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REMINING AND RESTRUCTURE OF A TAILING DEPOSIT

Technical Feasibility

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FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
MINING ENGINEERING

Abstract

For more than 100 years, Panasqueira mine (Barroca Grande and Rio) has been a source of various mineral concentrates such as wolfram and tin while copper, zinc and silver were extracted as by-products. Nevertheless, apart from the concentrates that have fed the European industry, the process of mining and beneficiation has produced generated tremendous amounts of waste materials throughout, this is evidenced by the massive piles of tailing waste on the riverbed of the Zêzere River. The Panasqueira tailings have been studied and investigated by various authors over the years, and they raised various threatening environmental issues such as Acid Mine Drainage (AMD) generation, soil and water contamination due to sulphide oxidation, and tailing dam instability due to exposure to the climate. Apart from that, the tailing depositions can be potential economic mineral resources. Therefore, due to the negative environmental impacts and the potential mineral resources, a technical and economical solution to mitigate this site was proposed. This dissertation forms part of the conceptual study that aims to develop a recoverability strategy and remediation plan for Rio tailing dam with the aid of Vulcan Software (developed by Maptek, Australia). Vulcan software was used to construct the tailing resource model for resource estimation, mine planning, and design. This process was undertaken in five basic steps: database management, deposit modelling, pit design, pit production, and rehabilitation design. In total, 108 samples consist of bulk samples and core drill that were analysed with Energy Dispersive X-Ray Fluorescence (XRF), and Conductive Plasma Emission Spectrometry (CPES) was used as the geochemical data input of the model. In addition to that, drone survey data and digitised contour map data were used as surface topographical data to construct the site model. Using Vulcan applications, imported data were managed, manipulated, and analysed to produce both 2D and 3D models for visualisation. The classic statistical analysis and traditional inverse distance square estimation method were used to determine the average grade values for five study minerals in the tailings, which along with material volume data made it possible to estimate the size of the potential tailing resources. The results for the five minerals studied produced average grade estimations of 11.82 % As, 0.41 % Cu, 17.21 % Fe, 0.31 % W, and 0.89 % Zn, with mineral resources estimated at 3.04 $\times 10^6$ m^3, of which only 1.32 $\times 10^6$ m^3 can be exploited through a direct digging and loading method. To remediate the site, the hydraulic barrier cover system is proposed to cover the restructure and reshaped dam slope. Even through estimation results show that is a certain volume of minerals that can be remining for reprocessing these results was affected by the shortage of data and sampling depth as many of the samples, as well as the error margin of base surface topographic map data. Therefore, this study results must only be used as a feasibility study data input but not for decision making unless more data is made available to improve the model accuracy and representativeness.

Keywords

Acid mine drainage; Estimation; Modelling; Remining; Resources; Restoration, Restructure; Tailing; Maptek Vulcan

TO:

Samantha and Zechariah

Declaration

A dissertation submitted to the Faculty and the Board of Examiner of the Department of Mining and Geo-Environmental Engineering, University of Porto – Faculty of Engineering (Faculdade de Engenharia da Universidade do Porto - FEUP), Portugal as partial fulfilment of the requirements for the degree of Master in Mining and Geo-Environmental Engineering -2016/2017.

I have clearly stated the contribution by others to jointly - authored works that I have included in my dissertation.

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List of Symbols and abbreviation

%	percentage
°C	Degrees Celsius
AMD	Acid Mine Drainage
BRGM	Bureau De Recherches Géologiques Et Minières
CIZ	Central Iberian Zone
CPES	conductive plasma emission spectrometry
CSV	comma-separated values
DRX	Diffraction des rayons X
EC	European Commission
ERT	Electrical Resistivity Tomography
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GPR	Ground Probing Radar Profiling
GPS	Global Positioning System
IGM	Instituto Geológico e Mineiro
Km	Kilometre
m	meter
m^2	meter square
m^3	Cubic meter
MHz	Megahertz
mm	millimetre
MMSD	Mining, Minerals and Sustainable Development
Mt	million tonnes
ODBC	Open Database Connectivity
ppm	parts per million
SD	Sustainable Development
UTM	Universal Time
WHO	World Health Organization
XRF	X-Ray Fluorescence

CHAPTER 1:INTRODUCTION AND BACKGROUND

1.1. Overview

Mining is one of the primary human operations that are responsible for the extraction of valuable minerals (commodities) or other geological materials from the earth crust to meet the increased global demand for commodities that are used by human being as needs to survive, and as sustainable resources. It is worthnoting that non-renewable resources are the commonly extracted commodities, and that different minerals may be exploited from the earth crust - either in their purty state or in the concentrated, using surface mining methods or underground methods. Given that minerals are found normally in compound forms to separate them from waste rocks, different mining techniques are usually used to separate them from waste, and this is the beginning of the waste generation on the mining process chain, as materials are separate, based on mineral concentration, commonly known as the cut-off grade.

Mine waste are usually classified into two categories, namely: waste rocks and tailing. The waste rock are synonymously referred to as the non-mineralised and low-grade mineralised rock extract from, around or within the orebody during the exploitation refered to the materials with a low concentrate than a defined cut off. In some cases, these rocks may be left behind on their original geological position, but in most instances, especially on the surface operation, these materials are extracted along with the mineralised materials before they end up in stockpiles around the mine site, and then they are processed late or left unprocess. The separation decision is usually based on the processing plant operation criteria, and economic or financial constraints. The latter, often referred to as processing waste, refers to waste solids or slurries that remain after the treatment of minerals by the hydrometallurgical separation involved in crushing, grinding, size-sorting, leaching and flotation, which is done to remove the valuable minerals from the gauge. Generally, mining waste can be generated from exploration, exploitation and the extraction of minerals, governed by the legislation on mines, the technology of extraction and separation, and mineral deposit characterisic. For advanced operations, the pyrometallurgical process has another form of waste called slag, which is usually produced by its low quantity, compared to the waste rocks and tailing. The subject of tailing waste deposition has been controversial issue all over the world due to its environmental impact when failure arises. Since the past years, there has been different waste storage, and deposition that has been studied throughout the world for various reasons, but a majority of them have been studied for environmental and social concerns only in recently years we have seen the increase studies for economic benefits.

According to Eurostat in 2014 about 2 503 million tonnes of waste materials were generated in the EU - in 28 countries and this was the highest amount recorded for the EU-28, for which a times series exists (data for even years) since 2004. A summary of waste generation distribution goes as 34.7 % (870 million tonnes) contributed by construction; (28.2 % or 706 million tonnes) by mining and quarrying; 10.2 % (255 million tonnes) by manufacturing; 8.3 % (208 million tonnes) by households, and waste and water services generated (9.1 %). The remaining 9.5% was waste generated from other economic activities, mainly including energy (3.9 %), and services (3.8 %) (Eurostat 2014). Since that, everything start with mining in total mining is the source of two third waste volume at the global waste scale. In 2014, Portugal has contributed about 14.586 million tonnes, and at least 2.743 million tonnes (19 %) came from mining and solidifier second after recyclable waste that contributed about 4.683 million tonnes. Figure 1.1 shows how EU Member States waste contribution per inhabitant which are mainly due to differences in the generation of mineral waste and countries economy structure.

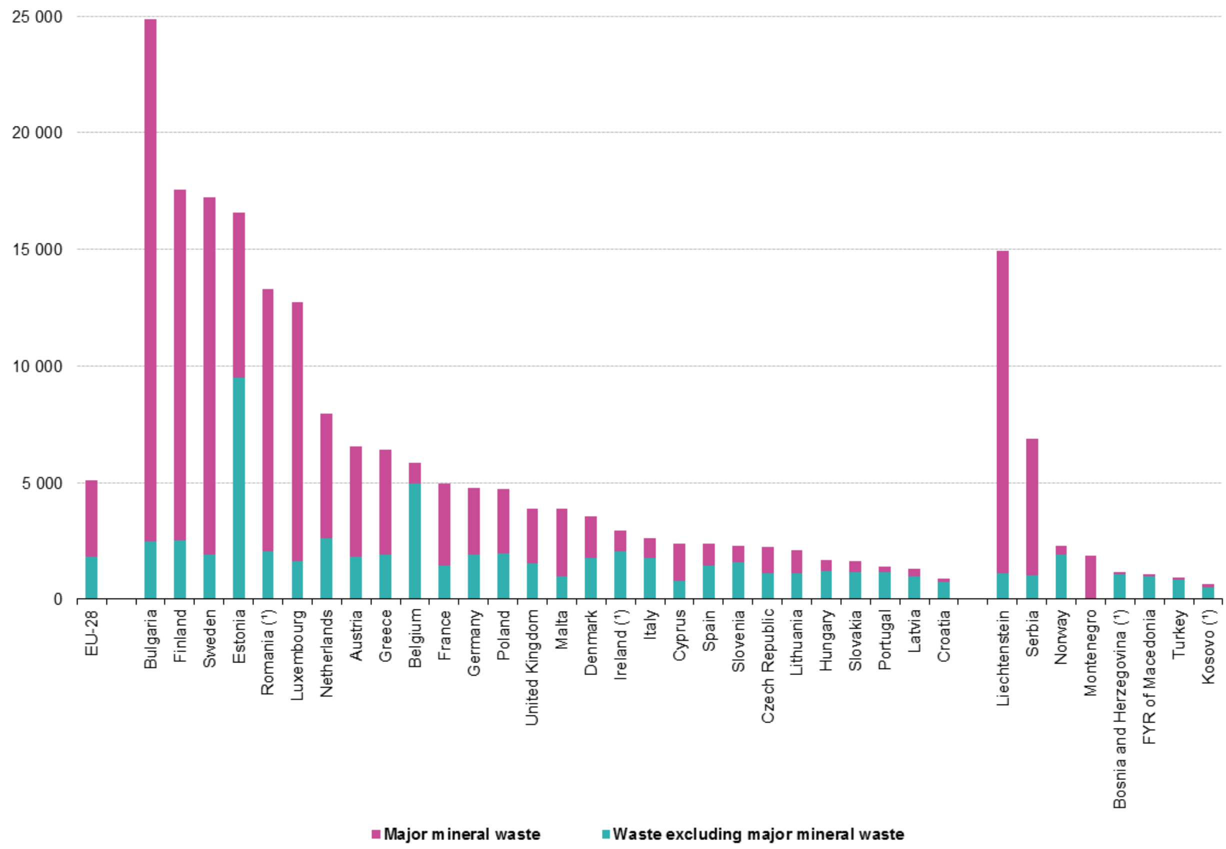

Figure 1. 1. Waste generation, 2014 (kg per inhabitant): Source: Eurostat (2014)

Historically, there was no database about mining waste material deposition anywhere in the world, until in the early 1990s when America (USA) and Europe started recording such information about the location, the physical-chemical characteristics of mining waste, other industrial deposits, as well as the environmental impacts. Nevertheless, the only records available that are well-documented were written after some of the historical tailing dam failure around world as from 1917 to April 2017 there were 242 tailing accidents recorded over the world. In Europe major know accidents are the Stava tailings dam failure, near Trento, Italy in on 19th July 1985 that killed 268 people and cover about 435,000 square metres over 4.2 kilometres; the Aznalcollar mine tailing dam accident in Spain in April 1998, which affected about 2 656 ha of Donana Nature Park, Baia Mare mine in January 2000, and the Baia Borsa mine incident in March 2000 which happened in Romania. While the accidence of the decade is the failure of Fundão tailings dam at Germano mine, Brazil in November 2015 that was due to insufficient drainage as results of redesign, leading to liquefaction of the tailings sands shortly after a small earthquake end up releasing the slurry pollutes North Gualaxo River, Carmel River and Rio Doce over 663 km; and the latest one is 12 March 2017 Tonglvshan Mine in China that flooded the fish pond downstream of approximately 27 hectares. It was after the abovementioned historical events that different nations started realising the need to investigate and document mine waste deposition within their territories, mainly sulphide and heavy minerals tailings, as they have observed them to be a threat to the environment, society, and resources, such as water, soil as well as the impact on greenhouse gas emissions (BRGM 2001, Puura, Marmo, and Alessandro 2002, Garcia et al. 2017, ICOLD 2001, Bowker and Chambers 2015).

Following these incidents, various studies and investigations have been done, and it has called for debates at different levels to reduce environmental pollution in order to conserve energy, to prevent loss of lives and properties, and to respond to the scarcity of natural resource conservation (Hammond 1988). Between the years 2000 and 2002, the Mining, Minerals and Sustainable Development (MMSD) research project was carried out to examine the role of the mineral sector in terms of contributing to sustainable development, and how that contribution could be improved by the International Institute for Environment and Development. After the MMSD study, the “Breaking New Ground” report was published, highlighting the greatest challenges facing the world today, as integrating economic activities with environmental integrity, social concerns, effective governance systems, and access to information. This project elaborates the social barriers to sustainable development, such as mistrust between the miner and communities where the operations are taking place. The mistrust between the two groups is known to be due to the unfair distribution of costs and benefits from the resources due to the fact that communities mostly view them as robbed they resources, and they are left with massive environmental problems.

Concerning the environmental integrity, one of the challenges that threaten the mining sector towards a sustainable world economy is the negative environmental legacy of the mining industry, which includes the abundant mines and the massive volume tailing deposited around the world, causing major environmental problems such as AMD. Several recommendations were drawn up to address in the report, in order to increase the mining sector contribution and to accelerate the Sustainable Development (SD) plan of the mining sector. In addition, all recommendations were drawn up within four dimensions or ‘pillars’ of sustainable development, namely: social, environmental, political, and economic pillar. In terms of mine legacies, the report recommends that the worst affected sites must be identified, and they must be given a priority for remediation, in order to protect critical natural features/areas and to limit further ecological environmental damage.

Europen Commission Proposed New Directive in June 2003 and this was implemented as the European Directive 26/21/EC of 15 March 2006 on the management of waste from extractive industries to oversees the permit conditions, storage, monitoring, and control of the mining waste to guarantee that the environment and the entire society’s health is protected. The aim of the Directive is to emphasise European member states to reduce environmental and health impacts of waste, and to improve the EU’s resource efficiency. In addition, its objective is to reduce the amount of waste generated, and to promote waste generation as a resource when it is unavoidable, achieve higher levels of recycling, and the safe disposal of waste. Every EU member state is required to carry out investigation, create a database that periodically update for their closed waste facilities which may potentially cause threats to the environment and human health caused by waste from the extractive industry through BAT and taking account of specifics of the operation and its location (Articles 1 and 4.3).

Like most European countries in Portugal, the Regional Information Network Decision-Support System for Environmental Risk and Disaster Management (e-EcoRisk) project which was part of the EU - Programme for research, technological development and demonstration on energy, environment and sustainable development was carried out between 2004 and 2006 . The e-EcoRisk project was established to a contribute to the decision-making process of environmental and civil protection agencies with the responsivity to assess, prevent, mitigate, and control the probable and actual effects of large-scale industrial spills on the environment. The sites were selected based on various reasons such as their legacy, their current status, and the interaction with the environment, particularly the rivers. Different site investigation and characterisation techniques (geotechnique and geophysical) were used throughout to collected data and information for visualisation and interpretation to understand the environment impacts, as well as to propose a solution to the challenges. e-EcoRisk database allows access to the system information in real time from fixed and mobile wireless devices via a regional enterprise network (Internet), using terrestrial and satellite high bandwidth telecommunication systems. Nevertheless, several sites were not fully covered by this e-EcoRisk project this has left more work needed to study the those sites as they are observed as threat.

1.2. Motivation

For more than 100 years, the district of Panasqueira in central of Portugal has been known as the global sources of wolframite and tin mineral concentrate. In addition copper concentrate along with a minimal quantity of zinc and silver mineral concentrate were extract as by-products. The extraction of minerals has been excavated from several hydrothermal mineralisation deposits within the district of Panasqueira since it was discovered (Candeias 2013, Ferreira da Silva et al. 2013, Smith 2006).

Mining is a dynamic and complex operation; unlike other industrial sectors, its negative distresses on the environment are indisputable. This is evident to the visual disturbance of man-made mountains created out of uneconomical materials, and both fine and coarse tailing are the residue of the processed materials. The acid mine drainage, and heavy and toxic metal contamination of the riverbanks of Zêzere River and surrounding district such as Barroca Grande, S. Francisco de Assis, Rio, Barroca, and Dornelas do Zêzere are some environmental challenges that have been studied by various scholars for the past years. The study area of interest is Cabeço do Pião (Rio) tailing that is about 5.1 km from Barroca Grande. Barroca Grande is where the current underground adit processing plant and offices are located. In fact, it is the current Panasqueira mine operation address after it was relocated from Rio in 2001 (Boulet and Larocque 1998, Jung 2001, Moore and Luoma 1990, Naicker, Cukrowska, and McCarthy 2003).

The processing plant was relocated to Rio around 1927 when owner at time abandoned Vale de Ermida plant, and it has been operated using gravity, electromagnetic, and flotation separation. It is a fact that in those years, the level of minerals extraction technology was low and the plant was changed from time to time, and the environment regulation was quite poor. More than one million cubic metres of complex, fine-to-fine sulfide materials are deposited on a mountainside overlaying the Zezere river, imposing huge contamination risk.

A bulk of tailing has been stored in the pond and around a mountain that is located on the edge of the Zezere river with an average height of 90 m and slope angle around 35 degrees.

According to Ávila et al. (2011), the deposition of tailing at Rio site can be traced back to 1905, and it operates until 1996. The entire site has been exposed to the atmosphere conditions until June 2006 when the arsenopyrite stockpiles which are located near Rio village was capped with geotextile and clay layer to minimise the atmospheric environment impacts (Crosby 2001, e-EcoRisk 2007, Gilchrist and Mahmoud 1999). To minimise the hydrological environmental impact, two acid drainage treatment plants were set up around Barroca Grande and Rio in order to collect, pump and treat the seepage of acid mine drainage water from the tailing dams. The acid effluent is normally neutralised with lime $Ca(OH)_2$ to promote the precipitation and flocculation of metal when the pH increases. The treated water was pumped into the river or re-used in the processing plant, while the mud and slush were disposed via pipes in the open pond. The set-up prevention has never worked as expected, notably during the winter and period of heavy rainfall as the system ends up overloaded, and it overflows as a result of the AMD water enters the Zêzere river. The Zêzere River is part of the water supply source that feed the three dams, which supplies water to major towns and villages such as Castelo de Bode and Lisbon. In general, it contribute a portion to the water system of Lisbon. These reserves have a total capacity of 1.86 $x10^6$ m^3 of water that are used for human consumption, recreation, fishing, agriculture and sporting (e-EcoRisk 2007).

According to Candeias, Melo, et al. (2014), Rio tailing is a source of acid mine drainage that enters the Zêzere river with a pH of approximately as 3 and high metal concentrate on which As and Fe concentrations reduce downstream from ADM, due to the adsorbs and coprecipitate to form a compound iron oxyhydroxides. In general, the hydrological impacts on the area due to AMD from the tailings of Rio that are currently understood to a certain extent, mainly because their geological background has been studied extensively, and it has even shown that there is no know nearby aquifer. The great threat to the environment and the hydrogeological system will be the spill of the dam due to the slope stability failure, or it may trigger heavy rainfall that can fill the dam, which could be a potential danger and major disaster to the three downstream and the entire ecosystem.

The unconfined tailing and open impoundments are the major sources of pollution in the entire area as the results of oxidation of sulphides and the unknown internal structure of the dam. The Rio tailing dam geochemistry and mineralogy has been under investigation over the years by various author and each study was a bit different from each other some of them are Ávila, da Silva, and Candeias (2016), Ávila et al. (2011), Ávila et al. (2008), e-EcoRisk (2007).

Most studies were conducted to assess, identify, quantify or predict the environmental effects from the high arsenic and iron concentration level record on the river. It has also been reported that the tailing has had the highest concentrate of recovered minerals such W-Zn-Cu, which was due to the fact that the dam was built when the technology of metal recovery was quite poor. This has motivated researcher to study the reprocessing the tailing materials to extract minerals in order to generate funds for the rehabilitation of the site. This will be done since that the tailing dam is located at a crucial location, so if anything goes wrong, it will be a major disaster to the river, which is the source of water to the three dams downstream and the communities. The generation of the funds is necessary, as there are no funds from the National Program of Mine Rehabilitation due to the fact that the tailing site is a properties of the municipality of Fundão, meaning it is not state owned. The rehabilitation of the site is a significant step to reduce the risk of the failure of the dam, and to avoid any further environmental incidents.

1.3. Problem statement

Given the background statements, it is necessary to summarise the threats and challenges concerning the Rio tailing to the Zêzere River and the entire ecosystem:

Problem 1: Acid Mine drainage and contamination as results of high heavy metal concentrations (Cu-Zn-Cd-Fe) in the stream sediment and Zêzere River due to discharge from ponds which has about 731 034 m^3 (Ávila, Da Silva, and Farinha 2007, Ávila et al. 2008, Candeias 2013, Candeias, da Silva, et al. 2014, Ferreira da Silva et al. 2013).

Problem 2: Geotechnical and physical instability, and due to the present of slippage zones and the seepage paths, which are due to unknown internal structures of the dam, the scarcity of information, and data of the dam, as well as poor maintenance programs in place, which all increase the risk of the dam to collapse (Grangeia and Matias 2003).

Problem 3: Potential ecological and carcinogenic risks due to the soil contamination by airborne polluted dust (aerial transportation and deposition of particles) when direct ingestion of soils or inhalation of particles in air and ingestion of vegetable grown on the contaminated soil mainly due to the As and Cd concentrate (Candeias et al. 2015, Candeias, da Silva, et al. 2014).

Problem 4: Vigorous visual impact and the high potential risk to continue releasing toxic chemicals and solid materials, due to the long exposure to atmosphere climate conditions through soil erosion by wind has transport toxic matter into the nearby area, and risk to humans and animals to be sucked in tailing mud (Candeias et al. 2015, Candeias, da Silva, et al. 2014).

Problem 5: Hidden commodities - Economic potential risk assessment for raw materials are essential for the sustainable functioning of modern societies as motivated by EU (Directive 2006).

Generally, the entire area of Rio tailing district can be classified as toxicological risks due to high concentrate of metals such as arsenic and cadmium that have been detected over the years.

1.4. Significance of the study

Mine planning and design solutions are complex and tedious work carried out by different experts from the various areas such as mining; geology and finance. This involved defining the mineralisation of interest boundaries mine arrangements in the section, based on the geological, hydrogeological, social, and environmental, technical, and economic data available. In the past, this process was labour and paper intensive, time consuming, costly, and not to mention a prone error on design and quantifying minerals deposits. The development and continuity development on the field of computer application and numerical modelling over the years has been noted also on the mining industry. Computer application in mining has become essential tools from data and information management, planning and design process. Therefore, the benefits used by Maptek Vulcan software in this study is simply to assess the available data collected from various sources, and to use them to define the status of the Rio tailing dump resource. The results of this project will contribute significant to the future planning evaluation tailing dump evaluation to determine the recovery of the major minerals on the tailings for economic purposes, and strategic environmental and social management plans to minimise the environmental impacts on the Zêzere River, and to meet the legislation and regulations.

1.5. Objective of the project

The aim of this project is to determine the technical preliminary feasibility and plan the exploitation of the tailing muds materials from the Cabeço do Pião (Rio) tailing dam to extract and reprocess the valuable and sulphide minerals effectively for economic benefits, and mining waste management to minimise further acid mine drainage impact using Vulcan mining software. This should be carried out using the available data and information from earlier researchers. Therefore, to achieve the overall aim of the project, the following three objectives set to reach for this aim are:

1. To create geological resources model and estimate the quantity and quality of the Rio tailing dam materials for exploitation with aid of computer software.

2. To develop and design a mining extraction plan for the tailing dams and transportation system to the plant with an aid of computer software. Ensure that produced designs and plans are as practical as possible.

3. To develop a combining mining waste environmental management and site rehabilitation the re-sharpening of the topography to minimise further environmental impacts and instability.

1.6. Scope of work

The aim of this study is to utilise Maptek -Vulcan software to construct the geological model of the Cabeço do Pião (Rio) tailing dam, and then plan the extraction and haulage strategies to extract valuable minerals (W-Cu-Zn), and plan the rehabilitation of the dump. The study follows five basic stages of mine planning from exploration database management, geological dump modelling, extraction design, production scheduling, and site rehabilitation.

1.7. Dissertation outline

The format of the dissertation will reflect the quantity of the work carried out in each relevant area. In this chapter, the author began by providing an overview of the project by stating the motivation factors along with the problem under a series of sub-heading. In the following chapter, the author continues to highlight the condition of the site under study and the need for urgent intervention by using the available the tools. It goes on the following chapter where the tools are applied to find solutions to the problems stated before to achieve the project objectives. Then in the second last chapter, an overall discussion was done before concluding and recommendations were drawn up in the last chapter.

- Chapter 1 this introduction section that gives the study overview, problem and motivation factors, the objectives and it significant to the society.
- Chapter 2 reviews the investigation work carried out thus far at the site and its discovery, then it goes on to review the computer applications as a tool in mining planning and design project
- Chapters 3 go into greater detail about specific aspects of the project simple to solve every objective with the aid of computer software system;
- Chapter 4 summarise the works carried out in chapter 3 and highlight some of the major challenges encountered in the process of carrying out the work.
- Chapter 5 provides conclusions and makes recommendations about future to improve the results and solve the problem better.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

To understand the significance of this study, and its future contributions, an extensive literature review was undertaken to understand current issues and the solutions to minimise the acid mine drainage and contamination of Zêzere river by Rio the tailing dam. This chapter is divide into two parts; in which one part is about site mining history and environmental issues, and then the second part is about computer applications as a tool in mining planning and project design.

2.2. Rio tailing historical and environmental conditions

2.2.1. Study Area and climates

Cabeço does Pião tailing also known as Rio tailing dam is part of Panasqueira mine district, which is in the municipalities of Fundão, Castelo Branco District, Central of Portugal. The district is located between the Gardunha and S. Pedro de Açor Mountains to the west of the Central Portugal depression Cova da Beira (Beira Baixa province) about 20 km south-west of Serra da Estrela the highest mountain in the mainland Portugal with 1993 m (Figure 2. 1). The local topography ranges have an altitude from 350 to 1080 m (Reis 1971), with a deep valley. The climate that has a major influential to AMD and the stability of the dam, it is known to be aggressive in the district with the hot summer period and dry while winter is very cold, rainy and windy. The annual average temperature is 12 °C, normally range from 0 °C during winter to 30 °C in the summer time. The precipitation average per year is 1200 -1400 mm; with frequent snow experience at the altitude above 700 m while the evapotranspiration in the region has an average around 1 080 mm (inag, 2016). The stream, except for the Zêzere river, are usually dry in summer and flooded in winter. The river is the source of the water to the nearby communities for drinking, agricultural, fishing while the land used for cattle breeding and cultivation (Ávila et al. 2008, Candeias 2013, Candeias, da Silva, et al. 2014). In addition, the tailing dams are properties of the municipality of Fundão and they have never been included in the National Program for Mine Rehabilitation. Figure 2.2 shows the view of the study area and the district nearby it also shows the imaginal boundaries of the district in line that goes through the river.

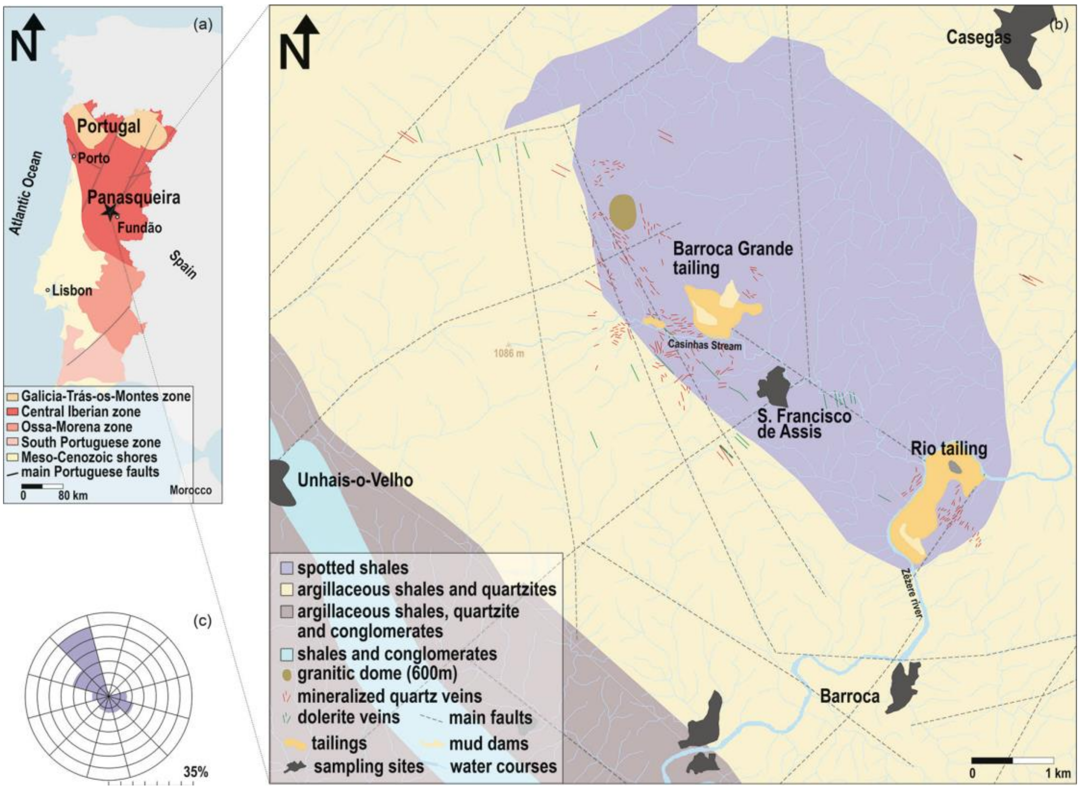

Figure 2. 1. a) Panasqueira location in Portugal map, b) Panasqueira tailing deposition sites and the main geological units, c) A wind rose of the prevailing winds on the top of the mine, on Barroca Grande (Ávila, da Silva, and Candeias 2016)

Figure 2. 2 Panasqueira tailing deposition sites on Barroca Grande and Rio tailing dam separate nature by Zêzere river (Google Earth image, 2013)

2.2.2. Geology and mineralisation of the district

The geology of the district has been studied by numerous researchers, and it has been well documented over the years. Panasqueira mineral deposits are examples of the postmagmatic hydrothermal ore deposition associated with Hercynian plutonism, this mean all the mineral deposit within the licences area can be classified as hydrothermal type deposit. Based on the palaeographic and tectonic zoning theory that was developed by Julivert et al. (1974), (Lotze 1945), the deposit is seen as part of the Central Iberian Zone (CIZ), where the Sn–W deposits, such as that Panasqueira is spatially related to the contacts between the sin tectonic muscovite – biotite and the metasedimentary country rock. The mineralisation zone has an average length of 2 500 m, with the width ranges between 200 to 2 200 m and the depth outspreads as 500 m (Cavey and Gunning 2006a). The district is one of the largest known and mined economical wolfram vein deposits in the world; it has been mined for more than 100 years. During the Hercynian Orogeny, the Beira-Schist Formation was subject to lower greenschists grade regional metamorphism, and composed of thousand-meter-thick sequence of lower marine fyschoid, schist, greywackes, lenticular, thinly bedded mudstone, shales and arenites (Bloot and Wolf 1953, Cavey and Gunning 2006b, Conde and Económica 1971, Kelly and Rye 1979).

The Panasqueira deposit lithology is dominated by tungsten from Cambrian to upper Cambrian age, and it forms an outcrop of about 35 km^2. The deposit lies in folded metasedimentary sequence known as the upper Precambrian – Cambrian-aged Beira-Schist Formation sequence that consists of a series of stacked, sub-horizontal and hydrothermal quartz veins intruding into the Beira schists. Some quantity of mafic rocks dolerites types was observed, particularly near S. Jorge da Beira (NW–SE sub-vertical). There are no granite crops out in the area; nevertheless, a granite cupola muscularly recognised with increasingly alteration was penetrated at shallow depths in the mine (Kelly and Rye 1979). The paragenesis is complex, and various scholars who studied this deposit have agreed on the four stages of mineral formation:

1st - the oxide silicate phase (quartz, wolframite; cassiterite);

2nd - the main sulphide phase (pyrite, arsenopyrite, pyrrhotite, sphalerite, chalcopyrite);

3rd - the pyrrhotite alteration phase (marcasite, siderite, galena, Pb–Bi–Ag sulfosalts);

4th - the late carbonate phase (dolomite, calcite) (Breiter 2001, Conde and Económica 1971, Corrêa de Sá Sá, Naique, and Nobre 1999, Noronha et al. 1992).

According to Kelly and Rye (1979) the district of Panasqueira has more than 65 minerals that include sulphides, sulphosalts, oxides, carbonates, silicates, phosphates, and tungstate minerals. Apart from quartz, dominate other minerals such as beryl, mica, and fluorite are some of the common minerals in the area. Most of those minerals can only be analyse at microscopically level and this one of the interesting part of many scientists. Over the years, the mine has been producing wolframite and cassiterite concentrate along with copper as a secondary concentrate from chalcopyrite while arsenopyrite rejected to the tailing with arsenic as high as 30%.

2.2.3. Historical mining activities at Panasqueira area

Even though history indicates that mining in this area can be traced back to the Romans and the Moors time when tin was extracted, and there is no exact date on that. All activities can be classified as illegal operations. However, it can be testified by some debris around the district. According to Cavey and Gunning (2006b), the first prospecting licences was issued in 1886 and the first reference to wolframite mineralisation in Panasqueira mine documented dated to 1888, and the Panasqueira licence covered an area more than 2000 ha. In 1896, Sojitz Beralt Tin & Wolfram (Portugal) SA was founded through the consolidation of Portuguese companies with the international partnership to develop and manage mine on the extraction of tungsten as an industrial commodity for the first time in the world. In 1928, the operation was taken over by Beralt Tin & Wolfram Lda currently the licence is owned by Almonty Industries a Canadian company.

The first processing plant was set up at Vale de Ermida this evidence to the present of old infrastructure and the piles amount of old tailing with volume about 1000 000 m^3 from the earliest year of production as for late 1895 to 1928, and it site was abandoned when the new a plant was constructed at Rio in 1928. The construction of the plant at Rio was to take advantage of the local ore discovered and water from the river for milling operation and power generation (Cavey and Gunning 2006b, Crosby 2001, Leal 1945). For years, the plant at Rio has been feed with ore from various site but mostly the conveyed ore from Barroca Grande along a 5.1 km cableway to the processing plant to Rio crossing the Zêzere River (Ávila et al. 2008, Candeias, da Silva, et al. 2014, Cavey and Gunning 2006b, Leal 1945). For over 100 years, the waste materials from the extraction and from the mineral processing plant have been disposed near Rio, and the history is indicating that this operation can traced back from 1901 until 1996 when the operation deactivated. Currently, the wastes rocks and tailing are deposited in the Barroca Grande tailings area as shown in Figure 2.2 and 2.3.

Figure 2. 3. Photography view of S. Francisco de Assis (SFA), located downstream Barroca tailing (Ávila, da Silva, and Candeias 2016).

Rio tailing dump found near and draining directly to the Zêzere river, is where the tailing deposition has been done for more than a century there is total amount about 1 9140 434 m^3 tailing and on which over 731 034 m^3 has been deposited on the open – air impoundment constructed with high metal concentrate level. The tailing deposit has an average height of 90 m and slopes angle about 35 ° (Figure 2.3). Due to the fines grinding procedures and classification system used over time, the grain size distribution of the materials varies significantly. There are three types of materials classified as coarse sterile materials from the mine composed of schist and quartz (1 200 000 m^3); coarse tailing (sterile material) from the heavy media separation, this cover sand, mud and slush (Ávila et al. 2008). Near to the village of Rio there is about 9 400 m^3 of arsenopyrite stockpiles separated during milling flotation processing and it was capped with geotextile and clays in 1996 to minimise it AMD after it has been exposed all those years (Crosby 2001, e-EcoRisk 2007, Gilchrist and Mahmoud 1999).

Since the discovered of the high-grade vein mineralisation at Panasqueira-Barroca Grande site the entire operation was moved from Rio to Barroca Grande where there is about 7 000 000 m^3 coarse tailing materials and two mud dams with total volume about 1 193 885 m^3 (one active, and one old and deactivated) deposited. On this site is where the underground room and pillars mine, processing and mine plant, offices, employee accommodation and Salgueira water treatment plant are located

(Cavey and Gunning 2006b). Salgueira water treatment plant is one of the surface treatment set up to treat water from the old tailing pond and new pond, mine drainage water and seepage from the base of the tailings. Lime is used as treatment chemical to treat polluted water by precipitate the sludge that pumped to the tailing dam while the treated water is re-used in the plant or pump in the river streams. Another water treatment plant is found at Rio. Panasqueira mine is one of the few mines in the world that contribute significate during both good days and bad days in term of economic and political. It has passed through different economic crisis and its production is from 1947 to 2001 about 96 456 tonnes of WO_3, 4 901 tonnes of SnO_2, and 28 924 tonnes of Cu from more than 27 x 10^6 tonnes of rock except for a brief period at the end of World War II and a second closure in the mid 1990's (Cavey and Gunning 2006b). Nerveless, there is huge controversy about it significant negative environmental and social impact on the district over the years.

2.2.4. Previous study Environmental Considerations

Here are some of the notable research articles written by various authors related to the environmental and social impact as results of the existence of Rio tailing deposition.

Dinis da Gama (2002) study the geotechnical and laboratory of the tailings in the River Zêzere waste heap. This study investigates was done by drilling six boreholes and collect core samples to investigate geotechnical and hydrological behaviour, that is, stability, landslides, a formation of ravines and erosion. The samples were analysed at Beralt Tin and Wolfram laboratory to determine the granulometric and mineralogical characteristics of Rio tailing materials. Those core samples were again analysed by (Grangeia et al. 2009) with additional samples of mud and water that were collected around the tailing dam to carry out an integrated investigation of the Rio tailings - Panasqueira mine (Centre Portugal). An integrated investigation was simple multi multidisciplinary investigation research that used geophysics analysis, geochemistry analysis and borehole information with the aid of Geographic Information System (GIS) to characterise and presents results in the spatial domain. This approach was carried out to determine the environmental impact and find solution those challenges. Both study state that the analysed samples mineralisation distributions were significantly varied and the materials were too fine with a potential to ca be transported as dust or in suspension by the surface waters and accumulates on solid materials. They highlight that the coexistence of wolframite, cassiterite, sulphides, carbonates, and silicates is responsible for the geochemical behaviour in the Rio tailings environment and the AMD formation is the results of weathering of sulphide-rich materials. This mainly due to the climate condition of the site also. The presence of melanterite (Fe^{2+} (SO_4) ·7(H_2O)) and minor amounts of rozenite (Fe^{2+} (SO_4) ·4(H_2O)) and szomolnokite (Fe^{2+} (SO_4) · (H2O)) were observed with a Diffraction des rayons X (DRX) identification. The conclude that the oxidation of the tailing and flow from open impoundments main source of pollution in the surrounding area and is responsible for the mobilisation and migration of metals from the mine wastes into the environment. This was justified by the stream sediment and water samples that were found to be contaminated a distance downstream.

The second major site investigation done at Rio site was the geophysical survey consisted on Ground Probing Radar (GPR) profiling and Electrical Resistivity Tomography (ERT) was carried out by Grangeia and Matias (2003). The objective was to investigate the physical properties and supporting structure of the tailing dam. This technique was chosen based on the literature to delineate geometrical features and near-surface heterogeneities, to detect seepage paths for safety evaluation and to provide data to be compared with geochemical data (Campbell and Fitterman 2000, Panthulu, Krishnaiah, and Shirke 2001, Poisson et al. 2009, Sjödahl, Dahlin, and Johansson 2005, Van Dam et al. 2005, Vanhala et al. 2005). The geophysical survey layout is shows on Figure 2.4. ERT data were acquire with the Syscal R1 Plus resistivity meter with the dipole-dipole array, ten meters electrode separation and a maximum dipole separation factor of eight and inverted by using the Res2div ver.3.4 of geotomo software. The ERT data were used to investigate heterogeneities in the mud impoundment materials, as well as, to locate schist bedrock under the tailings. While the GPR data that were used to determine the thickness of the tailings and to locate eventual supporting structure were obtained by using the PulseEkko IV with a 100 MHz unshielded antenna was the equipment (Grangeia and Matias 2003). The results of the GPR was able to map shallow subsurface stratigraphy in the mud impoundment and tailing slopes as well as to distinguish bounding surface and horizontal bedding. On the other hand, the results of the ERT was capable to shows the bedrock limits on the mud impoundment. Based on the interpreted of the survey the dam was seen an environmental threat in case its failure due to a massive amount of mud in tailing, a low resistivity that assumes due to the higher water content and too fine particles.

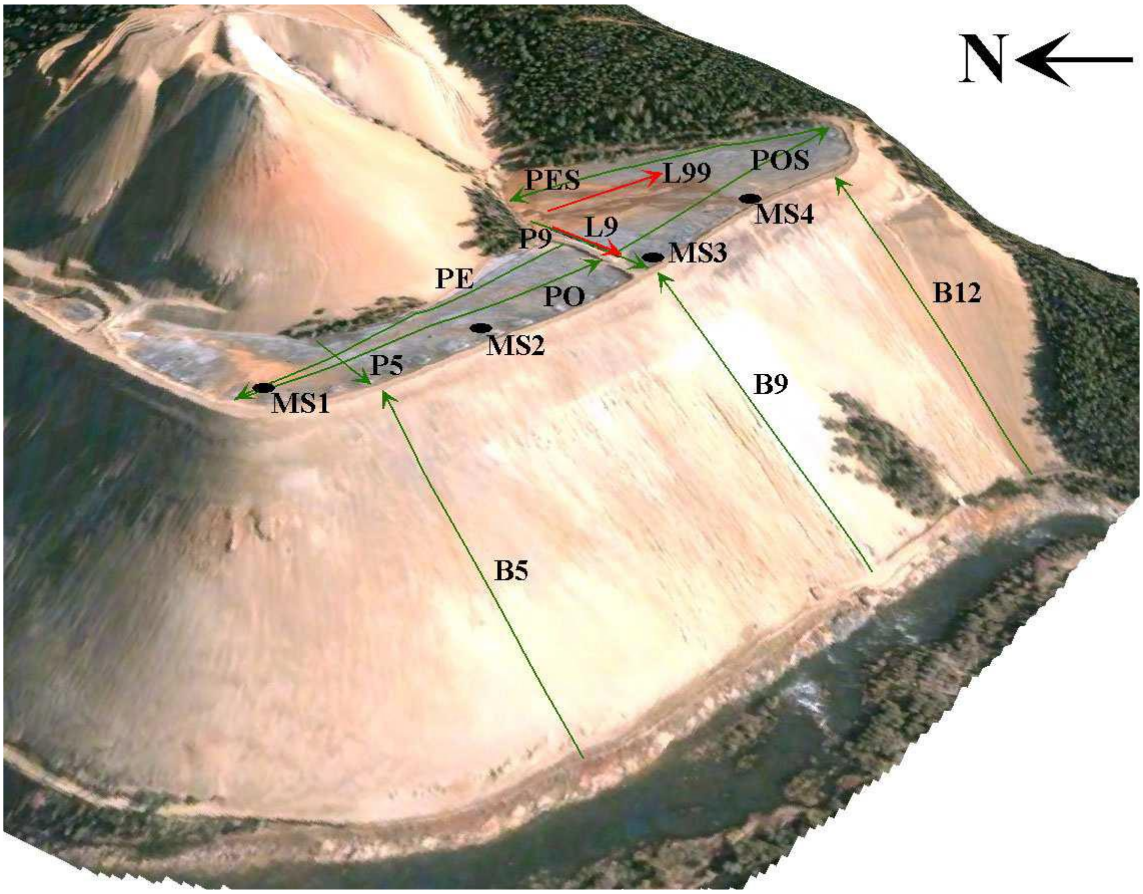

Figure 2. 4. Perspective (3D view) of the geophysical survey: Green - GPR profiles; Red - dipole-dipole profiles (Grangeia et al. 2009).

Following the e-EcoRisk project, that was started by the EU commission to contribute to the decision-making process of environmental and civil protection agencies charged with the mandate for assessing, preventing, mitigating, and controlling the potential and actual effects of large-scale industrial spills on the environment there were some anomalous distribution of some heavy metals discovered on the sites. To understand that anomalous distribution and transfer mechanism to the secondary geochemical environment the geochemical research (Ávila et al. 2008). They selected the geochemical results from the e-EcoRisk to study and understand the dynamics inherent to leaching, transportation, and accumulation of minerals such as As, Cd, Cu and Pd in different sampling media. This was done in line with the primary goal of environmental risk and emergency management that aim to reduce environmental and civil risk by selecting a risk prevention or reduction program from the set of options available to facilitate site remediation and help alert authorities where there is a fault. They conclude mining and beneficial methods used at mines over the years are responsible for the high-level metal content on the tailing dams in the area. The oxidation of sulphide tailing and flow from the uncover impoundment are the primary source of pollution in the area this was evidence by the anomalous contents of Ag, As, Bi Cd, Cu, Zn, Sn, and W downstream.

Following those three investigations, there was a study by Grangeia et al. (2009) that investigate and integrate the results of the above-mentioned investigation study, and this was done to further increase the understanding of Rio tailing on the environment, compare and correlate the results to understand the risk of that deposition. What is significant in this approach was the visualisation of the data in the 3D models of various variables to understand and compare they correlation. Apart from the results from the earlier study other location were also sample and located with the GPS and they coordinate were recorded and converted to the UTM coordinate to correspond to the true location for modelling purpose. They result indicate that the geophysical has high resolution than a geochemical model. The area of very low resistivity near the interpreted bedrock and coincident with a steep, mud fulfilled and not permanent stream. While the high resistivity area was above low resistivity on the L9 ERT resistivity section. Due to the complex geophysical and geochemical properties of the tailing dam along the external influence, they indicate that the tailing dam has a high risk to the environmental due to the difficulty to acquire the data to predict resistivity response signature.

To characterise the surfaces water chemical along the Zêzere river and predict the precipitation minerals the geochemical research was done by (Ferreira da Silva et al. 2013). Surface water samples were collected at selected location to evaluate the influence of the tailings and ADM on the nearest streams as well as the way it contaminated the main Zêzere river through diffusion. The results shown that the AMD discharge from the Rio tailing has pH low as 3 and high metal concentrate (As and Fe) those depleted downstream from the ADM once As absorbs, coprecipitate and form various compounds with iron oxyhydroxides. Other minerals such as melanterite and minor amounts of rozenite and szomolnokite were observed on Rio tailing basement. They conclude that even there are no aquifer systems on the studied are if any failure of the dam can lead to a major catastrophic to the reserve dams and ecosystem as completely.

To understand the environmental impact due to tailing dams on the nearby towns a geochemical investigation was carry out on S. Francisco de Assis, an agricultural village located between Barroca Grande and Rio tailing with about 700 inhabitants. The goals of this study were to assess toxic metals associations, determine the associated between the potential toxic elements and their spatial distribution, to identify the possible contamination sources, and assess the risk of the threat of toxic elements to the local communities of S. Francisco de Assis when ingestion of vegetables that grow in their village. To achieved the goals of the field sampling were collected from rhizosphere samples, vegetable (Solanum tubersum sav and Brassica olerácea L.) which are the significant part of the community food, irrigation water and road dusts samples in privates' residences. All the vegetable samples analyses were reported to be contaminated by having a high ratio of arsenic, cadmium, and lead, while the proportion of copper, zinc and magnesium was low to the guideline and above even the proposed level by the FAO/WHO. The level of metal and metalloid in the water was low and acceptable based on the Portuguese law but the water pH was slightly acidic. Based on the Ontario guidelines, the level of Arsenic in the rhizosphere was recorded more, 20 times high than the agricultural reference, which is 11 mg $kg^{-1.}$ The dust samples analysed exceed also the reference acceptable risk and maximum acceptable values of As, cd, Cu, and Zn. The Wind and hydrological factors were classified as the responsible factors on the transportation mechanism of elements from the source's water been the medium while the soil is retention media. They conclude that the residences are exposed to health risk through the intake of toxic elements mainly arsenic, cadmium and lead by consuming their vegetables, which grow in their yard (Ávila, da Silva, and Candeias 2016, Candeias 2013, Ferreira da Silva et al. 2013). When the geochemical results and environment risk assessment was done based on the risk assessment code Ag, Cd, Cu, and Zn were classified as high-risk chemical while As as medium risk minerals (Candeias et al. 2015).

In general, all the researchers have come to the same conclusion that Barroca Grande tailing and Rio tailing are the major source pollution and contamination to the Zêzere river and the entire environment through AMD and contamination as well as contain very high concentrate toxic metal suspension. The continuity of mechanical and chemical dispersion at the dams is evidence of ongoing problem that continue affecting the district. The Rio tailing dam is estimated to have an average grades mineralisation as followed: 4000 ppm for W, 6 800 ppm for Zn, 2 494 ppm for Cu and 76 350 ppm for As. Another major concern raised is the stability of the Rio dam due to the poor geophysical structure understanding of the dam and the climate influence such as heavy winter rainfall and hot summer. Even through a lot of study and investigation has been carried out to define the impacts and threats poses by the Panasqueira and open-air impoundments (Barroca Grande and Rio tailings) to the Zêzere river and environmental a little has been done to solve this majesty. Apart from the arsenopyrite stockpile (~9 400 m^3), that was capped with geotextile and layers of clay in June 1996 (e-EcoRisk 2007).

2.3. Mining computer application in mining planning and design

In the past 60 years or so quantifying mineral resource, planning and design of mine operations it has never been a simple stuck but rather than a stressful, labour intensive, costly and time consumer, estimation, and design errors. All those has been due to massive data handling or lack of data, lot of paperwork and misplacing of information that is needed for decision making to extract minerals or abandoned it or even plan they deposition of facilities such as tailing dams. This situation has been discharging and many mining problems have been abandoned results on major challenges found today. One of the examples cited by Lane (1999) was the feasibility study of Palabola open pit mine at Palabola mine, a copper operation that also operates a smelter and refinery complex based in the town of Phalaborwa, in South Africa. It is on the record that three engineers carry out a feasibility; on which two were working on site at Phalaborwa while the one in Johannesburg, the distance between them is 500 km. They manually created a detailed polygonal model of the ore body and drew up plans and section that shows the grades of the polygon. From those plans and section together with planimeter and calculators, they were able to estimate the tonnages and grade for the first trial pit and then for a second trial before selected the final ultimate pit. This entire process is known to take them at least about two years and it was done on single cut-off grade because if they could have to try more than one grades it will take again a long time, costly and a lot of documentation.

But in recently years the advance in computer technology and mathematic knowledge it results on computer technology become powerful tools in mining industry as they are provided benefits to consider several majors factors those influence mining project outcome, efficient mine planning and management information systems for dynamic judgement. In facts, computer application has made it possible to obtain high accurate and superior quality results at high speed. Several companies have developed mining computer application in this case belief summary about one other well develop and common use software in the mining industry will be discussed below.

2.3.1. Maptek Vulcan software

This section gives a general overview of the mining computer application used in this study to create the geological model and mineral reserve evaluation as whereas the mine planning production. Maptek Vulcan is a dynamic graphical three-dimensional (3D) Modelling and Mine Planning Software, developed by Maptek Ltd in Australia. It was chosen for this purpose due to it availability at the University for the Students for training and its ability to validate and transform raw mining data into dynamic 3D models, which are accurate for operations plans and mine designs base on the literature. Generally, Maptek Vulcan is one of the few mining computer applications available today on the market that can start using from exploration and geological modelling, mine design and development, mine operations, optimisation and scheduling down to the final stage mine closure and rehabilitation ((Maptek 2012)). The complete software is developed by using advance mathematical and statistical algorithm modelling and integrated tools mainly from the survey, drill and blast, grade control, geotechnical analysis, geostatistics, and Lerch & Grossmann for optimisation.

Vulcan is user-friendly software that allows the construction models, data management and validation database those directly created from historical records, drillholes and sampling logging, geophysical, lithological data, digital and GIS data with a minimum need of digitisation. This mining application has gone through a different revolution since it first development when it was a mini software to a dynamic application that can manage and visualise very large and complex data sets, coordinate the information and generate models at high speed. Vulcan is current applied in mining operations from geological modelling of resources and mines design until mine closure and restoration without discontinuity system by simply dynamic updating plans as data change. The software is available in eight Bundle package that can be purchase depend on user need or operation stage, and the Bundle are further divided into four modules or more.

2.3.2. Mine design and Planning using Vulcan

Normally mining is referred only to the extraction of minerals from the earth crust but, mining is the process that starts from the characterization of minerals deposit (morphology, mineralogy, texture, physical, chemical, and environmental) after that it is when the planning of the extraction can begin. The planning of the minerals extraction usually depends on the mining method selected and the equipment to use but all are controlled by the deposit size and depth. The similar approach that is used to design the open pit mine or a mountain mine is also applicable to the used to planning and designing methods to mining extraction from manmade deposit tailings materials (valuable minerals). Vulcan is like other common mining computer applications that follow the traditional mining operation activities from the exploration, development, operation and production schedule and rehabilitation. In the following section, each major step will be discussed in the context of Vulcan:

Database construction: the process starts with the construction of the databases that will contain at least three main general data set mainly from the either topographic survey, exploration (geochemical and geophysical survey), visualisation of the survey and/or geological and hydrogeological modelling.

Vulcan recognises two different database styles: Header and ODBC style. The headered database: structure the design to correspond to the raw data and columns in the data file correspond to the fields in the design. The raw data files are in ASCII/CSV format that is imported using the design, which controls the final database structure. The databases are stored depend on the raw data, and the common Vulcan databases are Drillholes, Composes, Samples and Geotech. The data import are collar, survey, and assay. The ODBC databases make it possible to read information from common external databases created with Microsoft Access or acQuireTM. The second step in a process database construction is to generate a digital model (surface and solid triangulation) by using a sophisticated mathematical approach known as triangulation. Triangulation network are generated in a planar surface which is divided into irregular triangles, in which the vertices are the know points and when lift each point and, when lifting each point to it real altitude level, each triangulation triangle in a 3D model. Image registration is part of triangulation that aimed to a correlation between the images coordinates and real-world coordinates. Prior to the next steps, block modelling the triangulation has to pass the entire validation test. The test check for the closure for opening or holes in the triangulation, the consistency fails if a single edge is shared between more than two triangles that may be an internal wall, and then the test of self-intersection check for crossing triangles. This the significant step as the boundaries of the deposit or the site are defined. The testing is used to make sure that the construct triangulation can be used to calculate volume with a minimum error.

Block Construction: Block modelling processes in which a mineral deposit is a divide into the accurate collection of cells or blocks of different sizes, that describe a particular feature (e.g. mineral deposit) in three-dimensional space as illustrate in Figure 2.5. Blocks are assigned a series of attributes (e.g. rock code, weathering code, minerals grade, geotechnical code, a percentage of dilution etc.) that describe some physical attribute relating to the mineral deposit. This process allows geologists, geostatisticians and mining engineers to apply varies tools to create, visualise and manipulate complex block—and sub-block—models based on user-defined block dimensions and sizes. Vulcan can able to generate as 2.147 billion blocks and each block can assign up to 300 attributes. The centre of each block is used in estimation calculation and it is assumed that the properties of the block centre are homogenous throughout the block or heterogeneous if the data are available to support the claim. The size of the blocks is either determined by estimation quality or for the mining method selected. For modelling or estimation, the ore body is used, frequently, regular blocks and a great collection of regular blocks to stand for the overall mineral body. Block modelling allows for faster more efficient modelling and the use of more complex estimation methods that were not previously viable in the past with classic estimation (Sinclair and Blackwell 2002).

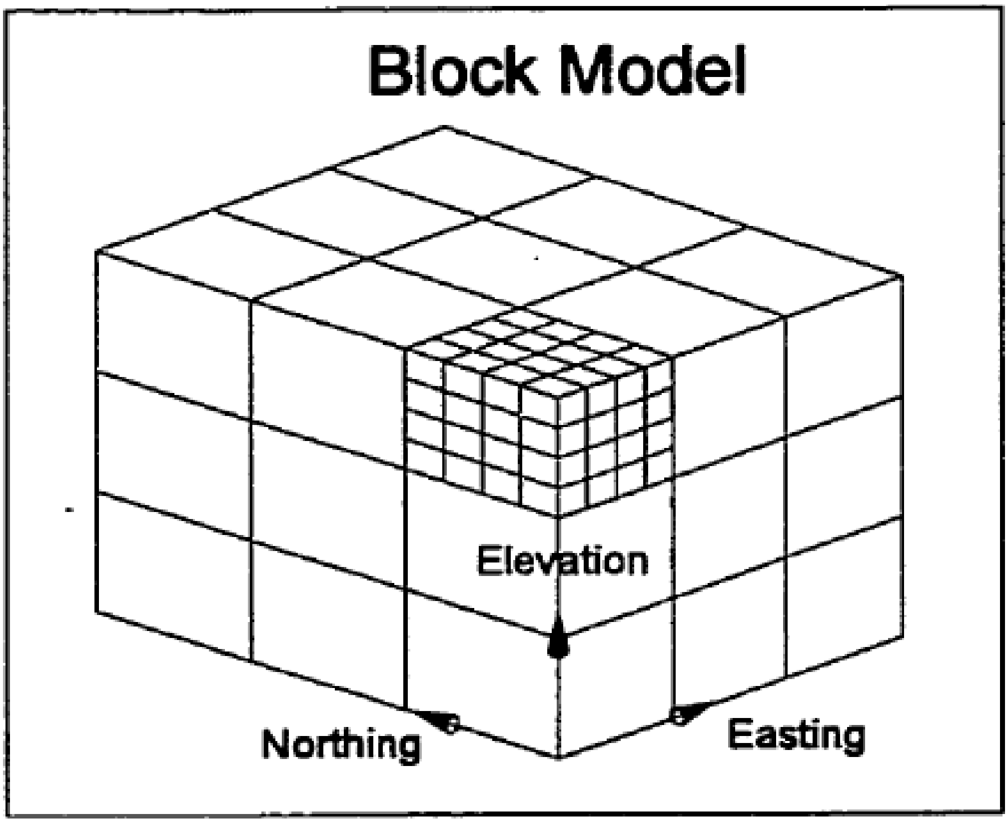

Figure 2. 5. Block Model Concept (Milawarma 1995)

Compositing: Prior to the block estimation or grade estimation, the next steps is compositing. Compositing term in mineral resource evaluation is refer to the procedure by which the values of adjacent samples from boreholes are combine so that the value of the longer down-hole intervals can be assess. The grade of each new interval is calculate based on the weighted average of the original sample value. The objective of this is to remove sampling bias as a precursor to grade estimation in block modelling and the effect of smoothing assays across drillholes and to produces ore body intersections, either lithological composites or grade composites. Vulcan has six compositing approaches are Straight, Run Length, Bench, Intersect Select and Geology (lithology). Geological interpretation and exploration of data (pure statistical analysis) are carry out to prepare the data for estimation and determine the best estimation techniques that can applied on the next stage blocks estimation grade after compositing.

Grade Estimation: Block estimation or Grade estimation per block in Vulcan is the process of interpretation values from a database or file into the block model. Grade estimation can be done by using either simple traditional such as nearest neighbour inverse distance and advance geostatistics estimation techniques such as simple kriging, and ordinary kriging, indicate kriging, indicate simulation and uniform conditioning. The geostatistical estimation uses sample points taken at distinct locations in a landscape and creates (interpolates) a continuous surface The Geostatistical estimator provides two groups of interpolation techniques: deterministic and geostatistical. All methods rely on the similarity of nearby sample points to create the surface.

Reserve Estimation: Upon complete the block grade estimation, the following step is Block Reserves Estimation. Block reserves are calculated according to the parameters set in the early from the file (solid triangulation and polygons). Vulcan has an option either to use the General Reserves, Polygon or Advance Reserves approach. The general option is the simplest approach that allows reserves calculation for up to six variables, using multiple block selection, grade cut offs and reports breakdown by zone. The Polygon is similar to the General option except that it uses triangulations projection from polygon to define the block selection criteria. Advance Reserves option allows for more complex reserves calculation. Multiples triangulations may be reserved simultaneously and customised report is generate based on these values. Block reserves are to be calculated restricted by regions that are represent by solid triangulations or triangulations that are project from polygons.

Once estimation revealed throughout this dissertation, it will largely be used about the estimation of grades and tonnages. This because estimation also used to estimate other spatially distributed property such as rock-type, density, porosity or contaminant concentration.

Mine design and optimisation: Once the blocks grade and reserves estimation is completed and validate the next step is to design the pit or mine and carry out the pit optimisation. Vulcan Pit design tools are very powerful as they can be used to create modify open pit, leach pad, dump and stockpile strings. Pit Optimisation tools allow one to define the optimal pit limits of an ore body based on the predefined constraints. The two 3D advanced algorithms of optimisation as Lerchs & Grossmann and the floating Cone algorithm. The tool allows the values to calculate manuals or automatically and is flexible when applying costs to optimisation.

Those major steps followed in the process of planning and design mines using Vulcan software by using the data that acquire from the different sources as mention already.

CHAPTER 3: REMINING AND RESTORATION ACTION PLAN

3.1. Introduction

This chapter will present and elaborate in general fashion; the steps that have been followed in the case of planning and design the extraction of the tailing reserves at Rio tailing dam. The chapter is divide into five main section with each sub-section. The steps corresponding to the objectives of the project starts with the data collection and processing, tailing model block modelling, tailing resource estimation, exploitation planning and design, and finally reshaping and restoration plan. The general purpose of this chapter is to provide details of the word breakdown carried to achieve the objectives of the project with the aid of the Vulcan mining software.

3.2. Data collection and Processing

To achieve the objectives of this study the set of information and data required to be collected in a different format and from different sources to construct a tailing model of the site in Vulcan software. The nature of the data used in the construction of the geological model and mine design are very comprehensive and the processing of the data to be acceptable for import into any software is essential. Therefore, in this section a brief description of the data collection from various source and the modification implemented on the data prior to the modelling and extraction design will be present here. Three data sets collect and used for geological model construction and design are named as: 1955 contour map was assumed as a base topography map data source for the original surface triangulation, geochemical samples analysis data for the geological characterisation and drone survey data for surface tailing dam triangulation. All the samples location coordinates were georeferenced.

3.2.1. Base topography map -T1955DATA

The tailing block model was constructed with the digitize base topography map data of the site corresponding to the contour map of the site of February 1955, obtained from the Beralt Tin and Wolfram (Portugal) S.A. The 1955 base topography map that refers as the original site topography map was required to provide the information on how the site topography was initial before the deposition of the tailing materials. The map used in this study was the Surface Plan - Contour map for Panasqueira Planta de Superficie - Couto Mineiro da Panasqueira) drawn at the scale of 1: 10 000, and dates back as February 1955 (Figure 3.1). Since that, the map provided in JPG format and this format does not immediately integrate directly into the model but it was imported into the ArcGIS/Vulcan for digitising to generate contour lines and points. The data generated was able to create a database with the information stored as a point data file with three attributes: Easting(X), Northing (Y) and Elevation (Z) in meters, and stored in a LASer (las) file format as final input into Vulcan software (Figure 3.2). In total 3 992 points were digitised and used to create the 1955 Surface Triangulation (1955ST). The data were digitised and transform into an ETRS 89-PTTMO: EPSG: 3 763 coordinate systems as the georeferenced system.

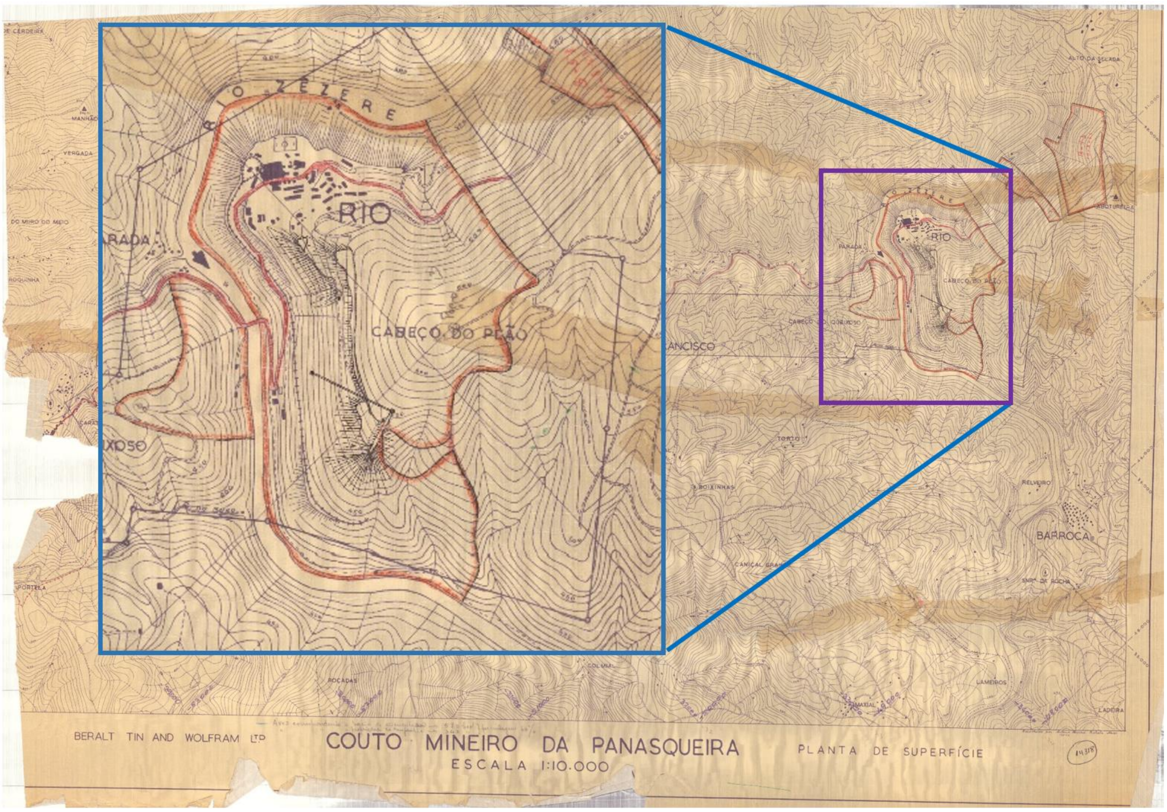

Figure 3. 1. Original part of the contour map – February 1955 (Source: Beralt Tin and Wolfram Ltd)

3.2.2. Geochemical analyses data

The geochemical data record used for this study corresponds two the investigation was undertaken: 2002 - Core drilling sampling and 2016/7 - Bulk sampling. Below two geochemical data set are discussed to provide the information on how the data were acquire and used.

3.2.2.1. Core drilling samples data

Between the 22 May 2002 and 10 July 2002, unsystematic 6 boreholes were drilled to recover core samples by using a Bonne Esperance probe by IGM (Instituto Geológico e Mineiro) at Rio Tailing dam. They are shown in Figure 3.3 as DH_1 to DH_6 as presented in Table 3.1 with it details.

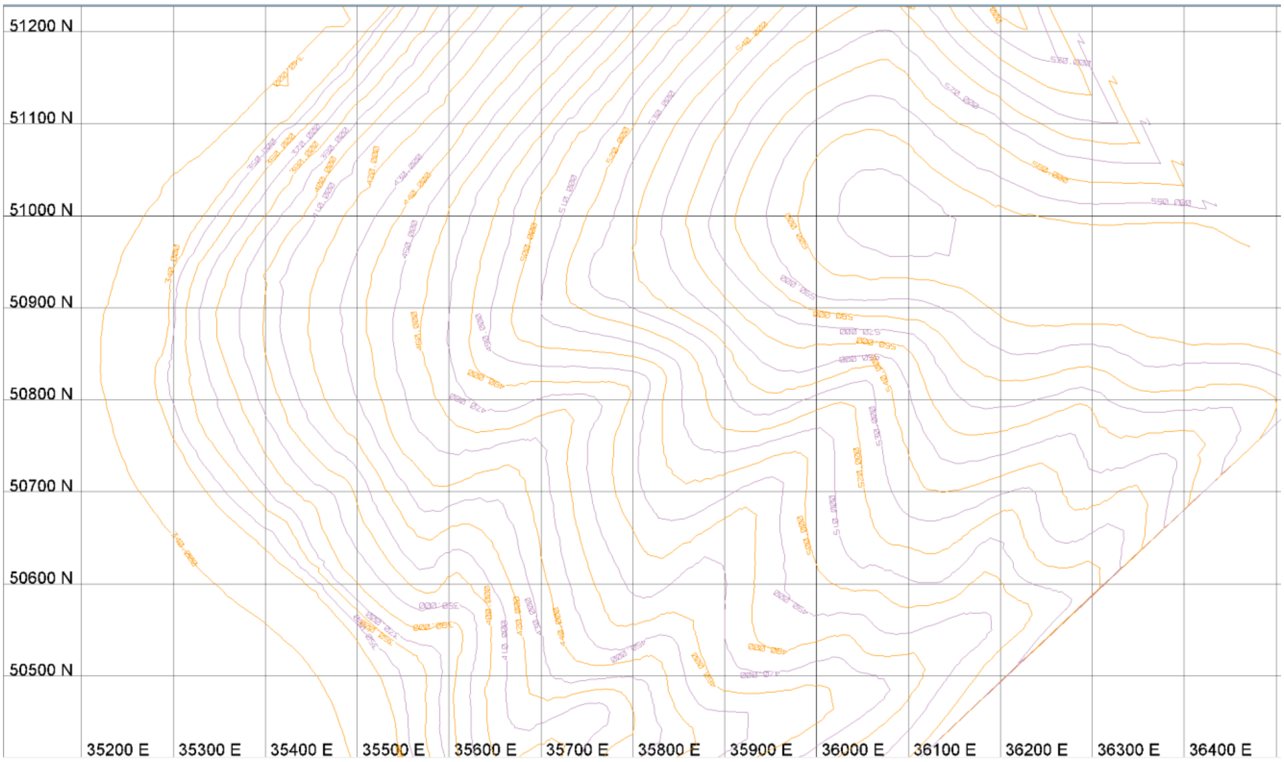

Figure 3. 2. Digitised base topography contour line – February 1955

The objectives were to recover the core samples that can be investigated for geotechnical and hydrological behaviour for stability and environmental concern. In total 36 samples were extracted from the core drill samples and they were chemical analyses in which 18 (3 per hole) were analyses in 2002 at BERALT Laboratory and the other 18 were analysis in 2005 at IGM-INETI.

The complete geochemical data acquisition process and results are elaborated by (Ávila et al. 2008, Dinis da Gama 2002, Grangeia et al. 2011) in this case the author will present only a short analysis procedure and equipment's used as it is significant to understand it.

At IGM-INETI the X-Ray Fluorescence (XRF) was used to analysing S and W while As, Cu, Zn and other elements were analysed by conductive plasma emission spectrometry (CPES). The reason the S and W were analysed with the XRF is due high stability and accuracy analysis of the XRF compare to the CPES). Reference materials (SO1, SO2, SO3, SO4, FER1, FER2, FER3, and FER4 from the Canadian Centre for Mineral and Energy Technology; PACS-1 from NRS26 CNRC; and 2711 from NIST) were used to determine the accuracy and analytical precision by duplicate samples in each analytical set. The confidence limits were calculated to be within the 95 % confidence limits of the recommended values given for this certified samples materials while the standard deviation was between 5 and 10 % (Grangeia et al. 2011). The complete results table of the interest minerals for this study is present on the appendix and Table 3. The six drill holes coordinates were obtained with a GPS and georeferenced with UTM coordinates to ETRS89-FS29, EPSG: 25829.

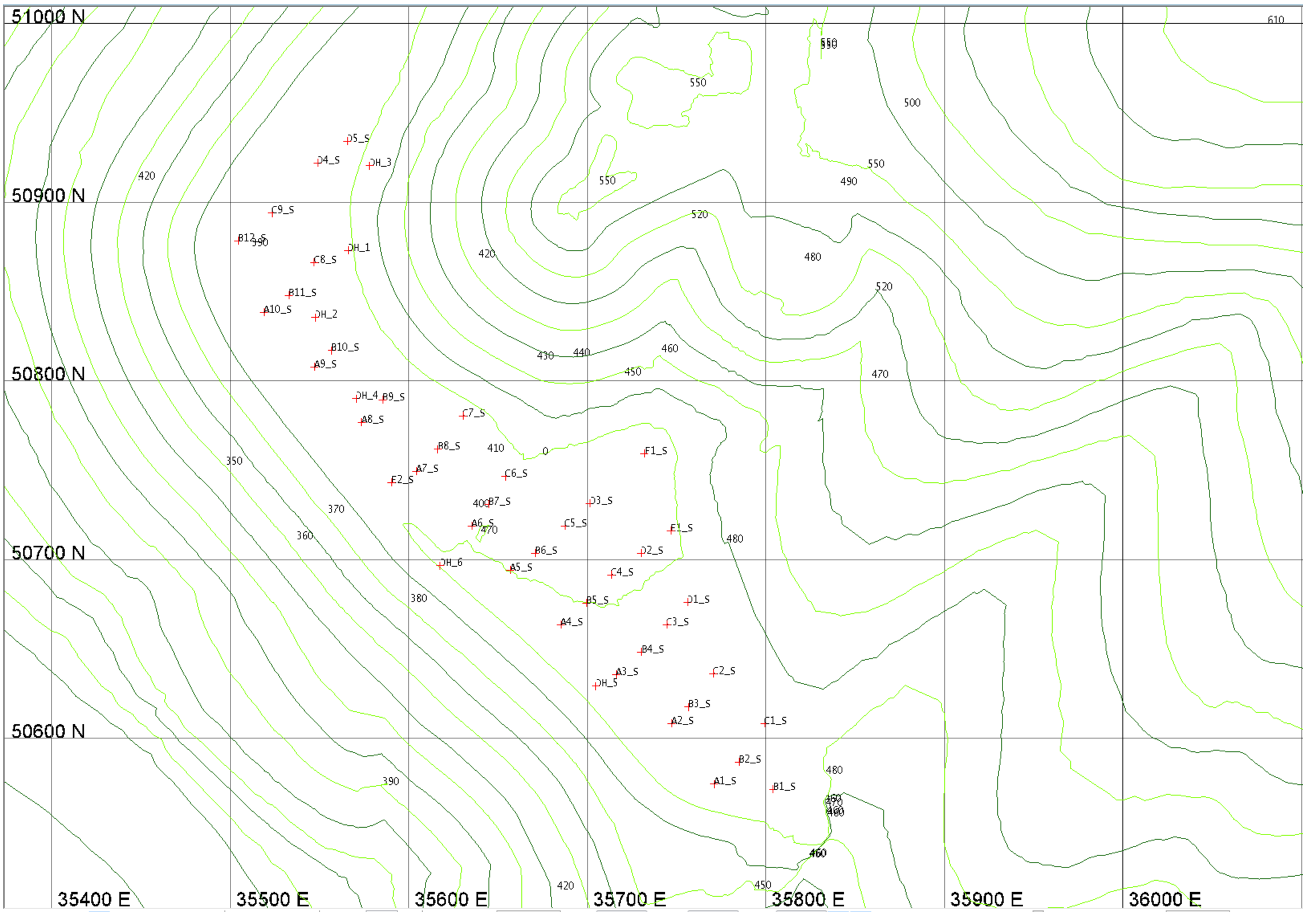

Figure 3. 3. 46 sampled location on 2017 topography

Table 3. 1. Boreholes Identification

	DH_1	DH_2	DH_3	DH_4	DH_5	DH_6
Surface orientation	0	S40°W	S20°W	0	0	S40°W
Angle of inclination (°)	-90	-45	-75	-90	-90	-45
Drill length (m)	24.08	43.45	26.77	21.95	34.63	40.13
Core diameter (mm)	123	123	123	123	123	123
Number of samples per core	3	8	3	7	7	8

Technical data for all boreholes are given in Appendix as well as, the depth of the samples (relative to the top of the borehole).

3.2.2.2. Bulk samples data

Between the December 2016 and January 2017, 38 locations were sampled on for which 32 locations were sampled twice at superficial depth about (0.5 to 0.6 meters) and deep depth 2 meters; 2 locations sampled at 0.5 to 0.6-meter depth and 4 location sample at the depth of approximately 2 to 2.5 m. The samples were collected in a rectangular grid of 40 x 20 m by excavating with the excavator as shown in Figure 3.4 and them location are shown in Figure 3.3. In total 2 x 69-bulk sample was collected for geochemical analyses that undertaken by DEM-FEUP (Department of Mining Engineering- Faculty of Engineering of the University of Porto) where the samples were dried at a temperature of 50 ºC during 24 hours. The heavy metals were analysed by Energy Dispersive X-Ray Fluorescence (XRF) method using an X-MET8000 instrument (Oxford Instrument). The instrument was set to the Mining Mode that allows a fast and accurate analysis with low limits of direction. The compiled table with all the information about interest minerals for this study is present on the Appendix. Thirty-seven samples holes coordinates were located with GPS in an ED50 FS 29, EPSG: 23029 systems and all the samples were drilled vertically. There are labelled as A1_S - A1_S to F1_S were A represent the row while the number represent a column. The elements that were analysed in the samples are Bi, Ca, Cd, Cu, Fe, Hg, K, Mn, Pt, Rb, Se, Sn, Ti, W, Zn, Zr and As.

Figure 3. 4. Bulk sampling process with Wheel Hoe Excavator

3.2.3. Tailing topography map - T2017DATA

To determine the change in the topography between February 1955 and February 2017 a topographic survey was carried out to create a new topographic map. A flight of aerial photography survey with a drone that was carried at the site on 23 February 2017, by Eye2MAP (Portugal) S.A. The database was developed with the data collected inform of the image with the drone file with three attributes:

Easting(X), Northing (Y) and Elevation (Z) in meters. The elevation assumes the Z to be on the surface of the deposited tailing materials and it was considered as positive. These data points were then used to create the new map and tailing dam triangulation, which refers as the 2017 surface triangulation (2017ST). The information in the database for developing the model is stored as a point data see the appendix. In total 36 998 584 points were recorded and used to create the topography map (Figure 3.5) that creates the 2017 Surface Triangulation with Vulcan. The drone data for the topography were obtained in an ETRS 89-PTTMO: EPSG: 3763 coordinate systems.

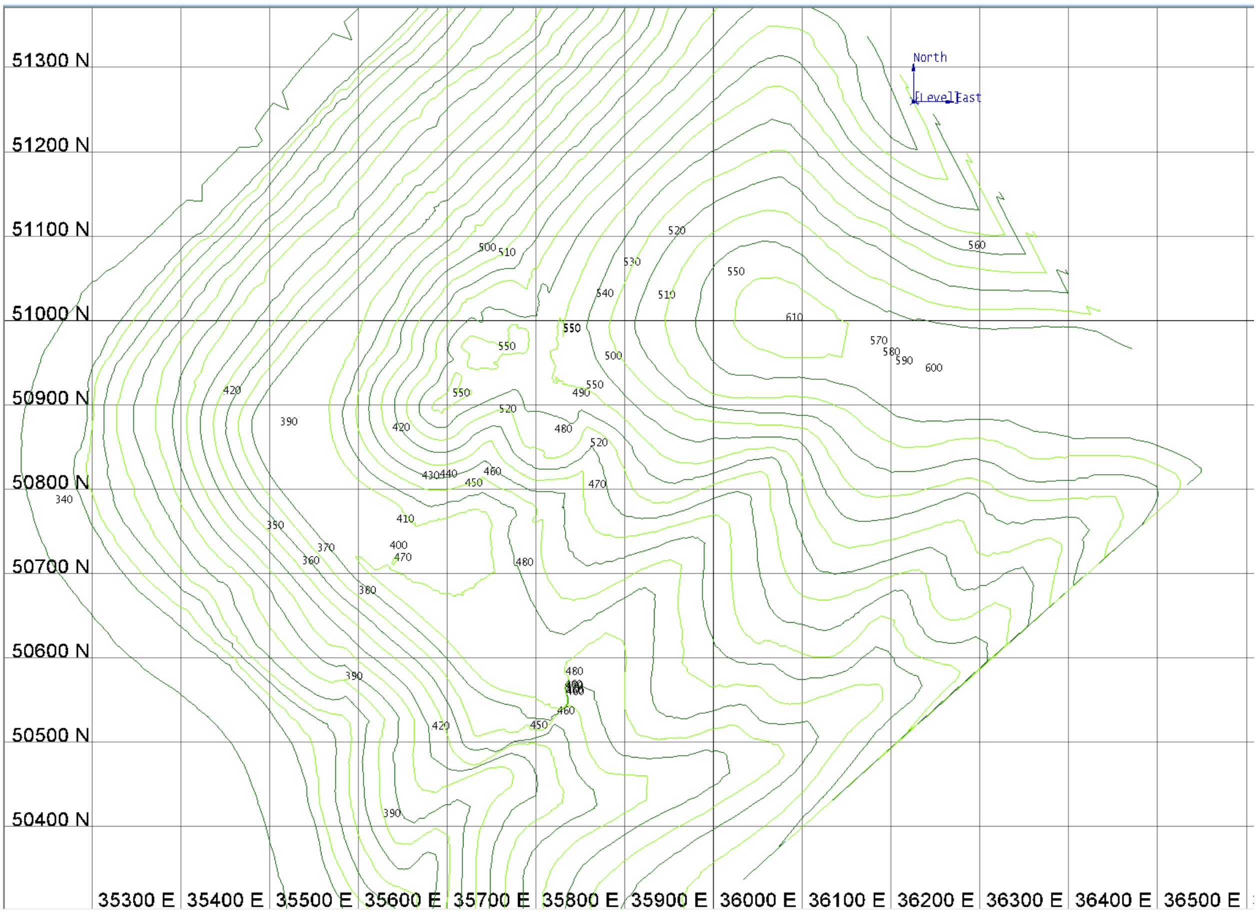

Figure 3. 5. Scan topography contour line – February 2017

To determine the volumetric, change the two-surface triangulation were merged to create a solid triangulation by Boolean them to calculate the volumetric difference between the 1955ST and 2017ST Solid triangulation.

3.2.4. Summary statistical analysis with Excel

The summary statistical analysis data of the 5 minerals taken into consideration for this study as it was calculated using Microsoft excel to help us measure central tendency, the dispersion, skewness and kurtosis of the two campaigned is presented in Table 3. 2.

Table 3. 2. The geochemical analysis results for five minerals studied.

	As	Cu	Fe	W	Zn
Sum	1227.09	41.36	1795.99	30.84	113.47
Minimum (%)	0.31	0.01	0.00	0.03	0.00
Maximum (%)	24.00	1.16	31.28	0.87	23.00
Range (%)	23.69	1.15	31.28	0.84	23.00
Mean (%)	11.80	0.40	17.27	0.30	1.09
First quartile	8.48	0.16	5.60	0.16	0.24
Third quartile	16.08	0.56	26.98	0.41	1.40
Standard Error (%)	0.62	0.03	1.10	0.02	0.22
95% confidence interval	1.22	0.05	2.18	0.03	0.44
99% confidence interval	1.62	0.07	2.88	0.05	0.58
Sample Variance (%)	39.58	0.07	125.64	0.03	5.11
Standard Deviation (%)	6.29	0.26	11.21	0.18	2.26
Coefficient of variation	0.53	0.66	0.65	0.59	2.07
Skewness	-0.39	0.53	-0.54	0.38	9.00
Critical K-S sat. alpha = .05	0.13	0.13	0.13	0.13	0.13
Number of values	104.00	104.00	104.00	104.00	104.00

3.2.5. Coordinate system conversion

When focusing on the data availability and quality of the measurements several factors must be considered. Because the data and information used in this study were, extract from various source and they were obtained at separate times with different objectives as well as the different equipment/instruments it ends up that all data set were having they own different geographical coordinate system as shown in Table 3.3. To achieve the objective of this study and the data to be accurate to the reflect the true location sampled all the coordinate data were converted to a single geographical coordinate system by using the Maptek I-Site Studio to the PTTM06 of the ETRS89 datum coordinate system. I-Site Studio is an intuitive point cloud processing package for Maptek company and is used to Manage and define coordinate systems, including local mine grid coordinates, and easily transform data between systems.

Table 3. 3. The original coordinate system of the data

	String	Coordinate system	Code EPSG
Drone data	ETRS89	PTTM06 of the ETRS89 datum	3763
GPS-2001 data	ETRS89UTM	UTM-29N of the ETRS89 datum	25829
GPS-2017 data	ED50 1950 UTM	FS29	23029
MAP-1955 data	ETRS89	PTTM06 of the ETRS89 datum	3763

3.3. Modelling of Rio Tailing Dam

The first objective of this study was to construct a realistic tailing resource model for Rio tailing dam for further exploitation planning and extraction design with the facilitation of Vulcan software. The resource model was created through three main stages: data acquisition and management, geological modelling, and the block modelling the general procedures will be presented below. Firstly, the drill holes data were prepared in the Microsoft excel *comma-separated values* format before they were imported into Vulcan for the block modelling process. The Vulcan Modeller used on the construction of the block model are Mine Modeller Open Pit with the added tools from the such as Vulcan GeostatModeller, Vulcan GeoModeller, and Survey.

3.3.1. Data Management and Structure

The database structure used in Vulcan is a common hierarchical or tree structure that consists of two databases, namely: the Isis Database and Design Graphics Database. The Isis database is composed of two files, which is: the index file (.isix) and the database file (.isis). The index file that is used to store the drillholes, lithological, assay analytical, geophysical, survey and geochemical in form of Data System File (*.dsf). Then depending on the type of the data contained in the database, they are denoted by the file extension: Isis Database (.isis) and Design Graphics Database (.dgd).

In the Isis Database, design is recorded into the database as a header format, hence an Isis database is also called a Headered database, which this is the database where data imported are managed. The Headered Template design is an optimised Isis design that is used for drillholes, samples, geotechnical and composition information. The Isis database provider store benefits on the data from the drillhole, geophysical, lithogical and analytical analysis to be managed, to identify targets and preliminary resources, and to test and validate. It also provides drill holes plotting, grinding, counting, and 3D visualisation.

The Vulcan Explorer database (Design Graphics Database) has also two different database styles: the Headered and the ODBC. The database files are containers within the appropriated folder, whereby each of the databases contain the Design and the Objects. The design container comprised of the database design file that describes and enforces the structure of the database, it specified how many tables the databases containers, the name of those tables, and number and type of field contained within each table, while the objects sub-folder lists every drillhole record in the database.

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3.3.2. Data format and Structure

As stated in the literature review, in order to develop a resource or geological model, at least a set of data is required. In this case, at least the drill holes data and a topography data were the set of data available for model construction. In this section, the format and structure will be presented below.

3.3.2.1. Drill holes data

Two sets of data samples all in total 104 samples were made available and compile to construct the resource model for Rio tailing dam. The first set of data sample was the 36 samples from the 6 unsystematically drill core samples undertaken by IGM (Instituto Geológico e Mineiro) in 2002 (Dinis da Gama 2002). The core samples were analysed two times at different times in 2002 at BERALT laboratory and in 2005 at S. Mamede de Infesta INETI an accredited Laboratory by DCP (Grangeia et al. 2011). The second samples data set was 68 bulk samples from extracted from 38 locations this was undertaken by DEM-FEUP (Department of Mining Engineering- Faculty of Engineering of the University of Porto) in 2017.

The local latitudes of Rio tailing dam drill holes were with recorded northing, range from 50 571.427 to 50 934.270, the eastings range from 35 504.379 to 35 804.170 and the elevation range between 465.215 and 477.160 m. The first cores were drill has to vary depth from 21.950 to 43.580 metre while the bulk samples depth was about 2 metres. The drill holes database is presented in the 4 tables used for this project.

The collar table was used to store the UTM coordinates and elevation of the 45 samples location (referred as drill holes location) and they depth. The drill hole Identity (HOLEID) was used as the Primary Key that tells the database, which field ties data across all tables together with the Primary Key. A typical collar table is present in Table 3.4 while the whole data set presented in the Appendix.

Table 3. 4. Collar location of Rio tailing dam drill holes

HOLEID	EASTING	NORTHING	ELEVEVATION	TOTAL DETH
DH_1	35566.106	50873.108	468.533	24.08
DH_2	35547.542	50835.597	466.015	43.58
DH_3	35578.073	50920.413	473.455	26.77
DH_4	35570.46	50790.074	466.773	21.95
DH_5	35704.847	50629.308	472.064	34.63
DH_6	35617.567	50696.63	470.564	40.13
A1_S	35771.004	50574.355	474.699	1.01

A2_S	35747.166	50608.172	472.521	1.01
A3_S	35716.254	50635.786	471.226	1.01
A4_S	35685.342	50663.401	470.812	1.01
A5_S	35656.783	50694.109	469.951	1.01
A6_S	35635.357	50718.686	468.659	1.01
A7_S	35604.432	50749.384	467.686	1.01
A8_S	35573.521	50776.998	467.143	1.01
A9_S	35547.331	50807.72	466.600	1.01

a) Survey table

The drill holes azimuth and inclination data are stores in the survey table. In this work the notable drill holes are DH_2 and DH_6 dip direction were 45° with the azimuth of 220° and 200°, respectively. While drill hole DH_3 dip direction was 75° with a similar azimuth was as the DH_6. All bulk sample drill holes were sampled in a vertical this is indicated by the drill hole dips -90° to define a vertical down hole with bearing angle of zero. The typical survey is present in Table 3.5 for the first 5 drill holes.

Table 3. 5. Typical survey table

HOLEID	DEPTH (m)	AZ (°)	DIP (°)
DH_1	24.08	0	-90
DH_2	43.58	220	-45
DH_3	26.77	200	-75
DH_4	21.95	0	-90
DH_5	34.63	0	-90

b) Assay table

The assay table is merely the table that stores the qualities analysis and the physical properties of the samples such as the thickness of the sample in metre while assay, moisture content, and core recovery in percentage. The typical assay table is present in the Table 3.6.

Table 3. 6. Typical assay table

Holeid	From	To	As%	Cu%	Fe%	Zn%	W%	Recover %	Width	H_2O
DH_1	3.53	3.55	11.49	0.50	0.00	1.38	0.49	98	3.54	19.00
DH_1	11.77	11.79	3.51	0.20	0.00	0.6	0.36	98	8.24	17.20
DH_1	20.22	20.24	1.02	0.11	0.00	0.06	0.30	98	8.45	17.60
DH_2	0.78	0.80	15.57	0.70	0.00	1.13	0.19	98	0.79	15.40

DH_2	22.16	22.18	1.15	0.12	0.00	0.36	0.24	98	21.38	19.80
DH_2	38.91	38.93	1.15	0.08	0.00	0.08	0.27	98	16.75	34.80

c) Geology logging table

The geology table is used to store the lithology, thickness and description of the rock as they were recorded from the field mapping. Twenty-six core descriptions were used to classify the types of materials found on the dam based on the six drill boreholes of 2002. The major description is Ferruginous Crust Yellow, Brown and Red (FCYBR) with 30 values followed by Grey Mud (GYMUD) with 26 values the remained has between 1 to 6 values. There was some location where there was no description recorded. This classification was based on the tailing stratigraphy or location of the sample on the tailing dams. The example of the DH_1 drill hole is presented in Table 3.7.

Table 3. 7. Typical geological table data

HOLEID	FROM	TO	LITH	WIDTH	CORE DESCRIPTION
DH_1	0.00	3.40	GYMUD	3.40	Grey Mud
DH_1	3.40	3.75	FCYBR	0.35	Ferruginous Crust Yellow, Brown and Red
DH_1	3.75	4.05		0.30	
DH_1	4.05	4.20	FCYBR	0.15	Ferruginous Crust Yellow, Brown and Red
DH_1	4.20	5.60	GYMUD	1.40	Grey Mud
DH_1	5.60	5.74	FCYBR	0.14	Ferruginous Crust Yellow, Brown and Red
DH_1	5.74	7.10		1.36	
DH_1	7.10	7.50	FCYBR	0.40	Ferruginous Crust Yellow, Brown and Red
DH_1	7.50	8.50		1.00	
DH_1	8.50	8.70	FCYBR	0.20	Ferruginous Crust Yellow, Brown and Red
DH_1	8.70	10.00	GYMUD	1.30	Grey Mud
DH_1	10.00	10.20	FCYBR	0.20	Ferruginous Crust Yellow, Brown and Red
DH_1	10.20	11.60		1.40	
DH_1	11.60	12.40	FCYBR	0.80	Ferruginous Crust Yellow, Brown and Red
DH_1	12.40	12.88		0.48	

All data table were store in comma-separated values (CSV) file format in tabular data (numbers and text) in plain text. Files in the CSV format are import to and export from Vulcan programs that store data in tables, such as Microsoft Excel.

3.3.2.2. Topography data

The topography data are stored in files based on the format as Vulcan has two storage databases the design database polygon and the triangulation. The design database is a specialise type of Isis database, which store topography data in format of CAD objects (points, lines, polygons, layers etc.) it is created within Envisage and the data have a rigid structure with less flexible name convention. Data are stored in the points table and polylines tables. The point table in the design databases is used to store data as single coordinate field (easting, northing, and elevation) and those pointes are combined to make up makes up the polyline. The polyline table is the header table that can be viewed in Isis and it store general information about the lines, polygon and layer in the Isis database. The polygon data are stored with the information about the entire polygon that consists of the polygon ID, and the code for the polygon identification and description as well as the polygon type for either an open or a closed polygon, and the polygon value.

Triangulations are the highly accurate mathematic representation of the data in 3-dimension that can be used create complex model or feature from a set of data points, lines, polygon or import in the Envisage when created by other software such as I-Studio in the DXF or 00t format. There are two triangulations categories the surface and solid. They differ as the surface is an open 3D representative of the data while the solid is closed model body. The open refer to the triangulation that has a distinct edge and does not encompass a volume while the solid triangulation is the opposite of the surface. The triangulation model is series of 3-dimensions coordinates points and linkages between them, which form a series of triangulated planes that define a surface or enclose volume and are known to honour all the points' data. Some of the triangulation models commonly used in Vulcan are site topography or terrain model, faulted surfaces, pit shell and ore body models (Maptek 2012). The two surface triangulation created with the topography data are 2017ST.00t (36 998 584 points) and 1955ST.00t (3 992 points) all the points are represented by three attributes X, Y and Z (easting, northing and elevation) see the appendix.

The local coordinates of 1955ST.00t that is referred to the surface topography map of 1955 are between northing 49 941.820 to 51 668.65; easting 35210.700 to 36558.970; and collar elevation from 350.000 to 630.000 m. And for the 2017ST.00t that is referred as the surface topography map of 2017 it coordinates are between northing 35309.059 to 35893.480; easting 50404.436 to 51224.031; and collar elevation from 352.136 to 561.219 m. These data are provided on the filename as *Base topography data - T1955DATA.csv and Tailing topography data - T2017DATA.txt*, respectively.

3.3.3. Rio Project setup

After the data were gathered and organised on the structure that is supported by the Maptek Vulcan software the Project File (DG1) was set-up by first defining the project extends (boundaries) to create a work Area of the project. The project perimeter was determined with the minimum and maximum values of easting and northing plus a buffer space to create enough space around data for design and manipulation, which is actually the boundary working area of the project. In this study, the DG1 extents parameter that was used is present on Figure 3.6 with the project name RIOZMUDDAM as taken from Vulcan. The project coordinates are in metre and the default display grid was used even though the all data were converted to the PTTM06 of the ETRS89 coordinate system.

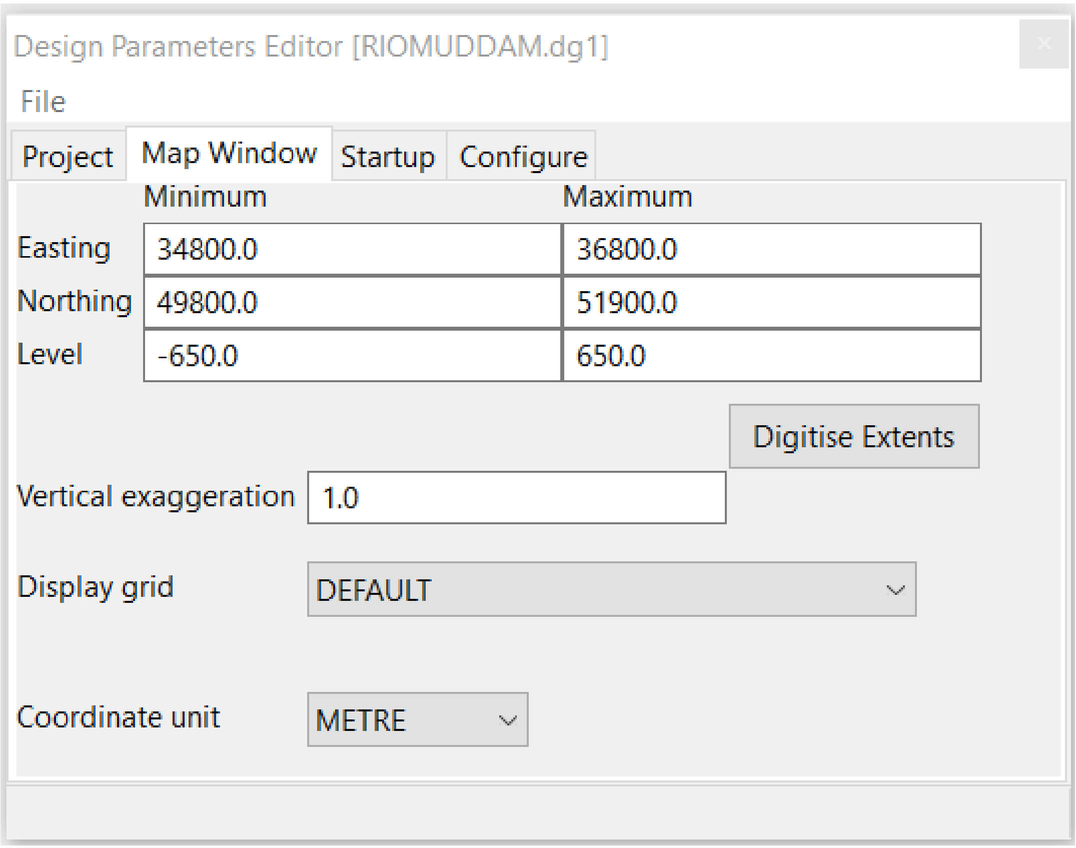


Figure 3. 6. Rio mud dam project coordinate extents

3.3.4. Import drillholes and triangulation data

3.3.4.1. Entering data

There are various ways to transfer data into Vulcan. In this case, the direct import option of data between the Vulcan and Microsoft Excel was used to enter the drill holes data into Vulcan Envisage. This is the simplest and effective way to move in the drillhole information into the Vulcan Isis drillhole database. Since that, the data were organised on the CSV format files they were imported into the CSV database file type as illustrated in Figure 3.7. Due to the structures hierarchical structure of the Isis database the lower tables is required to have an index field link the upper table that defined Data file to Record connection dialogue, in this case, the collar CSV was used as the Header table and the HoleId was select as an Index field of all the tables (Maptek 2012). The drill holes database created was viewed in Isis to ensure that the data imported were acceptable for the work. This was done by launching the Isis database and opening the database through the Vulcan Explorer. The database is sorted by drill hole that represent sampled locations and each hole has several associated tables imported.

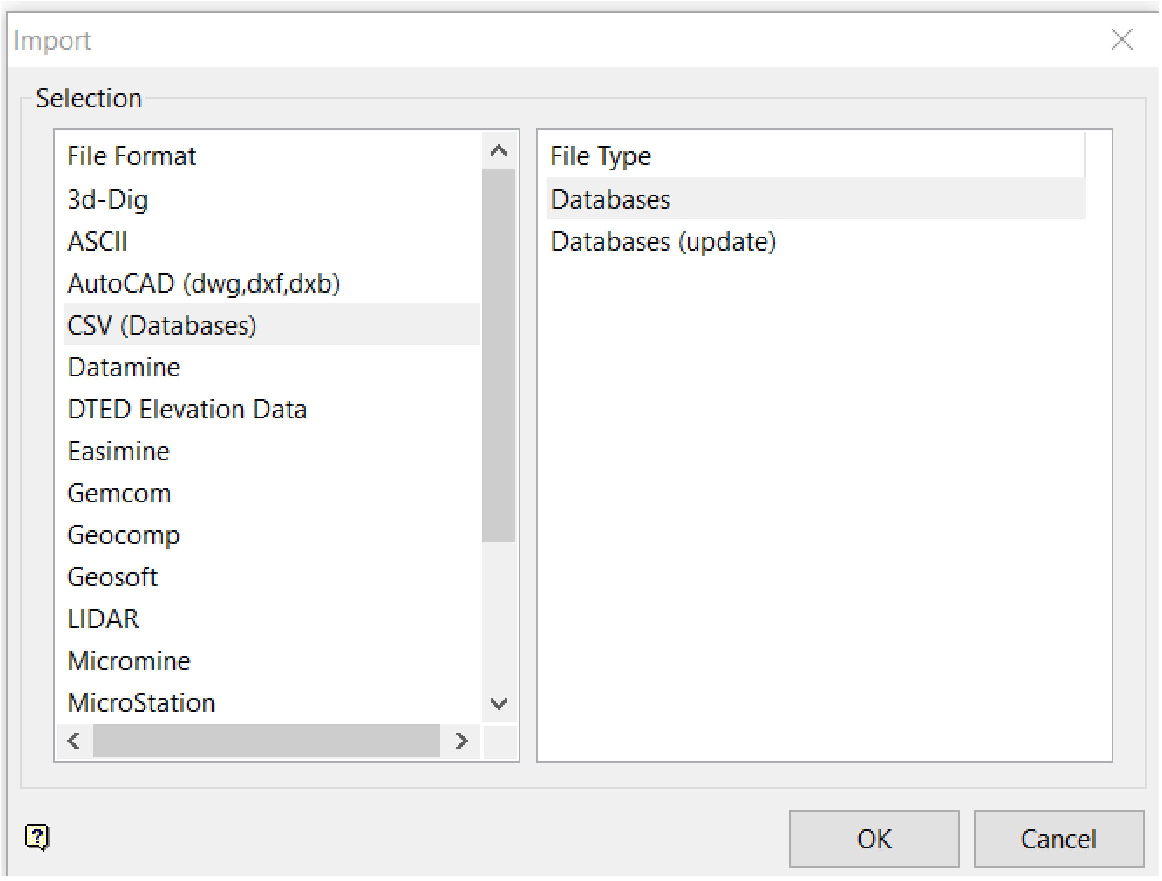


Figure 3. 7. Import CSV file into a new database

Topography files were imported directly in Vulcan Explorer by merely copying the folder/file from I-Studio and paste them in the project design folder/file. The other option used was by using the toolbar Model option then list all the triangulation in the computer and load them on the Vulcan Explorer and Drag-and-drop them into Envisage displayer to view them and validate them.

3.3.5. Validate and Display of data

3.3.5.1. Data validate

To ensure that the imported drill holes data are legitimate for modelling purpose and errors are eliminated to avoid any challenges in the modelling process the data were validate using the validation option in Isis. There are two-validation methods in Vulcan: The *Global Validation* that allows the content of a field to be check against the content of all other occurrences of the field in the databases; and the *Field-by-Field Validation* that allows for checking the content of the specified field against a variety of possible entries for that field. 4 checks status are selected to validate the data as shown in Figure 3.8 of the validation dialog box that is based on the data to be validated. The minimum validation check options required to be selected to run the validation two the unique collar check location to check for duplicates holes and down hole check to check for overlapping intervals to ensure assay intervals do not overlap.

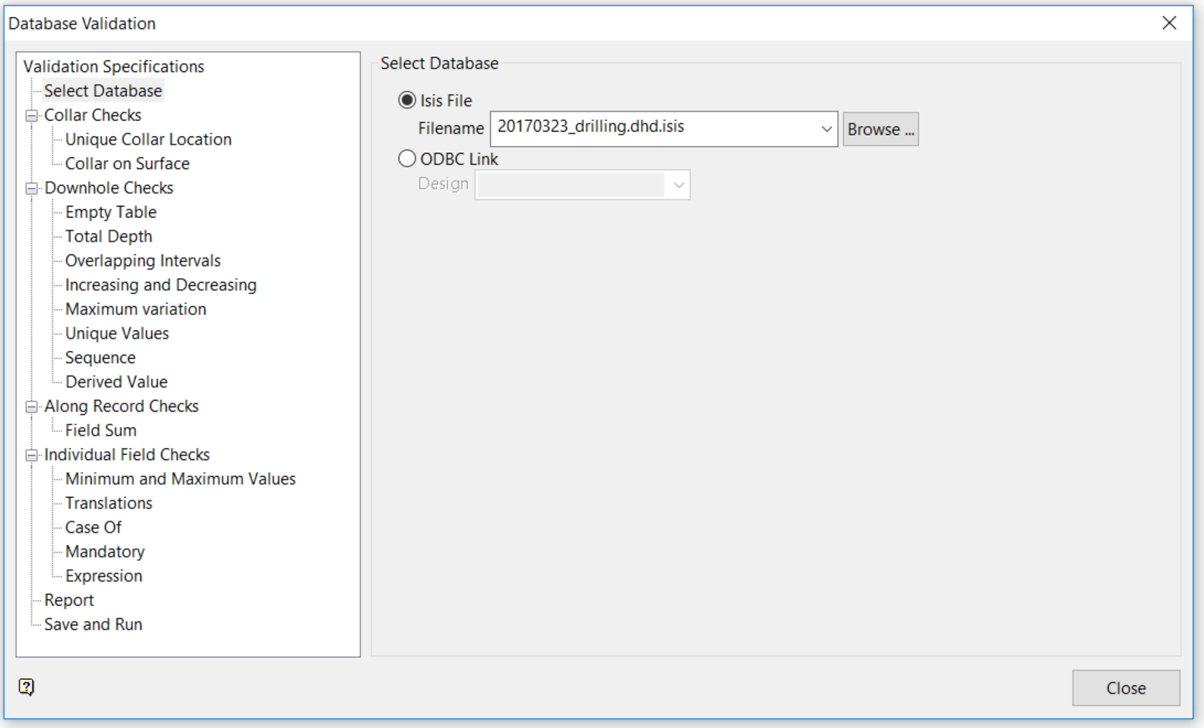
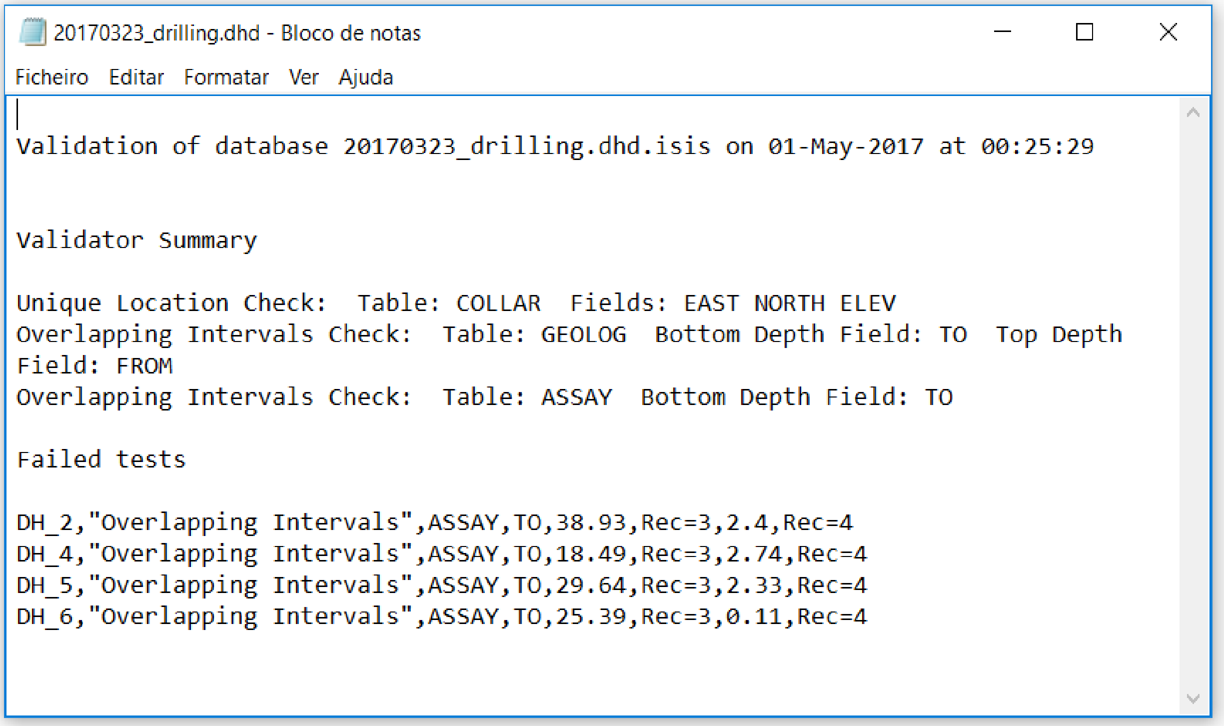


Figure 3. 8. Database Validation dialog box

Once the validation set-up is run, the validation report is generated to read. The major issue validated is to determine if there is any error encounter in the process during the test that limits pass the validation check. The output summary report of the process is generated in either CSV or Standard format that are viewed in notepad or excel format.



20170323_drilling.dhd - Bloco de notas

Ficheiro Editar Formatar Ver Ajuda

```
Validation of database 20170323_drilling.dhd.isis on 01-May-2017 at 00:25:29


Validator Summary

Unique Location Check:  Table: COLLAR  Fields: EAST NORTH ELEV
Overlapping Intervals Check:  Table: GEOLOG  Bottom Depth Field: TO  Top Depth
Field: FROM
Overlapping Intervals Check:  Table: ASSAY  Bottom Depth Field: TO

Failed tests

DH_2,"Overlapping Intervals",ASSAY,TO,38.93,Rec=3,2.4,Rec=4
DH_4,"Overlapping Intervals",ASSAY,TO,18.49,Rec=3,2.74,Rec=4
DH_5,"Overlapping Intervals",ASSAY,TO,29.64,Rec=3,2.33,Rec=4
DH_6,"Overlapping Intervals",ASSAY,TO,25.39,Rec=3,0.11,Rec=4
```

Figure 3. 9. Validation Error Report

Figure 3.9 presented the validation report that shows the name of the drill holes database test, the date, the summary of the validated checks used and the results of the failed test. The notepad report shows that there was an overlapping interval failure of the assay on four drill holes and it required to be fixed before the next stage of block modelling. The report indicates that when the data were imported there was overlapping intervals of the assay, this was because the samples were analysed at different laboratory and time. After the errors are addressed the database is saved and run for validation again until all validation check is passed.

3.3.5.2. Display of data

Another best option used to understand the drill holes location and layout based on the create database or composite database used is by displaying and interrogate option to view the drill holes on the Vulcan Envisage. The display tools in Vulcan are accessing through the Geology Modeller feature by simply loading the drill holes database needed to visualise then manipulate on the display. Nevertheless, before the visualisation of the drill holes or composite drill holes database, the requirement is to create a colour legend of all the attributes that have to be displayed. The legend is created through the Legend Editor Interface consists of the File menu, toolbar and a collection of colour legends. The File menu is displayed in the interface menu as well as along the top Workbench access menu.

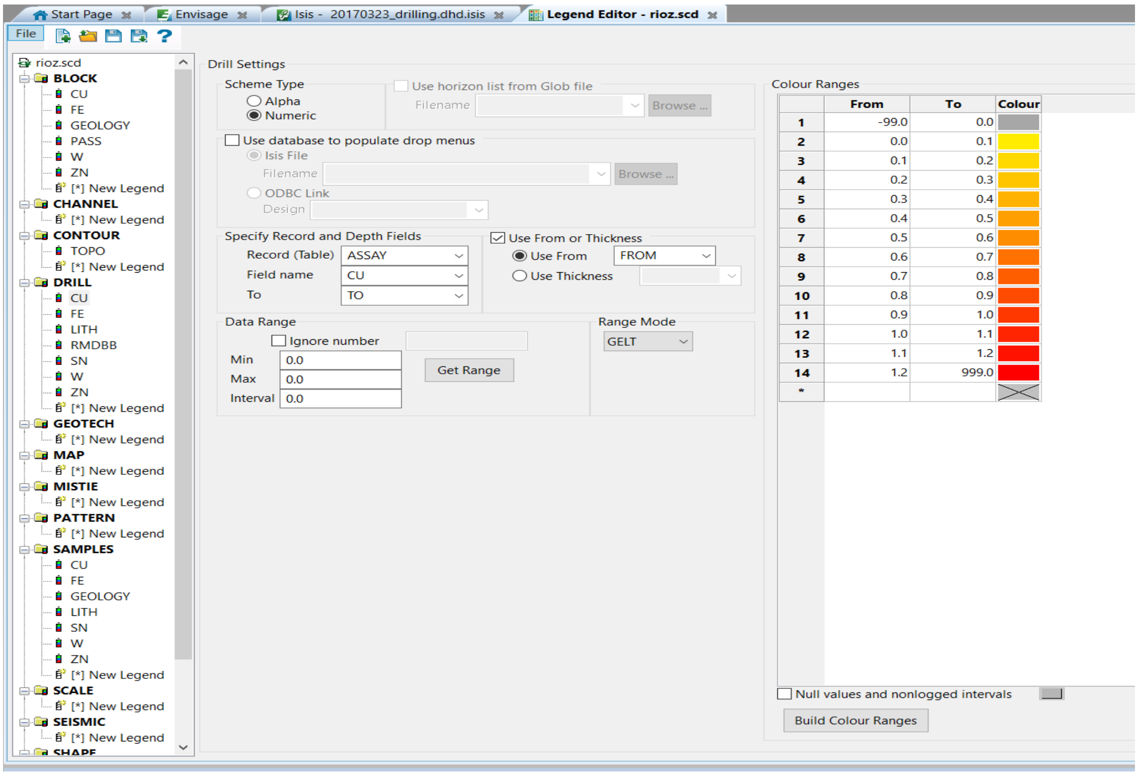


Figure 3. 10. Legend Editor Panel - Drill Legend

The File menu contains options that allow loading, close and saves colour scheme files, exit the Legend Editor application and, if desired, exit the Workbench application that is, close the current Vulcan session. The Legend Editor Toolbar that only contains five icons allow to the quick access of the common operations i.e. create a new colour legend file; open an existing colour legend file, save the current colour scheme, save the current colour scheme with a different name and help icon. The colour legends displayed below the Legend Editor Toolbar are grouped according to colour schemes files as shown in Figure 3.10 that display the drill colour setting of a copper grade based on the database. The entries in the Legend Editor were created to match with the database tables and field name exactly. This was done to avoid incorrect colour load or to make sure all the drill hole are load without errors or difficulties.

Vulcan Geology has a build in option to load drillholes on the Envisage when the database is open. This option allows loading drillhole base on the methods such as name, section, polygon, selection file, exclusive file, extents etc. The drillholes are displayed base on characteristics setting of the legend.

3.3.5.3. Data sorting

To display the lithology description information of the tailing dam it was necessary to extracted and sorted them and give them rock type code with colour that can be used to display as geological lithology description.

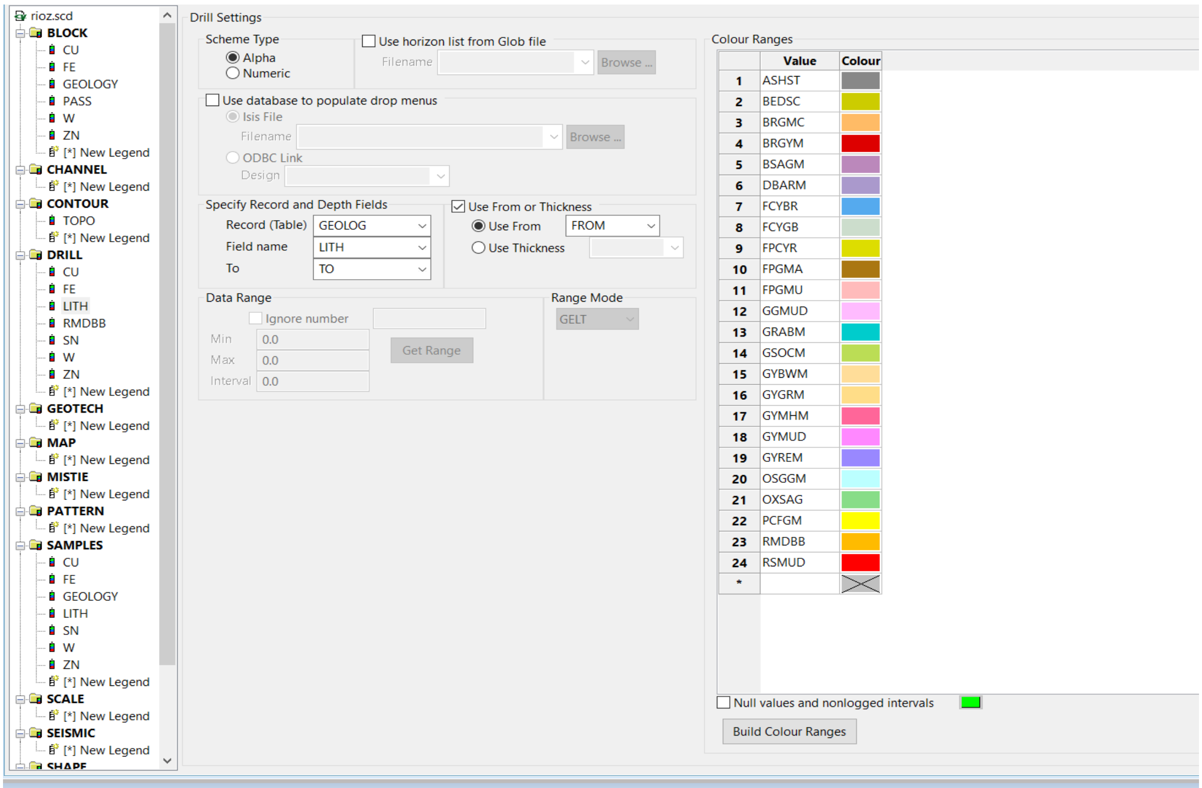


Figure 3. 11. Legend Editor Panel - Lithology Legend

Figure 3.11 shows the types of the rocks or lithological characteristic of the tailing classified based on the geological investigation information record in 2002. There were altogether twenty-four lithological types record and given short names while the full list is presented in the appendix.

3.3.5.4. Drillholes plotting

Vulcan Envisage has many built-in facilities that can allow validating and transforming exploration data such as the drill holes or geophysical data into 2D or dynamic 3D view. In a case of Rio tailing dam, there was two investigations carried at the different time and there display will be discuss as follow. In Figure 3.12, it shows the six drill holes that were drill on the dam in 2002, and it is evidence that this drill holes were not drilling on any systemic pattern by visualisation. The spacing between the holes vary significantly between 50 to 110 metres, and the holes were drill closed to the edge of the tailing dam wall. In the case of 2017, the drill holes or samples was taken systematically at drill holes spacing about 40 metres in the North-West area, and about 25 metres in the Southeast area (Figure 3.13).

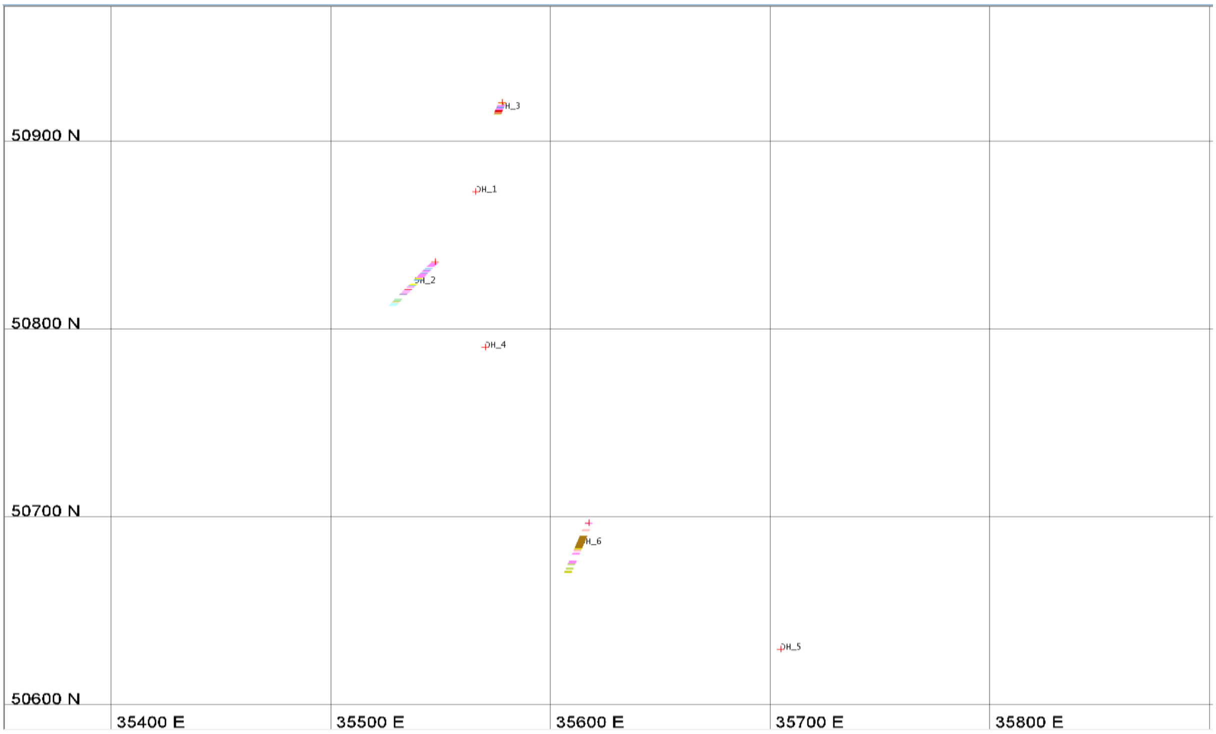


Figure 3. 12. 6 core drillholes points location displayed in Envisage

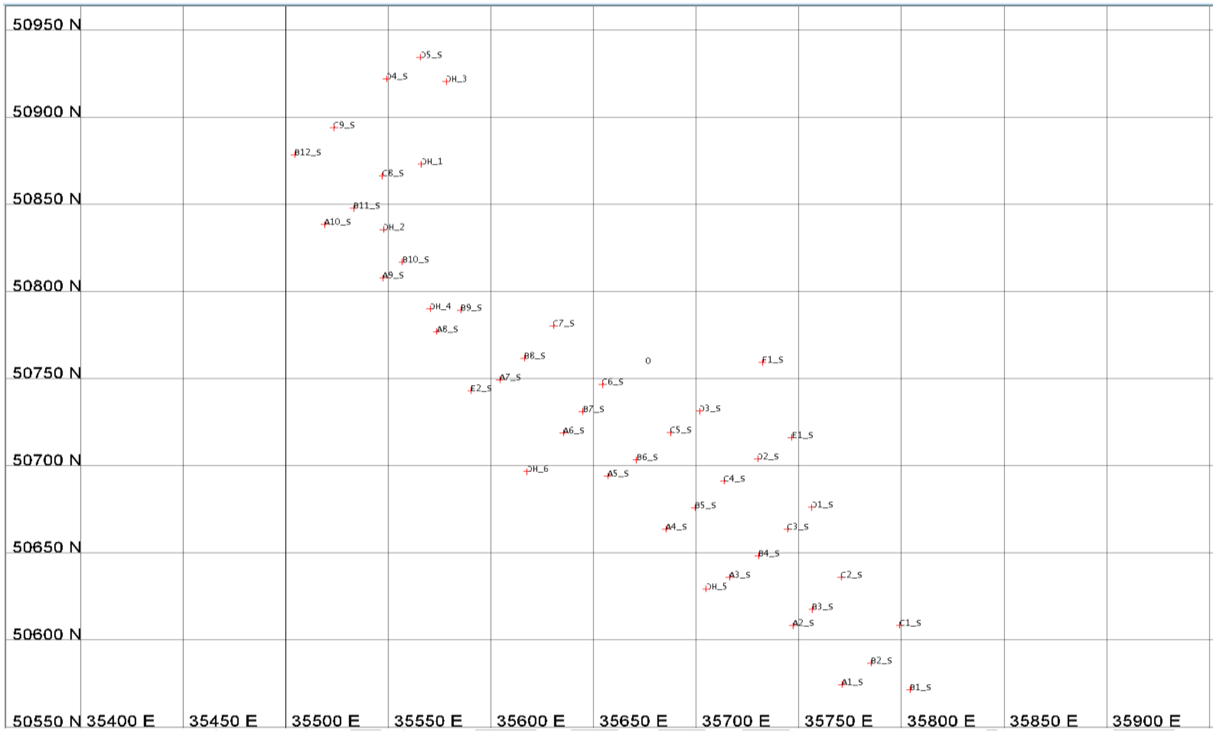


Figure 3. 13. 45 sample points location displayed in Envisage

3.3.5.5. Contouring display

Contour maps are essential to visualise the exploration data in order to check the holes spreading within the region. Figure 3.14 shows the digitise contouring from the Surface Plan - Contour map for Panasqueira (Planta de Superficie - Couto Mineiro da Panasqueira) that was drawn at the scale of 1: 10 000, and dates back as February 1955. It is clear in the figure that the area was a flat surface and it also shows the river and the valley which is shown by the river feed streams mostly in the centre map. It further shows the highest elevation level that is about 615 m above the sea level reference and the lowest point is the river at 345 m above the sea level reference. In general, the area is the mountain with a dip about 25 degrees and dip direction about 250 degrees.

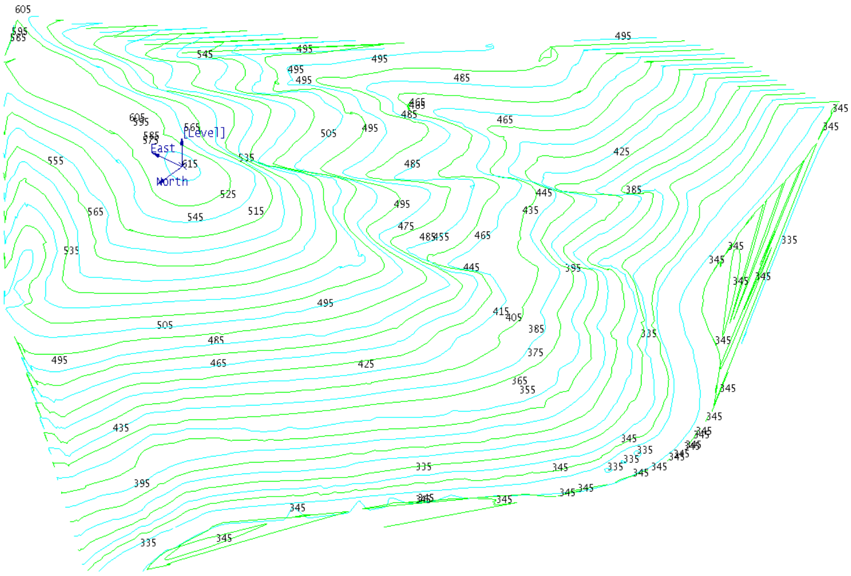


Figure 3. 14. Digitise contours at 10 unit intervals - February 1955

3.3.6. Data compositing

Drillhole data represents samples intervals as vectors there for block modelling and block model estimation the samples are required to be represented as points. Therefore, to convert the drillholes database data to the samples data the data has to be composite with the aim to remove sampling bias as a precursor to grade estimation in the block modelling drillholes assay data are composite to sample data in this study the straight composite was used. The straight composite method extracts each logged interval from a drillhole database and writes it out as composites point data. This is use to obtain a samples database that respect the distribution of logged samples intervals. This means that only one point will represent the whole interval, so that the data could be asymmetrically represent and grade estimation may slip valuable data near the ends of the interval (example in Figure 3.15).

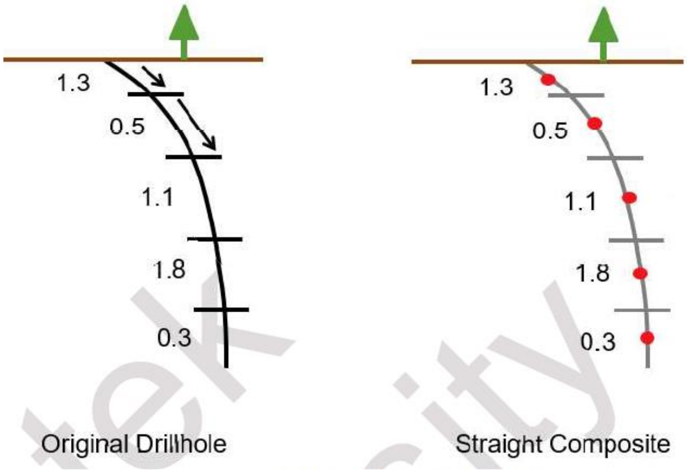


Figure 3. 15. Drillholes straight composite example (Maptek 2016)

To composite the drillholes database the tables used during compositing process are the assay table as a grade table and the geology table as a lithology characteristics reference table. The composition database created as the output of the process was used in the block modelling for grade estimation and resource estimation of the tailing resources. The typical composite database table is presented on the appendix C while the full file is accessible also in the link.

3.3.7. Statistical analyse by Vulcan

The histogram presented in Figure 3.16 shows the summary of the classic statistics analysis that was calculated with Vulcan software. This analysis further assists in observing and understanding the data central tendency, the dispersion, skewness and kurtosis. The results are similar to the one presented early from the excel calculation that shows that the tailing has highest average As with 11.00 % followed by Zn with 1.09 % while Cu and W with 0.38 % and 0.29 %, respectively. The level of uncertainty of the grade notes in cases of As and Zn with the variance of 39.1 % and 5.09 %, respectively. This information is shown in Figure 3.17 visualise clear that all the minerals does not have a bell shape for a standard normal distribution and this should be consider on the estimation stage as the data are inconsistency. On the other hand Zn has the strong positively skewed than other minerals. The traditional correlation between minerals concentration was determined as shown in Table 3.8, it is clear again that there is no correlation between the minerals deposition as the correlation values as weak ranging from -0.03 to 0.67. The strong correlation is only between Fe and As that is 0.67.

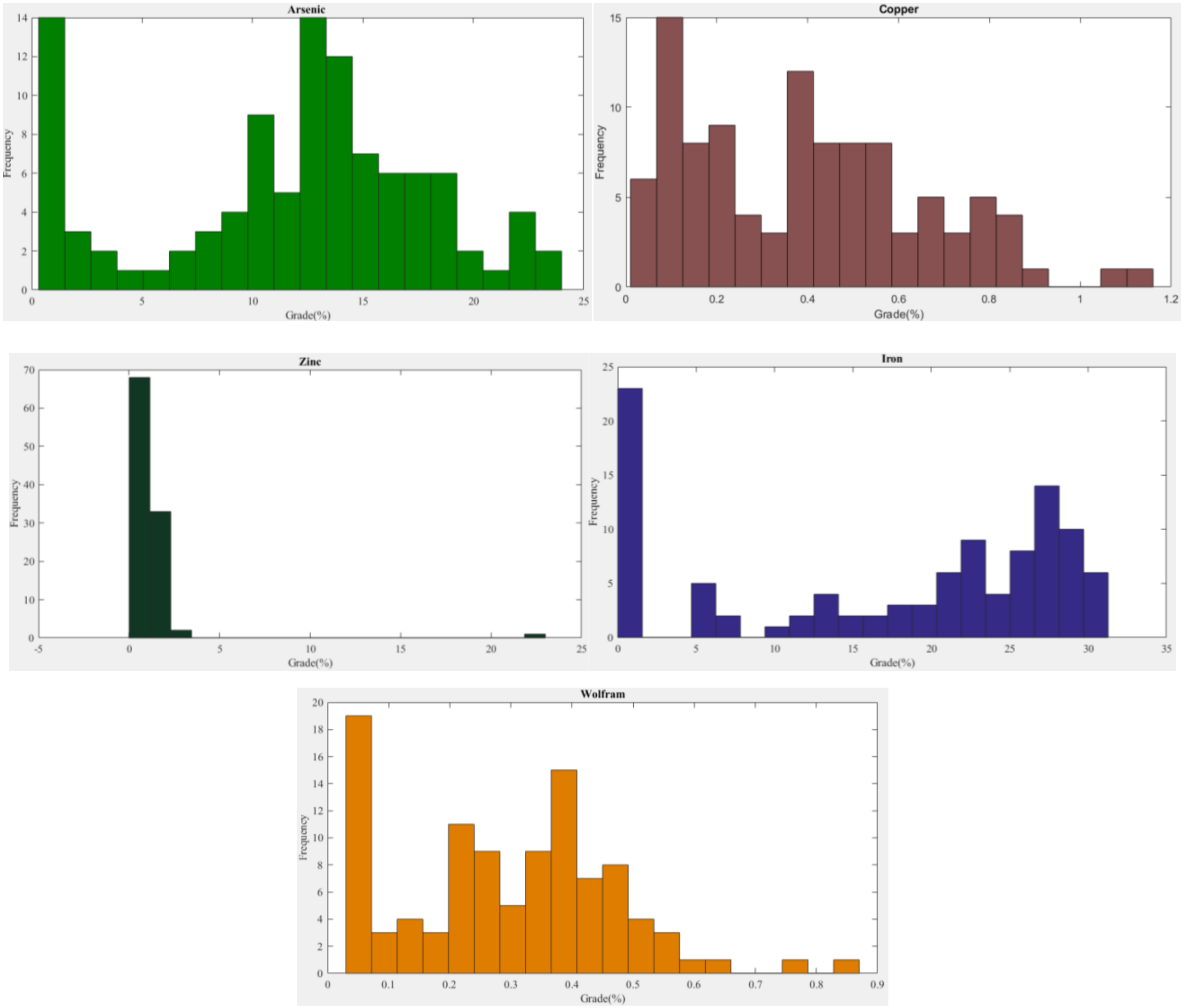


Figure 3. 16. Histogram of the drill holes data for Rio tailing (As, Cu, Fe, Zn and W)

Table 3. 8. Minerals concentration correlation

	W	Cu	Zn	Fe	As
W	1.00				
Cu	0.184	1.00			
Zn	0.084	0.109	1.00		
Fe	0.032	0.493	0.005	1.00	
As	0.109	0.433	-0.034	0.671	1.00

3.4. Tailing Resource Modelling and Estimation

To understand the geological controls on grade distribution throughout a tailing deposition is vital to the development of a robust valuation approach of mining potential resources. Nowadays 2D or 3D computerised model of geology, density, thickness and grade are essential to estimation mineral grade and resource. 3D Models main objectives are to display and provide the graphical view of the deposit shape in both the horizontal and vertical section view. The construction of the tailing resource model is similar to the geological model that normally demonstrates into three steps: block model construction, block viewing and manipulation, and grade and resources estimation. In the following section, each step will be discussed on how it was carried in the context of this project.

3.4.1. Block model construction

Block model construction is the initial step in the process of block modelling. Due to the significant of the resource model level of accurate required for the model to reflect the reality is high and the acceptable error is minimum. Therefore, to achieve that it starts with the familiarity with the location to be a model and the data gathered for block modelling. The construction of the block model in Vulcan is initial procedure with the creation of the block model definition file (. bdf) this access through a build in Block Modeller in Envisage or Block Model Utility in Workbench. The block model utility has six panels or options that have to be help defined the geological/resource block model (Orientation, schemes, variables, boundaries limits and exceptions) as shown in Figure 3.17.

The first panel is used to define the block origin and orientation. The origin is the easting (X), northing (Y) and elevation (Z) values points of the block that represent the lower left corner of the block model on the plan view or the map grid origin. The elevation value is referred to the lowest elevation at the site. The rotation of the block is define based on the deposit orientation, which can define as the bearing, plunge and dip. In this study, the bearing was 90°, while plunge and dip were 0° this was determined by analysing the drillholes data and topography.

The second option is schemes that allow defining the block extents and dimensions in the 3D spatial used to build the model boundaries. In this option, there are two sub-options the parent block scheme that defined the maximum block size in the model, and the *sub-blocks* that define the smaller blocks dimensions, which are the factor of parents, block size. Subblocks are essential to increase the accuracy of estimation and achieve better calculation in short periods.

The third panel is used to define the block variables (attributes) that used to create the model. Vulcan has the option to enter up to 300 variables that can be either numeric or alphanumeric value (geology, grade, etc.).

Then the fourth panel allows setting up the definition the block model boundaries were the individual block are going to end and what field's values assigned to the cells individual created. This is done by using triangulation that can either be an inclusive or exclusive interface to the previously entered variables that are used to define the boundaries whether a variable occurs inside or outside, above or below the boundary. The triangulation or topographic boundaries are given the priority, inversion and projection axes to define the direction for a surface model. Generally, the inversion and projection options are used to direct the blocking process in which areas and direction the blocks must be constructed in the model.

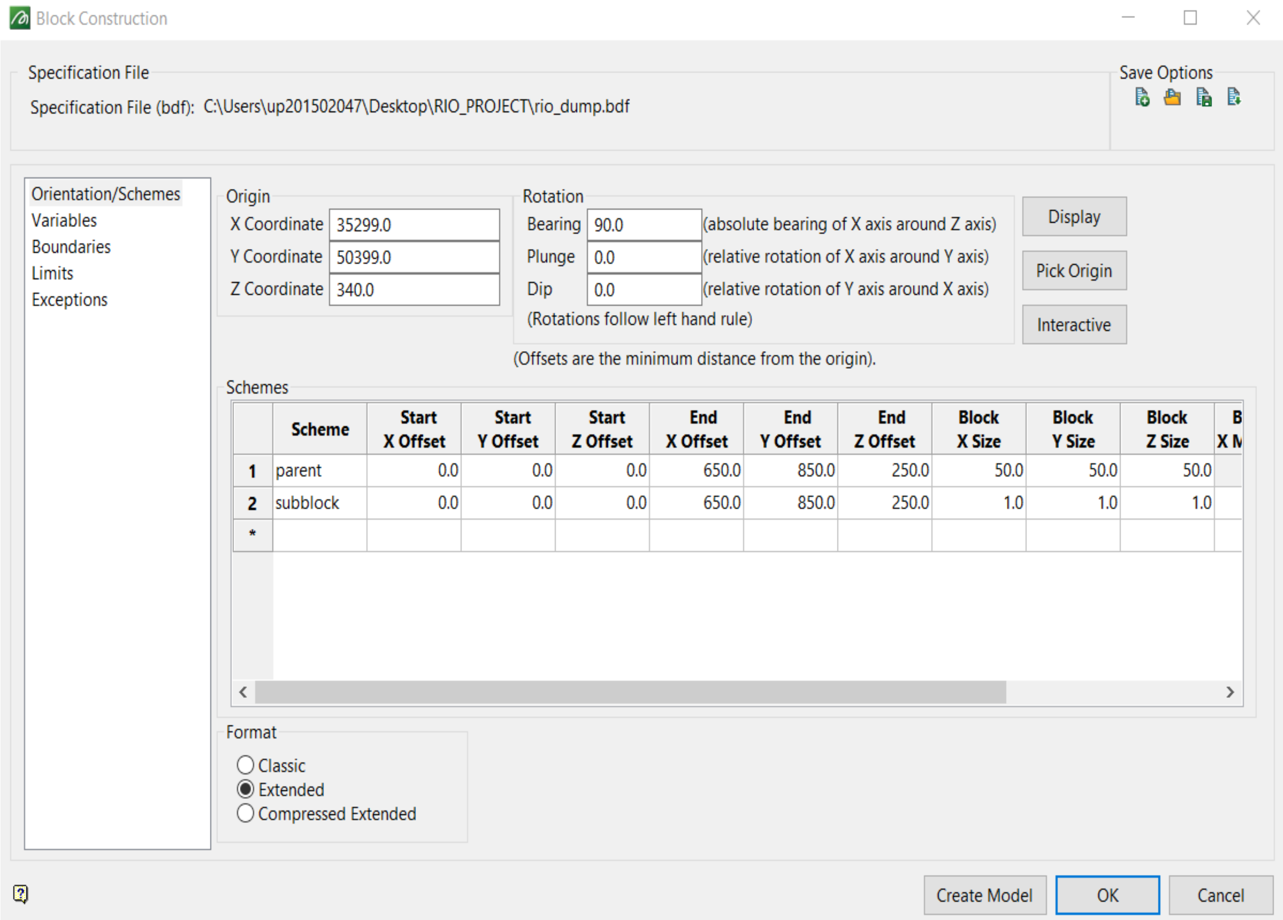


Figure 3. 17. Block construction new definition panel

Limits panel option is used to specify the maximum block dimension for blocks of the predefined variables. In this case, the values are definite using the boundaries values as defined early. Another panel is an exception that allows specifying conditions that must be matched by the blocks to be considered for as part of block model creation. This is an example of the area above the surface topography the boundaries been defined as air. Once all the prerequisite constraints are defined/filled in the block definition file then the block model file can them create. Figure 3.20 presented the summary information about the block model create. It originates at the lowest point on the topography map (35299,50399,340), it is non-regular structure model with the 3 329 391 blocks in total with a minimum dimension of 1 x 1 x 1 meter and maximum dimension of 50 x 50 x 50 meters. In total, 46 variables define each block upon inquiring as shown in Figure 3.28. The entire block model covered a surface area of 552 500 meters square.

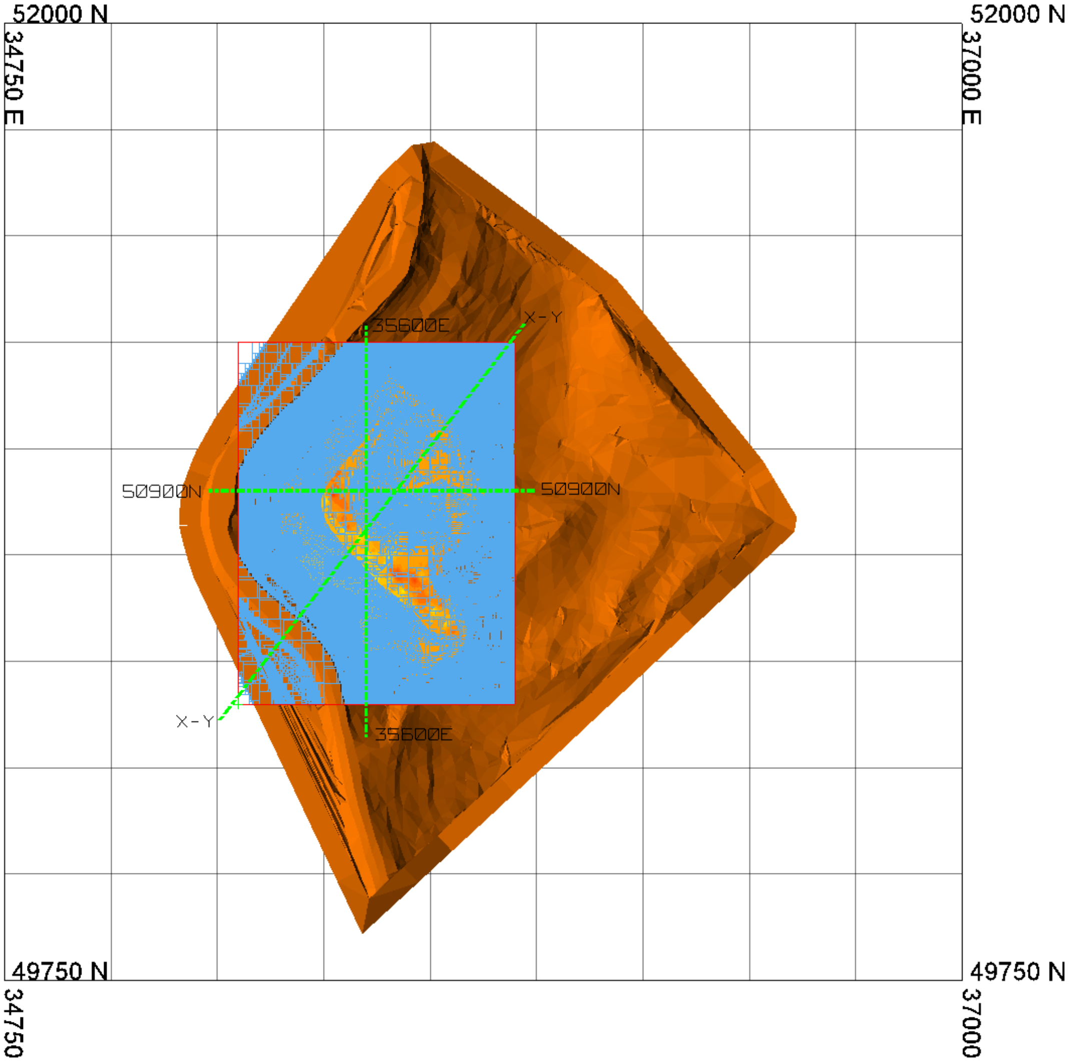


Figure 3. 18. Resource block model on plan view

3.4.2. Block viewing and manipulation

Block models are illustrative of the geological resource or mining scenarios, therefore, there is always a necessity to visually investigative the block model as a whole and validate the model. The purposes of visual investigation are to validate that the block create is locate in the correct spatial place, the block created are suitable for the task, sub blocks created are accurate to represent the interest blocks and ensure that the variable values are correctly assigned to the right blocks. The first importable parameter when visualise is verify the extents of the model this is to ensure that the area of interested is covered and if not, the model is modified to fit the meet the requirements or to cover the area. This is verified by loading both the block model and the drillholes in the display then view the block in the different orientation to make sure all the drillholes are inside the block boundaries.

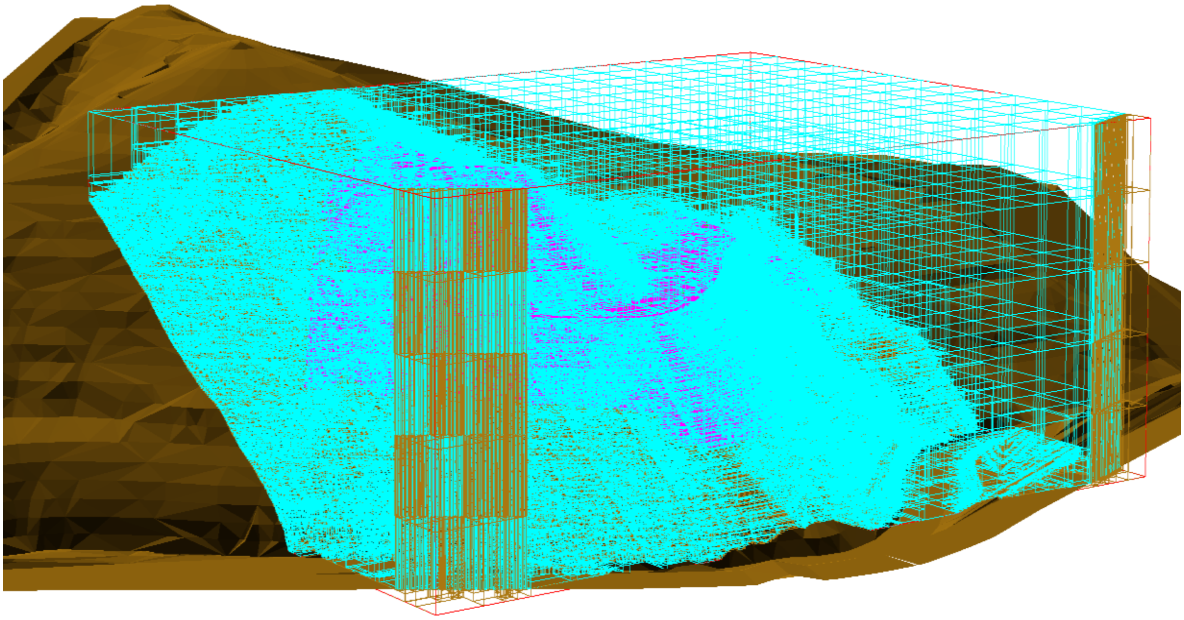


Figure 3. 19. Resource block model on 3D view

To ensure that the block dimension is appropriate to the data several options are used in Vulcan to viewing blocks in which one of them is by using load dynamic model option that was used in this study. Vulcan provides the different frameworks to display the variable based on grade, resource, geology and economic variables. In this study, the geology variables those were defined early in the process of block construction where used to displayed in both horizontal and vertical cross section view. Figure 3.18 and 3.19 present the resource block model on plan view and model on 3D view, respectively.

Figure 3.21 – 3.24 are a representation of the horizontal cross section view of the block model at 340 m, 480 m and 540 m, respectively. Figure 3.21 shows the grid section classification of the materials at 340 meters level in which the three-quarter of the portion of the grid is rock which classified as bedrock in brown colour expect the whitish portion which enters the aqua colour south-west and north-west this the Zêzere river which the bedrock was not defined this is represented as air. Figure 3.21 at 340 meters is a bit differs from Figure 3.22 as it shows the deposited materials classified as tailing on this case at the centre whitish colour at 460 meters.

```
Block Model Details

Model name          : C:\Users\up201502047\Desktop\RIO_PROJECT\rio_dump
History list        : rio_dump31Mar2017.bhst
Format              : extended
Structure           : non-regular
Compressed          : no
Smooth              : no
Number of blocks    : 3329391
Number of variables : 46
Number of schemas   : 2
Origin              : 35299.000000 50399.000000 340.000000
Bearing/Dip/Plunge  : 90.000000 0.000000 0.000000
Created on          : Fri Mar 31 16:55:40 2017
Last modified on    : Fri Mar 31 17:31:15 2017
Model is indexed.

Variables        Default    Type       Description
----------------------------------------------------------------
geology          rock       name
cu_nn            -99.0      double     copper nearest neighbour
cu_ivd           -99.0      double     copper inverse 2
zn_nn            -99.0      double     zinc nearest neighbour
zn_ivd           -99.0      double     zinc inverse 2
w_nn             -99.0      double     wolfram nearest neighbour
w_ivd            -99.0      double     wolfram inverse 2
fe_nn            -99.0      double     iron nearest neighbour
fe_ivd           -99.0      double     iron inverse 2
.
.
.
volume           -          predefined
xlength          -          predefined
ylength          -          predefined
zlength          -          predefined
xcentre          -          predefined
ycentre          -          predefined
zcentre          -          predefined
xworld           -          predefined
yworld           -          predefined
zworld           -          predefined

Translation Tables :
--------------------

geology :
    rock       = 0
    air        = 1
    tailing    = 2

Schema <parent>
Offset minimum : 0.000000 0.000000 0.000000
       maximum : 650.000000 850.000000 250.000000
Blocks minimum : 50.000000 50.000000 50.000000
       maximum : 50.000000 50.000000 50.000000
  No of blocks : 13 17 5

Schema <subblock>
Offset minimum : 0.000000 0.000000 0.000000
       maximum : 650.000000 850.000000 250.000000
Blocks minimum : 1.000000 1.000000 1.000000
       maximum : 50.000000 50.000000 50.000000
  No of blocks : 650 850 250

*** END OF INFORMATION ***
```

Figure 3. 20. Typical block model header information

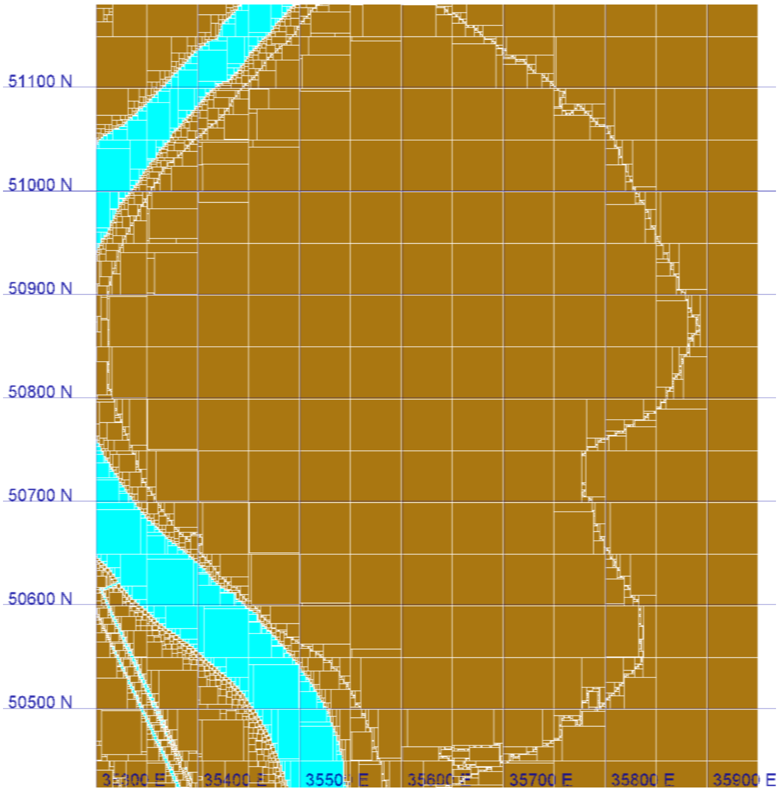


Figure 3. 21. Typical horizontal sections layout – 340 Level

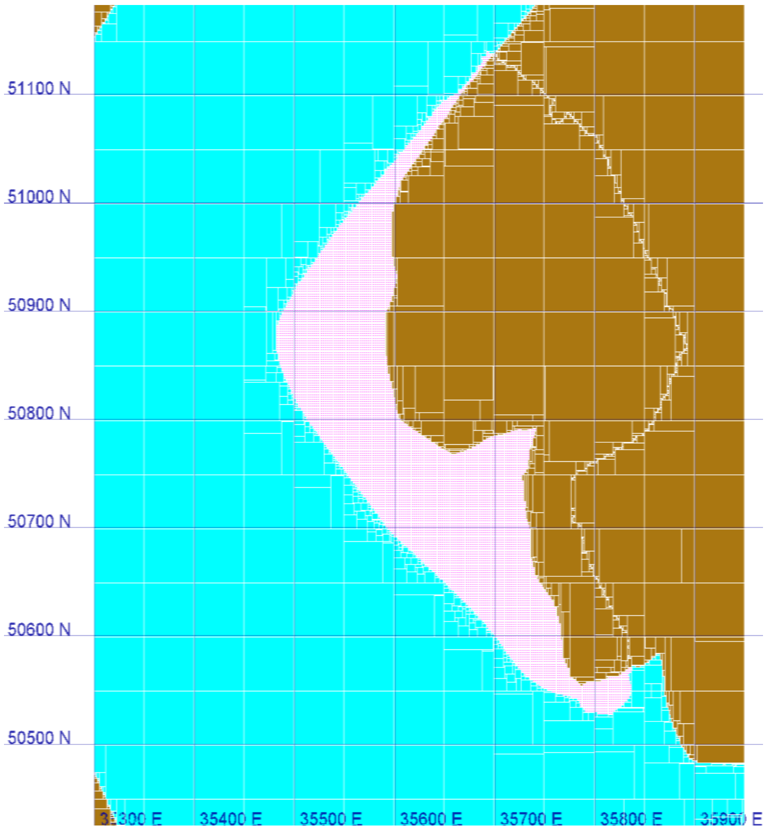


Figure 3. 22. Typical horizontal sections layout – 460 Level

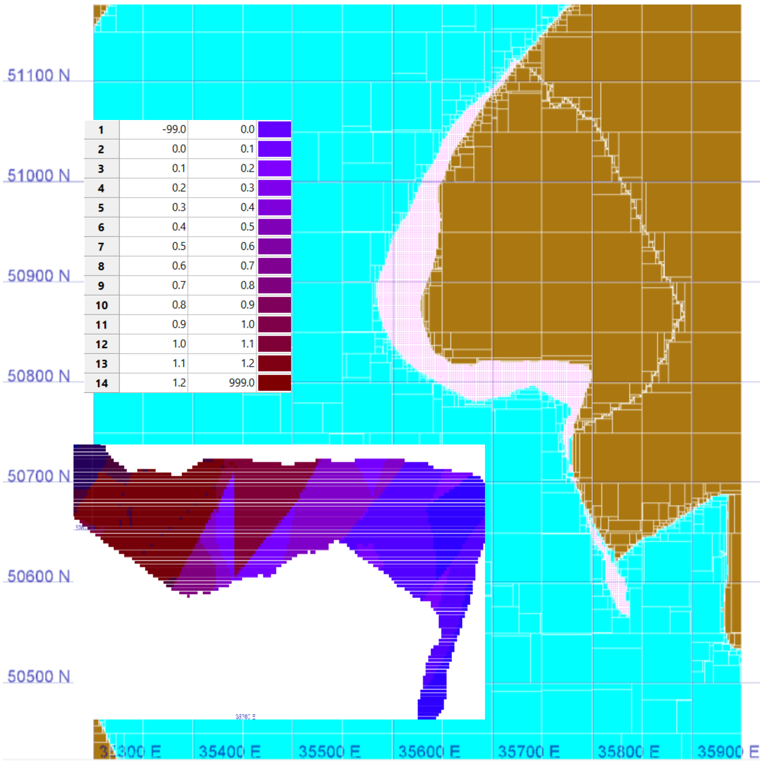


Figure 3. 23. Typical horizontal sections layout – 480 Level

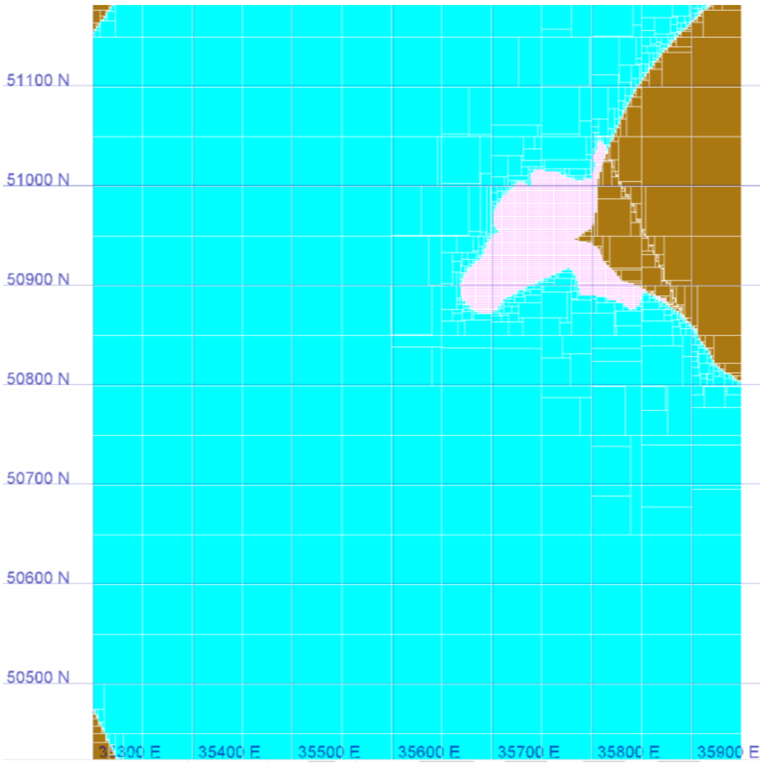


Figure 3. 24. Typical horizontal sections layout – 540 Level

Figure 3.23 shows the horizontal section at 480-meter level of the block with the insert more colour detail block portion that shows that distribution of minerals that is exactly how the blocks are classified based on the grade. The last horizontal cross section in Figure 3.24 shows the deposited tailing materials at the highest adjacent elevation about 560 meters.

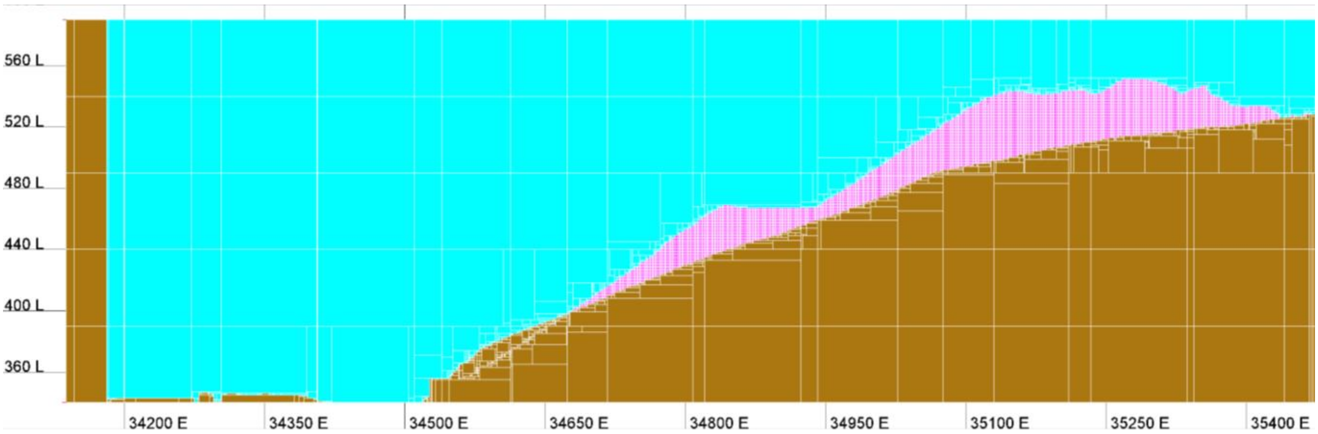


Figure 3. 25. Typical vertical sections layout – X-Y LINE

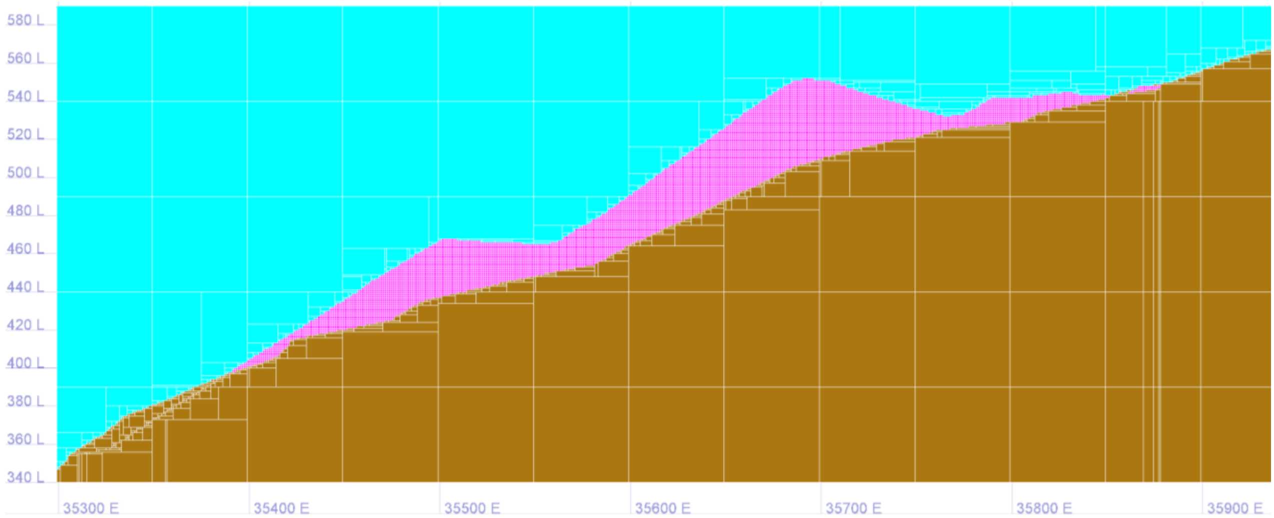


Figure 3. 26. Typical vertical sections layout – 50900N

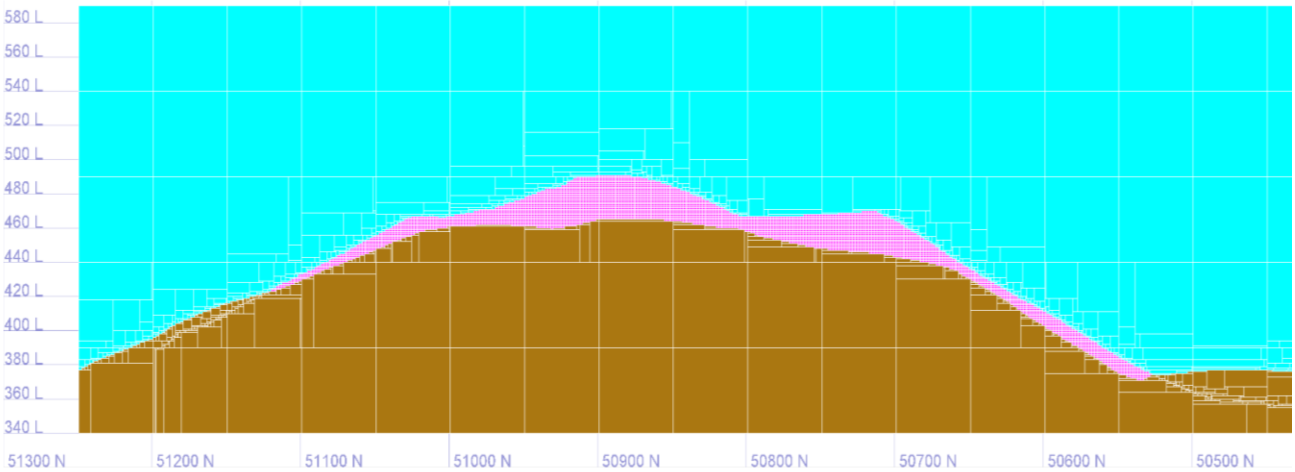


Figure 3. 27. Typical vertical sections layout – 35600E

To view the tailing dam on the vertical plan view three vertical cross section were created at X-Y LINE, 50900N and 35600E they are presented in Figure 3.25 – 3.27. It is evidences from the observation that the dimensions of the block vary from geological materials from 50 m x 50 m x 50 m to 1 m x 1 m x 1 m in the tailing geology. Generally, all the sectional views are different as illustrated in those Figures and the sectional lines are shown in Figure 3.18 as viewed on the plan view.

3.4.3. Data references and surface topography

All blocks were constructed as polygon with the centroid of XYZ coordinate and extent dimensions on the three directions. The cross section only shows the common three colours used to differential the geological materials, which are the aqua for the air, brown for bedrock, and violet for the tailing materials deposition. The geological boundaries of the block were defined by the polygon boundary and this was already shown by using the two surfaces topography that was taken at different time, and this give the difference in volume. The objective of block modelling is to construct the 3-dimension representative of the tailing dam that at display varies attribute. As discuss early the block model construct in this study comprise of layer model, a geology (materials) model, and grade model.

3.4.4. Grade estimation

Grade estimation is the process of interpolating values from database or file into the blocks of the block model. The objective of block modelling grade estimation is always to model the deposit as accurately as possible and estimate the grade distribution based on the data available. In this study, the quality of the tailing is referred to the grade estimation values of the main minerals in the tailing materials, which are part of the blocks. The five minerals average grades estimated are arsenic, copper, iron, tungsten, also known as wolfram, and zinc all grades were estimate in percentage.

In Vulcan, blocks model grade estimation is achieved through two steps: by creating the estimation parameter file (. bef) and running the estimation file. The procedure to create the estimation file start with the selection of the estimation method to be used. Vulcan modeller has six grade estimation tools of which five are geostatistics estimator tools. In this study, the traditional inverse distance power and nearest neighbour methods were the only one considered for Rio tailing dam grade estimation. The bef was created with the compositing database file (compositing.str. isis. isis file), triangulation (.00t) file and the block model (. bmf file). Prior to the creation of the bef, all triangulations were validated thoroughly to make sure that they provide correct volume and grade calculation in the block mode. Vulcan has three ways to specify estimation parameters and create the block estimation file (estimation editor, estimation wizard and block model utility) they all allows to create and modify the entry in a parameter for use in the grade block estimation. In the following section, some of the major parameters /options used for grade block modelling in this study are as follows:

1. The selection of the type of **estimation method** (inverse distance square and nearest neighbour for to validate the results of other estimation methods)
2. **Results estimation** variables report this refer to the output variables (Figure 3.29)
3. **Discretisation steps in X/Y/Z:** these step sizes indicate how many grid points to use inside a block or sub-block to estimate the block average. This is important to speed up the estimation process and in this case the 4 x 4 x 1 was use. To increase the accuracy in estimation the sub-blocks were estimate as parent block meaning that instead of using the extent of the sub blocks the estimation procedure replace a blocks extent with the extent of the parent bock.
4. **The distance to samples** as inverse average distance this the distance from the bock centre there are three options (standard Cartesian and anisotropic distance derived from the search ellipsoid, and anisotropic distance that derived from anisotropic weights) with sub-option to assign weighted to samples or not assign. In this study, the Cartesian option was used to compute the distance using the Pythagorean formula and all samples given equal weighted.

$$\text{Distance} = \text{sqrt}\,(dx^2 + dy^2 + dz^2)$$

   Where: dx – distance differences in the easting
   dy – distance differences in the northing
   dz – distance differences in the elevation

5. **The search region specifies** - there are three parameters to be specified: the search shape, the search orientation and the search distance. In this case, the ellipsoid shape was used with the semi major axis of 60 m while the minor axis of 5 m and the search orientation (bearing, plunge and dip) values were set to zero.
6. **The samples counts** are essential to define the minimum and maximum number of samples that have to be found within a region in order to generate an estimation value while the other hand octant-based search option is used to place a limit on the number of samples which can come from the given octant. For this estimation, the minimum number samples were select as 3 and maximum number samples per estimate as 16 while the octant-based search limited to 2 per octant. This done to reduce the imbalance problems associated with samples lying the in different direction.

7. **The inverse method** was normalised to calculate the anisotropic weightings, normalised to the search radii and enter the power controls the distance weighting used in the estimation that was a square in this study.
8. **Samples database** option specified the name of the database or map file that contain the sample data to be use for estimation. In this case the database was the compositing database file of the drillholes composite with straight techniques and the location of the samples is defined the as middle in all three directions. The character tag is defining by selecting the field character to limit the samples to a specific character field in this case it was geology then define the specific character values that was refer as the tailing.
9. Another essential part was to define the parameter that can filter the block model in such a way that blocks that are fit for the estimation process are identified and classified by passing the selection criteria's. The block selection options were used to define the target zone to limit the estimation to the blocks where a zone variable equal to zone value and the condition on the blocks to be estimated was applied to be zero of the inverse distance estimate value.

Generally, there are varies parameters that can modify depending on the required estimation this involved sample limits and soft boundaries parameters. For this study, various parameter that are not mention here were kept them at default level. After the estimation parameter file was create and all the parameters were modified the next stage was to run the file.

Block grade estimation in Vulcan can calculate as either separate or batch process. In this case, since that there were five minerals to be analysed the batch process was the option used to estimate the block grade for complex blocks. As indicate already during the construction phase of the blocks model **3 329 391** blocks were created each block describe by 46 variables. The block by block estimation results are presents in the Appendix and on the filename Block_Block_Estimation.xlsb.

Figure 3.28 shows the two different blocks reports results when the individual block variables were inquired then transfer into a CSV or ASCII format. Some of the notable information on those reports are the original location of the block and the block identity, the geometrical centre and the dimension of the block, the geology categories the choice between the three-defined geology (air, rock, tailing), and the block grade estimate along with other variables.

In this case, two blocks data report were inquiring at same level but one must be tailing geological characteristics deposit while the other has a rock geological characteristic that means natural bedrock. The dimension of the two block is different mainly because the all the blocks within the tailing geological were bid to 1 m x 1 m x 1m while the other vary up to 50 m x 50 m x 50 m. The value of -99.00 in both the reports and block model display is an indication that the block did not meet the requirement set up or it fall out of the boundaries. . Figure shows 3.29 and 3.30 average grade value of copper displayed in the block model at 460 m level for each block.

```
origin      =   35598.559    50794.579     460.000
centroid    =   35598.5000   50794.5000    459.5000
sides       =       1.0000       1.0000      1.0000
volume      =       1.0000       1.0000
id          =     1340617
geology     =     tailing
cu_nn       =     0.460000
cu_ivd      =     0.287633
zn_nn       =     1.480000
zn_ivd      =     0.763637
w_nn        =     0.460000
w_ivd       =     0.342961
fe_nn       =    26.879999
fe_ivd      =    16.162680
as_ivd      =    11.615888
as_nn_dist =    15.482821
as_ivd_pass =             2
as_nn       =    13.890000
as_ivd_nholes =             6
as_ivd_nsamples =            16
as_ivd_mean =    11.200000
as_ivd_sd   =     5.971101
as_ivd_avg_dist =    31.869574
cu_nn_dist =    15.482821
cu_ivd_pass =             2
cu_ivd_nholes =             6
cu_ivd_nsamples =            16
cu_ivd_mean =     0.305000
cu_ivd_sd   =     0.228719
cu_ivd_avg_dist =    31.869574
fe_nn_dist =    15.482821
fe_ivd_pass =             2
fe_ivd_nholes =             6
fe_ivd_nsamples =            16
fe_ivd_mean =    15.606250
fe_ivd_sd   =    10.171347
fe_ivd_avg_dist =    31.869574
w_nn_dist   =    15.482821
w_ivd_pass =             2
w_ivd_nholes =             6
w_ivd_nsamples =            16
w_ivd_mean =     0.338125
w_ivd_sd    =     0.137805
w_ivd_avg_dist =    31.869574
zn_nn_dist =    15.482821
zn_ivd_pass =             2
zn_ivd_nholes =             6
zn_ivd_nsamples =            16
zn_ivd_mean =     0.731250
zn_ivd_sd   =     0.735007
zn_ivd_avg_dist =    31.869574
```

```
origin      =   35743.447    50725.016     460.000
centroid    =   35743.5000   50731.5000    462.5000
sides       =      11.0000      35.0000      5.0000
volume      =    1925.0000    1925.0000
id          =     1285382
geology     =        rock
cu_nn       =   -99.000000
cu_ivd      =   -99.000000
zn_nn       =   -99.000000
zn_ivd      =   -99.000000
w_nn        =   -99.000000
w_ivd       =   -99.000000
fe_nn       =   -99.000000
fe_ivd      =   -99.000000
as_ivd      =   -99.000000
as_nn_dist =   -99.000000
as_ivd_pass =             0
as_nn       =   -99.000000
as_ivd_nholes =             0
as_ivd_nsamples =             0
as_ivd_mean =   -99.000000
as_ivd_sd   =   -99.000000
as_ivd_avg_dist =     0.000000
cu_nn_dist =   -99.000000
cu_ivd_pass =             0
cu_ivd_nholes =             0
cu_ivd_nsamples =             0
cu_ivd_mean =   -99.000000
cu_ivd_sd   =   -99.000000
cu_ivd_avg_dist =     0.000000
fe_nn_dist =   -99.000000
fe_ivd_pass =             0
fe_ivd_nholes =             0
fe_ivd_nsamples =             0
fe_ivd_mean =   -99.000000
fe_ivd_sd   =   -99.000000
fe_ivd_avg_dist =     0.000000
w_nn_dist   =   -99.000000
w_ivd_pass =             0
w_ivd_nholes =             0
w_ivd_nsamples =             0
w_ivd_mean =   -99.000000
w_ivd_sd    =   -99.000000
w_ivd_avg_dist =     0.000000
zn_nn_dist =   -99.000000
zn_ivd_pass =             0
zn_ivd_nholes =             0
zn_ivd_nsamples =             0
zn_ivd_mean =   -99.000000
zn_ivd_sd   =   -99.000000
zn_ivd_avg_dist =     0.000000
```

Figure 3. 28. Blocks variables reports

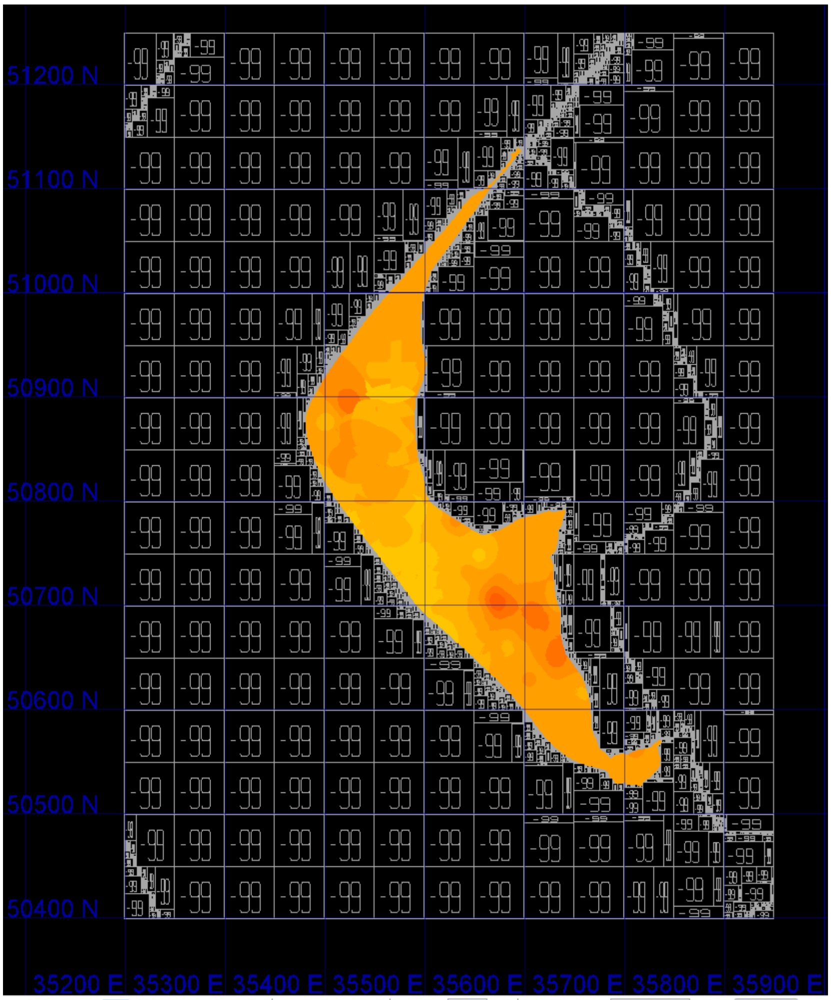


Figure 3. 29. Typical full grade block model copper estimation - vertical sections layout – 460 Level

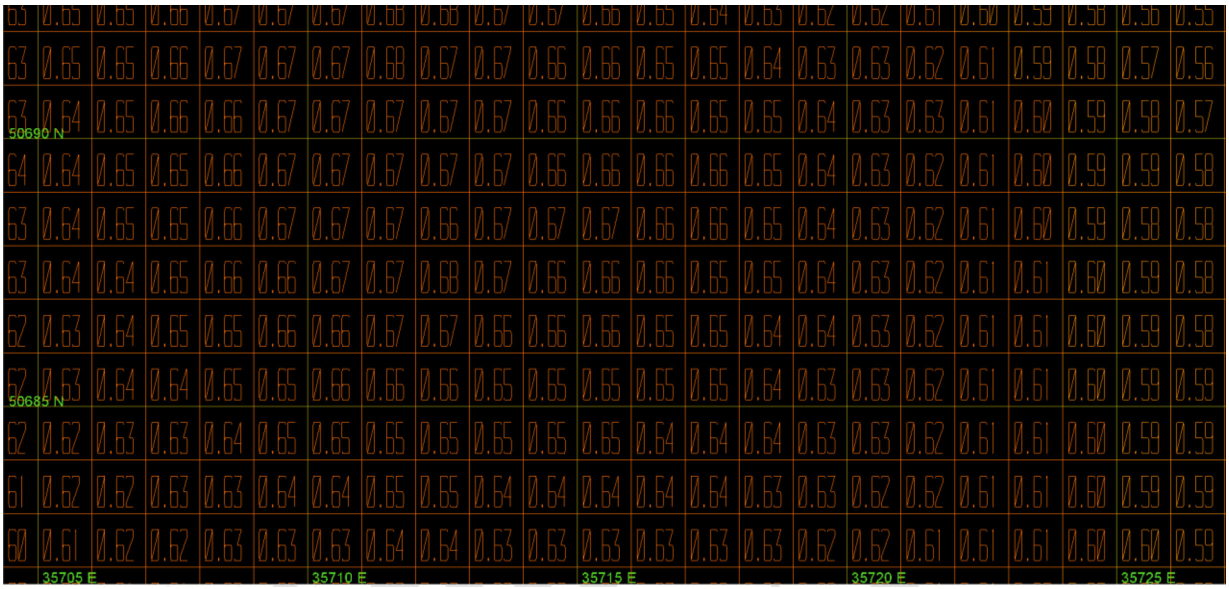


Figure 3. 30. Typical sectional tailing grade block model copper estimation - vertical sections layout – 460 Level

3.4.5. Tailing resource estimation

After the block average grade estimation was completed, the total resource for the tailing deposited was calculate. The resource estimation, in this case, is refer to a quantity of the tailing materials deposited on the area under study over the years referred from 1955. The resource was estimated without a cut-off grade and the density was assumed as 2.7 tonne per metre cube to normalise the data to mass or simple to deal with the volume than mass. As it has already mentioned all blocks within the tailing geological setting were created with 1 m x 1m x 1 m dimension to obtain a representative mining resources this was done to increase the results accuracy and minimise the estimation time of the computer. In this estimation Table 3.9 present the commodities quantitative data in the resource as the maximum and minimum average grade; average grade estimated and total mineral volume. The resource estimation was calculated based on with both the nearest neighbour method and inverse distance square.

Table 3. 9. Nearest neighbour and Inverse distance square method resource estimation

Inverse Distance Square Estimation						
Minerals	% Min grade	% Max grade	% Average grade	Tailing volume (m^3)	Tailing mass (t)	Minerals resources (kg)
As	0.384	23.631	11.857	3036931	8199714	972240053
Cu	0.049	1.041	0.424	3036931	8199714	34766786
Fe	0	31.16	17.075	3036931	8199714	1400101114
W	0.031	0.848	0.324	3036931	8199714	26567072
Zn	0.004	2.545	0.92	3036931	8199714	75437366
Nearest Neighbour Method Estimation						
Minerals	% Min grade	% Max grade	% Average grade	Tailing volume (m^3)	Tailing mass (t)	Minerals resources (kg)
As	0.31	24	11.672	2632143	7106786	829504074
Cu	0.03	1.16	0.395	2632143	7106786	28071805
Fe	0	31.28	14.341	2632143	7106786	1019184195
W	0.03	0.87	0.332	2632143	7106786	23594530
Zn	0	2.78	0.934	2632143	7106786	66377382
Difference in Estimation						
Minerals	% Min grade	% Max grade	% Average grade	Tailing volume (m^3)	Tailing mass (t)	Minerals resources (kg)
As	0.074	-0.369	0.185	404788	1092928	2021916
Cu	0.019	-0.119	0.029	404788	1092928	316949
Fe	0	-0.12	2.734	404788	1092928	29880641
W	0.001	-0.022	-0.008	404788	1092928	-87434
Zn	0.004	-0.235	-0.014	404788	1092928	-153010

The average resource estimated grade values when estimated with the nearest neighbour method are 11.672 % As, 0.395 % Cu, 14.341 % Fe, 0.332 % W and 0.934 % Zn. On the other hand, by using the inverse distance square method the average grades of As, Cu and Fe were estimate high compared to the nearest neighbour with 11.857 %, 0.424 % and 17.075 %, respectively. Wolfram and zinc average grade were also estimated to be lower as 0.920 % and 0.324 %, when compare to the nearest neighbour.

The total in-situ resource of Rio tailing dam was estimated to be 3. 037931x 10^6 m^3 by using the inverse distance square while with the nearest neighbour method it is estimated to be lower as 2.632143 m^3. The difference between the estimated values was calculate as shown above in the Table 3.9.

Warning*: 'Estimates are not reality; they are subject to error, the magnitude of which depends on the nature and quantity of sample information, spatial pattern, area to be estimate and the estimation method applied''* (Diehl and David 1979)

3.5. Planning and Extraction Design for tailing

The second objective of this study was to develop and design a mining extraction plan for the tailing resource for the deposited materials that should be transported to the processing plant. The planning and design of the resource start with the block model preparation that defines the in-situ resource, pit design and production scheduling using Vulcan Modeller and MineMondeller Open Pit to produced designs and plans are as practical as possible.

3.5.1. Block Model Preparation

The construction and the preparation of the geological block model have been discussing in detail in already in the previous section this is the base block model. The aim was to quantify the materials. The three triangulations used constructed block model: 1955 surface topography triangulation (1955T) merge with the 2017 surface topography triangulation (2017T) and solid triangulation (2017SPT).

To define the boundaries (partial) of the tailing materials within the block the boundaries options under the block construction was applied attributes to blocks based on their position relative to triangulation. In addition, this option allows the sub-blocking process to the block model. The process of allocating the block the attribute achieved by defining the triangulation variable, values, and priority, inversion and projection axes. The variables are attributes that the block must define this include grade, geology and directions. The value names are used to assign the area to solve area of conflict between triangulation. Once the materials defined with values names they are given priority level based on of the triangulation and inversion. The boundaries priorities level and inversion are an instruction to the blocking process of the correct geological relation between the various entities made up the resources.

In this case, the 1955 surface topography triangulation (original_topo_fix_04.00t aka 2017SPDT, 1955T) was given the value air with priorities 1 and inverse partial meaning to partial the block into in such a way that area above the classified as air while the one below as rock. The 2017 surface topography triangulation (topo_scan.00t shown in Figure 3.32 & 3.36 with model reddish colour) was assigned as the rock value with priority 2 without inverse define that the area beneath is rock. Waste solid triangulation model (waste_solid.00t shown in Figure 3.33) the merge product of the 1955 surface topography triangulation and 2017 surface topography triangulation that was assigned a tailing value with a priority of 2 without inverse which means all the materials were classified as tailing corresponding to the deposition of the tailing materials from as early as 1955 to 2017. All the triangulations were projected along the Z-axis to define the direction of a surface this was done because projecting on another axis it may cause the effect on the solid triangulation (see Figure 3. 32). For this study, the tailing materials study are assumed that they are homogenous materials.

Generally, the entire block model has the non-regular structure with the blocks size varies with the minimum dimensions of 1 m x 1 m x 1 m and maximum 50 m x 50 m x 50 m as already state in 3.2.1. However, as it is also mention concern the blocks within the tailing geological they were restricted constructed with the dimension of 1 m x 1 m x 1 m this was generally for estimation purpose.

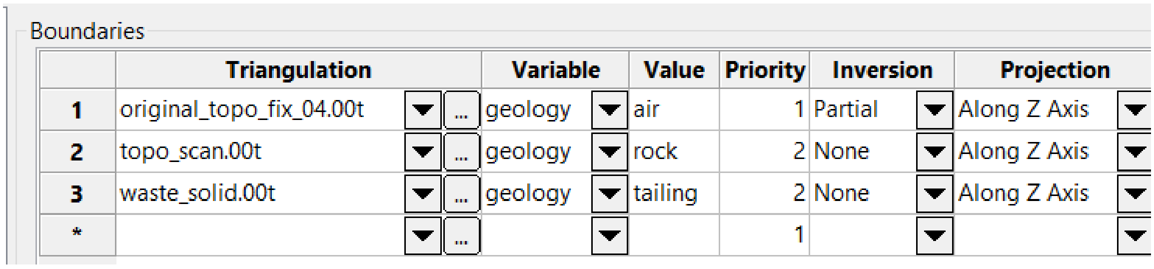


Figure 3. 31. Block model boundaries, priorities, inversion and projection

Based on the block model construction and preparation the in-situ resource was able to be determined as shown in Table 3.10. The block model volume is 850 x 650 x 250 (length x width x thickness) cubic metres in which 82.51 x 10^6 m^3 air, 52.58 x 10^6 m^3 rock and 3.04 x 10^6 m^3 deposited tailing. The minerals concentration was also estimated already and also presented with a high content of Fe at 17.075% and the lowest average concentrate mineral found on the resource is W with 0.324%. In this case, the density of materials use was keep as a default value at to simplify the calculation 1 tonnes per cubic again.

Table 3. 10. Estimate resource mineable report

Inverse Distance Square Estimation							
Block source	Geology	% As	% Cu	% Fe	% W	% Zn	Tailing volume (m^3)
rio_dump.bmf	air	0.000	0.000	0.000	0.000	0.000	82508012.000
rio_dump.bmf	rock	0.000	0.000	0.000	0.000	0.000	52577491.000
rio_dump.bmf	tailing	11.857	0.424	17.075	0.324	0.920	**3039497.000**

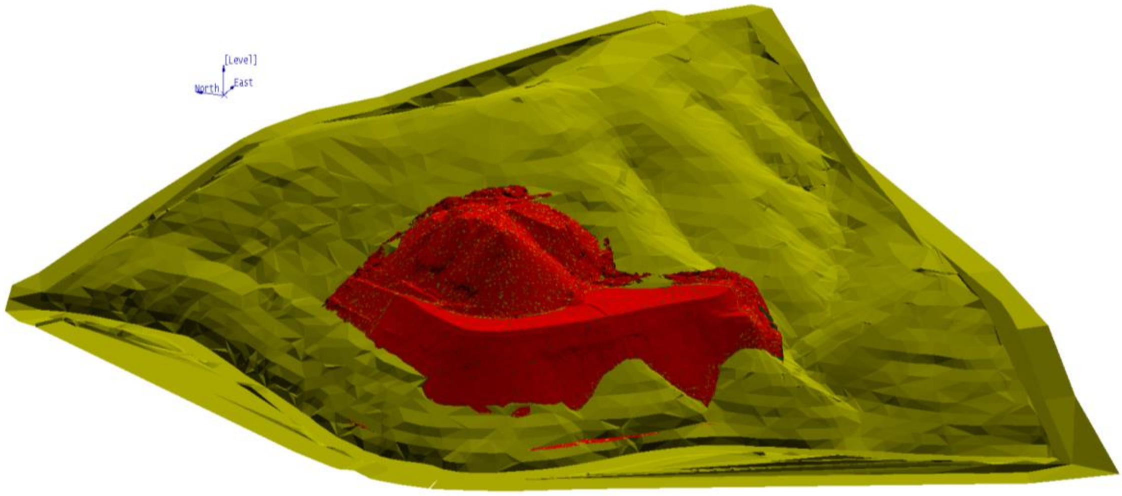


Figure 3. 32. Rio topography with tailing deposition model

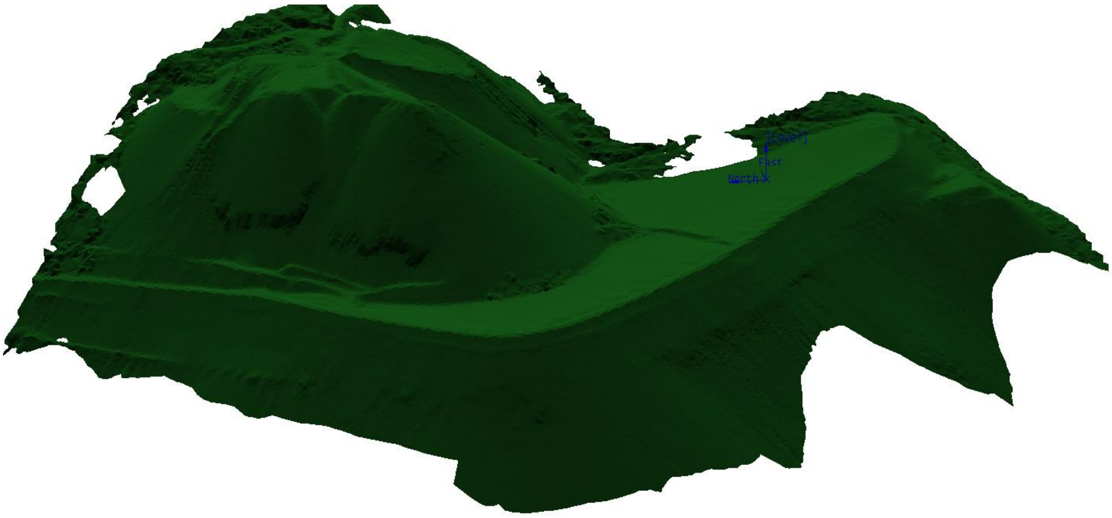


Figure 3. 33. Tailing deposit resources model

3.5.2. Extraction design

3.5.2.1. Dam structure

The in-situ resource of the tailing dam was determined as 3 039 x 10^6 m^3 and it covered top surface area of about 120 000 m^2 and the based floor area (previous area) was about 269 000 m^2.

The dam has an average strike of 350°, average dip 35° Left, average dip direction 250°, plunge average 1.061, average pitch 1.925° with the average slope length of 160 m and average height 90 m as well as the longest surface length about 435 m. The dimension of the dam is shown in Figure 3.34 and Table 3.11. The materials deposited were assumed to be homogenous and this consist of 3 039 4997 blocks each with 1 m x 1 m x 1 m.

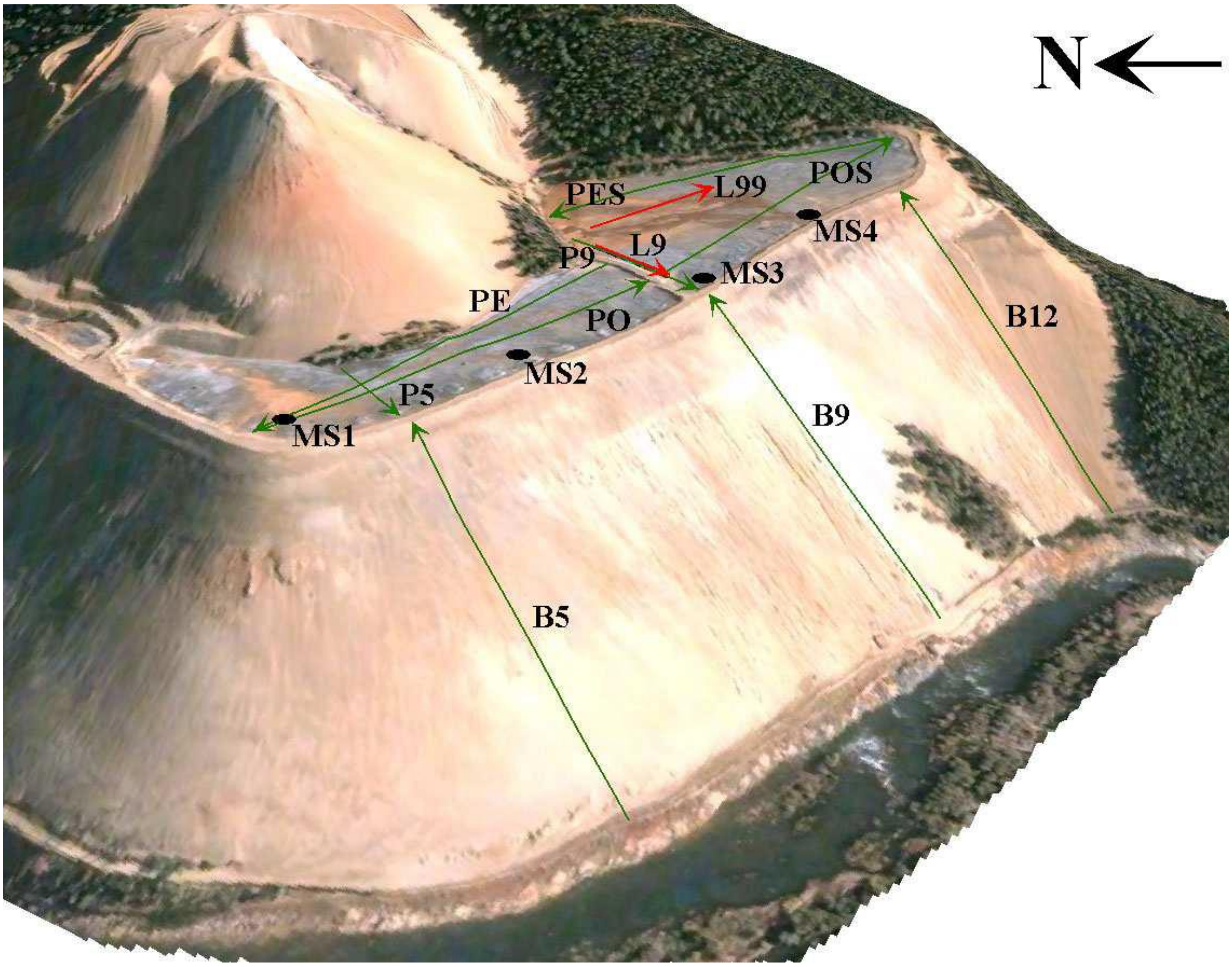


Figure 3. 34. 3D tailing dimension structure (Grangeia et al. 2009).

Table 3. 11. Tailing dimension

Profile lengths	Total length (m)
PE	216
PO	220
P5	52
P9	87
PES	207
POS	209
B5	184
B9	186
B12	200

3.5.2.2. Pit boundary

To extract the right materials, the surface limits were defined at the top surface and at the bottom of the dam. Vulcan has many design tools that can be used to design the pit boundaries, and in this case, the option tool used was the open cut design to design a pit structure using the top-down approach.

The determination of the surface boundaries is normally the first step in the process pit or mine design. The surface boundary of the pit was created with the polygon string that was digitised and register onto the topography surface of the dam as a crest of the pit. The bottom boundaries were controlled by the interface of the mainland surface and the river as shown in Figure 3.35 and 3.36.

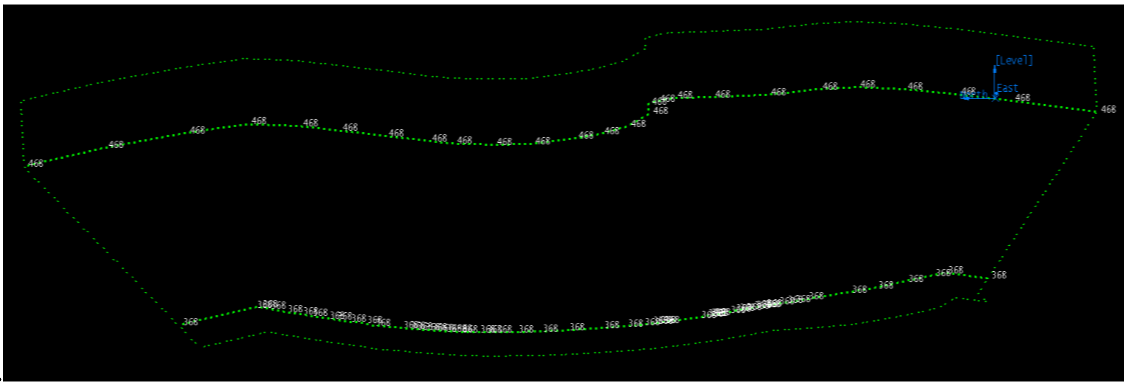


Figure 3. 35. Pit boundaries polygon

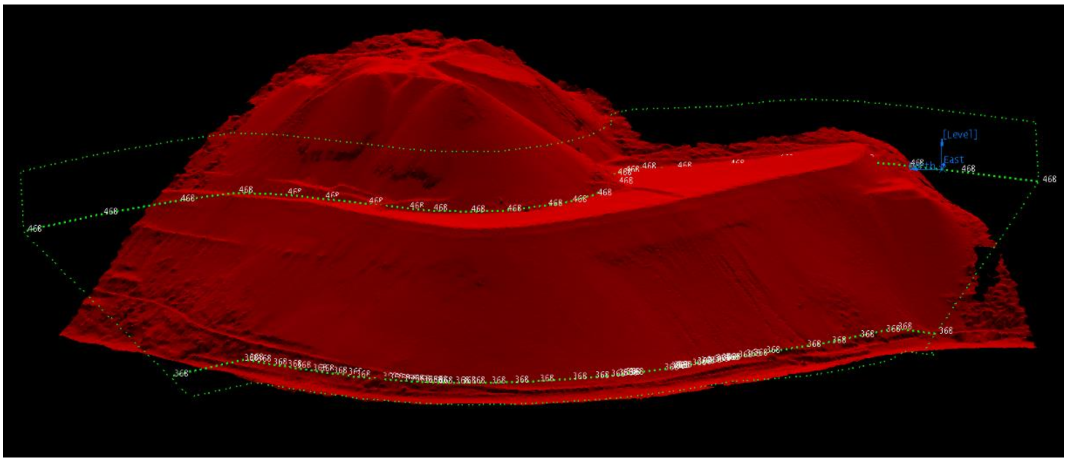


Figure 3. 36. Pit boundaries on the tailing topography model

3.5.2.3. Bench and berm design

The pit benches were designed as per bench elevation at height 10 m with the at least batter angle of 35° and vary berm width. To create the bench crest and toe at every 10 m altitude this was design with aid of Vulcan tools under the flag toe/ crest string by starting with the top surface boundary polygon-string that was created at the right elevation as a crest string of the pit. The bench width is created by defining the batter angle and berm width before the polygon string is projected to the next elevation to obtain the strips crest. The process continues until the pit bottom limits are reached. Figure 3.37 and 3.38 illustrate the sectional layout design of the benches.

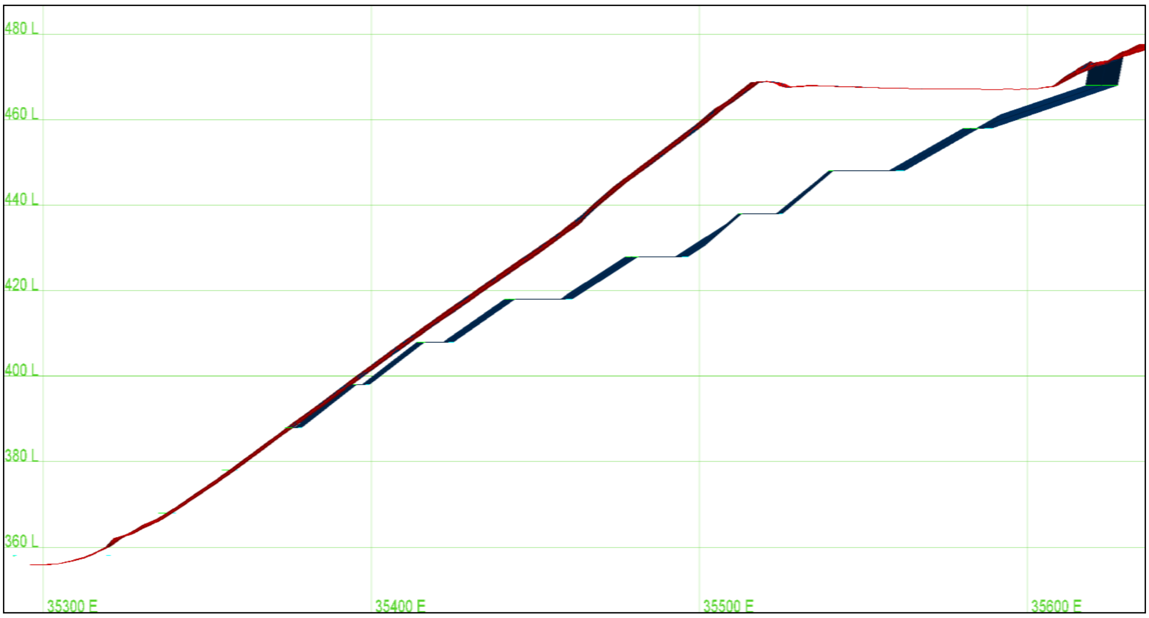


Figure 3. 37. The cross sectional showing bench layout (Pit resource)

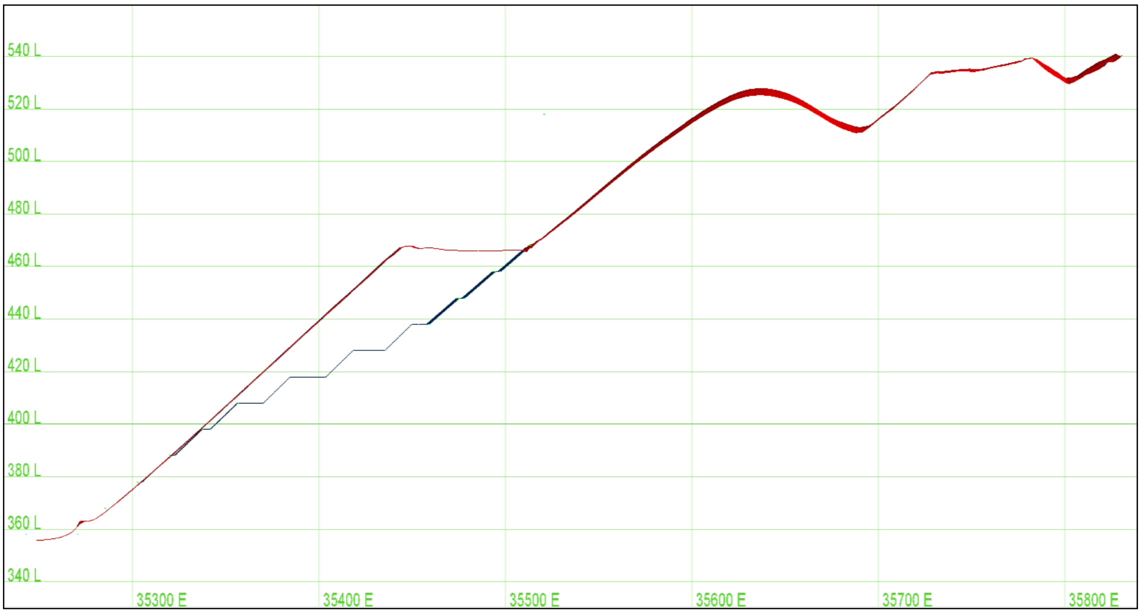


Figure 3. 38. The cross sectional showing bench layout (Entire tailing resource)

3.5.2.4. Strip Design

In total 21 polygon strings of crest and toe were created on the topography in strike direction of the dam at the interval height of 10 m with the slope angle about 35° and strip berm at least 2.5 m projected on each following bench grid. Figure 3.39 shows the polygon projected design of the benches while Figure 3.40 present the model of the strip after the strip was converted to create the surface triangulation model that was used in the next stage as the bench.

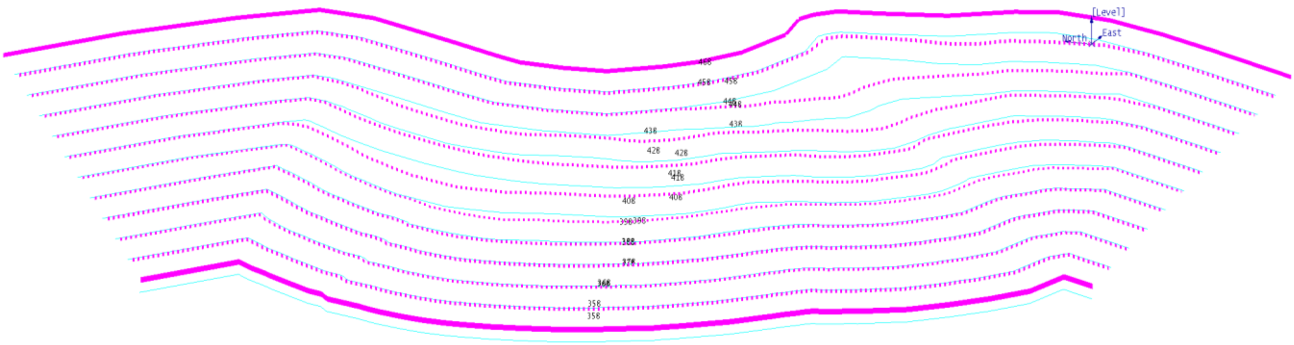


Figure 3. 39. Strip polygon of the pit design

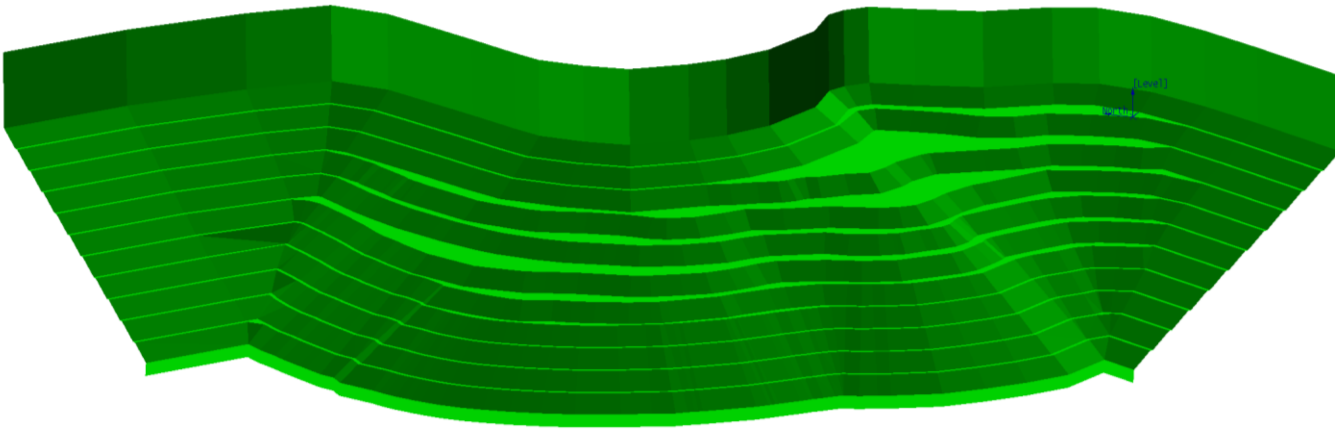


Figure 3. 40. Pit strip design triangulation model

3.5.2.5. Pit Design - Boolean

To design the pit or cut on the topography with the objective to extract the mineable materials target it is illustrated in Figure 3.40 and 3.41. The operation illustrates in that figure is known as Boolean in Vulcan. This is actually the option that cut/creates a solid by intersecting the two solid triangulation or surface triangulation. The triangulations model used in this process were the 2017SPDT, 1955T and 2017T. The procedure to create the pit cut by Boolean start with the validity of the triangulations then use the Exclude option on the Boolean to select the triangulation portion that must be retained than the one aimed to be reject. Secondly, the Invert Boolean option is used to invert to form a solid and reject other parts that have to be excluded. In this case, the reject part is the mined resourced that is shown in Figure 3.42.

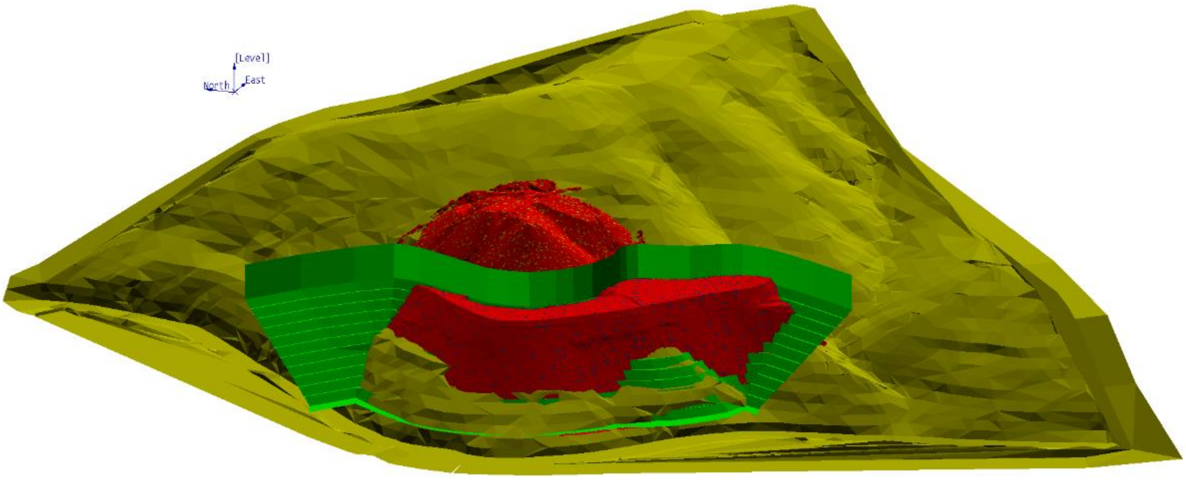


Figure 3. 41. Pit formation model by Boolean method

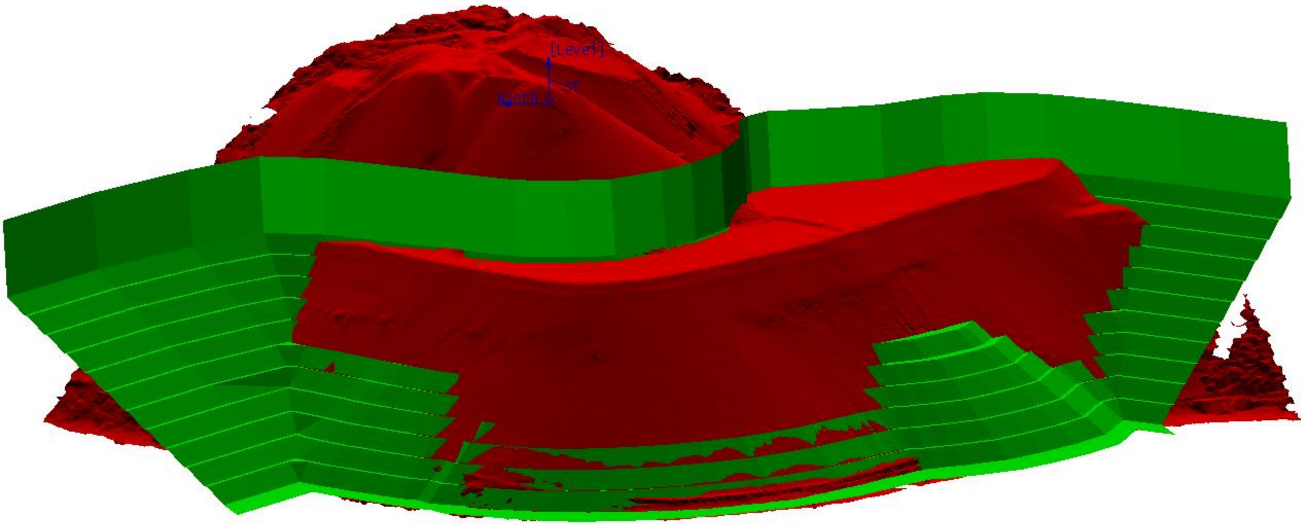


Figure 3. 42. Typical Pit formation model Boolean method – Intersecting triangulation

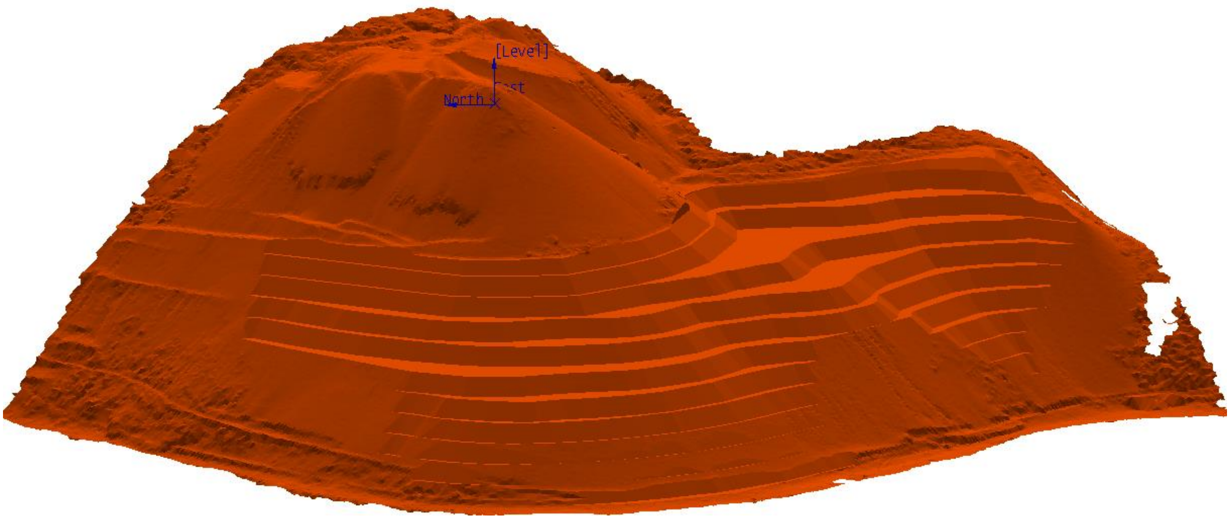


Figure 3. 43. Typical new pit formation model

3.5.2.6. Mineable resources calculation

The mineable resource was calculated based on 10 m height bench layer and the extraction design of the tailing materials on the dam. There was no cut-off grade used, as it was a matter of maximising the extraction all the sulphide-arsenic materials within the pond dam for processing purposes. Figure 3.44 illustrate the mineable resource in the different colour based on benches or layer on the topography of the area of the site while Figure 3.45 shows only the mineable resource volume of the 12 benches. The mineable resources volume is presented in Table 3.12 as calculated per bench as well as the average grade for the five minerals. As mentioned already there was no cut-off grade used to calculate this resource as the main objective is to extract the fully all the tailing materials on the pond of the dam. The results have shown that the bottom two bench 358L and 368L have no concentrate minerals to be extracted even through is part of the blocks that made up the total volume 1 317 357.61 m^3. For the 10 benches, the highest mineable volume is at bench 458L with a volume estimated to be 354 045.15 m^3 while the lowest mineable volume is at bench 378L estimated to be 69.52 m^3. The average concentration of minerals on the mineable resources varies from bench to bench, this evidence as the high concentration of minerals at the top bench and low concentration level at the bottom benches. The mineable resource has the average grade of 11.82% As, 0.41% Cu, 17.21% Fe, 0.31% W and 0.89% Zn.

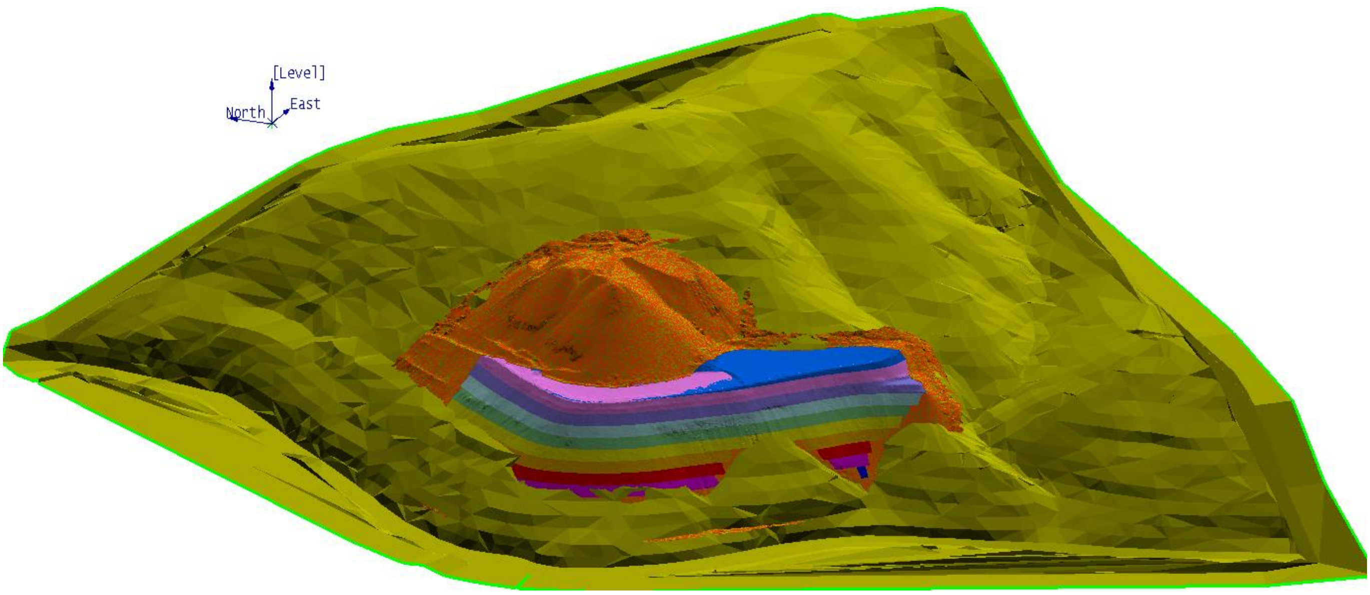


Figure 3. 44. Mineable resources model

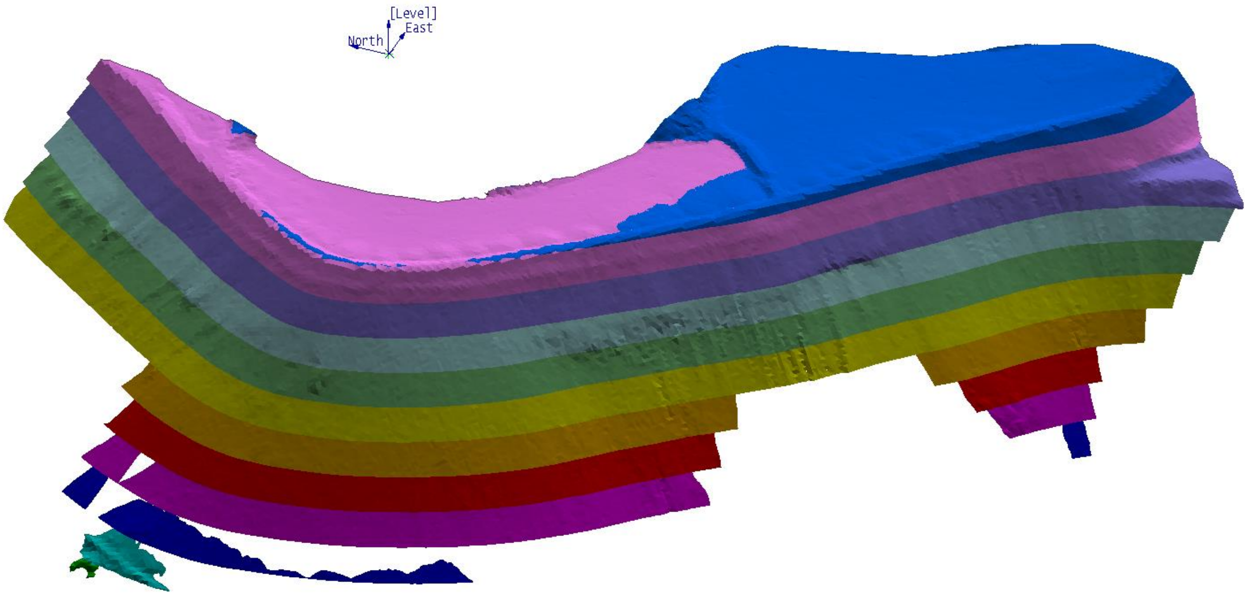


Figure 3. 45. Mineable resources model

Table 3. 12. Mining resource calculation of optimum per bench report

Mineable resources/reserve per bench							
Bench	Geology	% As	% Cu	% Fe	% W	% Zn	Tailing volume per bench (m^3)
358L	tailing	0.00	0.00	0.00	0.00	0.00	0.00
368L	tailing	0.00	0.00	0.00	0.00	0.00	0.00
378L	tailing	10.56	0.31	8.13	0.35	0.67	69.52
388L	tailing	9.49	0.31	9.86	0.33	0.68	1696.15
398L	tailing	9.82	0.35	13.65	0.32	0.74	12507.57
408L	tailing	10.08	0.36	14.03	0.32	0.76	39439.87
418L	tailing	10.68	0.38	15.33	0.32	0.80	106553.38
428L	tailing	10.84	0.38	15.30	0.31	0.81	166306.38
438L	tailing	10.74	0.37	14.96	0.31	0.80	241923.72
448L	tailing	11.29	0.39	16.40	0.30	0.83	340179.25
458L	tailing	13.59	0.46	20.45	0.33	1.05	354045.15
468L	tailing	15.37	0.46	23.97	0.27	1.12	54636.62
Total mineable resources/reserve							
Rio_dum	tailing	11.82	0.41	17.21	0.31	0.89	1317357.61

3.5.2.7. Final pit shape

Once the mineable resource of 1 317 357.61 m^3 is extracted it is estimated that about 1 722 139.39 m^3 of coarse tailing materials will remain unexploited for the processing and this is shown in Figure 3.43 and 3.46 models. While Figure 3.47 present the contour map of the site as it assumed to be visual prior the habitation and the reshaping of the entire tailing dam slopes.

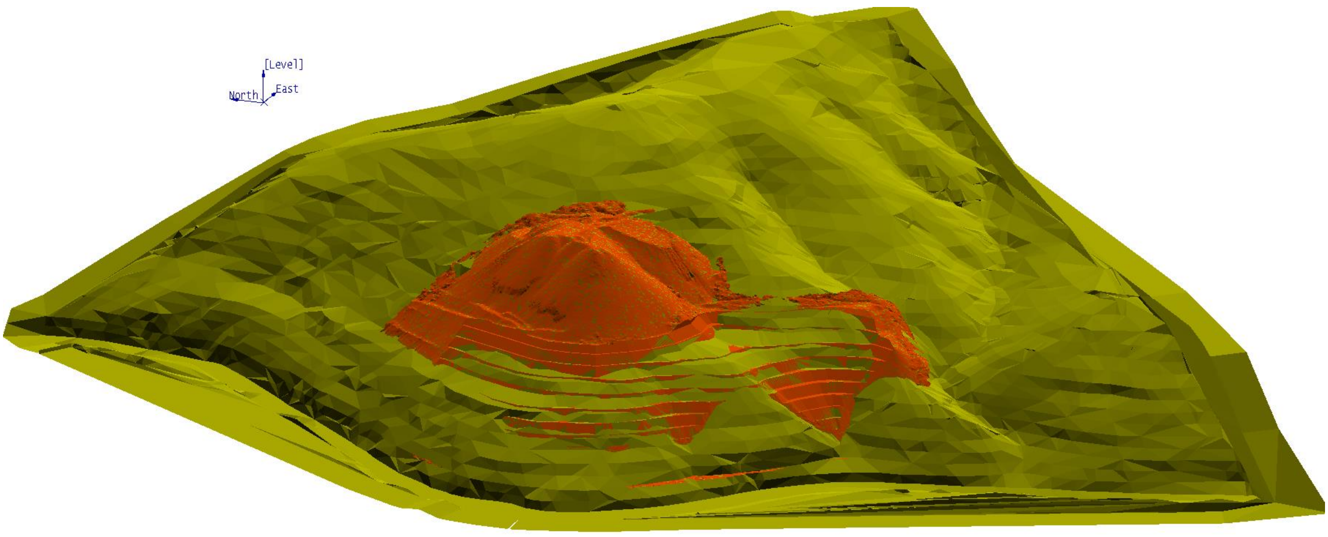


Figure 3. 46. Final model of the pit with coarse tailing unmined

Figure 3. 47. General aspect of the contour map of Rio tailing

3.5.2.8. Extraction method

It is envisage that the conventional approach of direct excavate-loading-haulage and dumping truck will the best option to mine of the Rio tailing resource. The trucks will transport from the tailing dam to the old processing plant that is locates at Rio processing plant as shown in Figure 3.51.

3.6. Remediation Planning of the Rio Tailing

Mining is a primary industry that based on the extraction of the valuable minerals parts on the earth's crust and majorities of the minerals are found in them non-native form this led to the need for further downstream processing such as flotation and dense medium separation. The separation of valuable mines from gauge leave millions of tonnes to know as tailing deposited near mining sites all over the world. The negative impacts of the deposited tailing both in term of environmental and social are some of the major threat to the ecosystem, especially to the water sources this is evidence as it has been discussed over the years by various authors and shit in mineral waste management policy all over the world. These negative impact often are due to the mining companies abandoning mining site due to the reason such as deposit depletion, relocation to new sites or economical reseasons. This impact is mostly observed only once the site is abandoned and no environmental control is carried out on the site.

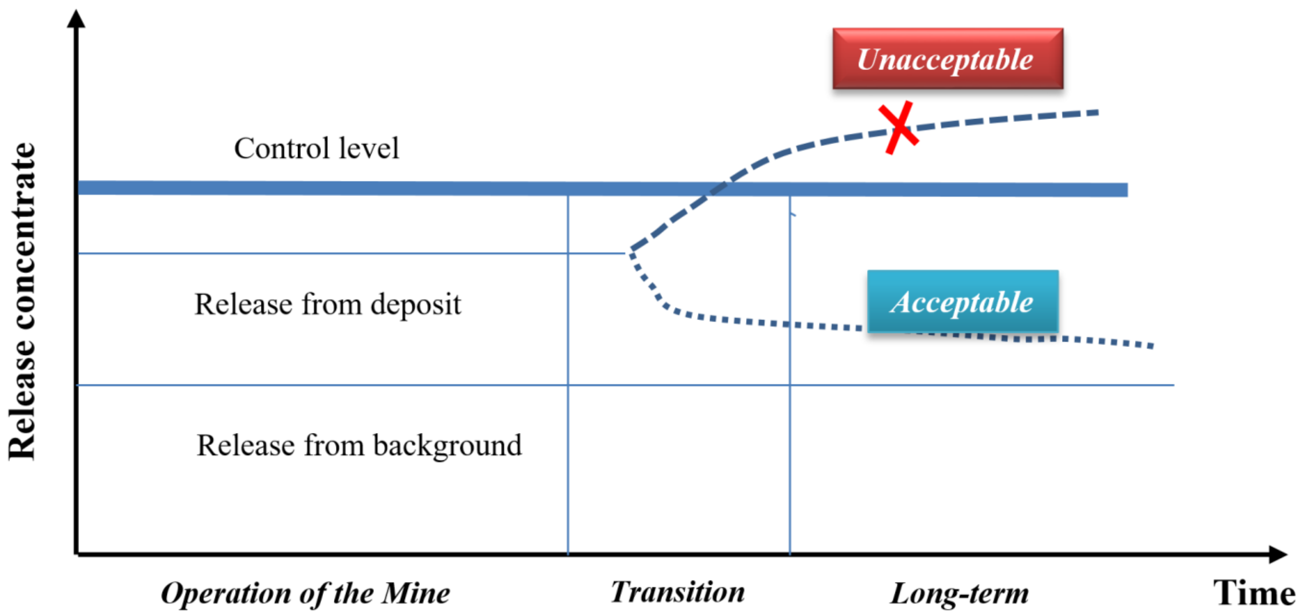


Figure 3. 48. Release levels of concentrate from an untreated tailings deposition

Figure 3.48 the illustration the general release of concentrate from tailing deposition and background over time into the river when the control is assumed applied. It shows that the acceptable and unacceptable condition when to apply a waste management control system. The impacts of the tailing deposit found on the banks of Zezere river at Rio town in the central of Portugal which is under study is one of the thousand sites around the world that is under threat of such unplanned deposited and abandoned tailing is an example of the unacceptable condition. The threat of Rio tailing is significant to the river is severe mainly due to the internal properties of the tailing that are not well defined and the harsh climate condition of the site.

It is known fact that to keep the release level and environmental impacts below control level during operation are normally not that challenges as the mining companies on site and dams are maintained, however, once the operation ceases this dramatically change sometime exponentially results on an environmental problem such as acid drainage and erosion. Due to the known negative environmental impacts as results of the existed of the tailing dam at Rio in this section the author aim is to discuss the proposed environmental remediation plan that aims to minimise further environmental impact and the release of contaminated due to the exist tailing dam and ensure that the dam slopes are stabilised for long-term to limit it potential risks failing and soil erosion. Human health hazards were related to ingestion of vegetation or water in the river is also a risk.

Generally, the is no a fix periodic frame on how the remediation proposed must last in place but it is always considered that such solution must last at least for more than 1 000 years if possible and the remediated site should become part of the environment. To understand the proposed solution to the environmental problems the author will start of with short belief about the current state of the site and tailing description, the proposed topography reshaped design and the top cover of the site. The proposed solution is expected to the removal of public safety concerns, provisions of a good medium for re-vegetation, implementation of erosional control methods to hasten water collection away from the site and limit water infiltration into the tailings all this must be achieved through a good design remediation plan and top cover of the tailing. Simple the remediation plan aims to address three aspects environmental safety, land productivity and aesthetics.

3.6.1. Assessment of the tailing materials and current infranstructure

According to the literature, Rio tailing is upstream tailing dam that was constructed around 1940s until 2001 as storage of the tailing from Panasqueira floatation processing plants. The volume of the deposit waste materials was estimated to be about 3.04 x 10^6 m^3 with an average density of 2.7 t/m^3 and cover top surface area of about 120 000 m^2 and the floor area about 269 000 m^2. The dam has an average strike 350°, average dip 35° Left, average dip direction 250°, plunge average 1.061°, average pitch 1.925° with the average slope length of 160 m and average height 90 m as well as the longest surface length about 435 m. The climate condition at the site that is a crucial factor on the dam stabilisation for Panasqueira region is very aggressive with hot and dry conditions during summer, and very cold, rainy and windy in the winter.

Based on the geochemical site investigation that was undertaken by Ávila, Da Silva, and Farinha (2007) the tailing dam has a varied grain distribution due to the successive finer grinding procedures and site climate condition. Figure 3.49 shows the topography image of the site and the tailing dam as well as the town of Rio were the processing plant was those years. The materials were usually classifieds as coarse sterile from the mine used for construction, the coarse tailing from the heavy media separation, sand, mud, and slush. The Rio tailing is known to contained abundant amounts of cordite, sphalerite, wolframite, quartz, nitrobarite, montmorillonite, ilitevermiculite, some silicates like kaolinite, and sulphate minerals. Rio tailing was also estimated to be have a high concentrate of heavy mineral they ranges are as follow: As (3 094 –240 000 mg kg^{-1}), Cd (28 – 4 028 mg kg^{-1}), Cu (78 –7 200 mg kg^{-1}), Fe (5.3 – 28.8 %), and Zn (142 – 27 000 mg kg^{-1})). Those values are based on the chemical analysis that was conducted on the six drill core materials from Dinis da Gama (2002) investigation report on Geotechnical and laboratory study of the tailings in the River Zêzere waste heap. The pond materials were described to have an average permeability about 3.6 x10^{-9} cm/s, the coefficient of consolidation also about 5.9 x 10^{-4} cm^2/s.

Figure 3. 49. Cabeço do Pião district and Rio tailings deposit image (Source: Google Earth image)

It is also reported that due to the expose of the tailing and the impoundment to the harsh weather condition, surface runoff and percolation of precipitation are the main influence factors of leaching of the tailing that led to acid mine drainage that pollute Zêzere river. The unsuccessful provisions wastewater canal that was built around the tailing to collected and treated before pumping them back into river has be flooded and proof not effective at all at this stage this the same to the drainage pile within the dam that is not functioning.

3.6.2. Slope reshaping

It has already demonstrated in section 3.5 that about 1.317 x 10^6 m^3 tailing materials will be extracted for reprocessing to recover copper or zinc or both minerals concentrate. Once the valuable minerals are extracted from the mud for copper and zinc the residual materials will be transported by conveyor or truck, redeposited, spread and compacted to form an unsaturated tailings deposition. This process involved dewatering tailing using vacuum and pressure filter so the tailing can be stacked this led to the water saving, reduced the environmental impact in term of space used, leave the tailing in dense and stable arrangement, and eliminated the long-term liability that the ponds leave. This type of tailings storage produces a stable deposit usually referred to as ‘dry stack. This is the first step to reduce the concentrate of minerals on the tailing materials for benefit of the environment. A moisture content of less than 20% can be achieved by using a combination of belt, drum, horizontal and vertical stacked pressure plates and vacuum filtration systems (Martin et al. 2002). Nevertheless, to ensure that the tailing materials are redepositing on the environmental and safely manner a proposed dam slopes reshape design was done as part of the rehabilitation plan as an immediate remediation measured applied to minimise potential risks of slope failing and erosion control as well as create the drainage system to reduce the water procuration.

The procedure of reshaping proposed involve the unexcavated tailing 1.721 x 10^6 m^3 sand tailing that will be pushed forward to downward to fill up the void with the dozers and the initial extracted volume of 1.317 x 10^6 m^3 (3.56 x 10^6 tonnes) mud materials that reprocessed. To calculate the total quantity of materials to be redeposited from the reprocessing plant plus the unprocessed remined volume based on the interest recoverable minerals taken an example of zinc. The example of zinc with average grade of 0.89% (8.9 kg/t) and the total mineable volume of the resource is 1.317 x 10^6 m^3 and assuming the processing plant recovery as 85%.

Total volume of zinc mined	=	Average grade of zinc x total mineable volume x density
	=	8.9 kg/t x 1.317 x 10^6 m^3 x 2.7 t/ m^3
	=	31 656 tonnes of zinc

Total volume of zinc recovered	=	Plant recovery x Total volume of zinc mined
	=	85% x 31 656 tonnes
	=	26 907.688 tonnes
	≈	27 000 tonnes

The calculations were carried out to demonstrate that even if the tailing materials reprocess the recoverable mineral volume is about 1% of the total volume planned to be excavated. It is clear that such a volume change is minimum even with dilution it will not affect the assumption that the same volume of tailing re-deposited on the site and reshaped.

The reshaping process is illustrated in Figure 3.50 by the arrows which showing the direction on which the tailing materials should be push or drag depend on the equipment on the process of the slope construction. The figure also shows the direction on how the materials move in which the tailing is transport by trucks to the plant and transported by conveyor or truck, redeposited, spread and compacted to form an unsaturated tailings deposition on the area indicate in the figure.

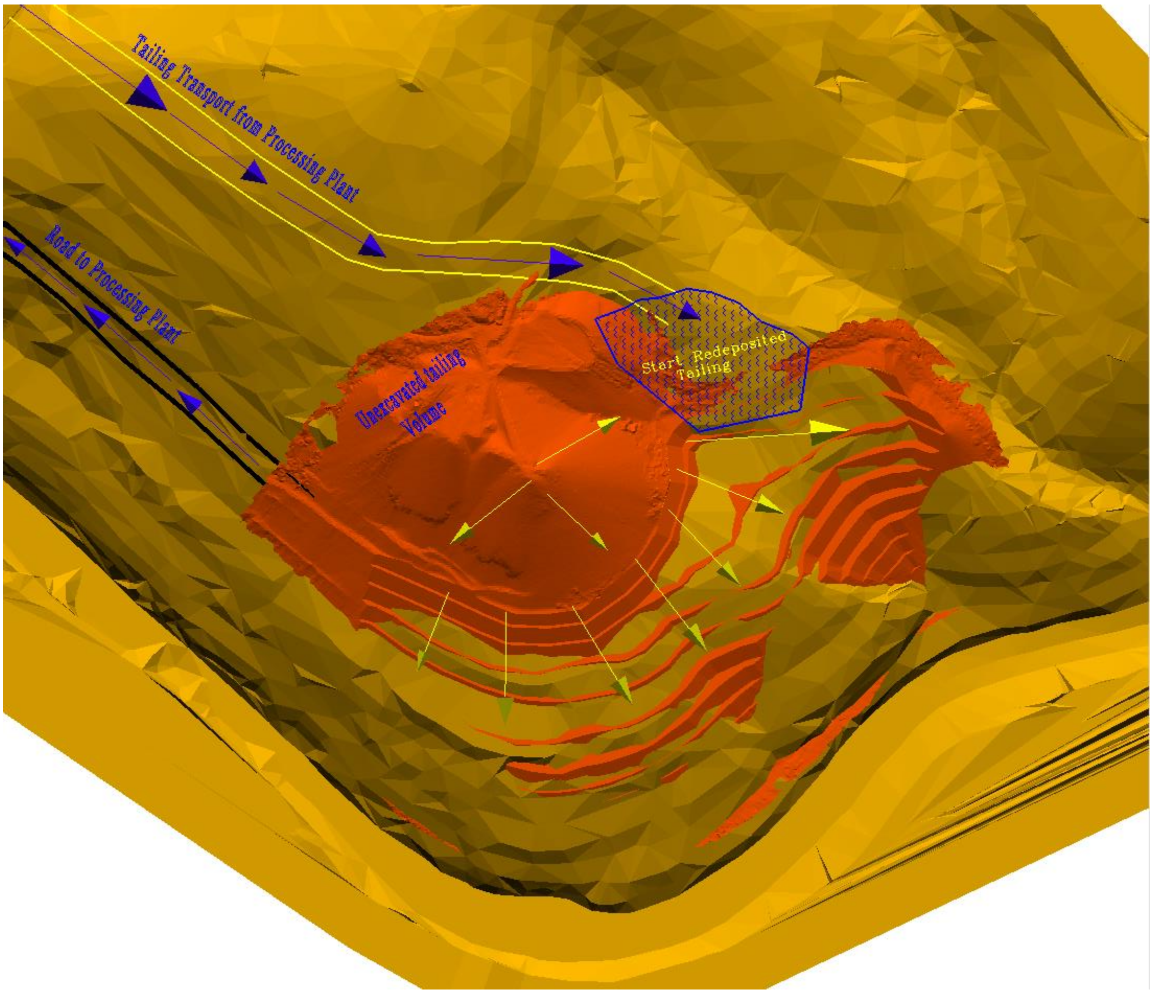


Figure 3. 50. Reshaping process demonstration and transport system

. Figure 3.51 present the final proposed reshape slope model that was constructed in benches. The slope is designed as per bench elevation at 10 m height with the at least 25° batter angle and vary berm width 5-6 m. It is clear to state that the total volume of tailing to be reshape will be almost equal to the original tailing volume of 3.04 x 10^6 m^3 that will cover a surface area at least 470 00 $m^{2.}$

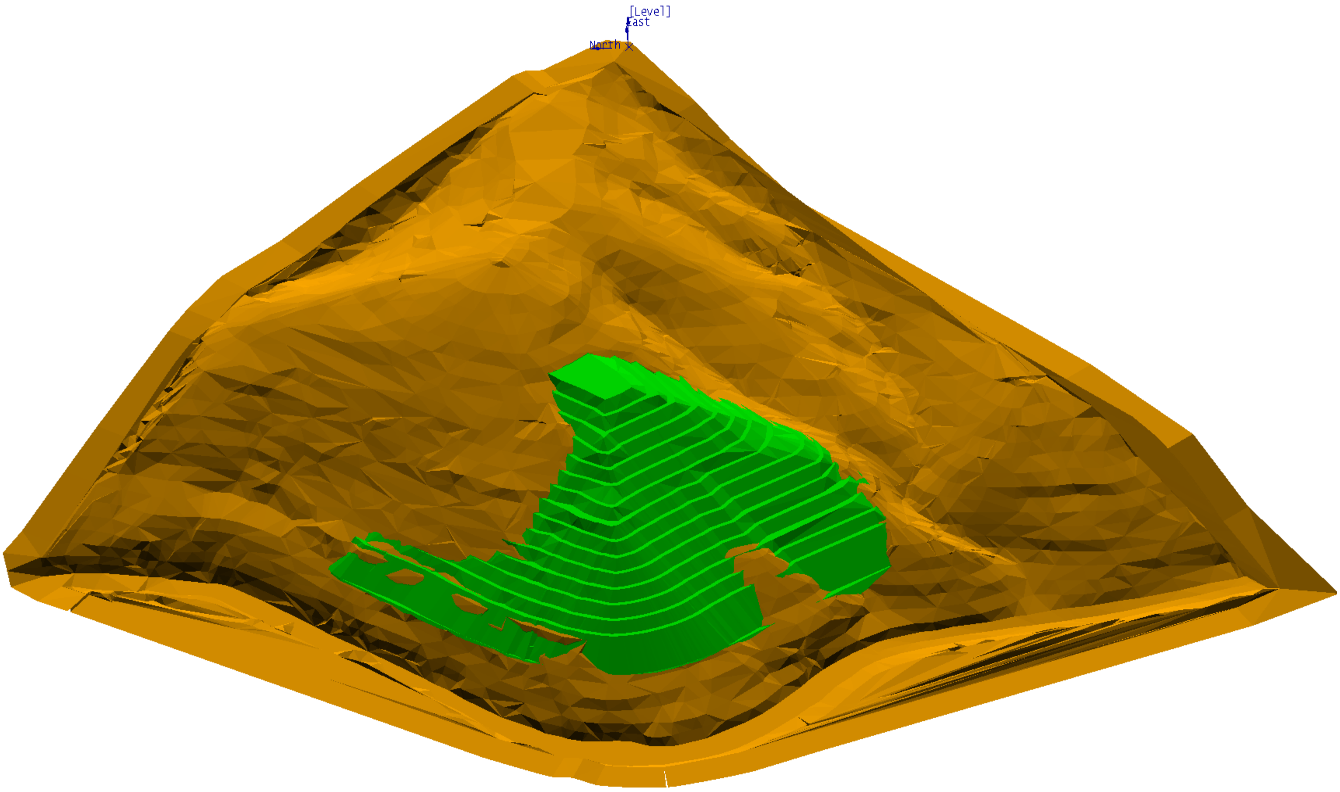


Figure 3. 51. Final Reshape slope model proposed

To display the reshaping slope design structure and analyse the slope a cross-section view was create from the plan view model as shown in Figure 3.52 and the sectional view as shown in Figure 3.53 with X-X line.

3.6.3. Cover for waste

3.6.3.1. Overview of tailing cover

Hart and Lassetter (1999) define tailing cover as a material that conceals the surface of mining by-products to assure that groundwater and surface environment will not degrade in the future. Cover system are essential part of waste management units to contain waste and waste materials (acid mine drainage, gas), to control moisture and air infiltration in waste and to prevent occurrence of odour, diseases vector, dust and air pollution and to prevent animal's accidences as well as provide a good environmental for vegetation growth.

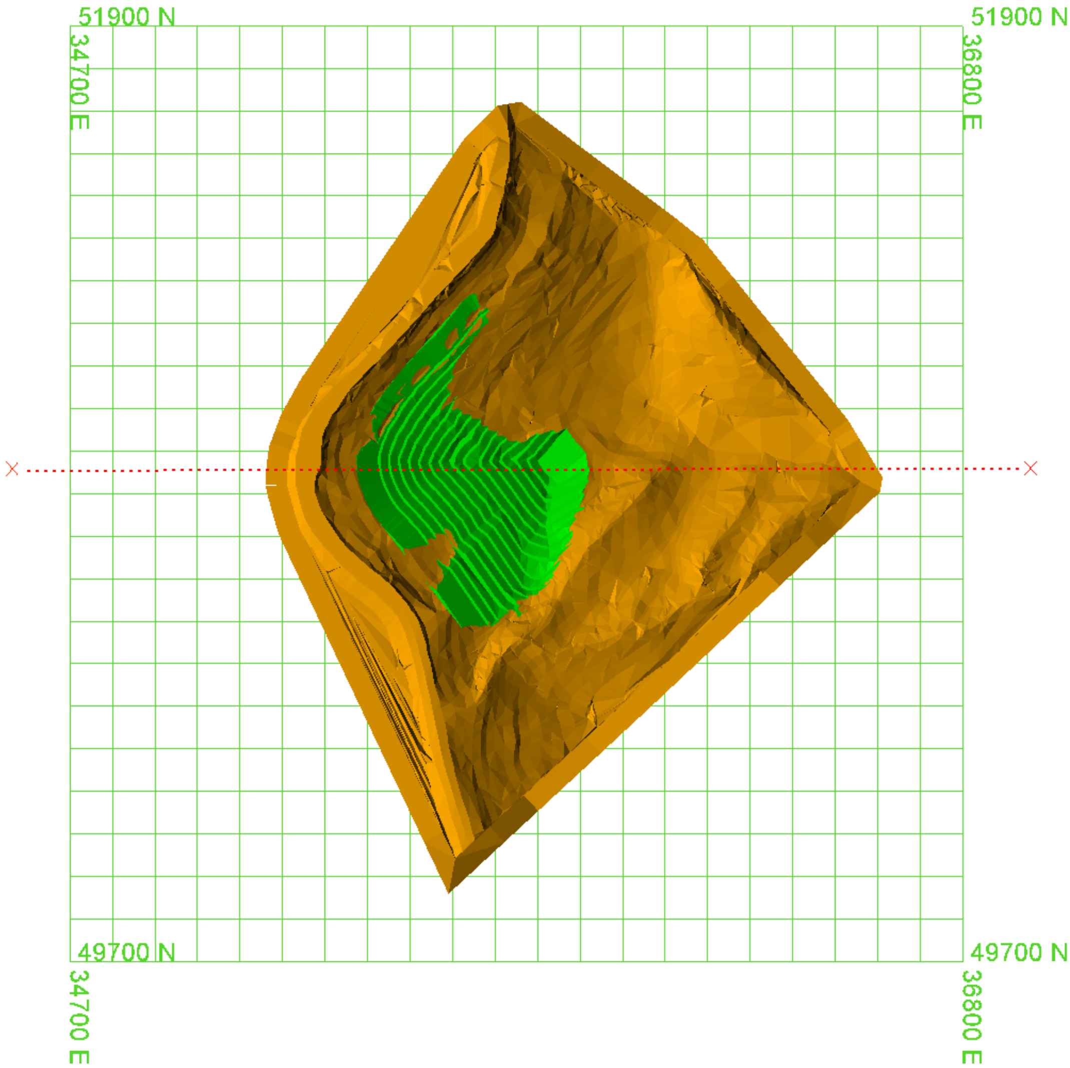
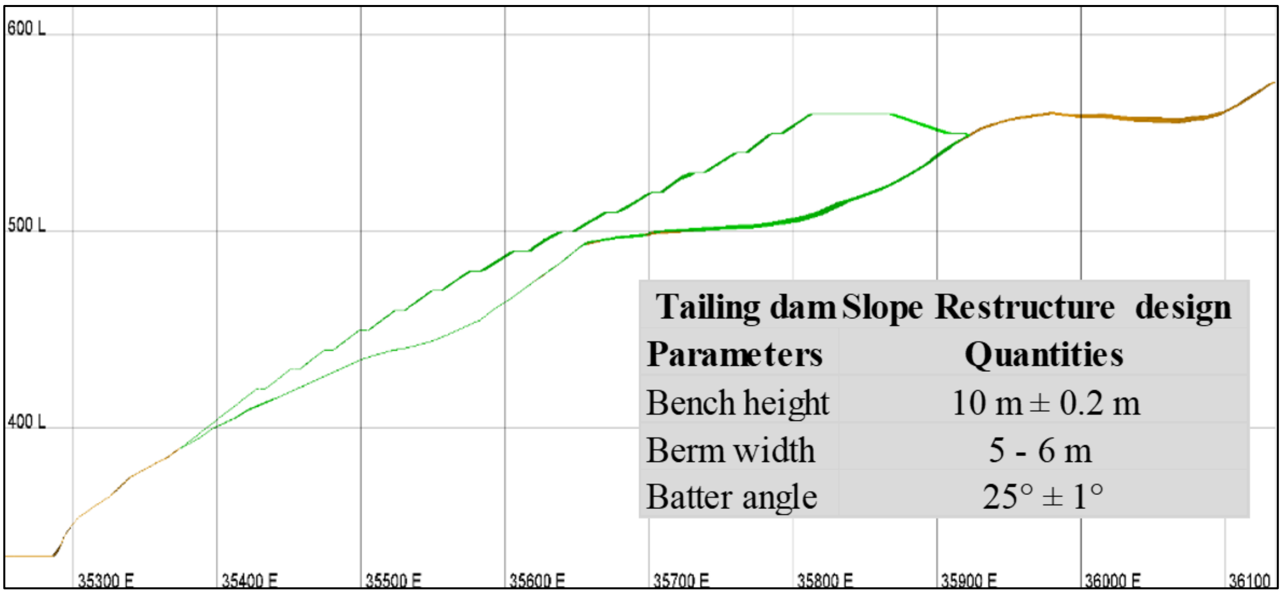


Figure 3. 52. Full plan view of the reshape slope



Tailing dam Slope Restructure design	
Parameters	**Quantities**
Bench height	10 m ± 0.2 m
Berm width	5 - 6 m
Batter angle	25° ± 1°

Figure 3. 53. Reshape slope sectional view at X-X

Generally, there are four common types of waste cover systems or barriers used in mining and environment with the objective to minimise the percolation of water in the soil. They are hydraulic (water shedding), oxygen (capillary) evapotranspirative, submerge and aesthetic cover.

The hydraulic cover is used a low permeability physical barrier to impede the downward migration of water into the acidic upper oxidised part of the tailings and into the groundwater. The common materials used are compacted clay layers, geosynthetic clay liners, and geomembranes. In some instance, a sand layer is placed below the clay layers to act as a capillary break.

The capillary cover normally is the system that consists of one or more layer of fines grained soil overlying one or more layer of coarse-grained soil. They determination is to limit the amount of oxygen going into the tailing either through water or multi-layer soil covers while the lower part of the layer still is unsaturated to support high suction at soil interface. If the tailing is cover with water this system is understood to reduce the acid generation potential by more than 95 % this is done on the wet location. In arid or semi-arid site multi-layers soil, the cover is normally use made up of the lower capillary break, overlain by clay or silt and an erosion protection layer.

The evapotranspiration option is used usually at the arid and semi-arid environment. This cover consists of a thick layer of fine-grained soil capable of supporting vegetation. They should special characteristics of fine-grained the storage capacity as they store a massive amount of water and low hydraulic conductivity even at a high-saturated site. The design of the evapotranspiration is depended on the frequency and intensity of rainfall, unsaturated hydraulic properties, of the soil and the vegetation. Silty sandy, silty and clayey silts are the most common materials used in this kind of this kind of system.

On the other hand, the aesthetic cover purpose is used to improve tailing surface appearance, limit tailing and surface runoff contact and prevent surface erosion. Normally used where there is a limited acid generation.

3.6.3.2. Closure option at Rio tailing dam

To decide the cover the option a site-site specific risk assessment and expected requirements for a remediate site were evaluated to define the best option. In this case, the recommended option was the hydraulic cover system. This option includes the design of the soil cover system and re-vegetation of the site to encourage the creation of the new bionetwork. Some of the advantages of this option are the provision of the growth medium for plant life, limit water ingress and oxygen diffusion into tailing, erosion prevention and it further reduce heavy metal leaching. Nevertheless, this option has also some drawbacks such as periodic maintenance after remediation, a large amount of borrowed materials for cover and high capital cost associated. Other options such as the capillary cover with water and synthetic liner only were discard due to the high capital cost and complexity to monitor at Rio site.

3.6.3.3. Cover measures

Based on the objective mentioned early the hydraulic cover option will be constructed to maximise moisture retention and promote the growth and re-vegetation of the native species at the site. It was also planned to promote surface runoff and drainage system then form part of the re-contoured design.

3.6.3.4. Proposed hydraulic barrier cover system

Based on the site climate condition, tailing materials chemical properties and re-contouring of the slope the profile of the cover is selected to consist of a surface layer, drainage layer, hydraulic barrier layer and foundation layer. The structures of the cover are designed to limit meteoric penetration by shedding runoff flow and aid limit water entry and oxygen diffusion into tailings materials as well as for tailing stabilisation. Figure 3.54 shows the proposed cover structure, and each section is discussed in detail to offer more information below.

The surface layer will provide the counterattack erosion by wind and water, provide a growing medium for vegetation and please the site aesthetic. This layer will also store water that infiltrated until its return to the atmosphere by evapotranspiration, prevent intrusion by burrowing animals and human as well as protect the underlying layer from climate changes. The recommended materials that can be used for the surface cover can be as borrowed topsoil or amended topsoil, riprap, mixture gravel soil or any locally available materials.

The drainage layer that is also known as internal drainage layer that will be responsible for limiting the build-up of hydraulic head on the underlying barrier layer which reduces the infiltration of water through the barrier and drains the overlying layer while it also helps to reduce erosion by controlling the time which the surface cover can be saturated. It also prevents excessive seepage force in surface layer materials to improve the slope stability.

Figure 3. 54. Schematic cross sections of cover system structure

Depended on the available materials but the suitable materials for this layer are such as sand, gravel and geocomposite drainage materials. A geotextile cushion layer can then be installed between the drainage layer of gravel and the underlying geomembrane layer as shown in Figure 3.54. Geomembranes and geotextile are manufactured polymeric materials that are used due to their non-porous structure, flexibility and ease of installation.

To further minimise the percolation of water and restrict migration of gases either from the atmosphere into the tailing or another way through the cover system the hydraulic barrier is essential for that purpose. Based on the experience gain in the USA it is recommended that both compacted clay and geomembrane are the best option for the long-term remediation to maintain low compacted clay permeability in a cover application to achieve prolong the life of the cover (Bonaparte and Yanful 2001). The life of geomembrane is normally affected by a factor such as a particle size distribution of the soils and granular angularity, acidity/alkalinity, sodium, lime hydration, concrete, metal ions present, the presence of oxygen, moisture content, organic content, temperature and microorganisms (Rollin 2004). Therefore, the selection of this should be based on the BAT (Best Available Techniques) Reference Document (BREF) entitled tailing waste.

Foundation layer is an essential section of the cover that provides the grade control for the cover system constructed and sufficient bearing capacity for overlying layers as well as to provide a smooth surface for installation of the geomembrane and geotextile. The suitable materials for the foundation are normally any uncontaminated soil available close to the site.

3.6.3.5. Surface water management and monitoring system

Inter-bench drains built from riprap will be constructed at no more than 10 m intervals to collect surface water and capillary water then treated before pumping into the river. To manage the water movement and movement of chemicals the monitoring system is required. It is necessary to develop the plan based on the be based on the BAT (Best Available Techniques) Reference Document (BREF) entitled tailing monitoring and water management

3.6.3.6. Revegetation

After the reshaping, the benches and the construction of the cover system it is expected that native grasses and shrubs seeds that must be collected during wintertime must be planned on the surface layer to prepare the ground for the new life when local plants take over once planted. The plants must be raised in the nursery and the seedlings transplanted on the benches. This way will control the spacing and arrangement of the plants.

CHAPTER 4: DISCUSSION

4.1. Introduction

This dissertation had three major's objectives those were mentioned in chapter one and articulate in chapter 3. This chapter will, therefore, present the discussion in the similar layout as the objectives by summarising the work carried out, and highlighting some of the successes and challenges.

4.2. Tailing Resource Modelling and Estimation

The first objective was to create the tailing resource model of the deposited tailing materials at Rio, and then estimate the quantity and quality of the tailing materials in terms of the volume and mineral grade with the aid of computer software. In this case, the creation of a tailing resource model is referred to as block modelling, where the block is constructed at the location of interest based on the geographical coordination collected. Block modelling is a process in which the defined block volume is divided into small parts, and each block is given a reference coordinate based on its geometrical central position. With the assistance of the Vulcan software, the main block was created, covering the tailing dam area with the origin coordinated as easting: 355299, northing: 50399, and elevation: 340. Based on the creation setup condition used to create the blocks in total, 3 329 391 irregular blocks with the sizes range from 1m x 1m x 1 m to 50 m x 50 m x 50 m were created. Using the information and the data collected from drill holes, sampling information four tables the collar, assay, survey and geology were compiled as the inputs data set of the modelling process. Those tables are together with two topography maps were used to define the tailing materials boundaries from the air and the bedrock, so this was categorised as a tailing resource. The two topography maps were the 1955T that were digitised to create acceptable original topography profile and the 2017T map that present the current profile of the site. In which all the blocks on the tailing geological segments created with fix size of 1 m x 1 m x 1m. The tailing section dimension was decided to be as small as possible because of the lack of data, and to increase the confidence on the estimated grade and resource by reducing the level of uncertainty. Each block defined by 46 attributes, that include the blocks identity, volumetric size, grade per mineral, resource and geology.

Upon completion of the construction of the block model, the block grade estimate process was carried to determine the grade for each block, bench and entire tailing dam resource. Due to the factor that the drill holes data were sampled data prior to estimation, the data were composite by using a straight compositing method to allocate value at the equal interval. Even though there are many different estimation methods to estimate grade in this case the method used were the inverse distance square and nearest neighbour they result were compared with classic statistical analysis results. The grade estimate for the five minerals study when estimated with the inverse square were 11.672 % As, 0.395 % Cu, 14.341 % Fe, 0.332 % W and 0.934 % Zn. The nearest neighbour method estimates the concentration of As, Cu and Fe to with 0.185 %, 0.240 % and 2.734 % compared to the inverse square while W and Zn grade were estimated to be low compared to the inverse square. Figure 4.1 shows the relationship between the three estimation methods results. It is shown on the graph that the results of the classic statistical analysis (CSA) are not much different from the average grades results of the inverse distance square method (IDS) and nearest neighbour method estimates (NND) for the minerals expect in term of iron there is a significant differences in estimation.

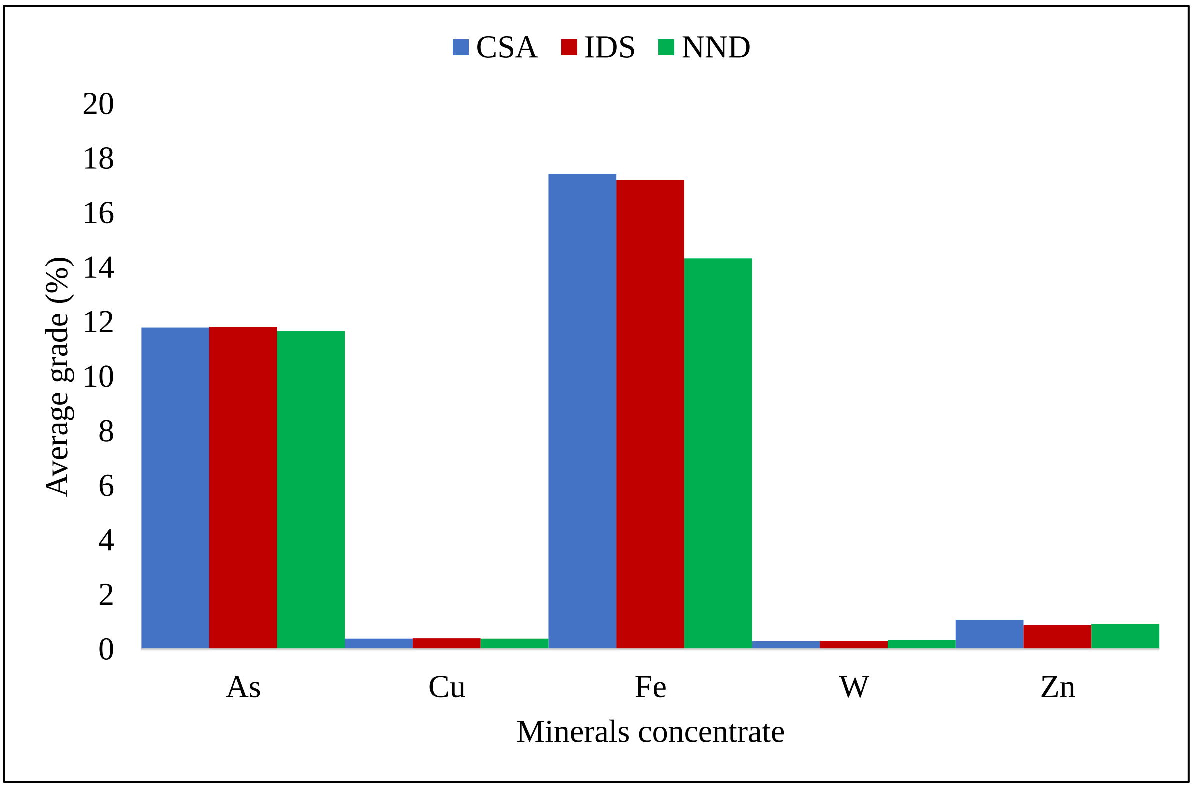


Figure 4. 1. Grade estimation comparison entire deposition

The discussion concerned the tailing modelling process has been discussed well in the previous chapter and it results has been presented in different figures such as plan view and cross section view. The development of the tailing model has not just come to right, as it is present here as there has been some important obstacle that has been encounter in the process. The first one was the insufficient and difficult to access of geochemical and geophysical data of the site available. The only data that provide a vast knowledge and information were the six boreholes (location) that give the geochemical and lithological data of the tailings the other sampled location only give chemical samples values of minerals per points. Due to the scarcity of the data as it has mentioned before it was decided that the traditional estimation methods of grade estimate applied to the block then to use more advanced geostatistics methods such as ordinal kriging or multi-variable kriging those may yield better estimation results than the traditional methods. Therefore, this shortage of data affects the reliability of resource model that must keep in mind when interpreting and applying the estimation or planning.

The second challenge encounter on the process of constructing the tailing model was the geographical coordinate system convention. As it has already stated that this project was based on the secondary data that were collected over the years during the geological construction, it comes to right that each data set available was surveyed with the different geographic coordinate system. The difference in the coordinate system imposes a challenge to locate the true locations of the boreholes on the blocks. Even thought that all the coordinates were converted from various system to the ETRS 89-PPTM06: EPSG: 3763 by using the advance I-Site Studio software there was still some uncertainty and error to locate the true location of the boreholes. Again, a precaution must be taken when interpreting and applying the collar data to any calculation since that the true location of the six significant boreholes drilled from the data set 2002 were located with certain error and they required to be verified and the system that was given as they original was not displaying at the correct location.

The third difficulty on the tailing resource modelling and estimation of Rio Tailing dam was imposed by the data of the original topography. In this dissertation, the topography that was used is the one that was drawn in 1955 and that was some years after the tailing materials has been deposited at the site. On the other hand, due to the technology that used at the time the accuracy of the map may not be as it was supposes to be. As this map was in hard copy format, it digitised to obtain the contours that were assumed as the topography of the site back in 1951. Even though that the map digitisation was carried out using two application software and the results were compared to select the best topography map the error magnitude both in the process and original data cannot be eliminated. This error was believed to have an impact on resource estimation also to a certain extent even if it has not been defined. Therefore, this model has resource estimation has to be used as a first approach only on the planning place of any further activities. To increase the confident level on this resource value estimate it is necessary to either carry out further investigation to determine the base profile of the site or obtain the geophysical data from Grangeia et al. (2002) when they investigate the internal structure, supporting structure and tailings thickness of the tailing dam.

4.3. Planning and Design

The second objective of this dissertation was to develop and design a mining extraction plan of the tailing resource estimated for the extraction of the major commodities copper, zinc and Wolfram. Based on the tailing model that was constructed and used to estimate the grade and the in-situ resource of the tailing dam as 3 039 497 m^3 the extraction strategic was developed. In total, there were 3 039 4997 blocks each with 1 m x 1 m x 1 m covered. The target area of exploration on this project was determined to cover the top surface area of about 120 000 m^2 and the floor area about 269 000 m^2.

As this is a technical solution and not an economical solution no economic variables were used to this mean that all the blocks which were within the tailing geological sector were assigned a grade value. The extraction plan of the portion tailing that was classified as the major threat to the environment was defined by setting up the surface boundaries. This surface boundary separates the coarse tailing and the fine mud tailing as presented before mark a significant part as they were the benchmark of the pit. In this case, it was decided that the top-bottom pit design method is applied to design the pit to extract the tailing mud in the bench each with 10 m height with a batter angle not greater than 35 ° and the berm width from 3 m to 8 m. Starting from the 468 m level designing downward the bench design cover until level 358 m. Each bench grade and resource determined to estimate the mineable materials. The results have demonstrated that bench grade varies in the entire commodity but what is noticed is the high concentration of iron and arsenic throughout dam. The total mineable resource was estimated to be about 1.317 x 10^6 m^3 that is approximately 43 % of the estimated deposited tailing materials over the years. The mineable resource was estimated to have an average grade of 11.82 % As, 0.41 % Cu, 17.21 % Fe, 0.31 % W and 0.89 % Zn base on the inverse distance square estimation method.

The best option that can be proposed mining technique for this project is the mechanical method of digging – loading – haulage that must start on the northern edge of the tailing dam at bench 358 m and progress below until the entire proposed mineable resource section explodes. This the side where the road is as shown in Figure 3.51.

As already mentioned in the previous section the concern about the accuracy of grade and the resource estimation due to the error on surface topography map must keep in mind when interpreting or plan any further step that the is certain degree error on the resource volumetric estimation and grade estimation due to the insufficient geological data for estimation.

4.4. Remediation Plan

The third mandate for this study was to develop a restructure and rehabilitation plan of the site to minimise further environmental impacts and increase the stability of the dam. The known effect of Rio tailing dam on the environment at this stage is still far from the reality, and based on the experience gain over the year around the world it is clear that no matter how many information available the future impact of the tailing dam failure or leakage cannot be defined. Rio tailing dam is at a strategic location in such a way that if it collapses or continues leakage the river will be polluted with heavy minerals and this will have a huge impact on the ecosystem cycle.

Therefore, the remediation and rehabilitation plan was developed starting with the re-deposition of the tailing materials from the reprocessing plant in the ‘dry cake’ or ‘dry stack’ form then reshape the tailing dam slope to prepare the site for the cover. Even though the large portion of tailings materials are going to be reprocessed to extract copper, zinc and wolfram the volume of the materials to return to the site the will still be high. The assumption is that between 1 to 5 % of the mineable resource will be sent to the market from the mineable volume of 1.31 x 10^6 m^3. The volume of the materials to be re-deposited and reshape will be the almost be equal to the current volume that was estimated to be around 3.04 x 10^6 m^3 and it will cover the surface area approximately 262 376 m^2. The tailings materials would be deposited in compacted 10 m bench height with the slope angle of 25^o. The re-depositing of the tailing at the low slope angle and the use of mechanical compaction techniques to compact the tailing materials during construction are all proposed design to achieve the long-term stability of the dam and redistribute the stress of the materials in the area. In this way, the risk of tailing failure will be reduced significant.

Restructuring and re-depositing of the tailing are only mainly aims to reduce the risks of the dam failure that may be trigger by either flood of the pond or geotechnical failure as the structure of the tailing dam is not yet well know at this stage. To solve the impact of the acid mine drainage and the leakage of heavy minerals into the river the proposed strategy is the capping of the tailing materials with the hydraulic cover system. The structure of the proposed cover is presented in the previous chapter and it is assumed that the proposed materials to be used for capping are locally available. Due to the aggressiveness of the climate on the area, the water management plan and monitoring strategies are essential to sure that surface runoff water is collected and treated then pump into the river.

CHAPTER 5: CONCLUSION

5.1. Conclusions

The aim of this dissertation was to determine the technical feasibility and to plan the exploitation of the tailings muds materials from the Cabeço do Pião (Rio) tailing dam with the assistance of Vulcan mining software. The mineable materials will be transported to the processing plant for reprocessed to extract the valuable and sulphide minerals effectively for economic benefits. In addition to that, it was required to develop the remediation plan to minimise the impact of acid mine drainage and tailing dam instability. By using the information and data available with the guide of the literature review and the personal knowledge of the author, this project was undertaken to achieve its aim. Therefore, the following conclusions can be drawn based on the completion of the project as related to the three objectives set up in chapter 1:

Even though the information and data were scarce and was complex to be converted to the format that applies the software, it is clear to state that the tailing resource model was created with the aid of the Vulcan software. Based on the model it was estimated that the about 3.04 x 10^6 m^3 of the tailing materials were deposited on site in 1955 to 2001 and about 1.300 x 10^6 m^3 was mud on ponds. As the focus of this study was mainly the five minerals, they average grades were estimated as 11.82 % As, 0.41 % Cu, 17.21% Fe, 0.31 % W and 0.89 % Zn by using the traditional inverse distance square estimation method. There was a difference in estimation of both the grade and resource when the inverse distance square estimation method compares to the nearest neighbour method. The differences in grade can be explained, partially, the method input set up estimation criteria such as the search shape and number of holes/samples to estimate the individual block. In the case of volume miscalculation of the resource, it may be due to the block dimensions to estimate mineable resources as the blocks were selected with special criteria and those which did not meet the criteria where not include on estimation. Even though the inverse distance square estimation results are recommended in this work it must be noted that it does not provide prediction standard errors, justifying the use of this model may be problematic.

The second objective was to develop and design the mining exploitation plan that is practically possible. By using, the tailing resource model that was created with the information and data obtained from various sources it was possible to develop a possible extraction plan. It is clear to state that this objective was achieved in such a way the total mineable estimated volume was as about 1.32 x 10^6 m^3 by using the Excavator-Truck System to transport the materials to the processing plant.

The third objective was to find a best environmental solution to the currently tailing dam that is a huge threat both in term of stability and environmental issues related to acid mine drainage and heavy metal release onto the river. The remediation and rehabilitation plan was developed. This involves the re-depositing of the dry stack tailing once the interest minerals are extracted: reshape of slope designed as per bench elevation at 10 m height with the at least 25° batter angle and vary berm width 5 - 6 m and applied the hydraulic barrier cover system, vegetation and develop and monitoring plan to minimise further environmental impacts and increase stability of the dam of the long-term.

Finally, it must restate that this project was carried out to determine the technical solution to the tailing dam that presents a major threat to the river and the ecosystem at large with the aid of the Vulcan software. It can conclude that Vulcan software is an application that can be used throughout the life of the mine in planning and designing. This can speed up the planning and design process and it also reduces the use of paperwork as all the information can be organised on the single system and shared with other computer application such as AutoCAD and Excel CSV. The only major requirement is to organise the input data and verify before entered the software to avoid miscalculation and wrong display of data.

5.2. Recommendations

One of the main challenges in this project was when constructing the tailing resource model of the site, as there was a shortage geological information and data as at some location there was no sample undertake. Therefore, the earliest recommendation is to carry out a geochemical and geophysical survey to increase the volume of the information available and fill up the areas that are not sample. On the other hand, since that there was a geophysical investigation carried out by Grangeia et al. (2002) it is essential to obtain those results and includes them in the model.

The second recommendation is related to the geographical coordinate system. As it has already mentioned that, there has been a challenge to locate the true location of the six boreholes it is essential that site is visited and locate the location of those boreholes.

The accuracy of the original topography that was used to create the base surface has been highlighted as a major issue on estimating the correct resource. Therefore, it is significantly important that the corrected map search and used in this process to estimate the resources.

The fourth recommendation is that since this dissertation has been the focus on the technical solution to extract the materials on the ponds that observe as the major threat to the ecosystem it is important also to analysis the economic viability of this project. The economic analysis and production analyses will be able to determine how much capital is needed to remediate the site.

Even though the remediation planned was developed, it is important to state that there is a need to study the materials physical properties. The capping plan is proposed to be done with the local materials therefore, it is also important that is needed to search for such materials in the area nearby.

Finally, the Vulcan software is dynamic and complete software that fully recommend being used in this kind of projects.

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APPENDIX

APPENDIX A

RIO TAILING DAM SAMPLE DRILL HOLES DATA

1. **Filename: Collar.csv**

HOLEID	EAST	NORTH	ELEVATION	TOTAL DEPTH
DH_1	35566.106	50873.108	468.533	24.08
DH_2	35547.542	50835.597	466.015	43.58
DH_3	35578.073	50920.413	473.455	26.77
DH_4	35570.46	50790.074	466.773	21.95
DH_5	35704.847	50629.308	472.064	34.63
DH_6	35617.567	50696.63	470.564	40.13
A1_S	35771.004	50574.355	474.699	1.01
A2_S	35747.166	50608.172	472.521	1.01
A3_S	35716.254	50635.786	471.226	1.01
A4_S	35685.342	50663.401	470.812	1.01
A5_S	35656.783	50694.109	469.951	1.01
A6_S	35635.357	50718.686	468.659	1.01
A7_S	35604.432	50749.384	467.686	1.01
A8_S	35573.521	50776.998	467.143	1.01
A9_S	35547.331	50807.72	466.6	1.01
A10_S	35518.774	50838.431	466.33	1.01
B1_S	35804.168	50571.427	477.162	1.01
B2_S	35785.152	50586.759	475.652	1.01
B3_S	35756.593	50617.469	472.695	1.01
B4_S	35730.402	50648.191	470.775	1.01
B5_S	35699.49	50675.804	470.007	1.01
B6_S	35670.946	50703.43	469.452	1.01
B7_S	35644.77	50731.068	467.846	1.01
B8_S	35616.212	50761.776	467.328	1.01
B9_S	35585.301	50789.391	466.777	1.01
B10_S	35556.758	50817.018	466.228	1.01
B11_S	35532.936	50847.75	465.769	1.01
B12_S	35504.379	50878.461	466.743	1.01
C1_S	35799.257	50608.417	474.81	1.01
C2_S	35770.713	50636.043	472.213	1.01
C3_S	35744.536	50663.68	470.723	1.01
C4_S	35713.624	50691.293	469.712	1.01
C5_S	35687.448	50718.931	469.174	1.01
C6_S	35654.169	50746.534	467.746	1.01

C7_S	35630.332	50780.35	466.974	1.01
C8_S	35547.056	50866.323	465.72	1.01
C9_S	35523.249	50893.972	465.902	1.01
D1_S	35756.317	50676.072	470.631	1.01
D2_S	35730.14	50703.709	469.572	1.01
D3_S	35701.597	50731.335	469.025	1.01
D4_S	35549.163	50921.854	465.705	1.01
D5_S	35565.679	50934.268	465.215	1.01
E1_S	35746.657	50716.125	469.506	1.01
E2_S	35590.254	50743.149	468.541	1.01
F1_S	35732.246	50759.239	468.475	1.15

2. Filename: Survey.csv

HOLEID	DEPTH	AZIMUTH	DIP
DH_1	0	0	-90
DH_2	0	220	-45
DH_3	0	200	-75
DH_4	0	0	-90
DH_5	0	0	-90
DH_6	0	200	-45
A1_S	0	0	-90
A2_S	0	0	-90
A3_S	0	0	-90
A4_S	0	0	-90
A5_S	0	0	-90
A6_S	0	0	-90
A7_S	0	0	-90
A8_S	0	0	-90
A9_S	0	0	-90
A10_S	0	0	-90
B1_S	0	0	-90
B2_S	0	0	-90
B3_S	0	0	-90
B4_S	0	0	-90
B5_S	0	0	-90
B6_S	0	0	-90
B7_S	0	0	-90
B8_S	0	0	-90
B9_S	0	0	-90
B10_S	0	0	-90
B11_S	0	0	-90
B12_S	0	0	-90

C1_S	0	0	-90
C2_S	0	0	-90
C3_S	0	0	-90
C4_S	0	0	-90
C5_S	0	0	-90
C6_S	0	0	-90
C7_S	0	0	-90
C8_S	0	0	-90
C9_S	0	0	-90
D1_S	0	0	-90
D2_S	0	0	-90
D3_S	0	0	-90
D4_S	0	0	-90
D5_S	0	0	-90
E1_S	0	0	-90
E2_S	0	0	-90
F1_S	0	0	-90

3. Filename: Assay.csv

HOLEID	FROM	TO	As	Cu	Fe	W	Zn	RECOVER	WIDTH	H_2O
DH_1	3.53	3.55	11.49	0.50	0.00	0.49	1.38	98	3.54	19
DH_1	11.77	11.79	3.51	0.20	0.00	0.36	0.60	98	8.24	17.2
DH_1	20.22	20.24	1.02	0.11	0.00	0.30	0.06	98	8.45	17.6
DH_2	0.78	0.8	15.57	0.70	0.00	0.19	1.13	98	0.79	15.4
DH_2	22.16	22.18	1.15	0.12	0.00	0.24	0.36	98	21.38	19.8
DH_2	38.91	38.93	1.15	0.08	0.00	0.27	0.08	98	16.75	34.8
DH_2	2.38	2.4	14.00	0.48	21.40	0.78	1.10	98	2.39	
DH_2	9.99	10.01	8.70	0.38	15.00	0.55	0.65	98	7.61	
DH_2	22.99	23.01	0.31	0.11	5.30	0.22	0.22	98	13	
DH_2	35.48	35.5	1.90	0.15	7.40	0.22	0.28	98	12.49	
DH_2	40.42	40.44	0.33	0.01	6.50	0.41	0.01	98	4.94	
DH_3	1.62	1.64	12.25	0.37	0.00	0.29	0.95	98	1.63	15.3
DH_3	9.32	9.34	5.81	0.32	0.00	0.37	0.60	98	7.7	16.7
DH_3	24.09	24.11	1.66	0.14	0.00	0.28	23.00	98	14.77	17.7
DH_4	1.22	1.24	14.04	0.36	0.00	0.35	1.00	98	1.23	13.7
DH_4	10.84	10.86	4.98	0.28	0.00	0.49	0.35	98	9.62	17.5
DH_4	18.47	18.49	0.64	0.07	0.00	0.37	0.19	98	7.63	18.3
DH_4	2.72	2.74	10.00	0.38	11.30	0.53	2.70	98	2.73	
DH_4	13.47	13.49	0.43	0.11	5.80	0.21	0.24	98	10.75	
DH_4	19.57	19.59	0.48	0.16	5.40	0.27	0.23	98	6.1	
DH_5	1.24	1.26	23.29	0.39	0.00	0.65	0.84	98	1.25	8.7

DH_5	14.97	14.99	0.96	0.45	0.00	0.32	0.98	98	13.73	24.7
DH_5	29.62	29.64	2.49	0.15	0.00	0.37	0.21	98	14.65	39.4
DH_5	2.31	2.33	19.00	0.21	18.00	0.87	0.91	98	2.32	
DH_5	7.99	8.01	24.00	0.72	28.50	0.61	2.10	98	5.68	
DH_5	16.52	16.54	0.64	0.19	6.10	0.33	0.13	98	8.53	
DH_5	31.99	32.01	0.68	0.20	5.40	0.26	0.11	98	15.47	
DH_6	5.12	5.14	10.02	0.54	0.00	0.26	0.84	98	5.13	12.1
DH_6	13.24	13.26	7.15	0.21	0.00	0.12	0.66	98	8.12	8.1
DH_6	25.37	25.39	1.47	0.10	0.00	0.20	0.35	98	12.13	23.1
DH_6	0.09	0.11	22.00	0.09	0.00	0.37	0.42	98	0.1	
DH_6	8.37	8.39	18.00	0.43	0.00	0.38	0.00	98	8.28	
DH_6	21.99	22.01	0.64	0.19	0.00	0.35	0.14	98	13.62	
DH_6	32.57	32.59	0.89	0.16	0.00	0.28	0.20	98	10.58	
DH_6	35.99	36.01	3.20	0.21	0.00	0.30	0.39	98	3.42	
A1_S	0.2	0.21	12.30	0.41	21.75	0.06	0.88	98	0.9	
A2_S	0.2	0.21	13.22	0.39	22.30	0.05	0.89	98	0.9	
A4_S	0.2	0.21	12.75	0.03	21.20	0.04	0.04	98	0.9	
A5_S	0.2	0.21	10.16	0.12	22.31	0.06	0.97	98	0.9	
A6_S	0.2	0.21	17.16	0.11	22.66	0.04	0.06	98	0.9	
A7_S	0.2	0.21	11.74	0.05	14.05	0.06	0.07	98	0.9	
A8_S	0.2	0.21	16.81	0.14	22.31	0.09	0.09	98	0.9	
A9_S	0.2	0.21	7.76	0.10	9.41	0.10	0.11	98	0.9	
A10_S	0.2	0.21	8.61	0.09	18.09	0.06	0.05	98	0.9	
B1_S	0.2	0.21	13.10	0.36	24.11	0.06	0.82	98	0.9	
B2_S	0.2	0.21	22.37	0.17	24.79	0.03	0.08	98	0.9	
B3_S	0.2	0.21	12.64	0.05	23.42	0.06	0.65	98	0.9	
B4_S	0.2	0.21	10.01	0.61	18.62	0.07	1.15	98	0.9	
B5_S	0.2	0.21	10.20	0.56	22.08	0.03	1.16	98	0.9	
B6_S	0.2	0.21	10.08	1.16	20.13	0.05	1.12	98	0.9	
B7_S	0.2	0.21	9.00	0.05	11.51	0.21	0.03	98	0.9	
B8_S	0.2	0.21	18.06	0.08	21.73	0.31	0.06	98	0.9	
B9_S	0.2	0.21	14.85	0.04	15.37	0.20	0.05	98	0.9	
B10_S	0.2	0.21	12.34	0.12	13.60	0.33	0.05	98	0.9	
B11_S	0.2	0.21	14.25	0.35	19.27	0.36	0.19	98	0.9	
B12_S	0.2	0.21	18.84	0.11	22.93	0.07	0.07	98	0.9	
C1_S	0.2	0.21	17.65	0.21	25.70	0.04	0.40	98	0.9	
C2_S	0.2	0.21	12.77	0.82	24.21	0.03	1.49	98	0.9	
C3_S	0.2	0.21	10.86	0.47	18.91	0.08	1.41	98	0.9	
C4_S	0.2	0.21	19.96	0.86	27.44	0.20	1.32	98	0.9	
C6_S	0.2	0.21	13.94	0.13	21.26	0.41	0.08	98	0.9	
C7_S	0.2	0.21	10.98	0.27	21.96	0.38	0.33	98	0.9	
C8_S	0.2	0.21	12.81	0.70	21.22	0.23	0.64	98	0.9	

C9_S	0.2	0.21	14.00	1.07	22.89	0.25	1.19	98	0.9	
D2_S	0.2	0.21	8.34	0.28	15.72	0.06	0.60	98	0.9	
D3_S	0.2	0.21	9.68	0.37	17.19	0.07	1.41	98	0.9	
D4_S	0.2	0.21	8.07	0.49	13.19	0.16	0.64	98	0.9	
D5_S	0.2	0.21	7.35	0.65	13.97	0.15	0.60	98	0.9	
E1_S	0.2	0.21	-99	-99	-99	-99	-99	98	0.9	
E2_S	0.2	0.21	-99	-99	-99	-99	-99	98	0.9	
F1_S	0.2	0.21	-99	-99	-99	-99	-99	98	0.9	
A1_S	0.99	1.01	20.68	0.51	29.94	0.24	1.07	98	0.9	
A2_S	0.99	1.01	15.69	0.54	29.28	0.18	1.54	98	0.9	
A4_S	0.99	1.01	21.77	0.51	28.07	0.27	1.13	98	0.9	
A5_S	0.99	1.01	19.19	0.67	28.55	0.26	1.75	98	0.9	
A6_S	0.99	1.01	13.91	0.49	27.98	0.38	1.30	98	0.9	
A7_S	0.99	1.01	15.99	0.46	25.47	0.33	1.16	98	0.9	
A8_S	0.99	1.01	16.85	0.71	26.95	0.39	1.25	98	0.9	
A9_S	0.99	1.01	14.74	0.63	26.42	0.38	2.29	98	0.9	
A10_S	0.99	1.01	16.88	0.72	26.31	0.38	1.11	98	0.9	
B1_S	0.99	1.01	18.75	0.79	27.25	0.15	1.26	98	0.9	
B2_S	0.99	1.01	22.29	0.57	29.60	0.12	0.95	98	0.9	
B3_S	0.99	1.01	17.18	0.46	29.93	0.24	1.55	98	0.9	
B4_S	0.99	1.01	12.90	0.87	30.25	0.48	1.84	98	0.9	
B5_S	0.99	1.01	14.51	0.55	29.53	0.44	1.55	98	0.9	
B6_S	0.99	1.01	20.36	0.76	31.28	0.54	1.42	98	0.9	
B7_S	0.99	1.01	15.21	0.86	26.91	0.47	1.43	98	0.9	
B8_S	0.99	1.01	14.17	0.51	27.03	0.47	1.63	98	0.9	
B9_S	0.99	1.01	13.89	0.46	26.88	0.46	1.48	98	0.9	
B10_S	0.99	1.01	17.25	0.89	26.53	0.38	2.78	98	0.9	
B11_S	0.99	1.01	13.83	0.78	26.03	0.44	1.51	98	0.9	
B12_S	0.99	1.01	14.45	0.54	28.48	0.50	1.41	98	0.9	
C1_S	0.99	1.01	18.86	0.57	27.37	0.06	1.20	98	0.9	
C2_S	0.99	1.01	12.06	0.35	29.03	0.34	1.09	98	0.9	
C3_S	0.99	1.01	13.00	0.79	29.28	0.49	1.58	98	0.9	
C4_S	0.99	1.01	16.17	0.69	28.89	0.43	1.48	98	0.9	
C5_S	0.99	1.01	18.54	0.45	29.58	0.34	1.67	98	0.9	
C7_S	0.99	1.01	15.29	0.80	25.45	0.50	0.87	98	0.9	
C8_S	0.99	1.01	12.39	0.56	26.13	0.50	1.56	98	0.9	
C9_S	0.99	1.01	12.72	0.37	27.00	0.38	1.85	98	0.9	
D1_S	0.99	1.01	10.19	0.41	24.29	0.37	1.15	98	0.9	
D2_S	0.99	1.01	10.32	0.42	26.66	0.38	1.02	98	0.9	
D3_S	0.99	1.01	14.26	0.49	29.76	0.57	1.64	98	0.9	
D5_S	0.99	1.01	16.41	0.20	30.25	0.40	1.08	98	0.9	
E1_S	0.99	1.01	12.72	0.61	27.43	0.47	1.47	98	0.9	

E2_S	0.99	1.01	15.43	0.27	27.40	0.44	1.00	98	0.9	
F1_S	0.99	1.01	11.73	0.41	27.40	0.41	1.29	98	0.9	

4. Filename: Geology.csv

HOLEID	FROM	TO	LITH	WIDTH	CORE DESCRIPTION
DH_1	0.0	3.4	GYMUD	3.4	GREY MUD
DH_1	3.4	3.75	FCYBR	0.35	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	3.75	4.05		0.3	
DH_1	4.05	4.2	FCYBR	0.15	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	4.2	5.6	GYMUD	1.4	GREY MUD
DH_1	5.6	5.74	FCYBR	0.14	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	5.74	7.1		1.36	
DH_1	7.1	7.5	FCYBR	0.4	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	7.5	8.5		1.00	
DH_1	8.5	8.7	FCYBR	0.2	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	8.7	10.00	GYMUD	1.3	GREY MUD
DH_1	10.	10.2	FCYBR	0.2	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	10.2	11.6		1.4	
DH_1	11.6	12.4	FCYBR	0.8	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	12.4	12.88		0.48	
DH_1	12.88	13.25	FCYBR	0.37	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	13.25	13.55		0.3	
DH_1	13.55	14.05	FCYBR	0.5	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	14.05	15.1	GYBWM	1.05	GREY AND BROWNISH MUD
DH_1	15.1	15.55	FCYBR	0.45	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	15.55	16.38		0.83	
DH_1	16.38	16.78	FCYBR	0.4	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	16.78	17.5	GYREM	0.72	GREY AND REDISH MUD
DH_1	17.5	17.7	FCYBR	0.2	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	17.7	18.8		1.1	
DH_1	18.8	19.1	FCYBR	0.3	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	19.1	20.15		1.05	
DH_1	20.15	20.45	FCYBR	0.3	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_1	20.45	21.65	GYGRM	1.2	GREY AND GREENISH MUD
DH_1	21.65	22.28	RMDBB	0.63	RIO MUD DAM BASE BEDROCK
DH_1	22.28	22.58	BEDSC	0.3	BEDROCK SCHITSTS
DH_1	22.85	24.08	ASHST	1.23	ARILLACEOUS SCHISTS SCHISTOSITY
DH_2	0.00	0.79		0.79	
DH_2	0.79	1.1	FCYBR	0.31	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	1.1	4.7	GYMUD	3.6	GREY MUD
DH_2	4.7	5.05	FCYBR	0.35	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	5.05	6.4		1.35	
DH_2	6.4	6.72	FCYBR	0.32	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	6.72	7.7		0.98	
DH_2	7.7	7.95	FCYBR	0.25	FERRUGINOUS CRUST YELLOW. BROWN AND RED

DH_2	7.95	9.8	GYMUD	1.85	GREY MUD
DH_2	9.8	10.15	FCYBR	0.35	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	10.15	10.9		0.75	
DH_2	10.9	11.08	FCYBR	0.18	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	11.08	15.6	GYMUD	4.52	GREY MUD
DH_2	15.6	17.00	PCFGM	1.4	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_2	17.00	17.35	FCYBR	0.35	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	17.35	18.4	FCYBR	1.05	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	18.4	21.4		3.00	
DH_2	21.4	22.65	PCFGM	1.25	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_2	22.65	23.25	FCYBR	0.6	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_2	23.25	23.9		0.65	
DH_2	23.9	24.25	FCYGB	0.35	FERRUGINOUS CRUST IN GREY AND BROWNISH MUD
DH_2	24.25	25.23	GYMUD	0.98	GREY MUD
DH_2	25.23	26.45		1.22	
DH_2	26.45	27.00	RSMUD	0.55	REDISH MUD
DH_2	27.00	29.48	GGMUD	2.48	GREY AND GREENISH MUD
DH_2	29.48	29.9	GGMUD	0.42	GREY AND GREENISH MUD
DH_2	29.9	31.00	GGMUD	1.1	GREY AND GREENISH MUD
DH_2	31.00	32.1	DBARM	1.1	DARK BROWN AND REDISH MUD
DH_2	32.1	33.8		1.7	
DH_2	33.8	34.00	FCYGB	0.2	FERRUGINOUS CRUST IN GREY AND BROWNISH MUD
DH_2	34.00	36.1		2.1	
DH_2	36.1	36.76	OXSAG	0.66	OXIDE SAND AND GRAVE
DH_2	36.76	37.43		0.67	
DH_2	37.43	38.92	OXSAG	1.49	OXIDE SAND AND GRAVE
DH_2	38.92	40.28	GYBWM	1.36	GREY AND BROWNISH MUD
DH_2	40.28	43.58	OSGGM	3.3	OXIDE SAND AND GRAVE IN GREENISH MUD
DH_3	0.	0.22	FCYGB	0.22	FERRUGINOUS CRUST IN GREY AND BROWNISH MUD
DH_3	0.22	1.16	GYMUD	0.94	GREY MUD
DH_3	1.16	1.85	PCFGM	0.69	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_3	1.85	3.8		1.95	
DH_3	3.8	4.55		0.75	
DH_3	4.55	4.9	FCYGB	0.35	FERRUGINOUS CRUST IN GREY AND BROWNISH MUD
DH_3	4.9	6.2	GYMUD	1.3	GREY MUD
DH_3	6.2	7.65	GYMUD	1.45	GREY MUD
DH_3	7.65	7.91	GYMUD	0.26	GREY MUD
DH_3	7.91	9.00	GYMUD	1.09	GREY MUD
DH_3	9.	9.5	GYMUD	0.5	GREY MUD
DH_3	9.5	11.61	FCYBR	2.11	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_3	11.61	12.8	GYMUD	1.19	GREY MUD
DH_3	12.8	13.99	GYMUD	1.19	GREY MUD
DH_3	13.99	15.75	GYMUD	1.76	GREY MUD
DH_3	15.75	20.45	BRGYM	4.7	BROWNISH AND GREY MUD
DH_3	20.45	21.4	BRGMC	0.95	BROWN AND GREY MUD WITH FERRURIFIOUS CRUSTS
DH_3	21.4	23.05	BRGYM	1.65	BROWNISH AND GREY MUD

DH_3	23.05	24.1		1.05	
DH_3	24.1	24.3	FCYBR	0.2	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_3	24.3	25.25	RMDBB	0.95	RIO MUD DAM BASE BEDROCK
DH_3	25.25	26.77	BEDSC	1.52	BEDROCK SCHITSTS
DH_4	0.00	1.4		1.4	
DH_4	1.4	1.5	FCYBR	0.1	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_4	1.5	2.73	GYMUD	1.23	GREY MUD
DH_4	2.73	2.9	FCYBR	0.17	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_4	2.9	4.13	GYMUD	1.23	GREY MUD
DH_4	4.13	4.4	FCYBR	0.27	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_4	4.4	5.7	PCFGM	1.3	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_4	5.7	7.6	FPGMU	1.9	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO FERRUGINOUS CRUST IN GREY MUD
DH_4	7.6	11.7	GYMUD	4.1	GREY MUD
DH_4	11.7	12.25	GRABM	0.55	GREYISH AND BROWNISH MUD
DH_4	12.25	13.1		0.85	
DH_4	13.1	13.4	FPGMU	0.3	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO FERRUGINOUS CRUST IN GREY MUD
DH_4	13.4	17.93	GRABM	4.53	GREYISH AND BROWNISH MUD
DH_4	17.93	20.35	PCFGM	2.42	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_4	20.35	21.5	RMDBB	1.15	RIO MUD DAM BASE BEDROCK
DH_4	21.5	21.95	BEDSC	0.45	BEDROCK SCHITSTS
DH_5	0.00	0.1		0.1	
DH_5	0.1	0.6	GYMHM	0.5	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	0.6	0.7		0.1	
DH_5	0.7	3.2	FCYBR	2.5	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_5	3.2	3.45	GYMHM	0.25	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	3.45	6.53	GYMUD	3.08	GREY MUD
DH_5	6.53	8.8	GYMHM	2.27	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	8.8	11.68	GYMUD	2.88	GREY MUD
DH_5	11.68	11.8	GYMHM	0.12	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	11.8	15.2	GYMUD	3.4	GREY MUD
DH_5	15.2	15.83	FCYBR	0.63	FERRUGINOUS CRUST YELLOW. BROWN AND RED
DH_5	15.83	20.65	BSAGM	4.82	BROWNISH AND GREYISH MUD
DH_5	20.65	20.8	GYMHM	0.15	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	20.8	21.4	PCFGM	0.6	PERCOLATION CHANNEL FERRUGINOUS CRUST IN GREY MUD
DH_5	21.4	24.08	GYMHM	2.68	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_5	24.08	24.39	GGMUD	0.31	GREY AND GREENISH MUD
DH_5	24.39	34.1	RMDBB	9.71	RIO MUD DAM BASE BEDROCK
DH_5	34.1	34.63	BEDSC	0.53	BEDROCK SCHITSTS
DH_6	0.00	0.75	GYMUD	0.75	GREY MUD
DH_6	0.75	1.08	FCYGB	0.33	FERRUGINOUS CRUST IN GREY AND BROWNISH MUD
DH_6	1.08	1.3		0.22	
DH_6	1.3	1.45	GYMUD	0.15	GREY MUD
DH_6	1.45	3.15		1.7	
DH_6	3.15	3.4		0.25	
DH_6	3.4	3.78		0.38	
DH_6	3.78	4.00		0.22	

DH_6	4.00	4.55		0.55	
DH_6	4.55	4.9		0.35	
DH_6	4.9	6.7	FPGMU	1.8	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO FERRUGINOUS CRUST IN GREY MUD
DH_6	6.7	8.38		1.68	
DH_6	8.38	9.00		0.62	
DH_6	9.00	9.95		0.95	
DH_6	9.95	10.43		0.48	
DH_6	10.43	12.1	FPGMA	1.67	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO. YELLOW BROWN AND RED IN HOMOGENEOUS GREY MUD
DH_6	12.1	20.4	FPGMA	8.3	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO. YELLOW BROWN AND RED IN HOMOGENEOUS GREY MUD
DH_6	20.4	21.3	FPCYR	0.9	FERRUGINOUS PERCOLATION CHANNEL YELLOW BROWN AND RED
DH_6	21.3	22.83	FPGMU	1.53	FERRUGINOUS CRUST AND PERCOLATION CHANNEL ALSO FERRUGINOUS CRUST IN GREY MUD
DH_6	22.83	23.88		1.05	
DH_6	23.88	25.38	GYMUD	1.5	FERRUGINOUS CRUST YELLOW. BROWN AND RED IN HOMOGEOUS GREY MUD
DH_6	25.38	28.33		2.95	
DH_6	28.33	29.83		1.5	
DH_6	29.83	32.65	GYMUD	2.82	GREY MUD
DH_6	32.65	33.63	GSOCM	0.98	GRAVEL AND SAND IN AN OXIDIZED CLAYEY MATRIX
DH_6	33.63	35.88		2.25	
DH_6	35.88	37.63	GSOCM	1.75	GRAVEL AND SAND IN AN OXIDIZED CLAYEY MATRIX
DH_6	37.63	38.58		0.95	
DH_6	38.58	38.6	RMDBB	0.02	RIO MUD DAM BASE BEDROCK
DH_6	38.6	40.13	BEDSC	1.53	BEDROCK SCHITSTS

APPENDIX B

RIO TAILING DAM TOPOGRAPHY POLYGON DATA

1. **Filename: Base topography data -T1955DATA.csv (3 992 points)**

Point	Easting	Northing	Elevation
1	36087.758	51023.93	630
2	36088.047	51023.895	630
3	36104.469	51012.793	630
4	36119.16	50999.656	630
5	36123.836	50993.199	630
-	-	-	-
-	-	-	-
1150	35821.156	50831.336	510
1151	35819.152	50832.781	510
1152	35816.48	50833.785	510
1153	35813.254	50834.898	510
-	-	-	-
-	-	-	-
3989	35672.66	51574.918	360
3990	35671.77	51590.727	360
3991	35667.539	51604.75	360
3992	35667.539	51604.75	360

2. **Filename: Tailing topography data - T2017DATA.txt (36 998 584 points)**

Point	Easting	Northing	Elevation
1	35691.14	50885.02	548.86
2	35692.01	50885.03	548.89
-	-	-	-
-	-	-	-
292	35692.52	50886.04	548.91
293	35691.57	50887.31	549.30
-	-	-	-
-	-	-	-
18388070	35590.19	50874.75	484.07
18388071	35589.36	50875.61	483.62
-	-	-	-
-	-	-	-
36998581	35559.72	51219.76	358.16
36998582	35557.27	51220.24	357.49
36998583	35560.65	51218.90	358.50
36998584	35557.37	51223.05	357.03

APPENDIX C

1. Rio tailing block estimation data

Rio tailing dam drilled holes compositing data: Typical straight composting

Filename: Straight_Compositing.xlsb

In total 104 samples were composite with a straight composting method to obtain a samples database that respect the distribution of logged samples intervals.

Part 1

DHID	MIDX	MIDY	MIDZ	TOPX	TOPY	TOPZ	BOTX	BOTY	BOTZ	LENGTH	FROM	TO
A10_S	35518.774	50838.431	466.125	35518.774	50838.431	466.130	35518.774	50838.431	466.120	0.010	0.200	0.210
A1_S	35771.004	50574.355	474.494	35771.004	50574.355	474.499	35771.004	50574.355	474.489	0.010	0.200	0.210
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
F1_S	35732.246	50759.239	468.270	35732.246	50759.239	468.275	35732.246	50759.239	468.265	0.010	0.200	0.210
F1_S	35732.246	50759.239	467.475	35732.246	50759.239	467.485	35732.246	50759.239	467.465	0.020	0.990	1.010

Part 2

	GEOCOD	BOUND	CU	W	ZN	FE	AS	LITH	LITH01	ORE	GEOL
A10_S	NONE		0.090	0.060	0.050	18.090	8.610		100.000	0	tailing
A1_S	NONE		0.410	0.060	0.880	21.750	12.300		100.000	0	tailing
-	-	-	-	-	-	-	-	-	-	-	-

-	-	-	-	-	-	-	-	-	-	-	-
F1_S	NONE		-99.000	-99.000	-99.000	-99.000	-99.000		100.000	0	tailing
F1_S	NONE		0.410	0.410	1.290	27.400	11.730		100.000	0	tailing

2. Filename: Block_Block_Estimation.xlsb

Block by block estimation assigned information and estimated results.

Part 1

Centroid x	**Centroid y**	**Centroid z**	**dim_x**	**dim_y**	**dim_z**	**volume**	**geology**	**cu_nn**	**cu_ivd**	**zn_nn**	**zn_ivd**	**w_nn**	**w_ivd**	**fe_nn**
Variable descriptions:								**copper nearest neighbour**	**copper inverse 2**	**zinc nearest neighbour**	**zinc inverse 2**	**wolfram nearest neighbour**	**wolfram inverse 2**	**iron nearest neighbour**
Variable types:							name	double	double	double	double	double	double	double
Variable defaults:							rock	-99.0	-99.0	-99.0	-99.0	-99.0	-99.0	-99.0
35311,5	50411	365	25	24	50	30000	rock	-99	-99	-99	-99	-99	-99	-99
35339,5	50428,5	366	19	41	48	37392	air	-99	-99	-99	-99	-99	-99	-99
35601.50	50690.50	447.50	1.00	1.00	1.00	1.00	tailing	0.10	0.23	0.35	0.39	0.20	0.27	0.00

Part 2

fe_ivd	**as_ivd**	**as_nn_dist**	**as_ivd_pass**	**as_nn**	**as_ivd_nholes**	**as_ivd_nsamples**	**as_ivd_mean**	**as_ivd_sd**	**as_ivd_avg_dist**	**cu_nn_dist**	**cu_ivd_pass**
double	float	float	integer	float	integer	integer	float	float	float	float	integer
-99.0	-99.0	-99.0	0	-99.0	0.0	0.0	-99.0	-99.0	0.0	-99.0	0
-99	-99	-99	0	-99	0	0	-99	-99	0	-99	0

-99	-99	-99	0	-99	0	0	-99	-99	0	-99	0
2.26	6.36	15.49	2.00	1.47	5.00	16.00	4.25	27.47	38.64	15.49	2.00

Part 3

cu_ivd_nholes	cu_ivd_nsamples	cu_ivd_mean	cu_ivd_sd	cu_ivd_avg_dist	fe_nn_dist	fe_ivd_pass	fe_ivd_nholes	fe_ivd_nsamples	fe_ivd_mean	fe_ivd_sd
integer	integer	float	float	float	float	integer	integer	integer	float	float
0.0	0.0	-99.0	-99.0	0.0	-99.0	0	0.0	0.0	-99.0	-99.0
0	0	-99	-99	0	-99	0	0	0	-99	-99
0	0	-99	-99	0	-99	0	0	0	-99	-99
5.00	16.00	-5.93	24.03	38.64	15.49	2.00	5.00	16.00	4.34	29.27

Part 4

fe_ivd_avg_dist	w_nn_dist	w_ivd_pass	w_ivd_nholes	w_ivd_nsamples	w_ivd_mean	w_ivd_sd	w_ivd_avg_dist	zn_nn_dist	zn_ivd_pass	zn_ivd_nholes
float	float	integer	integer	integer	float	float	float	float	integer	integer
0.0	-99.0	0	0.0	0.0	-99.0	-99.0	0.0	-99.0	0	0.0
0	-99	0	0	0	-99	-99	0	-99	0	0
0	-99	0	0	0	-99	-99	0	-99	0	0
38.64	15.49	2.00	5.00	16.00	-5.95	24.026203	38.640163	15.491766	2.00	5.00

Part 5

zn_ivd_nsamples	zn_ivd_mean	zn_ivd_sd	zn_ivd_avg_dist
integer	float	float	float
0.0	-99.0	-99.0	0.0
0	-99	-99	0
0	-99	-99	0

3. Rio tailing bench Resource estimation data (per bench)

Filename: Bench Estimation.xlsb

SOURCE	REGION	GEOLOGY	AS_IVD	CU_IVD	FE_IVD	W_IVD	ZN_IVD	TOTAL_VOLUME
rio_dump.bmf	Enclosed volume6_358.00t	rock	0.00	0.00	0.00	0.00	0.00	28.49
rio_dump.bmf	Enclosed volume6_368.00t	rock	0.00	0.00	0.00	0.00	0.00	432.56
rio_dump.bmf	Enclosed volume6_378.00t	air	0.00	0.00	0.00	0.00	0.00	18.48
rio_dump.bmf	Enclosed volume6_378.00t	rock	0.00	0.00	0.00	0.00	0.00	889.54
rio_dump.bmf	Enclosed volume6_378.00t	tailing	10.56	0.31	8.13	0.35	0.67	69.52
rio_dump.bmf	Enclosed volume6_388.00t	air	0.00	0.00	0.00	0.00	0.00	424.30
rio_dump.bmf	Enclosed volume6_388.00t	rock	0.00	0.00	0.00	0.00	0.00	2939.55
rio_dump.bmf	Enclosed volume6_388.00t	tailing	9.49	0.31	9.86	0.33	0.68	1696.15
rio_dump.bmf	Enclosed volume6_398.00t	air	0.00	0.00	0.00	0.00	0.00	745.28
rio_dump.bmf	Enclosed volume6_398.00t	rock	0.00	0.00	0.00	0.00	0.00	2091.67
rio_dump.bmf	Enclosed volume6_398.00t	tailing	9.82	0.35	13.65	0.32	0.74	12507.57
rio_dump.bmf	Enclosed volume6_408.00t	air	0.00	0.00	0.00	0.00	0.00	829.97
rio_dump.bmf	Enclosed volume6_408.00t	rock	0.00	0.00	0.00	0.00	0.00	7952.89
rio_dump.bmf	Enclosed volume6_408.00t	tailing	10.08	0.36	14.03	0.32	0.76	39439.87
rio_dump.bmf	Enclosed volume6_418.00t	air	0.00	0.00	0.00	0.00	0.00	1278.45
rio_dump.bmf	Enclosed volume6_418.00t	rock	0.00	0.00	0.00	0.00	0.00	20465.22
rio_dump.bmf	Enclosed volume6_418.00t	tailing	10.68	0.38	15.33	0.32	0.80	106553.38
rio_dump.bmf	Enclosed volume6_428.00t	air	0.00	0.00	0.00	0.00	0.00	1357.15
rio_dump.bmf	Enclosed volume6_428.00t	rock	0.00	0.00	0.00	0.00	0.00	15595.36
rio_dump.bmf	Enclosed volume6_428.00t	tailing	10.84	0.38	15.30	0.31	0.81	166306.38
rio_dump.bmf	Enclosed volume6_438.00t	air	0.00	0.00	0.00	0.00	0.00	1384.82
rio_dump.bmf	Enclosed volume6_438.00t	rock	0.00	0.00	0.00	0.00	0.00	28106.01

rio_dump.bmf	Enclosed volume6_438.00t	tailing	10.74	0.37	14.96	0.31	0.80	241923.72
rio_dump.bmf	Enclosed volume6_448.00t	air	0.00	0.00	0.00	0.00	0.00	1529.35
rio_dump.bmf	Enclosed volume6_448.00t	rock	0.00	0.00	0.00	0.00	0.00	22855.91
rio_dump.bmf	Enclosed volume6_448.00t	tailing	11.29	0.39	16.40	0.30	0.83	340179.25
rio_dump.bmf	Enclosed volume6_458.00t	air	0.00	0.00	0.00	0.00	0.00	3148.27
rio_dump.bmf	Enclosed volume6_458.00t	rock	0.00	0.00	0.00	0.00	0.00	17851.60
rio_dump.bmf	Enclosed volume6_458.00t	tailing	13.59	0.46	20.45	0.33	1.05	354045.15
rio_dump.bmf	Enclosed volume6_468.00t	air	0.00	0.00	0.00	0.00	0.00	2923.04
rio_dump.bmf	Enclosed volume6_468.00t	rock	0.00	0.00	0.00	0.00	0.00	1051.84
rio_dump.bmf	Enclosed volume6_468.00t	tailing	15.37	0.46	23.97	0.27	1.12	54636.62

4. Rio tailing dam block (under Bench Estimation.xlsb)

SOURCE	REGION	GEOLOGY	AS_IVD	CU_IVD	FE_IVD	W_IVD	ZN_IVD	TOTAL_VOLUME
rio_dump.bmf	Enclosed volume6.00t	air	0.00	0.00	0.00	0.00	0.00	82508012.00
rio_dump.bmf	Enclosed volume6.00t	rock	0.00	0.00	0.00	0.00	0.00	52577491.00
rio_dump.bmf	Enclosed volume6.00t	tailing	11.86	0.42	17.08	0.32	0.92	3039497.00
Total Volume of the Block								**138125000**

5. Definition

Inferred, Indicated and Measured Mineral Resource according to NI43-101

“In this Instrument, the terms "mineral resource", "inferred mineral resource", "indicate mineral resource" and "measured mineral resource" have the meanings ascribed to those terms by the Canadian Institute of Mining, Metallurgy and Petroleum, as the CIM Definition Standards on Mineral Resources and Mineral Reserves adopted by CIM Council, as those definitions may be amended.”

The terms Measured, Indicated and Inferred are defined by CIM (2005) as follows:

“A Mineral Resource is a concentration or occuaaarrence of diamonds, natural solid inorganic material, or natural solid fossilized organic material including base and precious metals, coal and industrial minerals in or on the Earth’s crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge.”

“The term Mineral Resource covers mineralization and natural material of intrinsic economic interest which has been identified and estimated through exploration and sampling and within which Mineral Reserves may subsequently be defined by the consideration and application of technical, economic, legal, environmental, socio-economic and governmental factors. The phrase ‘reasonable prospects for economic extraction’ implies a judgment by the Qualified Person in respect of the technical and economic factors likely to influence the prospect of economic extraction. A Mineral Resource is an inventory of mineralization that under realistically assumed and justifiable technical and economic conditions might become economically extractable. These assumptions must be presented explicitly in both public and technical reports.”

Inferred Mineral Resource

“An ‘Inferred Mineral Resource’ is that part of a Mineral Resource for which quantity and grade or quality can be estimated on the basis of geological evidence and limited sampling and reasonably assumed, but not verified, geological and grade continuity. The estimate is limited information and sampling gathered through appropriate techniques from locations such as outcrops, trenches, workings and drill holes.”

"Due to the uncertainty that may be attached to Inferred Mineral Resources, it cannot be assumed that all or any part of an Inferred Mineral Resource will be upgraded to an Indicated or Measured Mineral Resource as a result of continued exploration. Confidence in the estimate is insufficient to allow the meaningful application of technical and economic parameters or to enable an evaluation of economic viability worthy of public disclosure. Inferred Mineral Resources must be excluded from estimates forming the basis of feasibility or other economic studies."

Indicated Mineral Resource

"An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics can be estimated with a level of confidence sufficient to allow the appropriate application of technical and economic parameters, to support mine planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough for geological and grade continuity to be reasonably assumed."

"Mineralization may be classified as an Indicated Mineral Resource by the Qualified Person when the nature, quality, quantity and distribution of data are such as to allow confident interpretation of the geological framework and to reasonably assume the continuity of Mineralization. The Qualified Person must recognize the importance of the Indicated Mineral Resource category to the advancement of the feasibility of the project. An Indicated Mineral Resource estimate is of sufficient quality to support a Preliminary Feasibility Study which can serve as the basis for major development decisions."

Measured Mineral Resource

"A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are so well established that they can be estimated with confidence sufficient to allow the appropriate application of technical and economic parameters, to support production planning and evaluation of the economic viability of the deposit. The estimate is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that are spaced closely enough to confirm both geological and grade continuity."

"Mineralization or other natural material of economic interest may be classified as a Measured Mineral Resource by the Qualified Person when the nature, quality, quantity and distribution of data are such that the tonnage and grade of the mineralization can be estimated to within close limits and that variation from the estimate would not significantly affect potential economic viability. This category requires a high level of confidence in, and understanding of, the geology and controls of the mineral deposit."