oct-06				189,248	1.63	0.73	199,271	1.75	0.65	86,755	1.09	0.64							475,274	1.58	0.68
Nov-06				150,925	1.31	0.67	198,728	1.81	0.67	98,091	1.00	0.62							447,743	1.46	0.66
Dec-06				125,007	1.69	0.71	194,859	2.60	0.76	117,534	1.85	0.70							437,401	2.14	0.73
Jan-07				87,810	1.08	0.62	198,642	2.27	0.80	209,934	2.12	0.75							496,386	2.00	0.75
Feb-07				53,872	0.81	0.51	135,067	2.34	0.81	182,482	2.39	0.73	46,619	0.52	0.56				418,040	1.96	0.71
Mar-07				42,022	0.68	0.46	153,864	1.94	0.80	165,864	2.19	0.68	58,868	0.73	0.58				420,619	1.74	0.69
Apr-07				12,402	0.62	0.41	168,012	1.94	0.78	184,303	2.21	0.63	75,869	1.09	0.64				440,587	1.87	0.68
May-07				3,623	0.65	0.47	167,553	1.88	0.84	165,921	2.45	0.72	95,796	1.11	0.69				432,894	1.92	0.75
Jun-07							164,653	2.10	0.77	128,352	2.98	0.71	142,778	1.96	0.75				435,783	2.31	0.74
Jul-07							143,228	1.77	0.70	198,008	2.06	0.58	158,154	1.71	0.61				499,389	1.87	0.63
Aug-07							125,609	1.49	0.65	184,318	1.81	0.59	127,932	1.74	0.61				437,859	1.70	0.61
Sep-07							70,650	1.30	0.62	287,098	1.87	0.64	111,474	2.03	0.64				469,222	1.82	0.64
Oct-07							84,465	1.13	0.55	272,015	2.09	0.66	101,780	1.90	0.57				458,260	1.87	0.62
Nov-07							67,149	0.98	0.49	228,500	2.26	0.76	138,444	1.79	0.54				434,093	1.91	0.65
Dec-07							49,163	0.99	0.50	250,773	2.66	0.91	165,087	2.18	0.67				465,022	2.31	0.78
Jan-08							25,837	1.00	0.43	187,765	2.19	0.78	169,918	2.03	0.62	12,518	1.91	0.67	396,038	2.04	0.68
Feb-08							24,589	0.96	0.39	154,080	2.16	0.75	170,048	2.05	0.66	31,253	1.53	0.62	379,971	1.98	0.68
Mar-08							7,865	0.81	0.34	177,490	1.64	0.65	214,292	1.71	0.56	47,897	1.31	0.54	447,543	1.62	0.59
Apr-08										189,366	1.85	0.75	219,136	2.47	0.82	81,287	2.02	0.72	489,789	2.16	0.78
May-08										184,908	1.92	0.71	204,274	2.33	0.74	87,875	2.20	0.66	477,058	2.14	0.71
Jun-08										179,364	1.65	0.70	218,316	2.41	0.77	111,783	1.91	0.61	509,464	2.03	0.71
Jul-08										122,414	1.31	0.55	185,574	2.21	0.67	151,557	1.57	0.49	459,545	1.76	0.58
Aug-08										93,028	1.25	0.51	184,364	1.88	0.62	154,562	1.58	0.47	431,954	1.64	0.54
Sep-08										108,181	1.15	0.53	208,710	1.96	0.68	166,436	1.47	0.54	483,327	1.61	0.60
Oct-08										87,839	1.07	0.53	218,110	1.94	0.74	186,444	1.41	0.57	492,392	1.58	0.64
Nov-08										71,055	1.08	0.51	192,270	1.86	0.69	184,173	1.99	0.71	447,498	1.79	0.67
Dec-08										68,040	0.96	0.44	220,784	1.42	0.55	182,457	1.99	0.67	471,281	1.57	0.58
Jan-09										45,121	0.92	0.42	215,721	1.43	0.57	207,582	1.98	0.67	468,424	1.62	0.60
Feb-09										27,986	0.89	0.41	113,923	1.34	0.54	216,199	2.04	0.67	358,108	1.73	0.61
Total	3,443,827	2.69	0.90	3,556,613	2.22	0.79	3,948,657	2.08	0.72	4,541,662	1.91	0.67	3,958,242	1.86	0.65	1,822,023	1.80	0.61	35,527,314	2.34	0.81

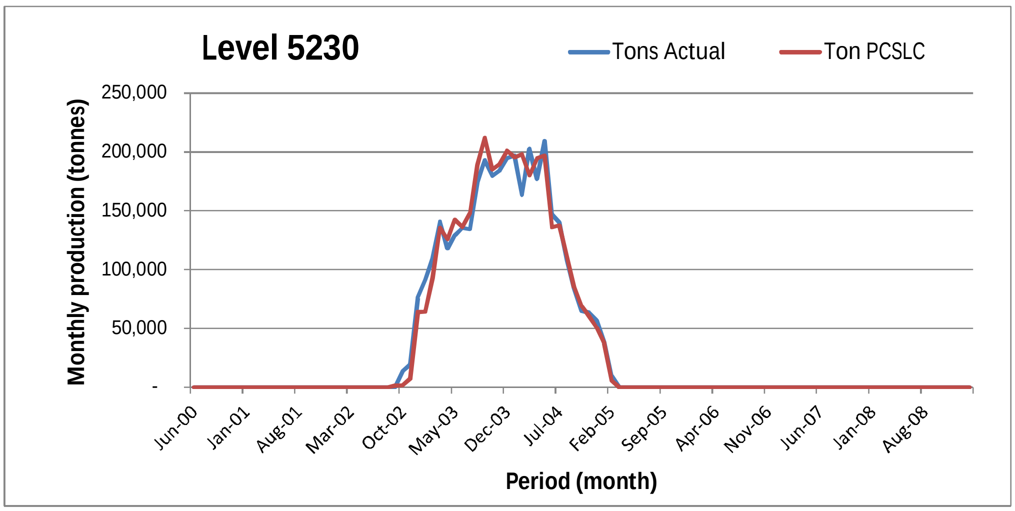
Appendix B. Graph tonnage per level

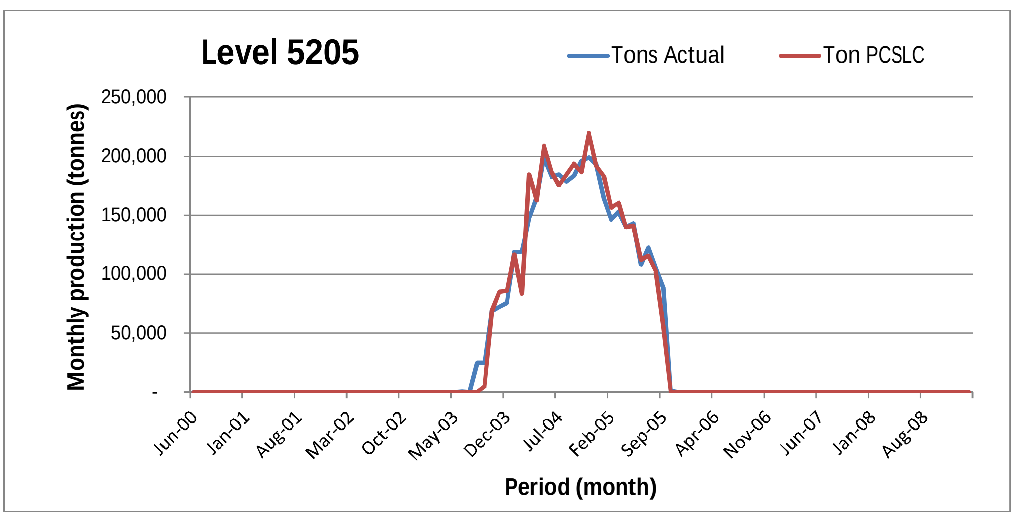


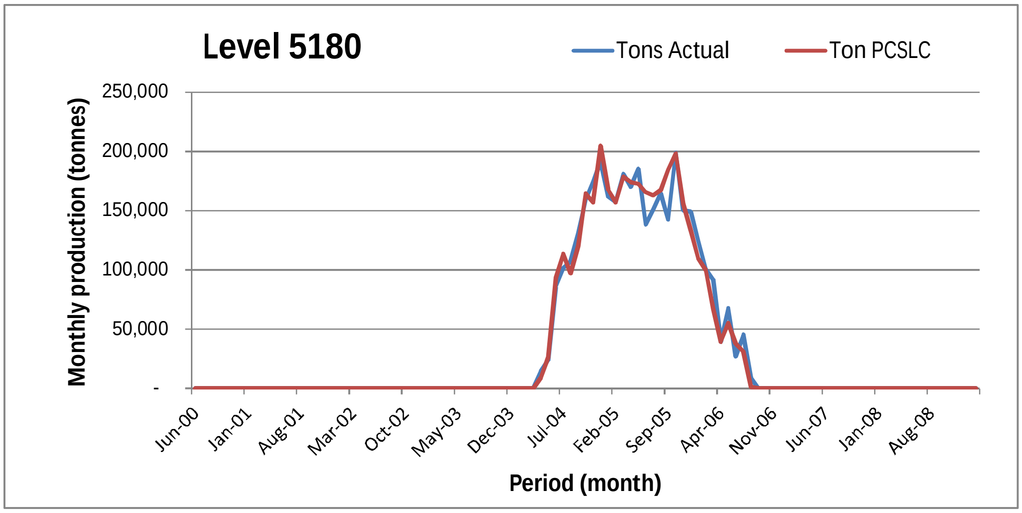


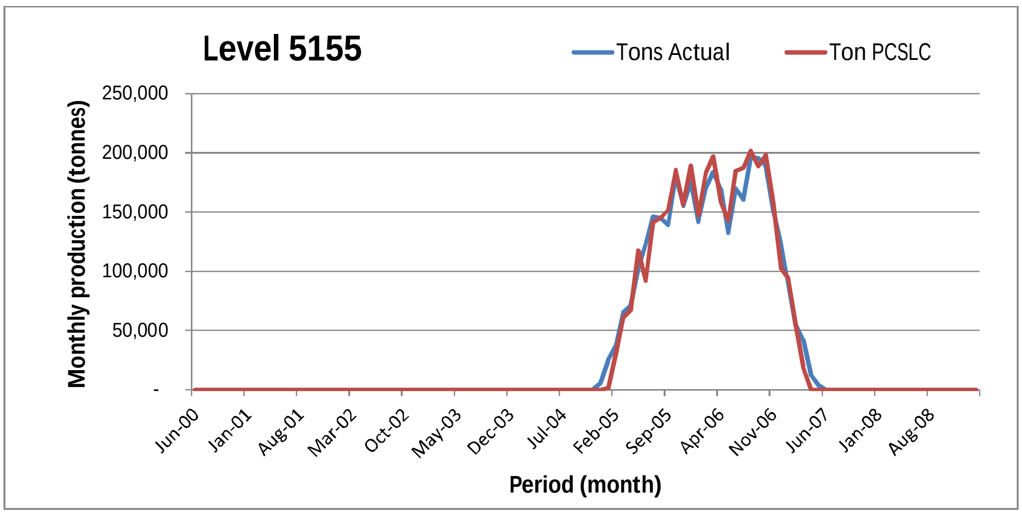


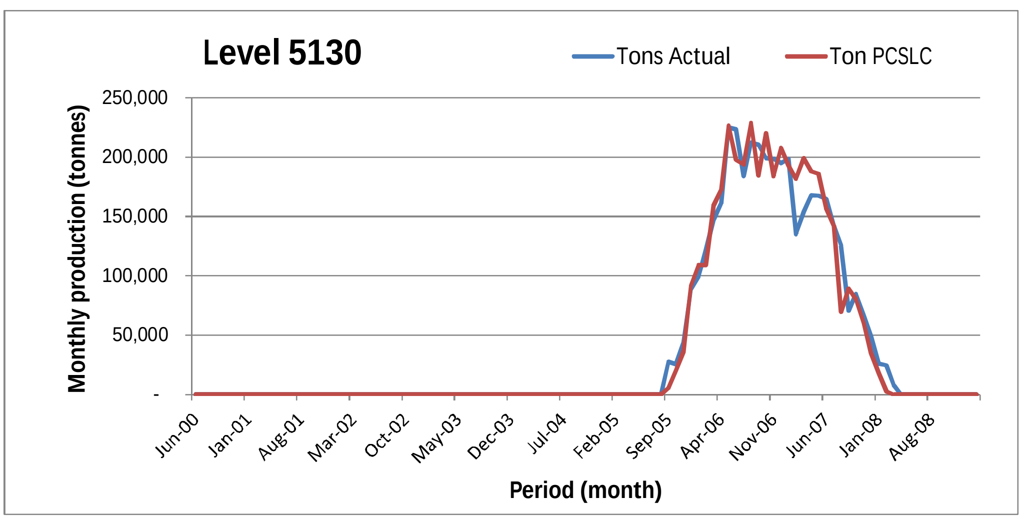

Level 5255
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)

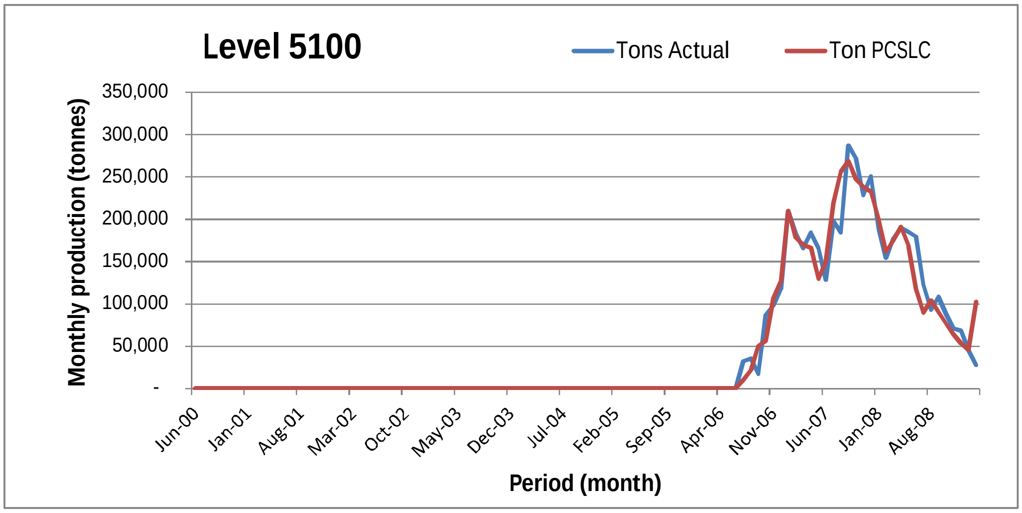

Level 5230
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)

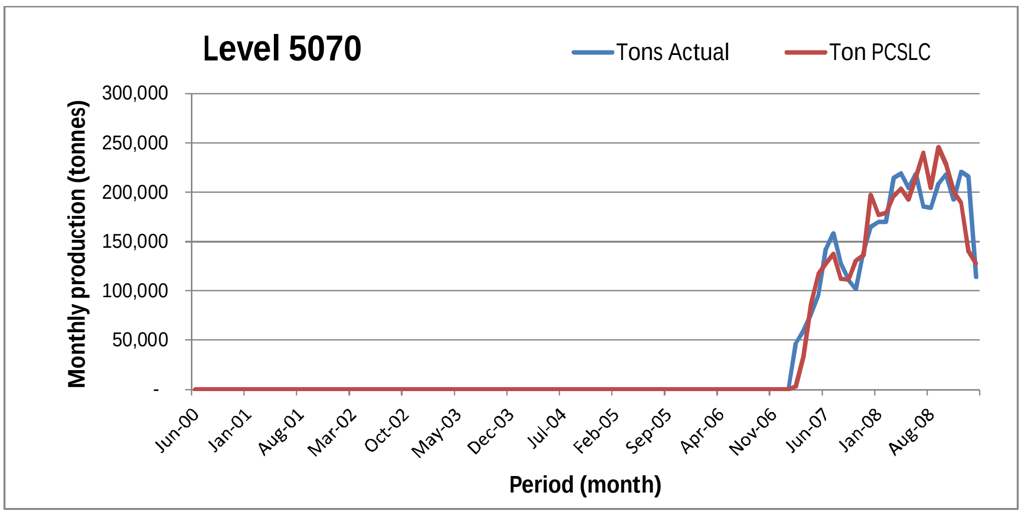

Level 5205
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)

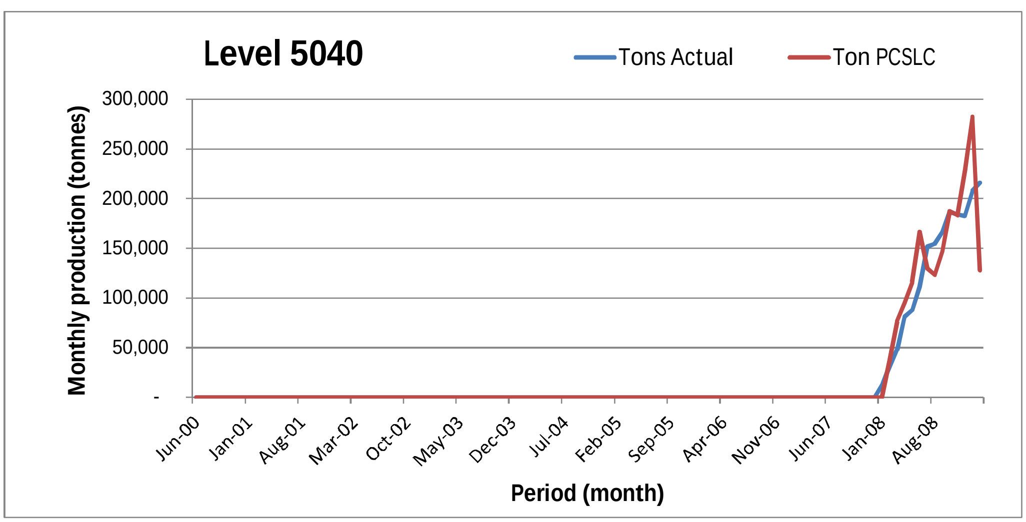

Level 5180
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)


Level 5155
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)


Level 5130
Tons Actual
Ton PCSLC
Monthly production (tonnes)
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)


Level 5100
Tons Actual
Ton PCSLC
Monthly production (tonnes)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)


Level 5070
Tons Actual
Ton PCSLC
Monthly production (tonnes)
300,000
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)


Level 5040
Tons Actual
Ton PCSLC
Monthly production (tonnes)
300,000
250,000
200,000
150,000
100,000
50,000
-
Jun-00
Jan-01
Aug-01
Mar-02
Oct-02
May-03
Dec-03
Jul-04
Feb-05
Sep-05
Apr-06
Nov-06
Jun-07
Jan-08
Aug-08
Period (month)

Appendix C. Smart Marker system

The system operating sequence describes the logical progress in which the electronic marker is detected and logged by the system. The sequence is summarized in Figure 111, with the following steps(Brunton, 2010):

1. Pre-programmed electronic markers are installed into drill holes in preparation for blasting. The markers are in their sleep mode with most circuitry inactive.
2. The rock mass containing the markers is blasted.
3. The marker is excavated by an LHD.
4. The transceiver system is located along a path which the LHD will take, preferably at a point where the LHD is forced to slow (e.g. production drive intersection with perimeter drive). There is one transmitter antenna and several receiver antennae spaced further down the LHD path (located on the drive roof). The antennae connect to an electronics module containing the receiving decoder circuitry and the antenna transmitter drive circuitry. The LHD presence is detected automatically.
5. As the LHD is detected the transmitter transmits a 0.5 second pulse at Logic 1 frequency(66.66 kHz) to wake-up any electronic markers in the bucket.
6. Markers in the LHD bucket wake-up, enabling the remaining circuitry to operate and listen for Logic 0 (64.10 kHz) or Logic 1 (66.66 kHz) signals. Contention resolution software in the markers will cause the marker to transmit its serial number when it is able to.
7. The receiving antennae spaced along the LHD path will receive the transmission from the electronic markers. The receiver decoding circuitry will resolve this signal into a binary sequence. The receiver will attempt to decode the serial number.
8. Both the binary sequence and the serial number are sent on via a serial port on the receiver module to a data logging system. The data logger also decodes the binary sequence and is able to apply error detection and correction techniques to the stream. Ideally the serial numbers computed by both the logger and by the receiver are the same. The result is dates tamped and logged.
9. The markers, once initiated, will remain active for 20 seconds before returning to the sleep mode. In this way the marker is able to recover from any false triggering that may have occurred prior to entering the reading zone.
10. The transceiver waits until initiated by the LHD entering the reading zone. It will listen for marker transmissions until either the LHD is detected leaving the zone or twenty second safter LHD detection. It will then resume waiting for the next LHD to pass.

The Smart Marker System, Smart Markers are automatically detected by Readers mounted to the back of cross cuts, perimeter drives or ore-passes (see Figure 112). The Readers operate automatically and do not require any slowing of production to detect Markers.

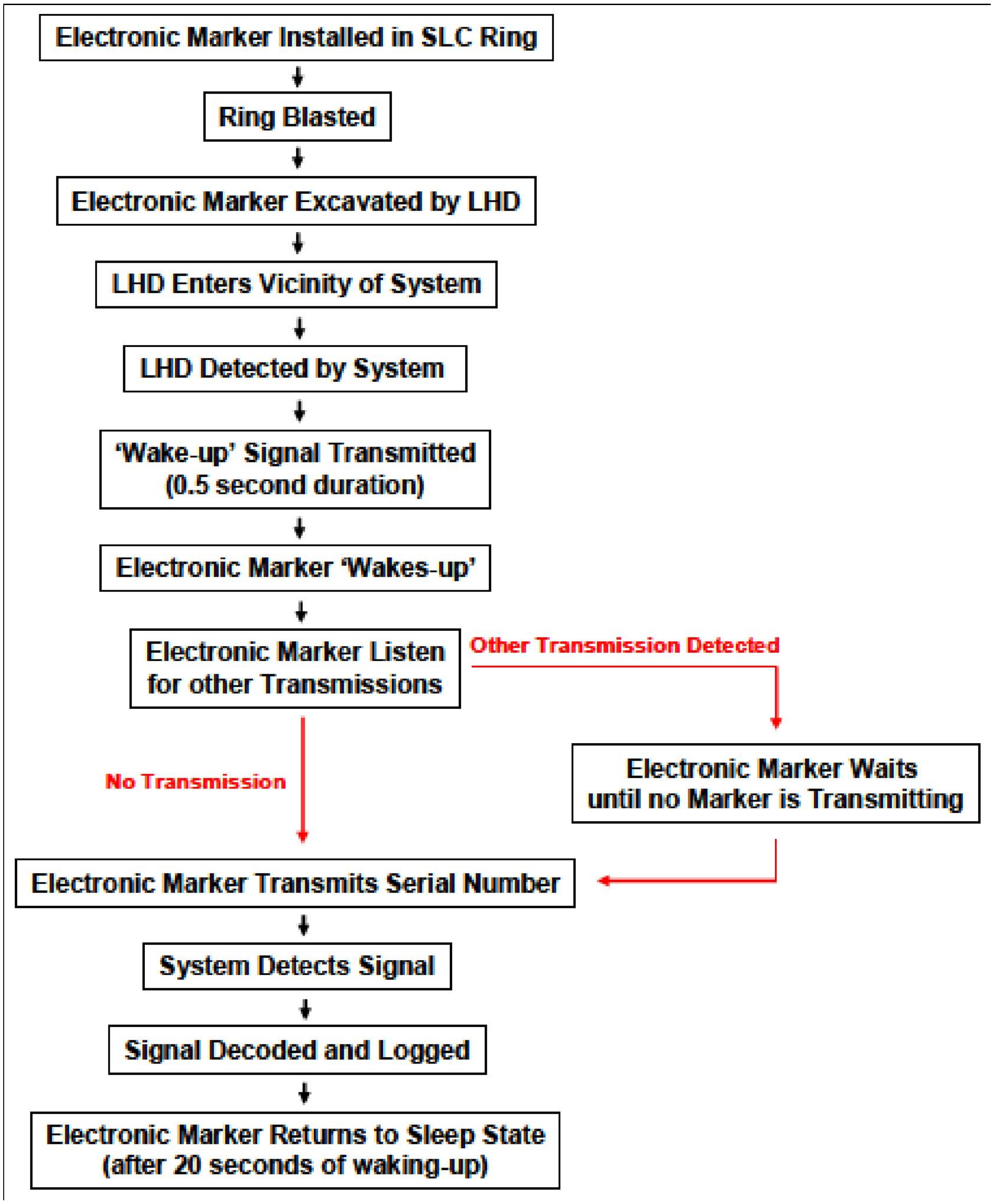


Figure 111: Smart marker system operating sequence

Because the Smart Markers are instantly detected as the LHD drives under the Reader, the exact time of extraction is known. The exact drawpoint from which Markers were extracted can be determined because each LHD is fitted with an 'LHD Marker'. As the LHD passes under the Reader, its ID is logged, along with that of any other Markers. Identifying the LHD can also help determine the draw tonnage and relate the flow of material with the tonnes drawn.

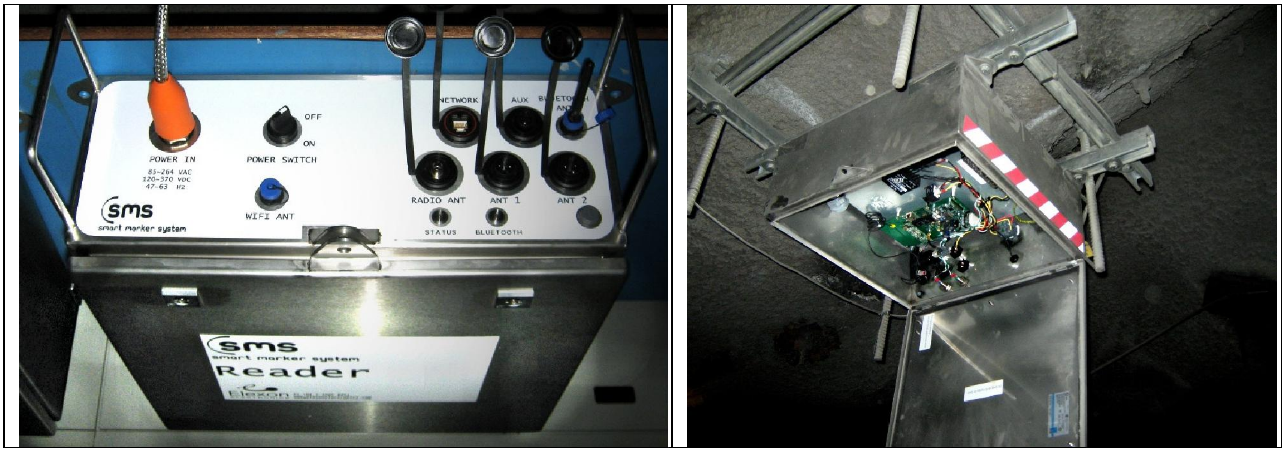


Figure 112: The Smart Marker System reader(Whiteman, 2012).

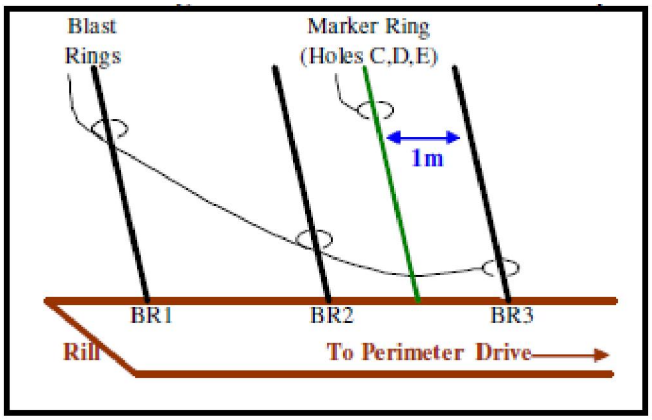
The time stamping of the detected Markers allows an animation to be generated that shows exactly which volumes of rock were over for every bucket of ore extracted. No changes need to be made to draw schedules to achieve this – it is provided automatically as soon as the system is switched on.

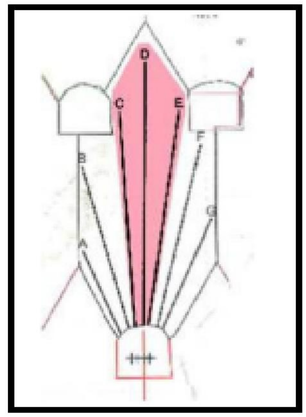
The high resolution data allows various draw strategies to be compared. For example, a mine can compare the rate of draw with the resulting effect of rock movement within volumetric zones. A mine can also compare the effects of drawing only from the left or right of the draw point; or the effect of 'rocking' the drawpoint by drawing from each side in a determined pattern (Whiteman, 2012).

Underground Marker tests were carried out at Newcrest's Telfer SLC mine in Western Australia. The Markers were installed in December 2008 and blasted in early January 2009, representing the first SLC production level test of the Smart Marker System. The setup of the test is illustrated in Figure 113 below, along with a few photos of recovered Markers in Figures 114.

For this first test, Markers were grouted into three installation holes, marked as "C", "D" and "E". The Marker ring was drilled 1 m from the blast ring. All holes sizes were 102 mm in diameter and the Velocity of Detonation (VOD) was approximately 4800 m/s. Smart Markers were spaced every 0.5 m inside their installation holes, with a passive steel marker placed after every second Smart Marker (see Figure 113). The purpose of the steel markers was to act as a 'control' during the test. By comparing the recovery of the steel markers with Smart Markers, success of Smart Marker recovery could be determined. A strobe light was also fitted to the Readers for this test. The Readers could be set up by the Scanner to trigger the strobe light for a short time whenever Markers were detected. When the strobe was seen by the LHD operator, the load was tipped into an adjacent crosscut so that the Markers could be recovered. This was relatively easy using a Smart Marker location finder. Note it is not necessary to physically recover Smart Markers during normal use; however it was important in this early test to physically recover as many Smart Markers as possible. This enabled the physical condition of the Markers to be assessed following blast and extraction.

The result from this first test was excellent. The detected Markers in the first 10m of the holes "C", "D" and "E" are shown in Figure 113. The first 10m depth represents the area with the greatest blast energy.





Colour Key:

Smart Markers	Steel Markers	Not Yet Detected

Installation Depth (m)	Hole C ID number	Hole C Marker Type	Hole C Status	Hole D ID number	Hole D Marker Type	Hole D Status	Hole E ID number	Hole E Marker Type	Hole E Status
10.5	-	-	-	-	-	-	2146	Smart	DETECTED
10.0	1019	Smart	DETECTED	1161	Smart	DETECTED	4101	Steel	
9.5	4353	Steel		1034	Smart	---	1157	Smart	DETECTED
9.0	2039	Smart	DETECTED	4269	Steel		2182	Smart	DETECTED
8.5	1058	Smart	DETECTED	1152	Smart	DETECTED	4345	Steel	
8.0	4305	Steel		1022	Smart	DETECTED	2067	Smart	DETECTED
7.5	2054	Smart	DETECTED	4037	Steel		2155	Smart	DETECTED
7.0	1014	Smart	DETECTED	1160	Smart	DETECTED	4156	Steel	
6.5	4364	Steel		1089	Smart	DETECTED	2110	Smart	DETECTED
6.0	1034	Smart	DETECTED	4238	Steel		2149	Smart	DETECTED
5.5	1057	Smart	DETECTED	1167	Smart	DETECTED	4331	Steel	
5.0	4242	Steel		1038	Smart	DETECTED	2114	Smart	DETECTED
4.5	1010	Smart	DETECTED	4219	Steel		2143	Smart	DETECTED
4.0	1003	Smart	DETECTED	1171	Smart	---	4102	Steel	
3.5	4234	Steel		1064	Smart	DETECTED	2069	Smart	---
3.0	1147	Smart	DETECTED	4067	Steel		1042	Smart	DETECTED
2.5	1002	Smart	DETECTED	1118	Smart	DETECTED	2101	Smart	---
2.0	1070	Smart	DETECTED	1030	Smart	DETECTED	1013	Smart	DETECTED
1.5	1066	Smart	DETECTED	4119	Steel		2107	Smart	DETECTED
1.0	4240	Steel		-	-	-	4273	Steel	

Figure 113: Detection results for the successful first SLC Smart Marker test

Figure 114: Inspecting markers after the first test

Figure 115 shows an operational Smart Marker from the test still embedded in a large rock in the LHD bucket.

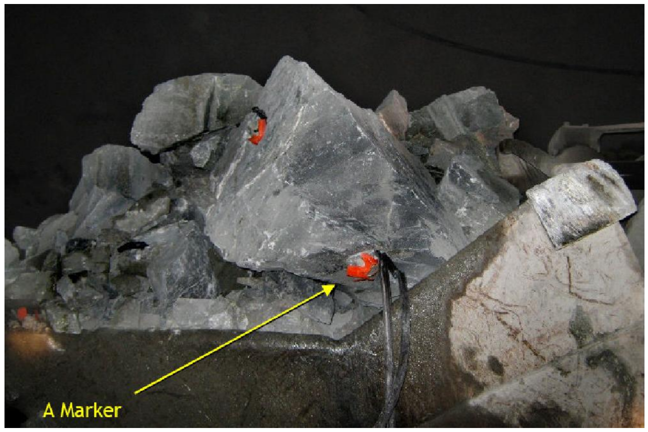


Figure 115: Smart Marker was successfully detected while embedded in the rock

Figure 116 shows a representation of the Smart Markers recovered and the color of the shaded cells in this data represent the sequence detected. The color sequence by order is as follow:

1. Light green
2. Dark green
3. Blue

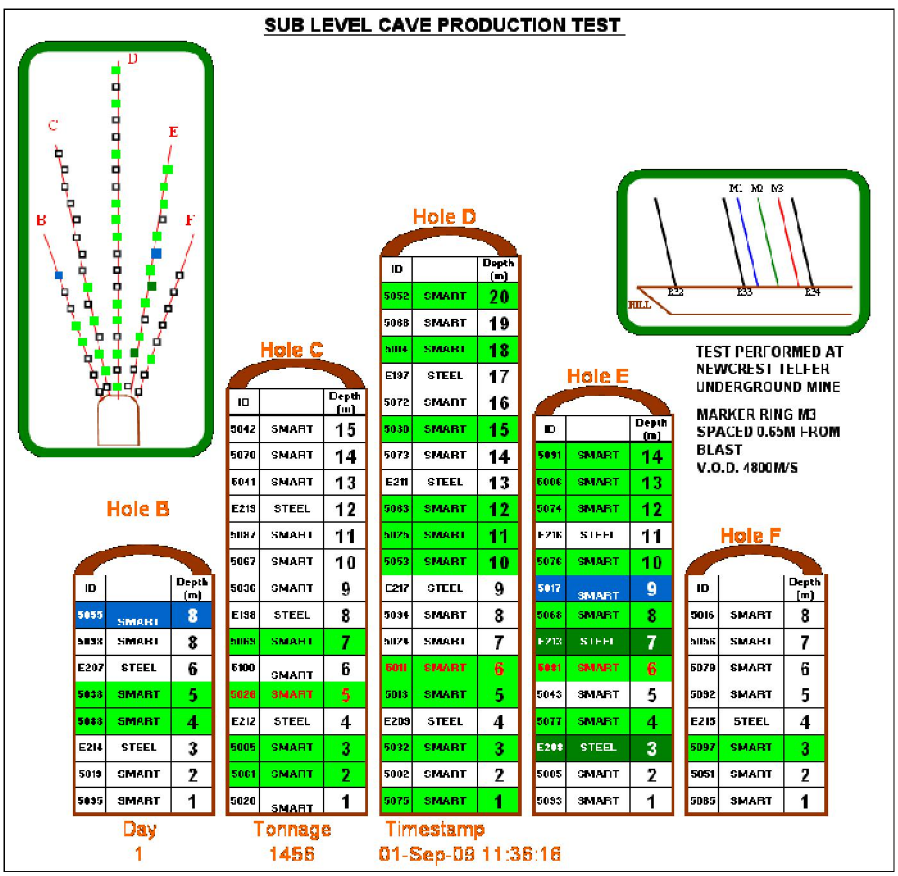


Figure 116: Representation of the Smart Marker detected

Finally Figure 117 shows how the RockView tool works automatically displaying Markers that are detected during normal ring extraction are shaded as green. Markers that have not yet been detected are shaded yellow.

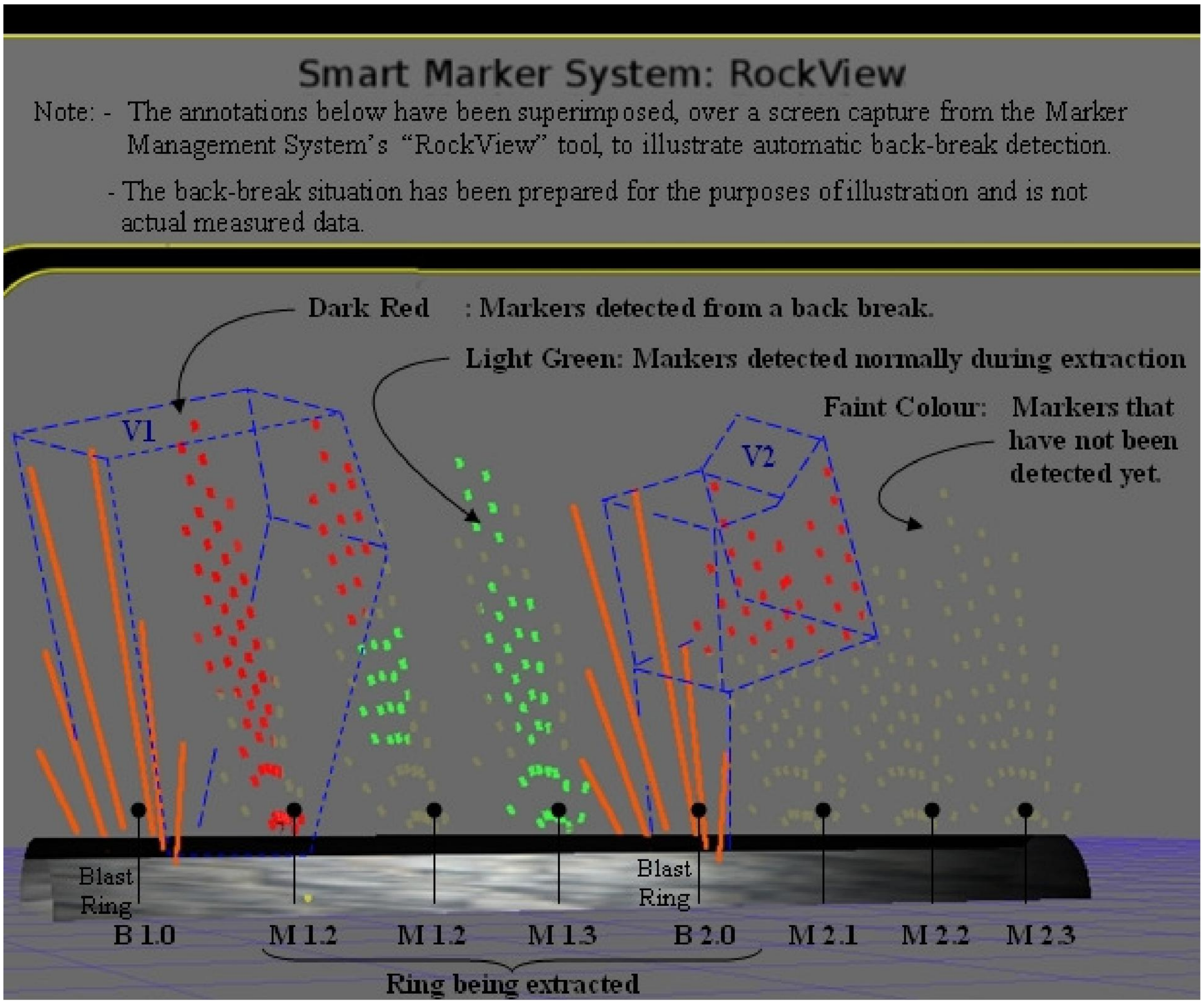


Figure 117: Smart Marker system (RockView)