RESOURCE ESTIMATION IN A HEAVY MINERAL SAND DEPOSIT USING BELOW DETECTION LIMIT DATA

Karina Boekhoud

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

Johannesburg 2011

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any University.

…………………………………………………………

(Signature of Candidate

………………… day of ………………………… year …………………

day *month* *year*

ABSTRACT

The objective of this research report is to investigate the variation of resource estimation at a heavy mineral sand deposit using below detection limit data

Best practise throughout the mining industry suggest regular audits to ensure the appropriate application of modelling techniques, reliability of the grade model and other factors contributing to the grade model such as analytical values (Dominy, Annels and Noppe, 2002). The heavy mineral sands industry is market driven. Correct resource and reserve estimation is essential when considering market negotiations.

Current estimation methodology at Hillendale mine uses the laboratory reported 'zero' data. The 'zero' data used for estimation is not considered to be best practise. External audits suggest the replacement of 'zero' data to 'null' data to lower kriging variance.

The current exploration strategy at Hillendale Mine comprises of WAC drilling, sample preparation and analyses of the sample with a Carpco® lift machine which uses magnetic susceptibility. Carpco® separated fractions are further analysed after compositing with grain counting and XRF analyses. This process is in general similar to other heavy mineral sand operations in South Africa.

Two datasets are used to estimate a geological resource. The 'zero' dataset is the original borehole data as analysed by the laboratory. In the 'zero' dataset, all the below detection limit data is assigned a '0' and the value is added as a number to the average calculation. With the 'null' dataset, the below detection limit data are left blank and are no value is added to the

average calculation. All other parameters and methodologies are kept the same for comparative purposes. The effect of the two datasets is compared to one another through basic statistical analyses, geostatistical analysis and visually through trend analysis on 50 metre slices through the mine. The geological estimates are compared to actual mine plant data through reconciliation to evaluate the influence of the ‘zero’ data compared to the ‘null’ data in a producing heavy mineral sand mine.

The result of the study will show that the global estimation and methodology for both datasets are similar. Cross validation checks using the ‘null’ dataset with the magnetic fractions are not possible. Both datasets follow similar trends of over- and underestimation. In general the resources’ are overestimated for the mineral deposit compared to the actual plant data. The overestimation of the ‘zero’ dataset is less than the ‘null’ dataset therefore a better estimation of the expected value.

It is recommended that future work is done in terms of investigating the appropriateness of the datasets, the effect of cut-off values and the appropriateness of the estimation method. In addition the effect of mining, in terms of mining to plan, as well as actual plant recovery should be investigated.

Table of content

List of Figures

List of Tables

List of Equations

LIST OF ABBREVIATIONS

CoV	-	Coefficient of Variation
CPC	-	Central Processing Centre
DTM	-	Digital terrain models
GPS	-	Global Positioning System
HMC	-	Heavy Mineral Concentrate
KZN	-	Kwa-Zulu Natal
LIMS	-	laboratory information management system
MSP	-	mineral separation plant
PWP	-	Primary wet plant
QAQC	-	Quality Assurance and Quality Control
RC	-	Reverse Circulation
ROM	-	Run of mine
SABLE	-	Standardised Approach to Drill hole Logging for Exploration
SAMREC Code	–	The South African code for the reporting of exploration results, Mineral Resources and Mineral Reserves.
SLA	-	Service Level Agreement
SQL	-	Standard Query Language
TBE	-	tetrabromoethane
THM	-	Total Heavy Minerals
VHM	-	Valuable Heavy Minerals
WAC	-	Wallis Aircore
XRF	-	X-ray fluorescence

DEFINITION OF TERMS

Carpco® analyses:	First pass high intensity dry magnetic separation of a heavy mineral sample into distinct groups based on their inherent properties. The separator places all materials in contact with the magnetic field into zones of steepest gradient and utilizes magnetic force and gravity to capture weakly magnetic materials. The running roll provides a centrifugal force for separating the magnetic and nonmagnetic materials (University of Vermont, 2006)
HS Mags (magn):	The first fraction removal of Carpco® analysis. It is the high susceptibility magnetic fraction, which consists mainly of magnetite.
0.8A Mags (mags):	The second fraction removal of Carpco® analysis. The material consists mainly of ilmenite (98%).
Magnetic Others (mago):	The third fraction removal of Magnetic susceptibility analyses and is ‘waste’ material such as garnet, epidote and tourmaline.
Non – magnetic (nmag):	The final fraction of Carpco® analyses. It consists mainly of zircon, rutile and leucoxene

1 The problem and its setting

1.1 Introduction

Mineral Resource and Reserve classification is a means of representing the risk associated with a mineral resource as reported through the resource statement. The numerous codes do not regulate the classification techniques or the estimation methods. Confidence in classification should take into consideration some practical aspects such as the drillhole spacing, analytical technique, sample representativeness, and grade continuity. The classification is therefore subjective to the competent person (Snowden, V. 1996).

In the mining industry the level and location of investment is determined by expected revenues and costs, adjusted for time and risk. The higher the expected revenues or the lower the expected costs, the more attractive an investment opportunity is. In the mineral sector, the factors that influence expected revenues, costs, and risks can be grouped into four categories of which one includes geological risk. The geological risk can be related to the likelihood and the degree to which the estimated mineralisation differs from the actual mineralisation mined. (Eggbert, R. B., 2010).

At every stage of a project, quality of data and methodologies should be at the forefront of the technical teams' mind and subject to regular audit. This is a critical part of quality assurance. These audits should synthesize and review the quality of the input data (geological and assay), applicability of modelling techniques used, reliability of grade models and of the various factors used to produce the estimate (Dominy, Annels and Noppe, 2002).

Mineral sands are deposits of ilmenite and other heavy minerals that are concentrated by weathering and beach processes. The minerals of value in mineral sands are predominantly ilmenite, rutile, zircon and their weathered equivalents. Titanium-bearing minerals of mineral sands deposits is one of the main sources of titanium feedstock used by white pigment producers for paints, paper and plastics. The titanium producers define the characteristics of the mineral products that are used to estimate mineral resources of mineral sands deposits. Other criteria apply to co-products of titanium, which must satisfy physical and chemical requirements of end-users, provided that a viable market exists for those mineral products (Spring, V. et al., undated)

Mineral sands are different to most commodities since they require the quality constraints as well as the physical properties to ensure a market (Jones, G, undated). The term “mineral sand” refers to the concentration of heavy minerals (HM) and is found in both beach sands and dunal sands.

1.2 The Problem

Resource estimation and the conversion to Reserves are of key importance for mining companies, from feasibility studies to day-to-day operations. A number of errors from sampling, assaying and geology are introduced during interpretation and estimation (Dominy and Noppe, 2002). With estimation one of the objectives is to obtain a global resource estimate and an estimate of the likely grade-tonnage curve within a deposit. According to Dominy and Noppe there are five issues that contribute to the possibility of an incorrect resource estimate, of which two include:

- poor sample and assay quality data;
- poor interpretation of grade distribution characteristics;

The heavy mineral sands deposit situated on the North coast of Kwa-Zulu Natal currently uses magnetic susceptibility analyses for estimating the fractional data as a first stage analytical technique. Magnetic susceptibility analyses uses a Carpco® lift machine (model MLH(13)111-5) in which the heavy minerals is separated into four magnetic fractions based on their individual characteristics. The Carpco® lift machine separates material in contact with the magnetic field. It uses force and gravity to capture weekly magnetic material. The running roll provides centrifugal force for separating the magnetic and non-magnetic materials (University of Vermont, 2006).

The fractions produced through the magnetic susceptibility analyses are derived through different settings on the Carpco® machine, dividing the Total Heavy Mineral (THM) into 'magn', consisting of mainly magnetite, 'mags' consisting of mainly ilmenite, 'mago' consisting of gangue material and 'nmag' with contains the non-magnetic fractions such as zircon, rutile and leucoxene.

This analysis is limited to a minimum THM content of 1.5%. If the is THM < 1.5% no magnetic susceptibility analyses is done to determine the additional fractions due to the equipment not being able to successfully separate such small quantities of material. The laboratory subsequently reports the fractions as 'zero'. The 'zero' values are therefore 'not analysed' by the laboratory. The reported laboratory result is used in the geological model as 'zero'.

It has been suggested through audits and resource reviews of a similar resource deposit adjacent to the current operating mine that the 'zero' value be changed to 'null' value for estimation purposes. The reasoning for the replacement of the 'zero' value to the 'null' value is for the improvement of the kriging efficiency. Kriging efficiency is a representation of the quality of the result of the estimation. According to the resource audit, it is found that the 'zero' values contribute to poor data quality (Shabala, S, van der Schyff W, 2010).

The current operation can review the effect of the replacement of the 'zero' value to the 'null' value with current drilling, analyses, modelling, mining and plant production figures.

This document will illustrate the difference of the different datasets in comparison to the final product through reconciliation.

1.3 Sub problems

1.3.1 Sub problem 1

What is the effect of modelling on the over or under-estimating of grade estimates. Do variations on the definition of below detection data from ‘zero’ to ‘null’ change the overall estimation methodology of an ore deposit looking at the statistics and estimation of the ore body? ‘Zero’ is defined as all below detection limit and is given a ‘0’. ‘Zero’ is added as a number that is included in the average. ‘Null’ is left blank and is not added as an assay in the average.

Block models of the two different scenarios of the resource are calculated and compared to evaluate the variation in the estimation when using the different scenarios.

1.3.2 Sub problem 2

Does reconciliation improve the confidence in the estimation methodology?

Continuous improvement relies on our ability to funnel and communicate the best improvement projects through to management approval and executing those projects in the most efficient way (De-Vitry, undated). The ultimate aim of reconciliation is to “measure, control and improve”, although the usefulness of reconciliation ultimately depends on the input data (Noppe, 2004).

Both datasets' estimations are used and reconciled with actual mining and plant data for corresponding time periods. The variation in estimated block model compared to actual plant data achieved is determined to review the effect of using the 'zero' versus 'null' from the laboratory datasets for estimation of the mineral resource.

1.4 Limits of research

The thesis is limited to the available Wallis Aircore (WAC) drilling data, currently available survey data and corresponding plant data from 2007 to 2010.

The analytical method is deemed appropriate for the deposit.

No cut-off grades are applied.

No corrective actions on the mining or plant will be done.

Reconciliation is limited to the actual block model versus actual mined and actual plant data and not planned mining.

1.5 The importance of the study

Currently the heavy mineral deposit under review uses the reported laboratory value of 'zero' to determine the Resource and Reserve statement. The 'zero' geological block model is also used for financial modelling. The thesis will look at the variations introduced in the geological block model by applying a ‘null’ value to below detection limit data. The influence will be evaluated against actual plant data by means of reconciliation to determine whether this method could be applicable, as recommended in the recent audit. The results of this thesis can be used for similar, future projects on the north coast of Kwa-Zulu Natal.

2 Regional and local geology

2.1 Regional geology

The Kwa-Zulu Natal coastal dune cordon is one of the highest in the world, reaching heights in excess of 180m and widths of up to 2 km (Ware, Whitmore and Uken, 2001). The dune cordon consists of a complex system of Quaternary stacked dunes of various geomorphologies, types and ages. The Quaternary period is characterised by large variations in climatic conditions in a relatively short time (Maud, 1968). The economic portion of the dunes consists of ilmenite, zircon and rutile (Ware, Whitmore and Uken, 2001). No economic concretions of ilmenite, zircon and rutile occur in some parts of these dunes.

Mineral sand deposits are located on the coastal regions of most continents and are classified as beach placer, paleo placer, dune and fluvial (Macpherson and Masters, 1983). Heavy minerals from the source areas are subject to weathering and erosion whereby the grains are released and made available for transporting to the concentration site with water being the dominant transportation mechanism. Local wind action concentrates the heavy minerals.

The dominant environment for mineral sand deposits is marine shoreline areas. A near-shore, marine, sand-dominated environment a high-energy winter storms coincide with the greatest amount of fluvial sedimentary input and in-situ erosion of pre-existing sediments is the typical environment. The wave action is the principal erosive process and a sandy beach may have a significant proportion of sand volume deposited as an offshore bar. Conditions pertaining, selective heavy minerals may be transported towards the shore to form a concentrated zone. More often, a long-shore current sets up a littoral drift with sufficient energy to move the lighter and smaller grained materials. During the final phases of the winter storms the lessened wave action produces a backwash down the beach that has sufficient strength to selectively remove the light materials (Macpherson and Masters, 1983).

2.2 Local geology

The Hillendale Mine is situated in northern KwaZulu-Natal approximately 20 km east of Empageni and 45 km south west of Richards Bay respectively. Hillendale is bordered by the Mhlatuze River on the north-western side and by eSikhawini Township on the south-eastern side (Sibiya et al, 2005) (Figure 1).

Figure 1. Locality map of Hillendale Mine

The Hillendale dune comprises mostly the older Pliocene parent Berea red sand as suggested by the relative position of the dune and the current level above sea level and present day elevation above current sea level. The silt values at Hillendale fluctuate between 15% and 45%, with an average of 23.5% and the thickness varying between 18m and 21m (Sibiya, et al. 2005). There is sporadic occurrence of medium to coarse grained, yellow to dark orange, low silt sands in parts of the Hillendale dune. This sand is less cohesive than the Berea type sands due to the lower silt content. There is no specific correlation between these sands and the Berea type sands but they possibly represent younger sediments with local Post-Pliocene river flooding or Pleistocene dune migration (Sibiya et al, 2005). There is a grey-brown, fine grained, semi-cemented sand / sandstone unit intermittently between 9m and 30m below surface in the central parts of the dune (Sibiya et al, 2005).

2.3 Mineral sand composition

Heavy mineral sands are described as a group of minerals commonly found together. The economic viable portion of these sands is usually ilmenite, zircon, rutile and leucoxene (Jones, 2009).

At Hillendale the average dune composition is approximate 71% sand, 24% silt (defined by fraction < 45μm) and 5% total heavy minerals as indicated in Figure 2. The composition is calculated from the borehole data, using the original assay database, which includes the ‘zero’ values, with no cut-off values applied.

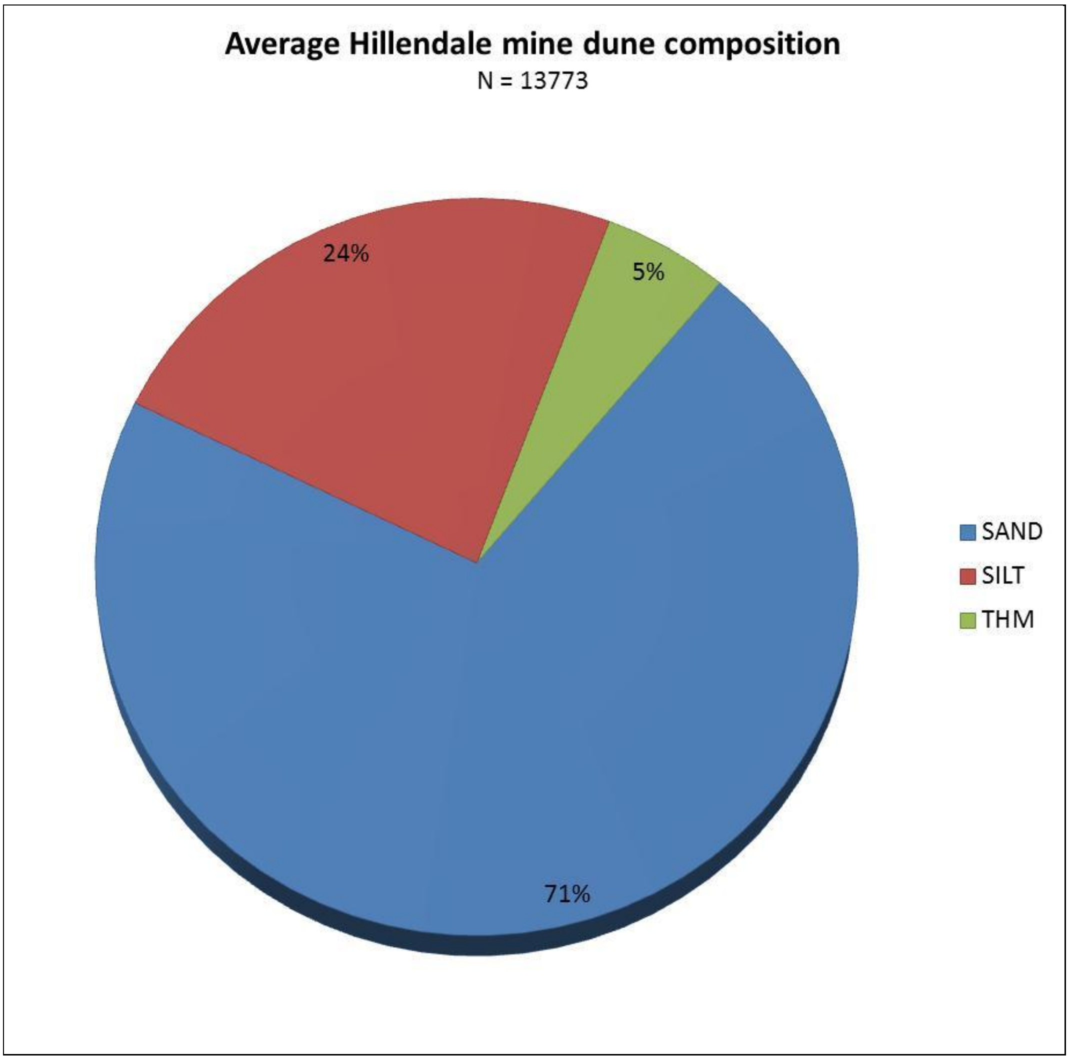


Figure 2. Hillendale Mine average dune composition

2.3.1 THM composition

2.3.1.1 'Zero' dataset

Evaluating the THM composition for the sample analyses **including 'zero' values**, the THM comprises of an average of 57% 'mags', 10% 'magn', 18% 'mago' and 15% 'nmag' as indicated in Figure 3.

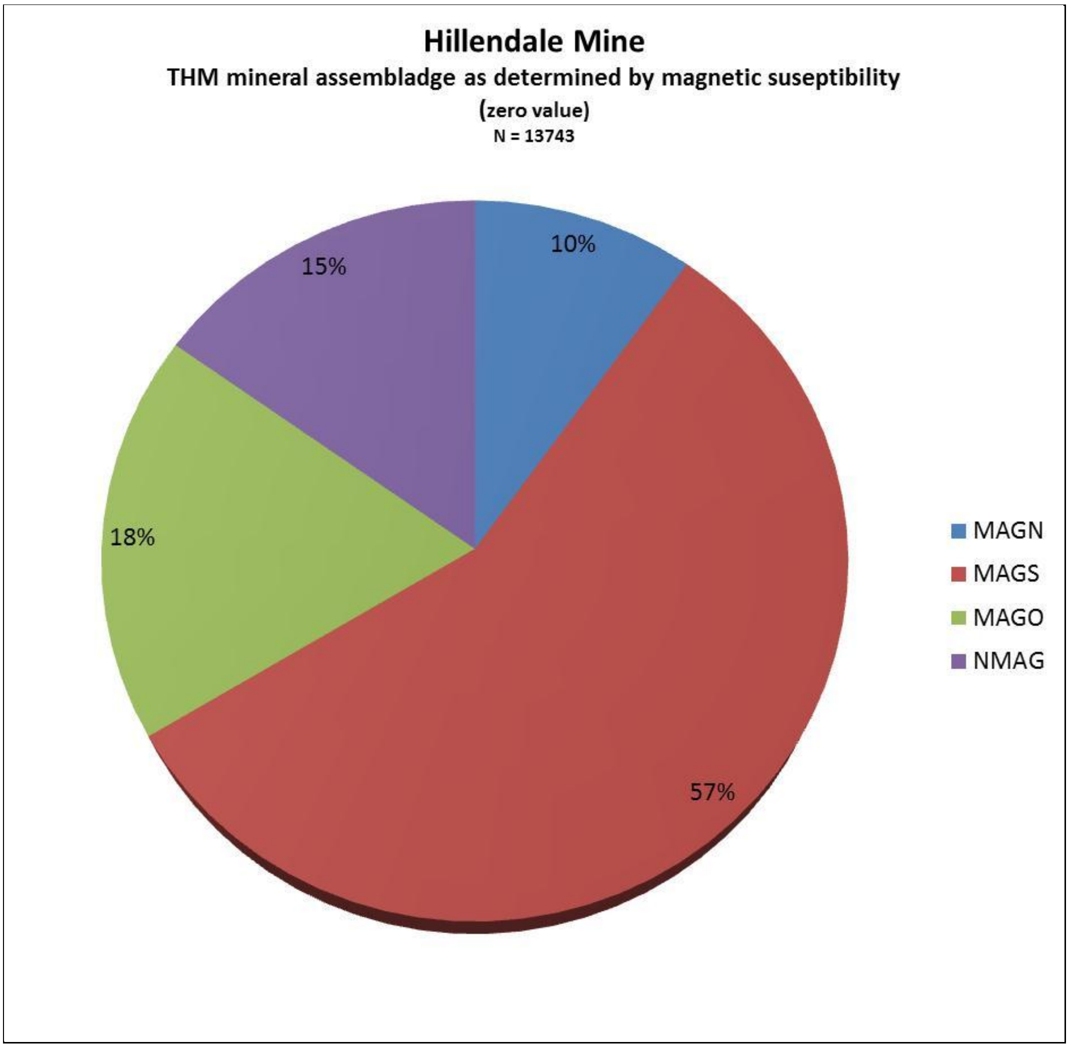


Figure 3. THM mineral assemblage for 'zero' values

2.3.1.2 ‘Null’ dataset

Evaluating the THM composition for the sample analyses with ‘zero’ values changed to ‘null’ values, the THM compositions changes to 67% ‘mags’, 12% ‘magn’, 22% ‘mago’ and 18% ‘nmag’ as indicated in Figure 4. The ‘null’ dataset is created whereby the assigned ‘0’ value is changed to a blank value in the database.

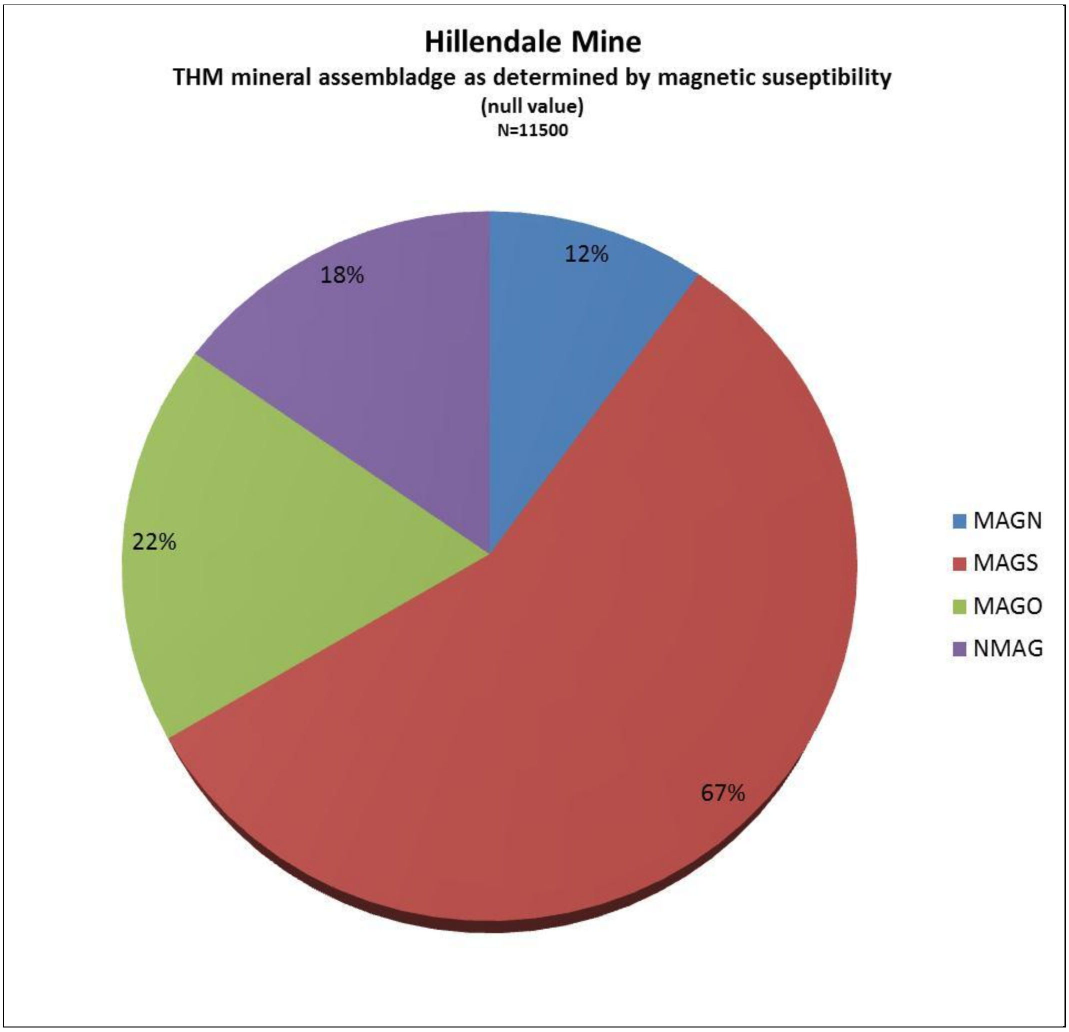


Figure 4. THM mineral assemblage for 'null' values

Table 1 is a summary of the comparative mineral assemblages of the two datasets. All the ‘null’ dataset fraction has higher values since the values are not diluted with the ‘0’ value assigned in the ‘zero’ dataset.

Table 1. Comparative table of the mineral assemblage of the ‘zero’ and the ‘null’ borehole datasets

	MAGN	MAGS	MAGO	NMAG
ZERO	10%	57%	18%	15%
NULL	12%	67%	22%	18%

2.3.2 Mineral composition of the THM

Figure 5 indicates the chemical composition of the three main fractions of the THM as determined with XRF analyses on the various magnetic separation fractions using the 'zero' dataset.

The 'mags' fractions has the highest percentage of TiO_2, Total Fe and Fe_2O_3 as expected since this fraction contains the highest proportion of ilmenite.

The 'mago' fractions contain the gauge minerals and have the highest proportion of 'other' chemical composition. The 'other' is elements such as SiO_2, MgO, Al_2O_3 and Cr_2O_3.

The 'nmag' fraction contains the highest proportion of ZrO_2, the main constituent of zircon which is derived from this fraction.

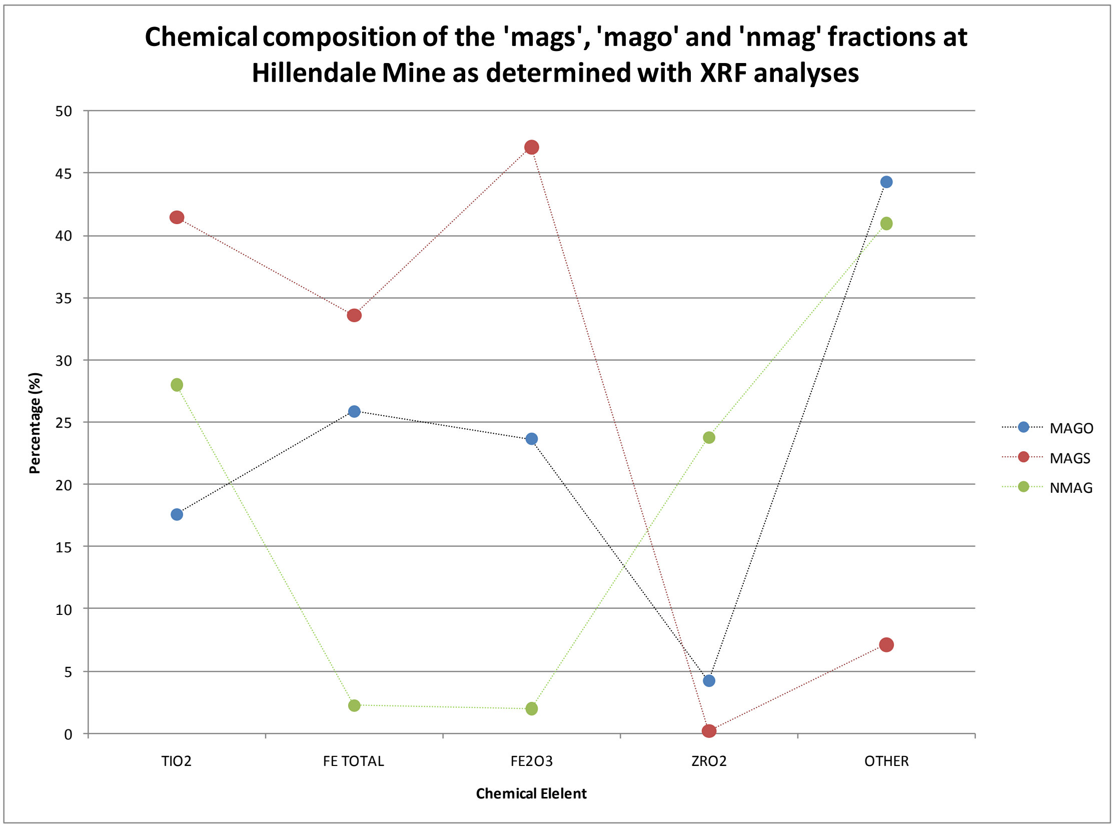


Figure 5. Chemical composition of the 'mags', 'mago' and 'nmag' fractions as determined by XRF

Figure 6 is the mineralogical composition of three fractions that define the THM at Hillendale using the 'zero' dataset.

It can be seen from Figure 6 that the 'mags' fraction contains almost 90% on average of ilmenite and negligible zircon, rutile and leucoxene.

The 'mago' fraction contains almost 35% ilmenite and more than 50% 'other'. The 'other' is minerals such as chromite, monazite, amphibole, pyroxene, kyanite, epidote, tourmaline, garnet and hematite. These minerals have a negative effect on the PWP beneficiation and influence the plant recovery.

The 'nmag' fraction contains almost 40% zircon, 20% rutile and 15% leucoxene.

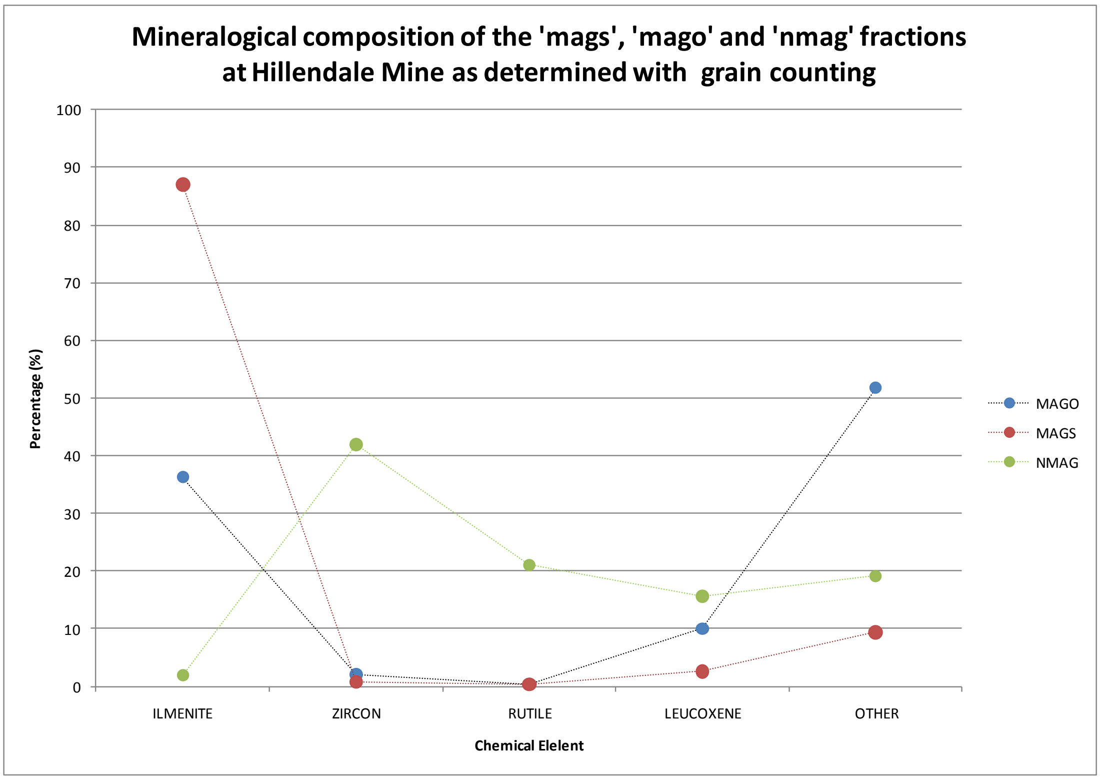


Figure 6. Mineralogy composition of the 'mags', 'mago' and 'nmag' fractions

2.4 Exploration

2.4.1 Drilling

Exploration drilling for Hillendale started with standard reverse circulation (RC) drilling and was subsequently changed to the Wallis Aircore (WAC) drilling which is a more reliable method than RC. Standard RC drilling works with compressed air that is forced down a double wall pipe. The air is forced back, taking the recovered sample with. This method has variable sample recovery due to the method of sample blowout.

WAC uses the same principal of compressed air. The air is however forced up in the inner tube of the drill rod. This method of the air forced into the inner tube allows for better sample recovery and potentially less sample contamination caused by the blow-out of the air as with RC drilling.

A total of 823 boreholes were drilled at Hillendale since 1998 to 2008 with WAC, with no drilling between 2003 and 2005 as indicated in Figure 7.

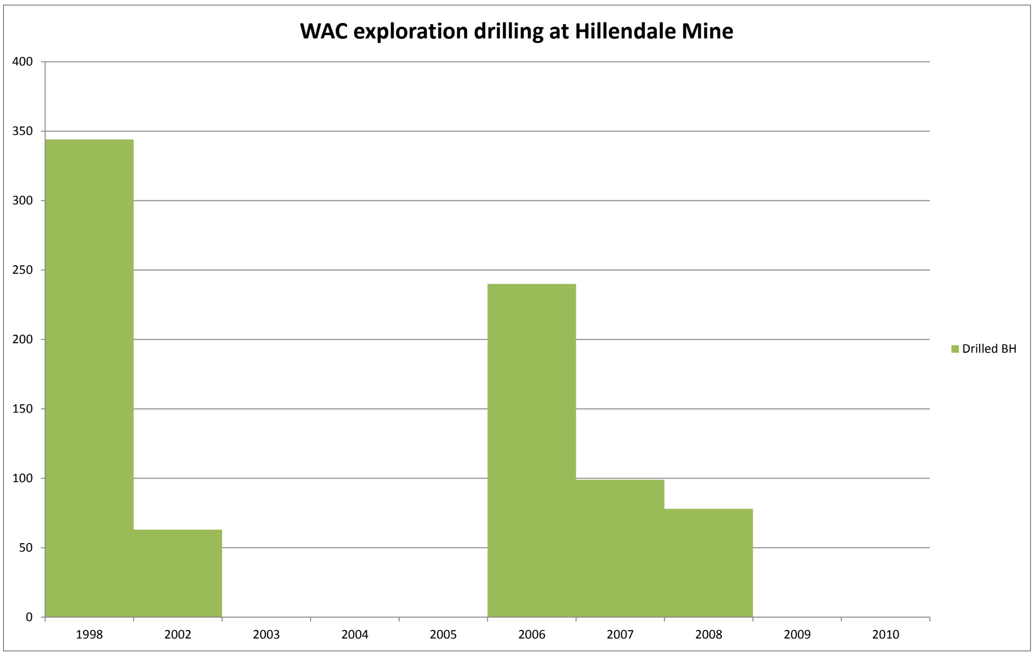


Figure 7. WAC exploration drilling at Hillendale Mine

Hillendale mine deposit has a minimum drillhole spacing is 50m x 50m for production purposes. The 50m x 50m drillhole spacing is achieved through continuous infill drilling from the initial 200m x 400m drillhole grid used for target generation as listed in Table 2. The minimum drillhole spacing seems to be adequate for the production purposes of the deposit as seen with the monthly reconciliation.

Table 2. Hillendale grid size strategy

Description	Grid
Initial Target Generation	200 x 400
Phase 2 infill drilling	200 x 200
Phase 3 infill drilling	100 x 100
Production drilling	50 x 50

The south western portion of Hillendale mine as indicated in Figure 8 is not covered with WAC drilling since mining activity started in the south western portion and it was thus covered by RC drilling.

HILLENDALE MINE
DRILLING GRID WITH WAC DRILL HOLES

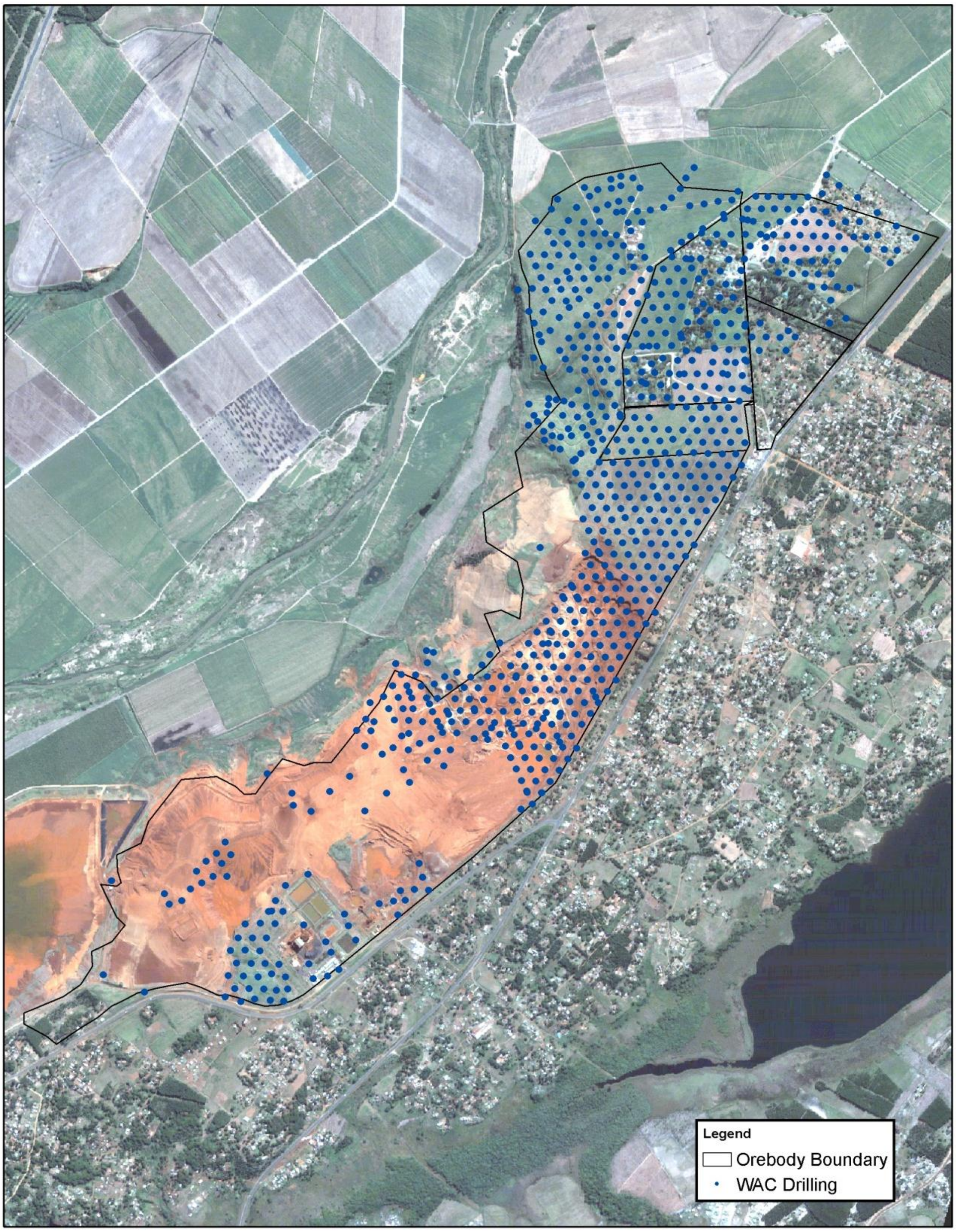


Figure 8. Hillendale WAC drilling grid

Drilling samples are taken at 3 metres intervals to co-inside with drill rod length. The 3 metre sample depth is preferred for consistency with depth measurement and the speed of drilling since no additional stopping or measuring takes place. For standardisation, the sampling interval of 3 metre rod lengths are adequate for the mining operations. The flexibility of the mining method allows to cater for the variation in mineralisation of the dune.

2.4.2 Logging

Geological logging is done in the field as the sample is being produced through drilling. A standardised logsheet and reference chart is used and information such as the colour, sand characteristics, moisture content, sample mass and drilling hardness is recorded. The colour is guided by the Munsell ® colour chart. Both the moisture content and drilling hardness is a subjective estimate from the field geologist.

Field panning is done to visually estimate the amount of silt and THM in the field sample. This is done on a standard sized sub sample of approximately a teaspoon size of the total sample taken. If the sample has no more estimated THM, another sample is drilled and visually checked where after the drillhole is stopped. This technique is used for validation purposes and the qualitative values are not used for estimation.

Logging data is captured regularly into a SQL database where after it is validated.

2.4.3 Exploration sampling and analyses methodology

Exploration samples are prepared at an onsite sample preparation facility and analysed in two different steps. The first analytical method is the laboratory magnetic susceptibility analyses done with the Carpco® lift machine. With Magnetic susceptibility analyses the sample is separated into four different ‘mineral’ fractions depending on the magnetic characteristics.

The second step of analyses at Hillendale Mine, is compositing the Carpco® fractions into larger groups. The composited sample is further analysed with mineralogical grain counting and XRF analyses. The process is described below. A similar process of analyses as used within exploration is used for production sample analyses.

2.4.3.1 Sample preparation

Field samples consist of the 3 metre sample interval as determined by the length of a drill rod. The 3 metre interval is being used to ensure consistency and was introduced with the previous RC method where the sample recovery was very variable due to the air blowout of the method (Sibiya et al, 2005). The sample length was kept for consistency when the WAC drilling technique was introduced. Samples are collected in a new plastic bag. The 3 metre sample can weigh between 12 – 20kg.

Once the sample is logged and panned the sample bag is sealed and marked. The sample is taken to the sample preparation facility, located at Hillendale mine. All wet samples are dried, either with a gas burner or in an electric oven. Due to the proportion of clay minerals, the dried samples consolidate and thus require subsequent crushing. The sample is crushed manually. The process that follows is similar for the dried samples as well as the dry field samples. The sample is split into four bags of approximately 1.5kg – 2 kg using a rotary splitter. The remainder of the sample is kept for geometallurgical test work at Hillendale, referred to as Zonework.

One of the prepared split samples is submitted to the 'Central Process Complex' (CPC) laboratory for analyses. Depending on the specific sample, a duplicate sample is submitted for analyses. At least one sample is kept for a future backup.

2.4.3.2 Magnetic susceptibility analyses

All the exploration samples are analysed at the in-house laboratory at CPC. Due to all the samples analysed at the same laboratory, there is consistency in the method of analyses. The sample preparation and analyses process at CPC is indicated in Figure 9 and described in the text below.

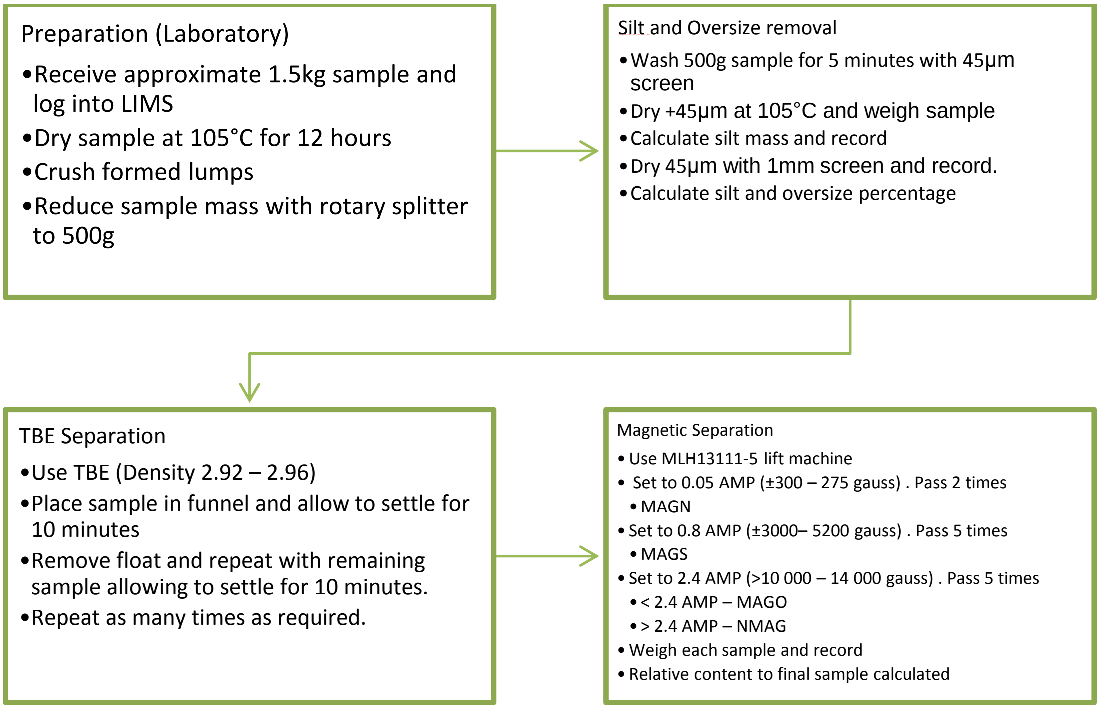


Figure 9. Laboratory sample preparation methodology

Analyses of heavy mineral sand use the physical characteristics of the minerals to separate the minerals into different categories specifically magnetism. The characteristics of some of the material is characterised in Table 3.

Table 3. Common mineral sands, their physical properties and chemistry (source Iluka, Jones)

Mineral	Valuable	Magnetic Susceptibility	Electrical Conductivity	SG	Chemical Formula
Ilmenite	Yes	**High**	**High**	4.5 - 5.0	$Fe.TiO_3$
Rutile	Yes	**Low**	**High**	4.2 - 4.3	TiO_2
Zircon	Yes	**Low**	**Low**	4.7	$ZrSiO_4$
Leucoxene	Yes	**Semi**	**High**	3.5 - 4.1	$Fe.TiO_3.TiO_2$
Monazite	No	**Semi**	**Low**	4.9 - 5.3	$(Ce,La,Th,Nd,Y)PO_4$
Staurolite	No	**Semi**	**Low**	3.6 - 3.8	$Fe_2Al_9Si_4O_{22}.(OH)_2$
Kyanite	No	**Low**	**Low**	3.6 - 3.7	Al_2SiO_5
Garnet	No	**Semi**	**Low**	3.4 - 4.2	$(Fe,Mn,Ca)_3.Al_2(SiO_4)_3$
Quartz	No	**Low**	**Low**	2.7	SiO_2
Source Iluka (undated)					

The 1.5 – 2kg split sample is sent to the laboratory where it is received and logged into the laboratory information management system (LIMS) system. All samples are dried for approximately 12 hours, where after they are cooled and crushed. The sample is reduced in size by a rotary splitter to approximately 500g.

The sample is screened with a 1mm sieve and the >1mm material is removed as classified as oversize. The remaining material is screened with a 45 µm screen. The <45 µm material is defined as silt. The material between 45 µm and 1mm is used to determine the total heavy minerals. THM are determined by dense medium separation using tetrabromoethane (TBE). The tetrabromoethane has a specific gravity of approximately 2.96. The density is checked daily as a control measure. The process produces the percentage sand and the percentage THM.

Samples with a THM greater than 1.5% are magnetically separated by a Carpco ® lift machine. The Carpco ® lift machine produces four fractions of magnetic susceptible material based on their electrostatic characteristics.

The Carpco® lifting machine is a high-intensity induced-roll magnetic separator that is top fed. It is designed to separate paramagnetic materials from non-magnetic materials (University of Vermont, 2006). The four fractions produced are ‘magn’, ‘mags’, ‘mago’ and ‘nmag’.

The first fraction removed is the high susceptibility magnetic fraction (HS Mags /’magn’), which is mainly magnetite. The material is passed twice through the Carpco® machine with the settings to 0.05 ampere and a magnetic field strength of approximately 257 – 300 gauss.

The second fraction removed is defined as ‘mags’ (magnetically susceptible) and contains mainly of ilmenite (98%). The machine is set to 0.8 ampere and 3000 – 5200 gauss. The 0.8 ampere fraction is passed five times through the Carpco® machine to ensure depletion.

Magnetic ‘Others’ (‘mago’) consisting of ‘waste’ material such as garnets, epidote and tourmalines are removed with an ampere setting between 0.8 and 2.4 ampere (10000 and 14000 gauss). The material is passed five times through the Carpco® machine to ensure depletion.

The remaining material is defined as the non-magnetic (‘nmag’) fraction and contains mainly of zircon, rutile and leucoxene (Sibiya et al, 2005)

2.4.3.3 Chemical and mineralogy analyses

Mineralogy and chemical analyses are done on composite samples of the individual Carpco® fractions. Composites are compared on a larger grid size of approximately 200m x 200m. A minimum composite length of 9 meters is usually selected. Samples where the individual corresponding fractions (‘mags’, ‘mago’ and ‘nmag’) are perceived to have the same geological and analytical characteristics are grouped together to form the composite used for the mineralogical and chemical analyses. The mass of the ‘nmag’ fraction is usually a constraint, since this fraction contributes only a small fraction of the THM (Sibiya et al, 2005).

As in many heavy mineral sand operations, the cost of the detailed mineralogical assessment along with the minimum mass required will require composite samples (Jones, 2009).

2.4.4 Quality assurance and quality control

There are a number of quality assurance quality control (QAQC) systems in place at Hillendale Mine. This includes laboratory control as set out in a service level agreement (SLA) with the laboratory, control samples and duplicate samples. No blank samples are used as a quality control protocol. Blank samples will not test any analytical process such as the silt removal, TBE or magnetic separation and is therefore excluded from the QAQC.

2.4.4.1 Laboratory control

2.4.4.1.1 Screen check

The laboratory does constant checks on the 45µm screens ensuring that it is kept in a good condition and performing as expected.

2.4.4.1.2 TBE check

The quality of the TBE is checked on a regular basis, with an allowable variance of the specific gravity between 2.90 and 2.98

Figure 10 illustrates the variation in TBE samples from the initiation of the 2006 drilling campaign. It can be noted that although the values are still within the agreed specifications, there is an upward trend within the TBE values.

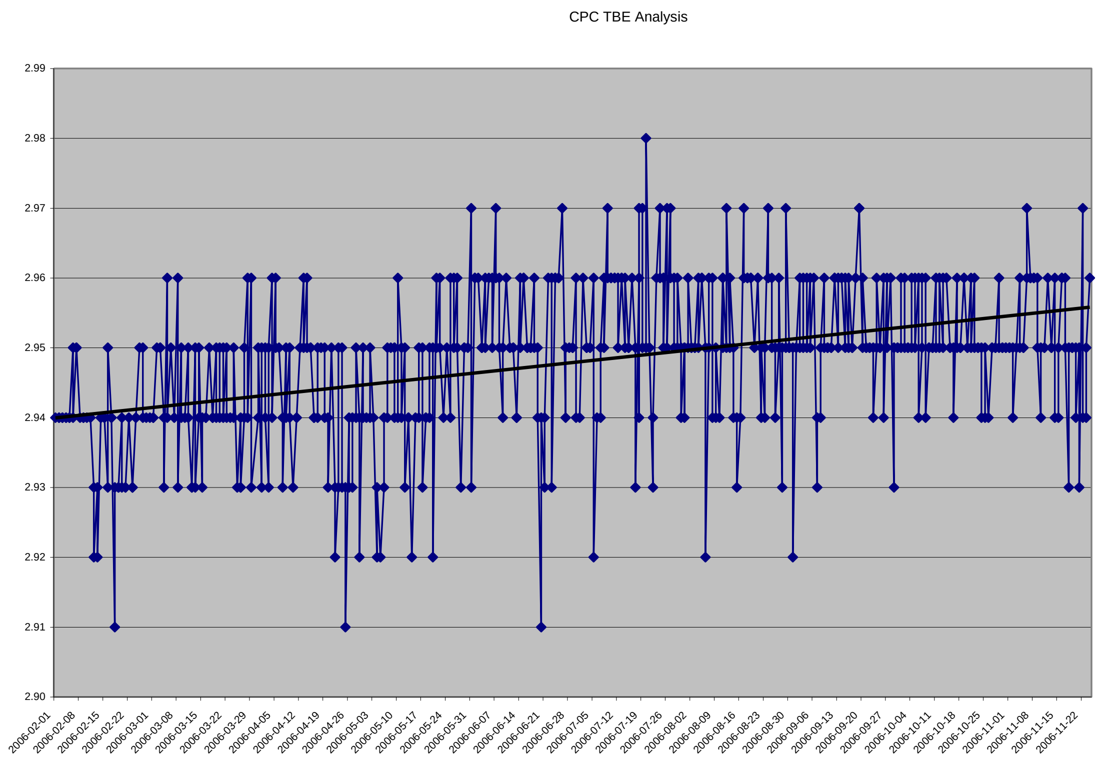


Figure 10. QAQC for TBE analyses

2.4.4.1.3 Carpco® equipment check

The Carpco® equipment is checked for amperage, pole gaps and gauss readings at the start, halfway through and at the end of each batch of 60 samples as listed in Table 4.

Table 4. Carpco® equipment check parameters

AMPS	ROLL SPEED (RPM)	POLE GAP	GAUSS READING KGauss	NO. OF PASSES	CARPCO EFFICIENCY
0.05	237	4mm	0.421	2	99%
0.8	237	4mm	4.06	5	98-100%
2.40	287	4mm	13.03	5	

A laboratory prepared control sample is used to monitor the instruments performance. Magnetic separation for the drilling programme is done on the Primary Wet plant (PWP) Carpco® (Orange Carpco®). This Orange Carpco® is specifically used for exploration samples to ensure consistency with machinery.

2.4.4.2 Control samples

Control samples are inserted at every 20th sample within the sequential exploration sample numbering system. The control samples are created from ore material acquired from the current Hillendale mining operations. The material is homogenised with a rotary splitter at the CPC laboratory where after ten to fifteen samples are submitted to the laboratory to determine the statistical average of the individual samples components such as silt, THM and the Carpco® fractions and deviation of the material. No other statistical methods are currently used to test for sample homogeneity. It should be noted that the control samples are not certified by an accredited laboratory and therefore not referred to as Standard Reference material.

Various control samples are created with varying silts and THM values. The range in values indicates the efficiency of the process with high / low silts and high / low THM values. The control samples are rotated in the submission sequence.

Currently it has been determined that a variance of two times the standard deviation is acceptable as a control limit. Deviations exceeding the range will be investigated. Corrective measures results in a batch being re-submitted.

Figure 11 is an example of the QAQC approach using the standard reference material before corrective measures. The green and blue horizontal lines are the control sample standard deviations, and the acceptable level of which the analyses should fall in. The actual sample deviation from the mean is a lot larger than the control sample, with a number of outliers in the uncorrected analyses. The control sample can clearly indicate where potential problems in the analyses are and can be addressed.

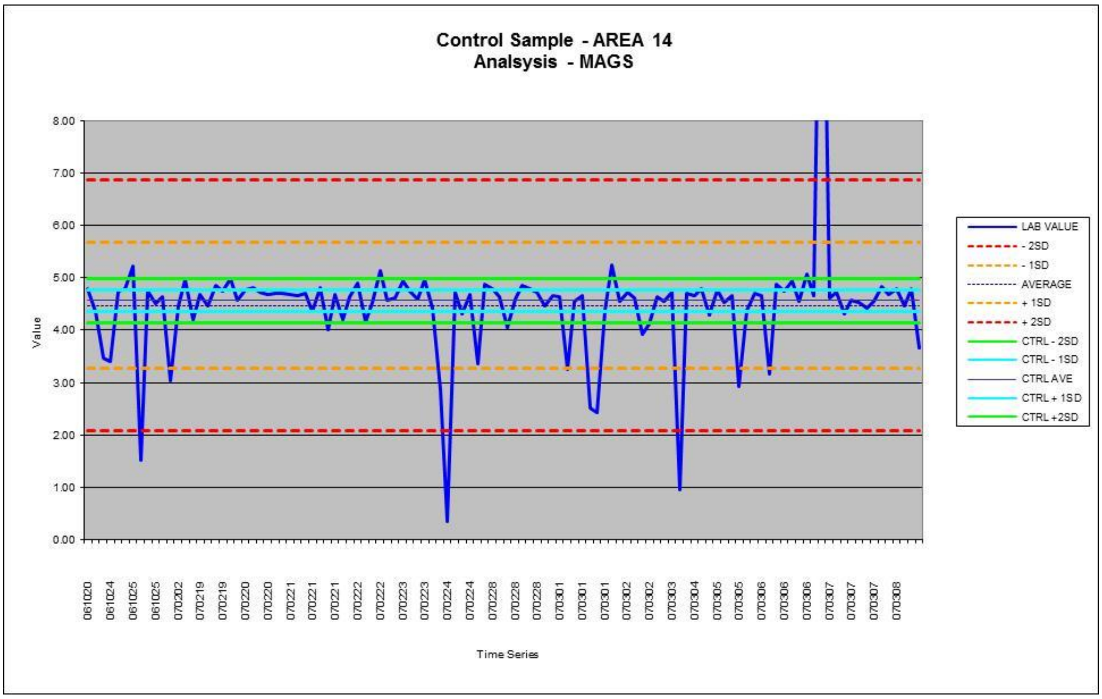


Figure 11. Control sample graph

2.4.4.3 Duplicate sample check

Duplicate samples are inserted after every 20th sample. The sample is a direct duplicate of the previous sample. Samples less than 3% THM are excluded for selection for duplicate samples. Duplicate samples exceeding the predetermined allowable percentage of control intervals will require a batch to be repeated.

2.5 Mining and beneficiation

2.5.1 Mining

A number of mining methods are used for the extraction of heavy mineral sands. The majority of these methods are dredging or dry mechanical mining. Due to the high amount of silt at Hillendale Mine, dredging is not possible.

Hillendale Mine is an opencast mine using hydraulic monitor guns. Mining is done in a sequence of four hydraulic guns with any two working at a given stage, with the additional hydraulic guns on standby to ensure uniform feed if maintenance issues arise or if the monitor guns need to be moved to ensure grade.

Mining is planned on 50m x 50m x 10m blocks. A maximum face height of 10m is determined for safe mining operations. Mining is highly dependent on the silt percentage, with both a maximum constraint per month allowed going to the residue dam, and a minimum silt percentage of 13% required for mining. Actual mining varies considerable from the planned schedule due to the dependence on the silt percentage and the variability the mining method allows. Figure 12 indicates a typical mining operation with two sets of hydraulic monitor guns in operation.

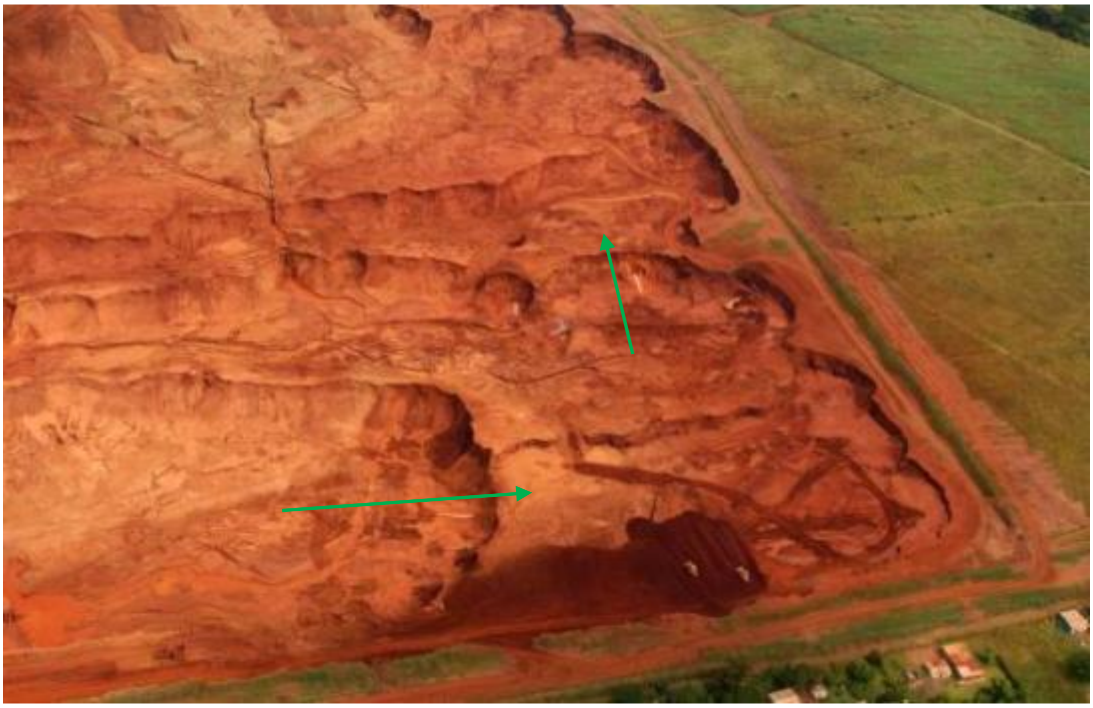


Figure 12. Mining at Hillendale mine with hydraulic monitor guns

The monitor guns propel water at a pressure of 40 bar onto a mining face causing the mining face to collapse. The material is broken up and forms a slurry that requires a minimum of 13% silt to ensure the heavy minerals are kept in suspension. The suspended heavy mineral slurry gravitates to a pump station where after it is transported to the primary wet plant (PWP) through surge bins. The surge bins are controlled to guarantee a constant supply and density of 35% - 45% solids to the PWP.

The mining method at Hillendale is best suited for the deposit since it accommodates the characteristic high silt. The flexibility allows selective mining and therefore have the best combination of low grade and high grade material. Mining is constrained to the 10 metre elevation above main sea level due to the water table level.

Hillendale Mine is designed to produce 1200 tonnes of slurry per hour to the rougher spiral feed of the PWP.

2.5.2 Beneficiation

The run of mine (ROM) to final product process is done in phases. The heavy mineral concentrate (HMC) is produced at the primary wet plant (PWP). The smelter feed, zircon and rutile is produced at the mineral separation plant (MSP) and the low manganese pig iron and slag is produced at the furnaces.

2.5.2.1 Primary Wet Plant

The PWP removes the silt from the slurry with de-sliming cyclones. The heavy minerals are separated from the sand by means of gravity separation with spirals. The final stage at the PWP is separating the magnetite from the heavy minerals with low intensity magnetic separators. The process concentrates the heavy minerals, which are stockpiled for transport to the MSP for further processing. Figure 13 is an illustration of the PWP beneficiation. The process is described in more detail below.

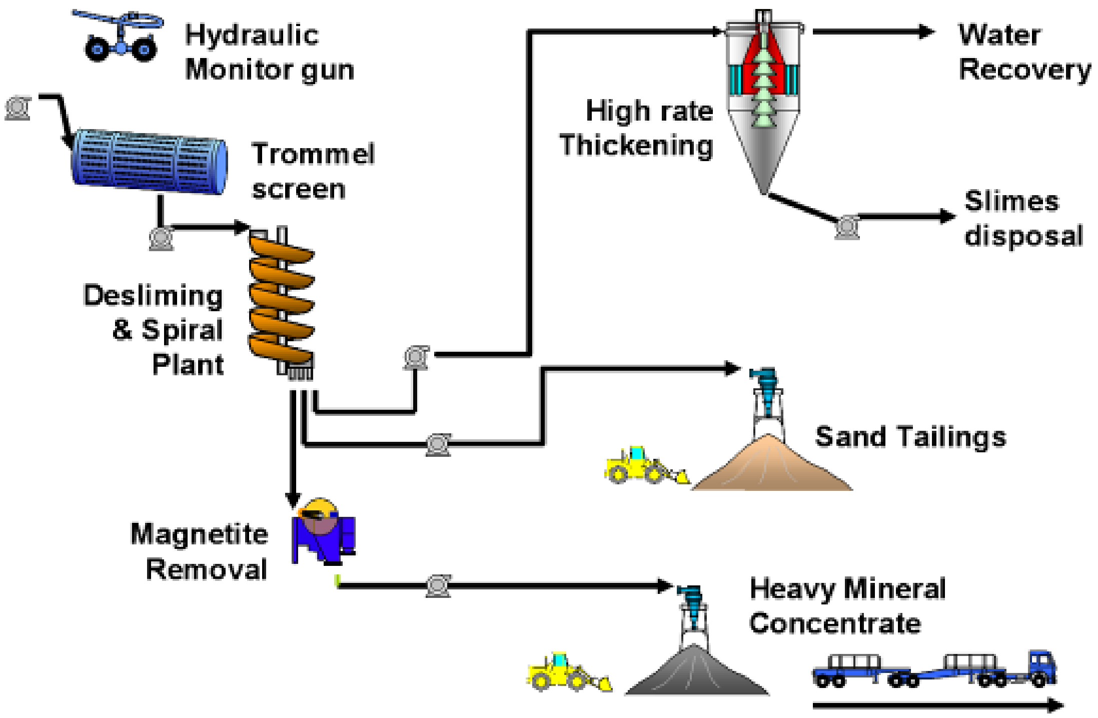


Figure 13. PWP beneficiation process (illustration from Exxaro KZN Sands)

At the PWP the oversize (>1mm) is removed by the trommel screen. The silt is removed from the slurry by de-sliming cyclones. The sand is separated into three parts: the heavy minerals, the fine remaining sand and the coarse remaining sand. This remaining sand is known as tailings. After this, the heavy minerals are separated from the sand by means of gravity separation with spirals. Lastly, the magnetite is removed from the heavy minerals with low intensity magnetic separators.

The slurry from the mine is separated into three different streams.

1. The first stream is the heavy mineral concentrate that is stockpiled for further processing.
2. The second stream is the silt which was separated from the run-of-mine. The silt is predominantly pumped to the slime dam.
3. The third stream is the sand (inclusive of the magnetite). The sand is produced in the primary wet plant is pumped back to the mining void

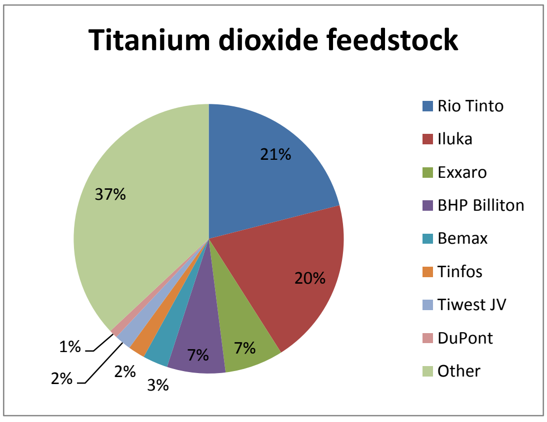
as backfill material. The sand is stacked with de-watering cyclones at an angle of 15°.

The PWP plant is sensitive to mineralogical changes, especially for minerals within the mago group. The 'waste' material, such as garnet, epidote and tourmaline. It is essential that adequate geological information and planning takes place to ensure the correct spiral settings are achieved in the PWP.

2.6 Heavy mineral sand market

Heavy mineral sand deposits consist of a number of mineral assemblages with the primary minerals of importance being ilmenite, leucoxene, rutile and zircon. These four minerals are grouped together and described as the valuable heavy minerals (VHM).

Heavy mineral sands product do not trade in the open market and the process is similar to coal and iron ore with supply agreements to costumers. The major supplier of titanium dioxide feedstock is Rio Tinto, with the major zircon producer Iluka as indicated in Figure 14.



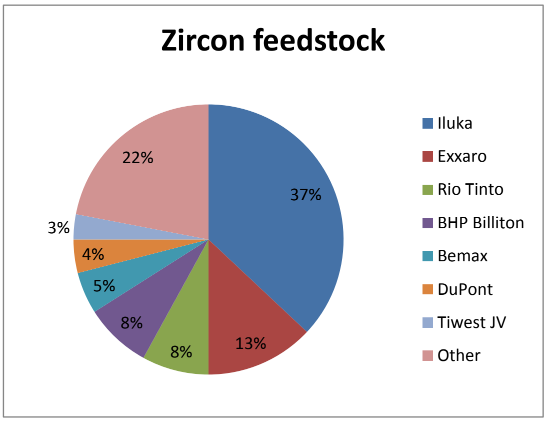


Figure 14. Titanium dioxide and zircon feedstock's (source: Jones, 2009)

The heavy mineral sands industry has struggled continuously with price increases lower than other commodities. There are three high barriers for entry which makes this a very difficult commodity. The three barriers are financing, metallurgy/processing and infrastructure (Paterson, 2011).

The heavy mineral sand industry has two product streams namely the zircon market and the titanium feedstock (ilmenite, rutile and leucoxene). The zircon market produces approximately 1.2Mtpa and is valued at US$1.2b (Paterson, 2011). The titanium feedstock's produces 6Mtpa and is valued at US$2.5b. From the Peterson 2011 Mineral sands industry report the uses, supply, demand and pricing is summarised below.

Ilmenite is a block oxide which is the main source of titanium dioxide pigment used as the white base in the manufacturing of paint and plastics. Leucoxene is weathering product of ilmenite and is primarily used as feedstock for pigment and in minority for welding rods.

Rutile is high in TiO_2 and is also used for pigment feedstock.

Zircon is used in the refractory and ceramic industry for the production of high temperature ceramics (Masters, 1991).

Figure 15 indicates the 93% of TiO_2 pigment that is used in paint and coatings, plastic, paper and other industries with the majority used in paint and coatings (Jones, 2009).

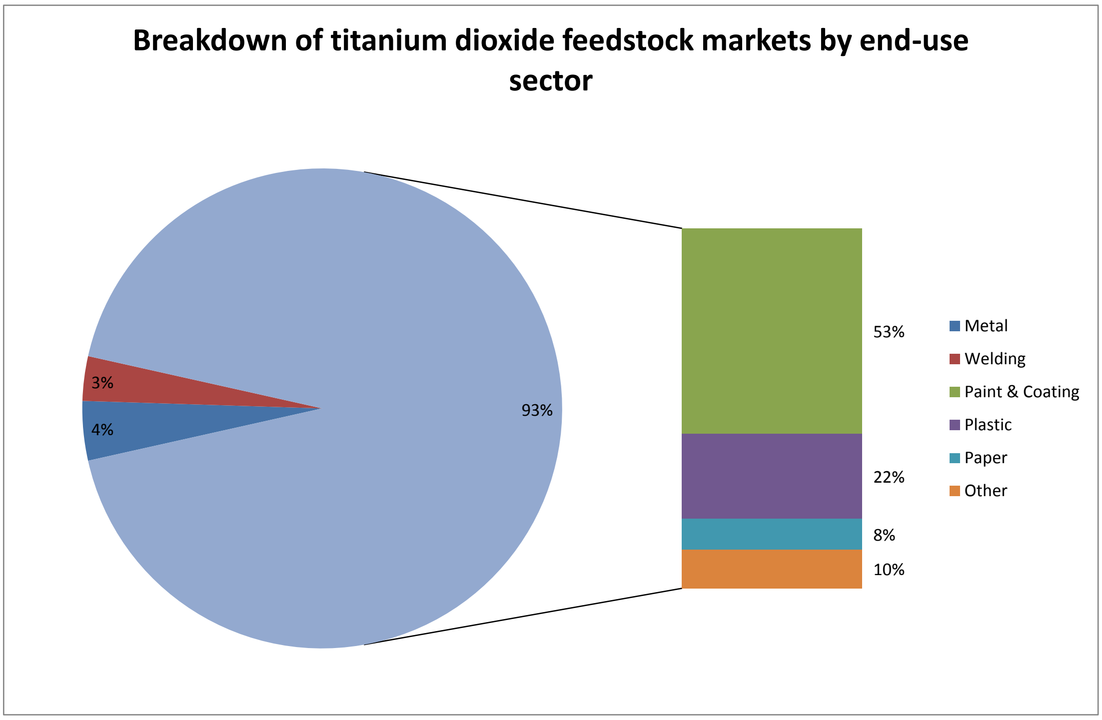


Figure 15. Breakdown of titanium dioxide feedstock markets by end-use sector, 2006 (from Jones, 2009)

Table 5 lists the various uses for the heavy mineral sands products.

Table 5. Mineral Sands Industry Uses (Paterson, 2011)

Product	**Percentage**	**Use**
Zircon	55%	Ceramics
	18%	Zirconia and Chemicals
Titanium Feedstock	57%	Pigments for paints
	23%	Plastics
	9%	Paper

The major supply for the heavy mineral sands market is Iluka Resources (ILU), which supplies more than 30% of the zircon market and 15% of the titanium feedstock. Two other companies are RIO Tinto /BHP with Richards Bay Minerals and Exxaro Resources with KZN Sands and Namakwa Sands.

The demand for heavy mineral sands per country is summarised below in Table 6:

Table 6. Mineral sands industry's demand (Paterson, 2011)

Country	Product	Demand Percentage
China	Zircon	43%
Europe	Titanium Feedstock	30%
North America	Titanium Feedstock	25%
China	Titanium Feedstock	20%

Until recently the heavy mineral sands industry has not increased dramatically. A recent deal with ILU has created a 70 – 75% increase in titanium feedstock and a 35 – 40% increase in zircon. This puts the titanium feedstock price at US$770/t and the zircon price at US$1600/t. The main driver is the increased urbanisation in developing countries (Paterson, 2011).

3 Estimation Methodology

Ordinary kriging is used as the interpolation method for determining the mineral resources from the available sampling at Hillendale Mine. In general heavy mineral sand ore bodies have a low nugget. For most heavy mineral sand deposits the inverse distance weighted method of estimation works effectively (Jones, 2009). This method was also previously applied at Hillendale Mine prior to 2006. It is suggested with resource audits that ordinary kriging should be used at Hillendale Mine (van der Schyff, W., Shaw, B, 2006). Mineral sands modelling are about quantifying the HM grade, thereafter the mineralogy and then the quality of the mineral specie (Jones, 2009).

3.1 Database and Data selection

All geological data is captured into Sable data warehouse ® (SABLE) geological database. SABLE® uses the principle of standardised logging and capturing to ensure consistency in data. The database is structured on a SQL Server database with one person defined as the super user. Validation functionality is built into the database and data is validated as captured to ensure no overlapping entries or non-contiguous entries or errors. Additional controls such as lookup tables and mandatory fields ensure a complete database.

The data is exported from SABLE® and imported into the SUPRAC database. For this thesis, only the WAC drilling method data is selected. There are no additional criteria for data selection.

3.2 Basic Statistics

3.2.1 Basic statistical analyses for the 'zero' value data

Basic statistical analyses are done on the full dataset; no bottom cuts or top cuts are selected for the initial data.

Looking at the average values of the THM as presented in Figure 16 approximately 10 % consist of the 'magn' fraction, 57% of the THM consists of the 'mags' fraction (containing approximately 90% of the ilmenite), 22% of the 'mago' fraction and 15% of the 'nmag' fraction that contains approximately 40% of the zircon.

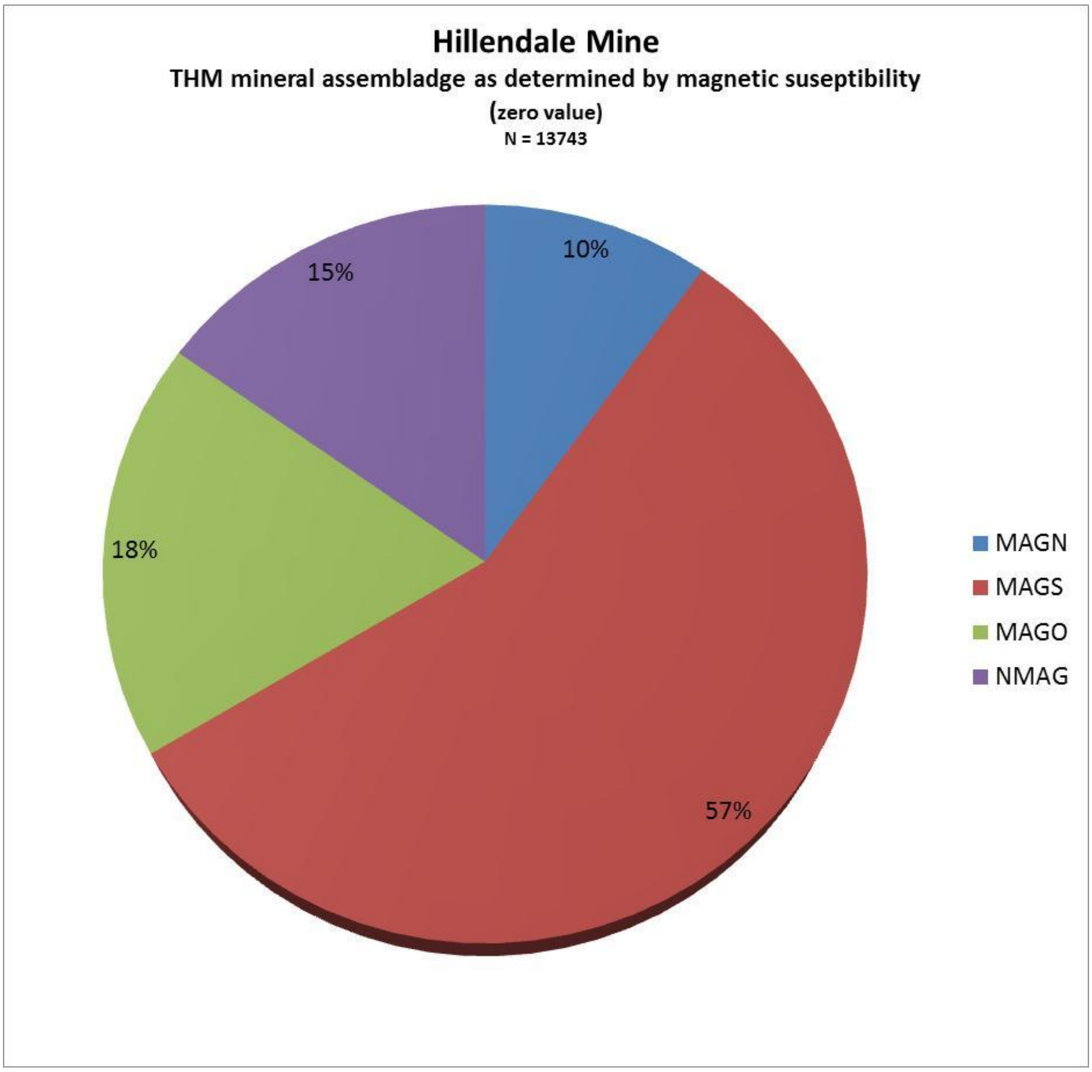


Figure 16. Total Heavy Mineral assemblage as determined by magnetic susceptibility analyses for 'zero' value dataset

Table 7 is the summary table of the basic statistics of the Hillendale borehole database including the ‘zero’ values as received from the laboratory.

Table 7. Summary data statistics for 'zero' value dataset

HILLENDALE MINE SUMMARY DATA STATISTICS ZERO VALUES						
	SILT %	THM %	MAGN %	MAGS %	MAGO %	NMAG %
N	13773	13773	**13743**	**13743**	**13743**	**13742**
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	96.79	51.11	5.46	36.75	25.79	14.59
Average	23.53	5.40	0.53	3.00	0.97	0.81
Range	96.79	51.11	5.46	36.75	25.79	14.59
Mode	19.08	0.44	0.00	0.00	0.00	0.00
Median	19.63	4.47	0.41	2.55	0.36	0.72
Variance	227.62	22.47	0.28	7.38	3.59	0.47
Std. Dev	15.09	4.74	0.53	2.72	1.89	0.69
Skewness	1.71	1.92	1.87	1.62	4.07	2.22
Kurtosis	3.99	6.10	5.69	5.71	21.07	18.47
CoV	0.64	0.88	1.01	0.91	1.95	0.85

Components show large ranges because no cut-off for the data is selected. As indicated in Figure 17 to Figure 22, the data fractions are positively skewed, with the ‘mago’ fraction having a very high number of data with less than 1 %.

The coefficient of variation (CoV) for magn% and mago% is > 1, indicating a large degree of variability within the dataset. Silt%, THM%, mags% and nmag% are <1 although still high.

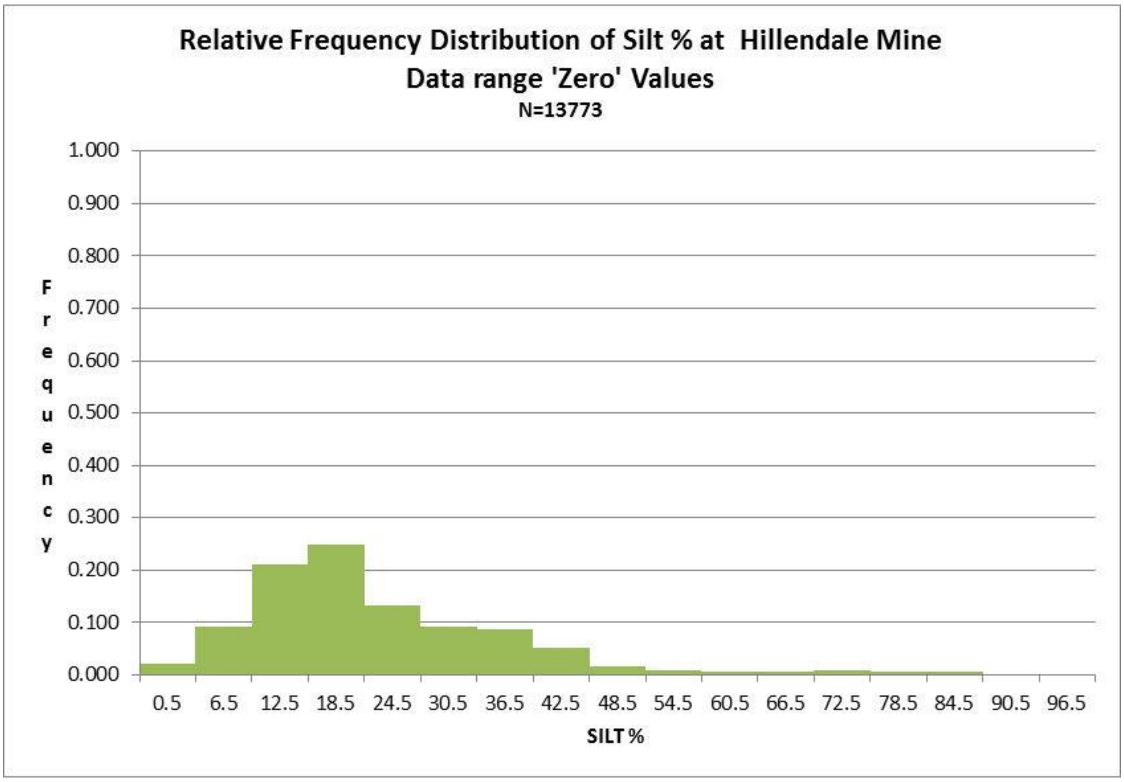


Figure 17. Relative Frequency histogram of silt% for 'zero' values at Hillendale Mine

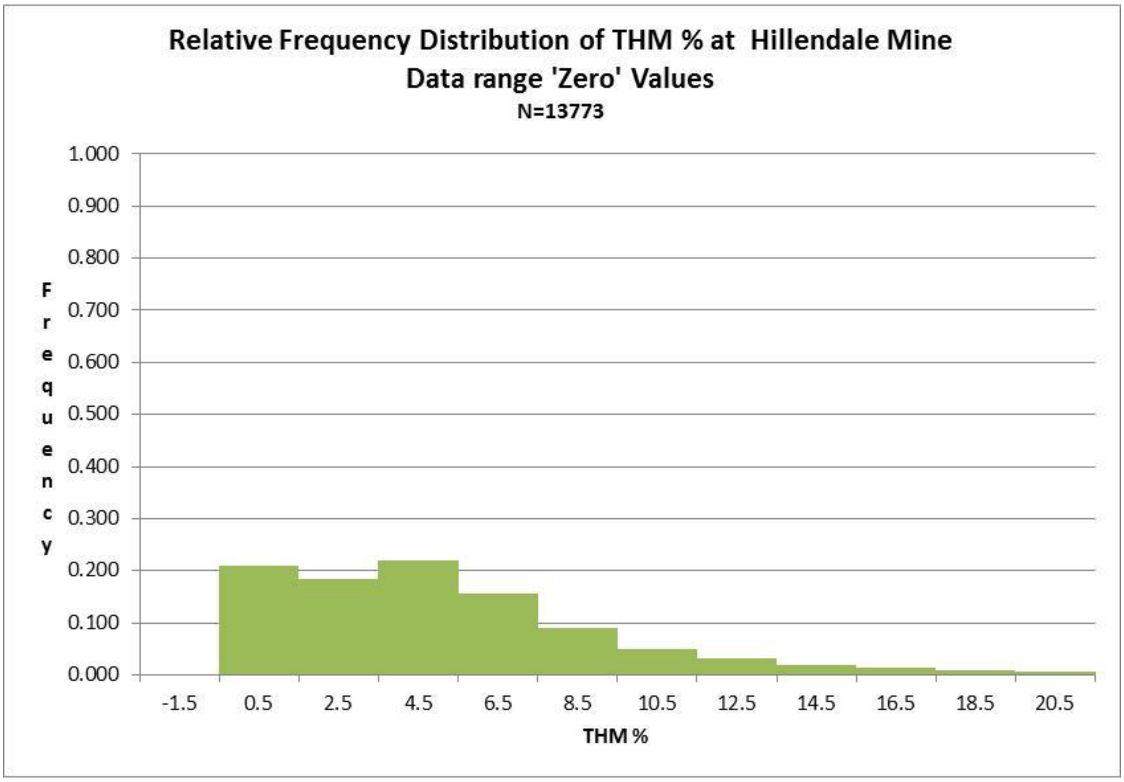


Figure 18. Relative Frequency histogram of THM% for 'zero' values at Hillendale Mine

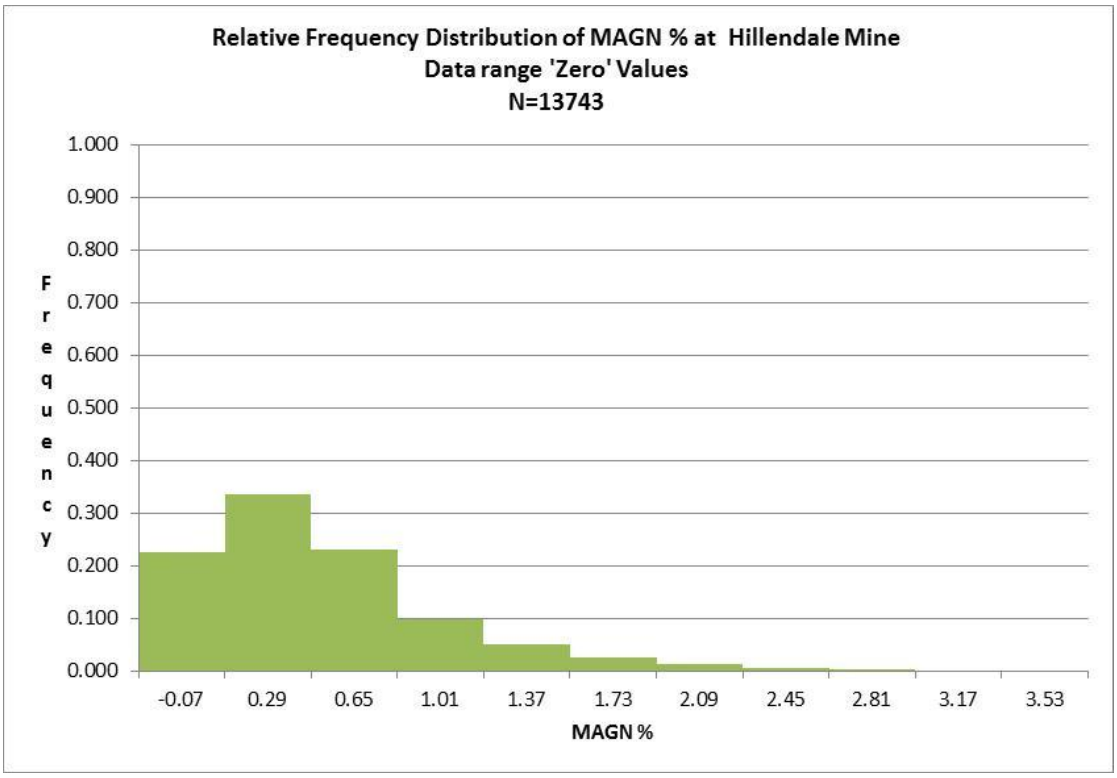


Figure 19. Relative Frequency histogram of ‘magn’% for ‘zero’ values at Hillendale Mine

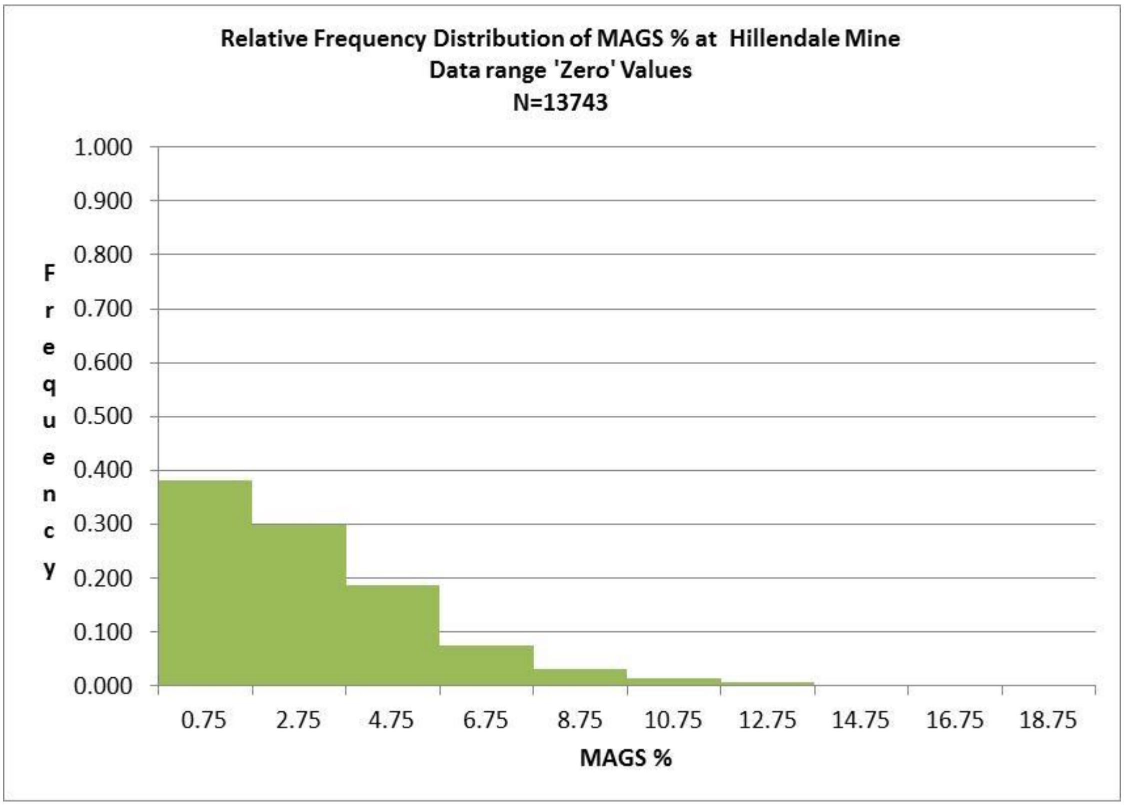


Figure 20. Relative Frequency histogram of ‘mags’% for ‘zero’ values at Hillendale Mine

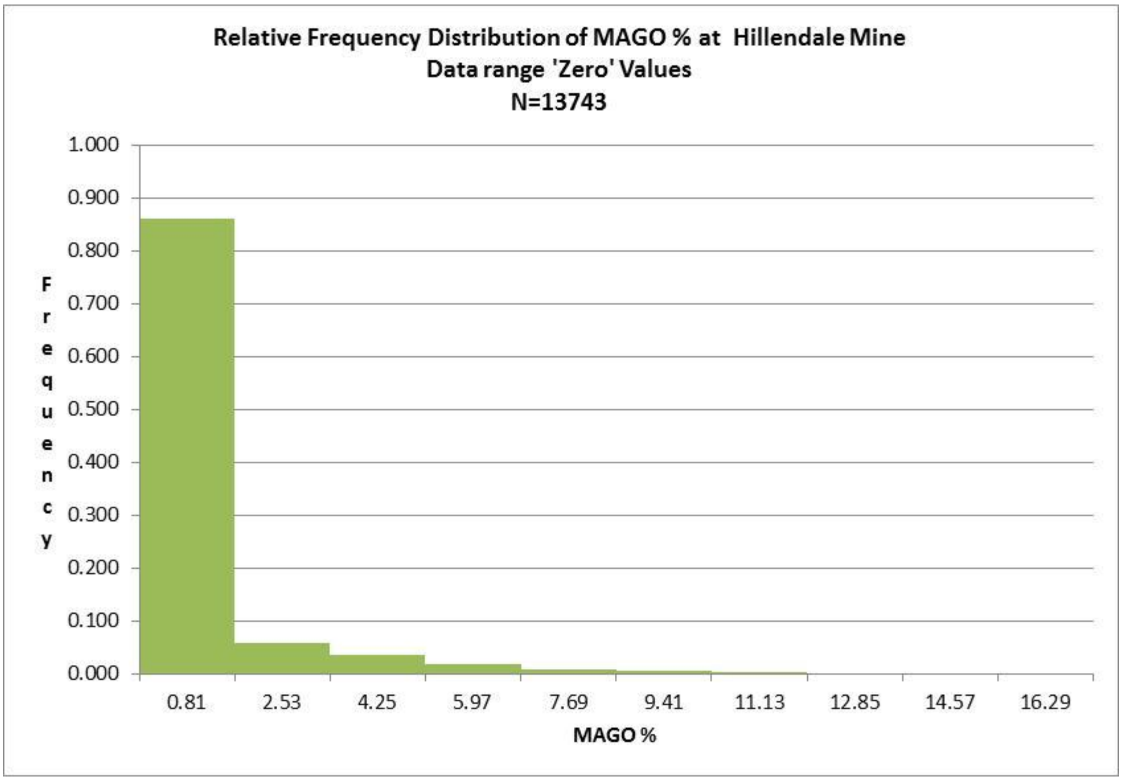


Figure 21. Relative Frequency histogram of 'mago'% for 'zero' values at Hillendale Mine

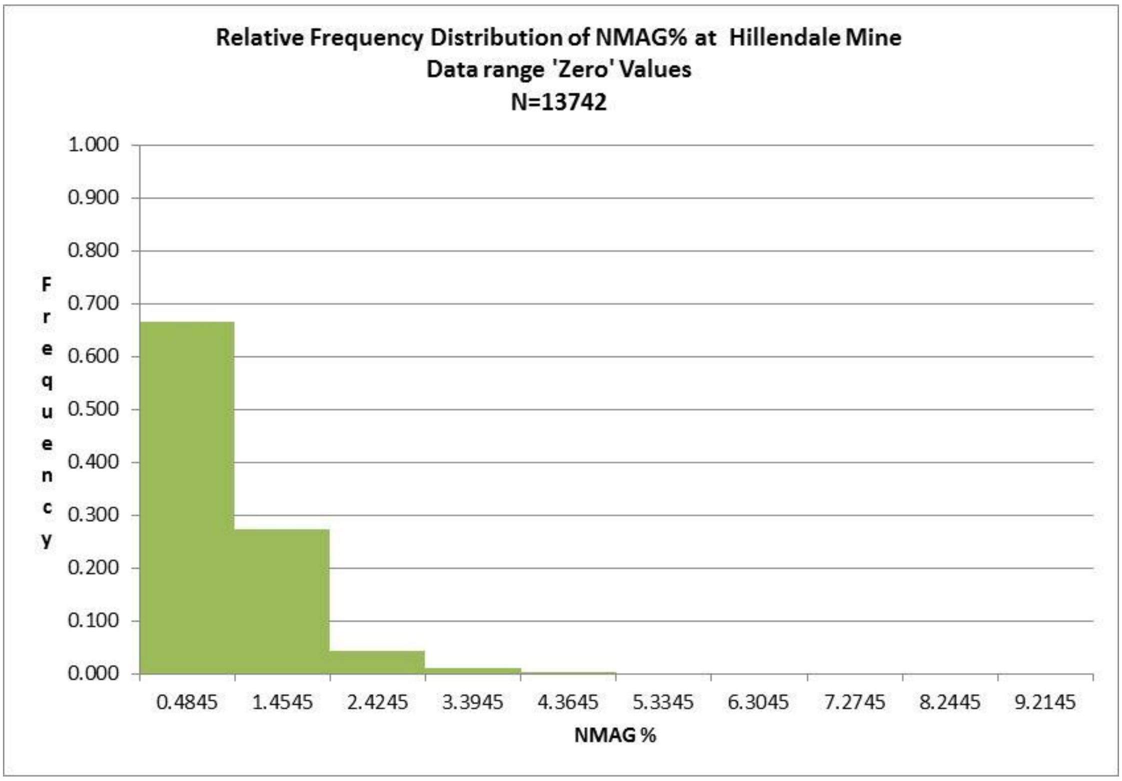


Figure 22. Relative Frequency histogram of 'nmag'% for 'zero' values at Hillendale Mine

3.2.2 Basic statistical analyses for the ‘null’ value data

Basic statistical analyses are done on the full dataset however here, ‘zero’ values for all the individual fractions and THM as assigned by the laboratory are replaced with ‘null’ values. No bottom cuts or top cuts are selected for the initial data. The ‘null’ dataset is created by leaving the below detection limit data blank and therefore not adding a value to the average calculation.

Looking at the average values of the THM as presented in Figure 1 approximately 12 % consist of the ‘magn’ fraction, 67% of the THM consists of the ‘mags’ fraction (containing approximately 90% of the ilmenite), 22% of the ‘mago’ fraction and 18% of the ‘nmag’ fraction that contains approximately 40% of the zircon.

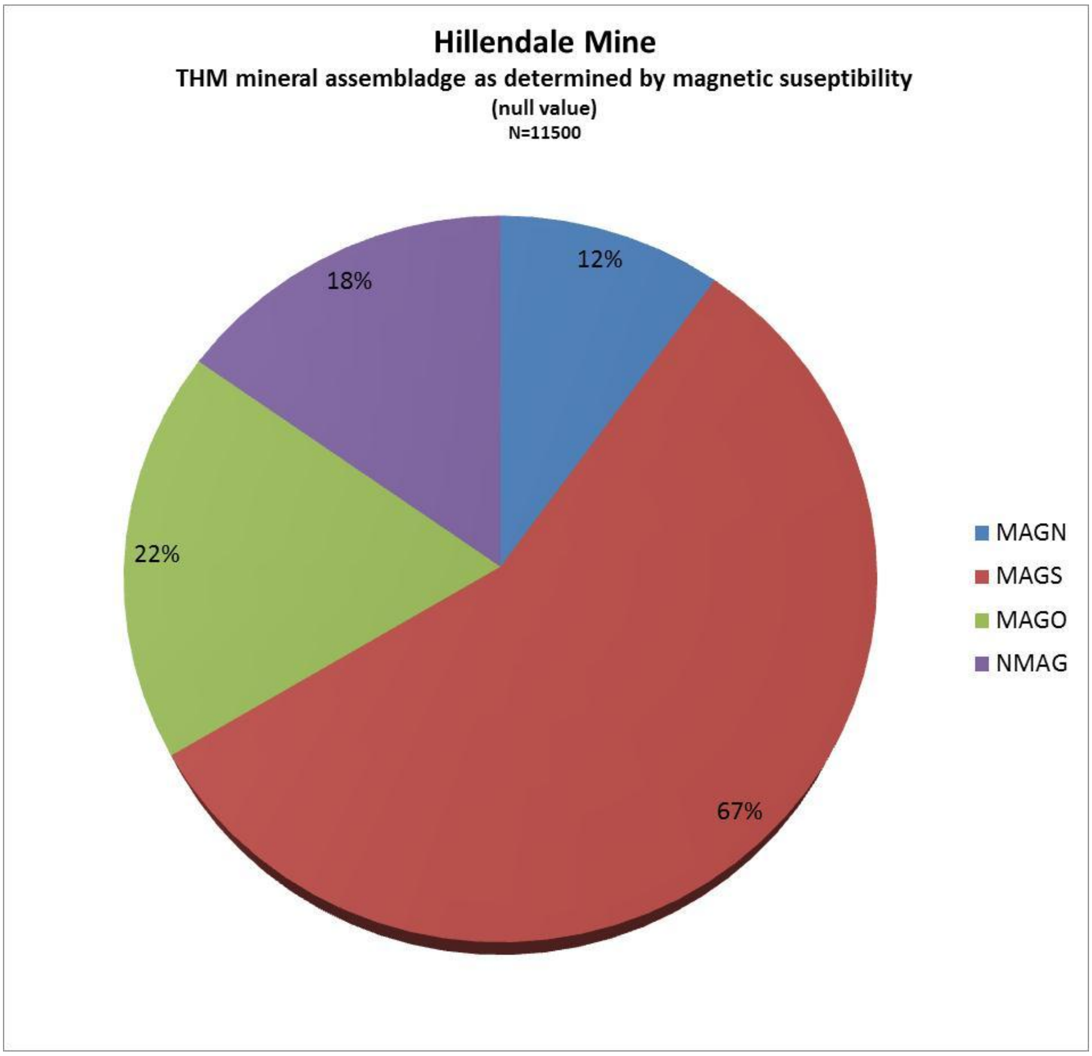


Figure 23. Total Heavy Mineral assemblage as determined by Magnetic susceptibility analyses for 'null' value dataset

Table 8 is the summary table of the basic statistics of the Hillendale borehole database for the dataset of ‘null’ values.

Table 8. Summary data statistics for 'null' value dataset

HILLENDALE MINE SUMMARY DATA STATISTICS NULL VALUES						
	SILT %	THM %	MAGN %	MAGS %	MAGO %	NMAG %
N	13766	13766	**11500**	**11525**	**11524**	**11525**
Min	0.15	0.01	0.01	0.03	0.01	0.01
Max	96.79	51.11	5.46	36.75	25.79	14.59
Average	23.54	5.40	0.63	3.57	1.16	0.96
Range	96.64	51.10	5.45	36.72	25.78	14.58
Mode	19.08	0.44	0.31	0.98	0.27	0.71
Median	19.64	4.47	0.49	3.04	0.43	0.83
Variance	227.46	22.47	0.27	6.75	4.06	0.41
Std. Dev	15.08	4.74	0.52	2.60	2.02	0.64
Skewness	1.72	1.92	1.96	1.84	3.77	2.88
Kurtosis	4.00	6.10	6.16	7.18	17.94	26.73
CoV	0.64	0.88	0.83	0.73	1.74	0.67

Components show large ranges because no cut-off for the data is selected. As indicated in Figure 24 to Figure 29, the data fractions are positively skewed, with the ‘mago’ fraction having a very high number of data with < 1 %.

The CoV for mago% is > 1 indicating a large degree of variability within the dataset. Silt%, THM%, magn%, mags% and nmag% <1 although still high.

The sum of the average’s to calculate the THM differs substantially from the average THM values in the ‘null’ dataset. The ‘zero’ values as added in the original borehole dataset is excluded and therefore overestimating the individual fractions.

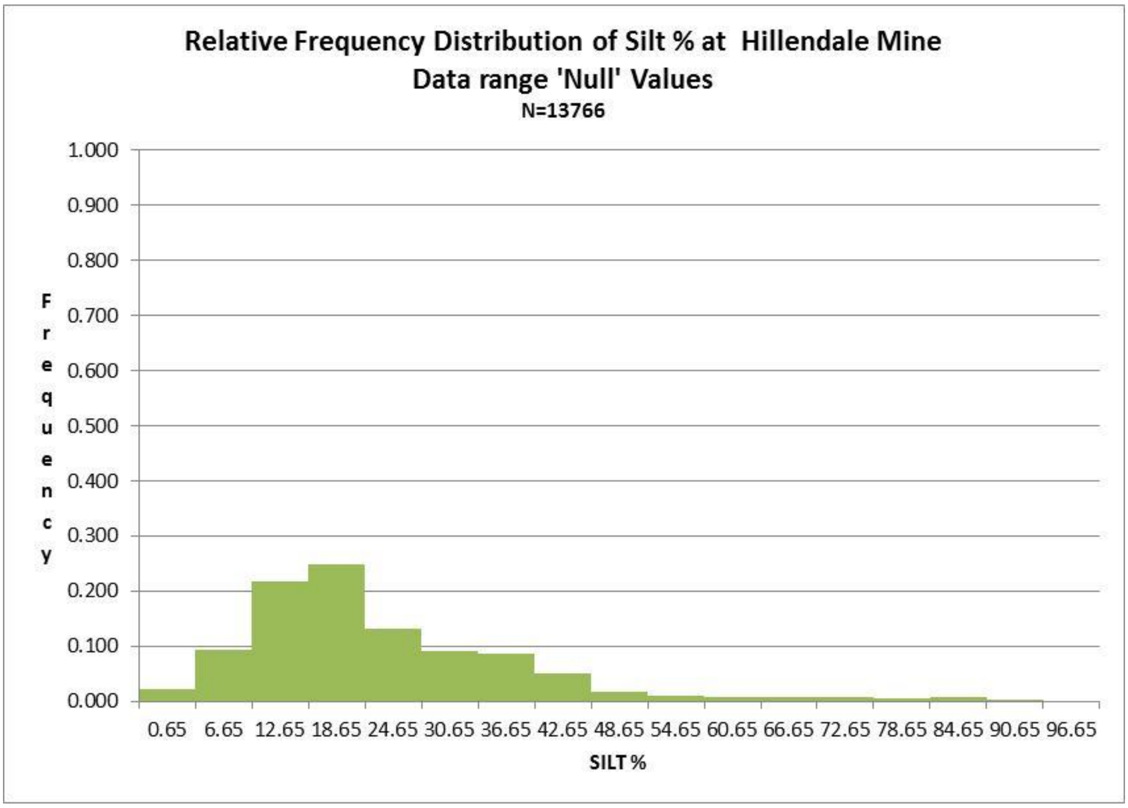


Figure 24. Relative Frequency histogram of silt% for 'null' values at Hillendale Mine

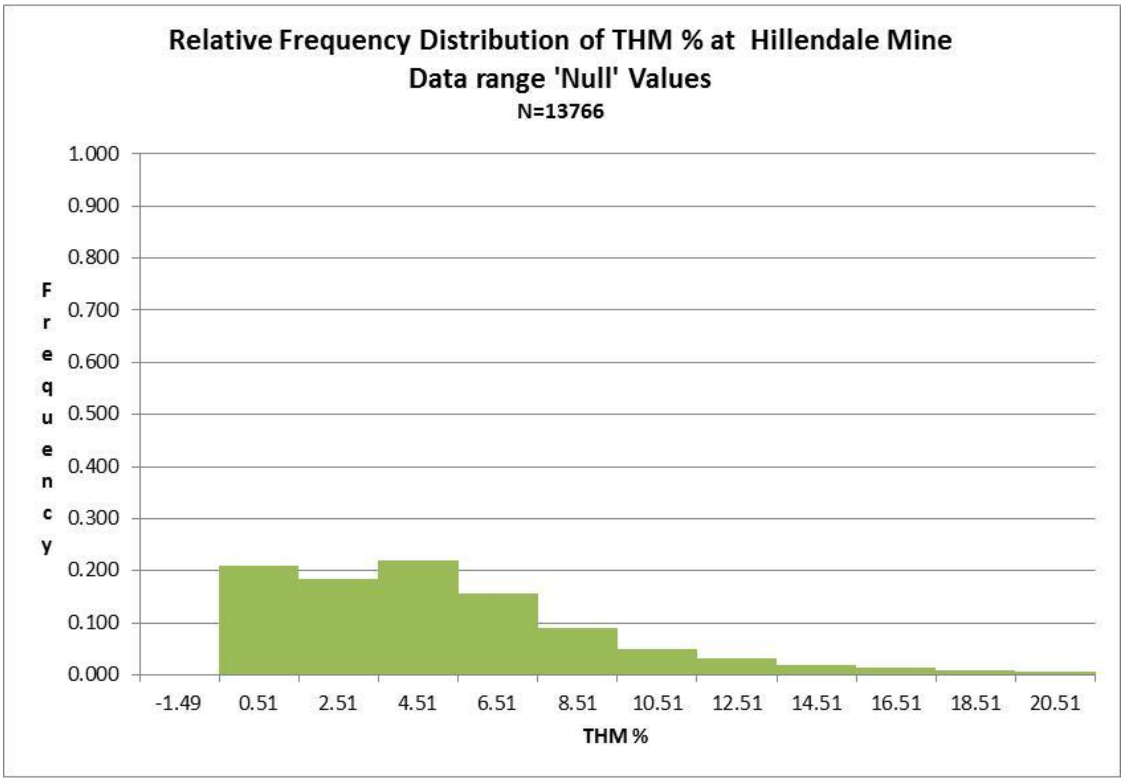


Figure 25. Relative Frequency histogram of THM% for 'null' values at Hillendale Mine

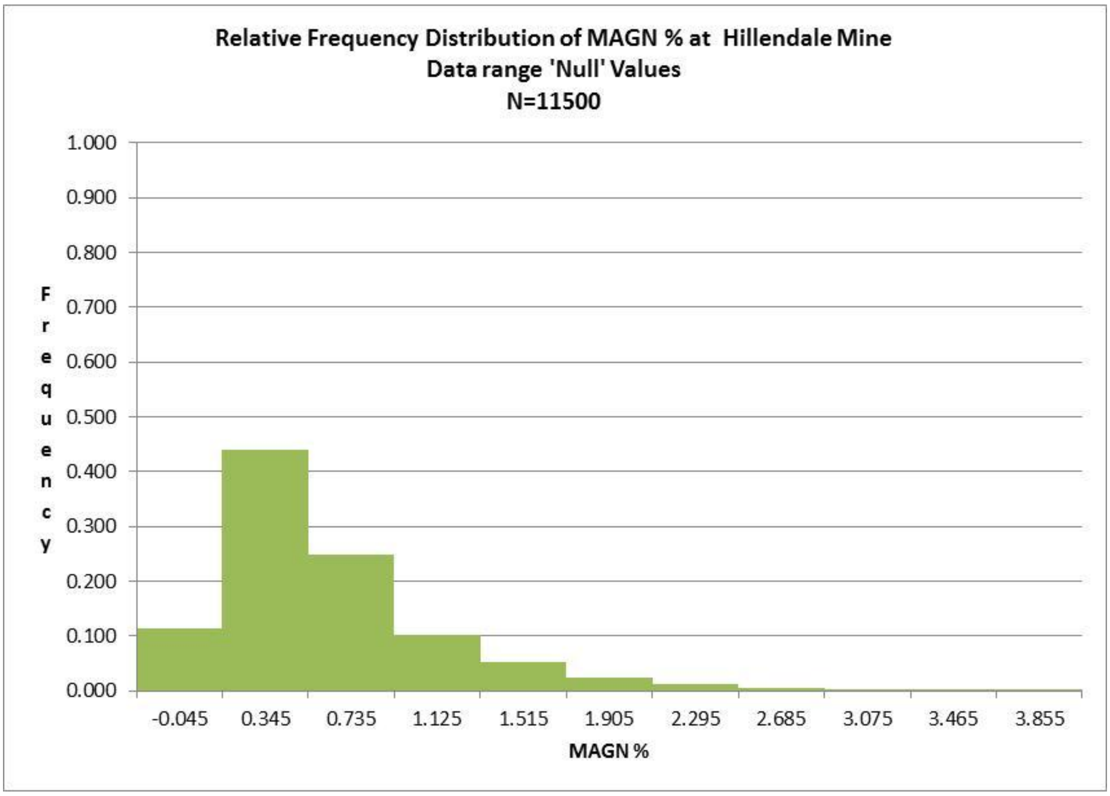


Figure 26. Relative Frequency histogram of 'magn'% for 'null' values at Hillendale Mine

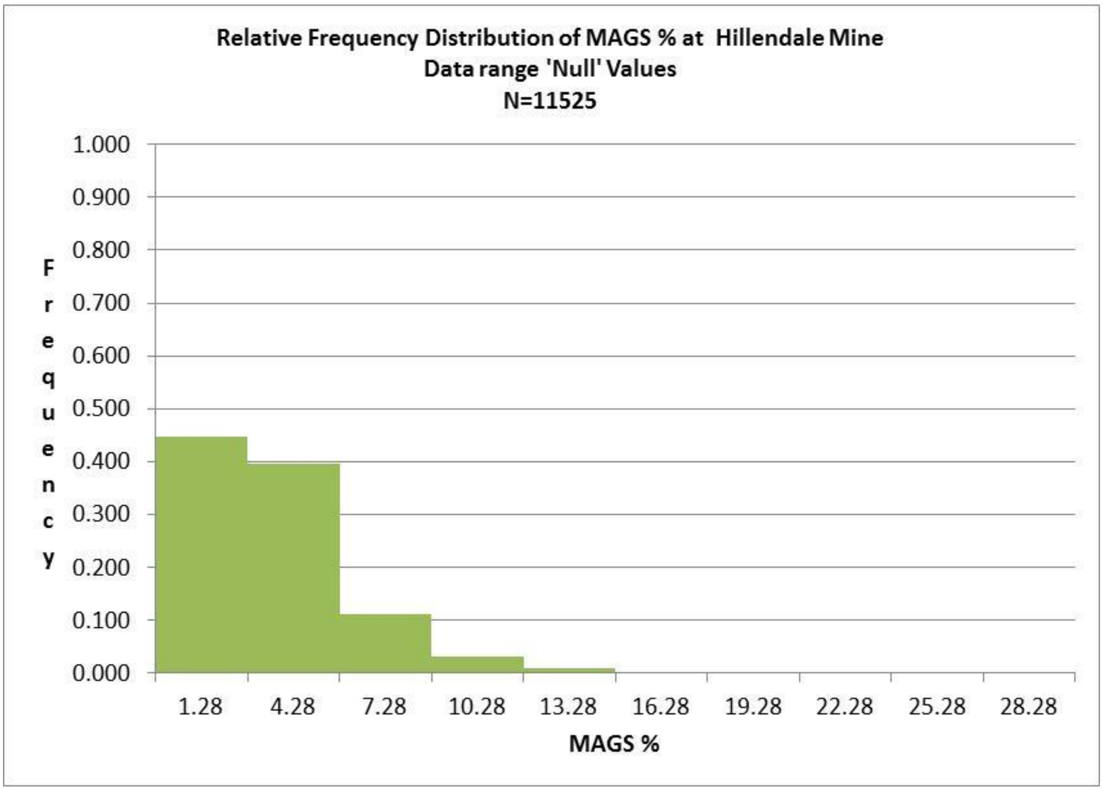


Figure 27. Relative Frequency histogram of 'mags'% for null values at Hillendale Mine

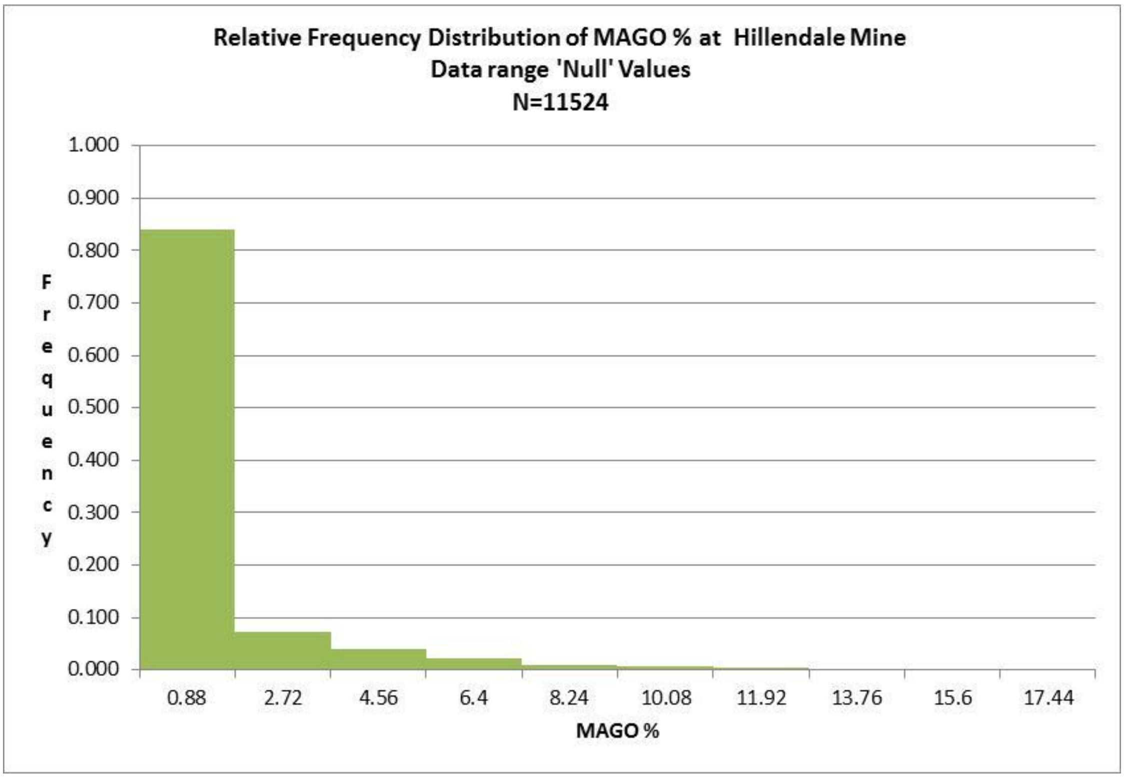


Figure 28. Relative Frequency histogram of ‘mago’% for ‘null’ values at Hillendale Mine

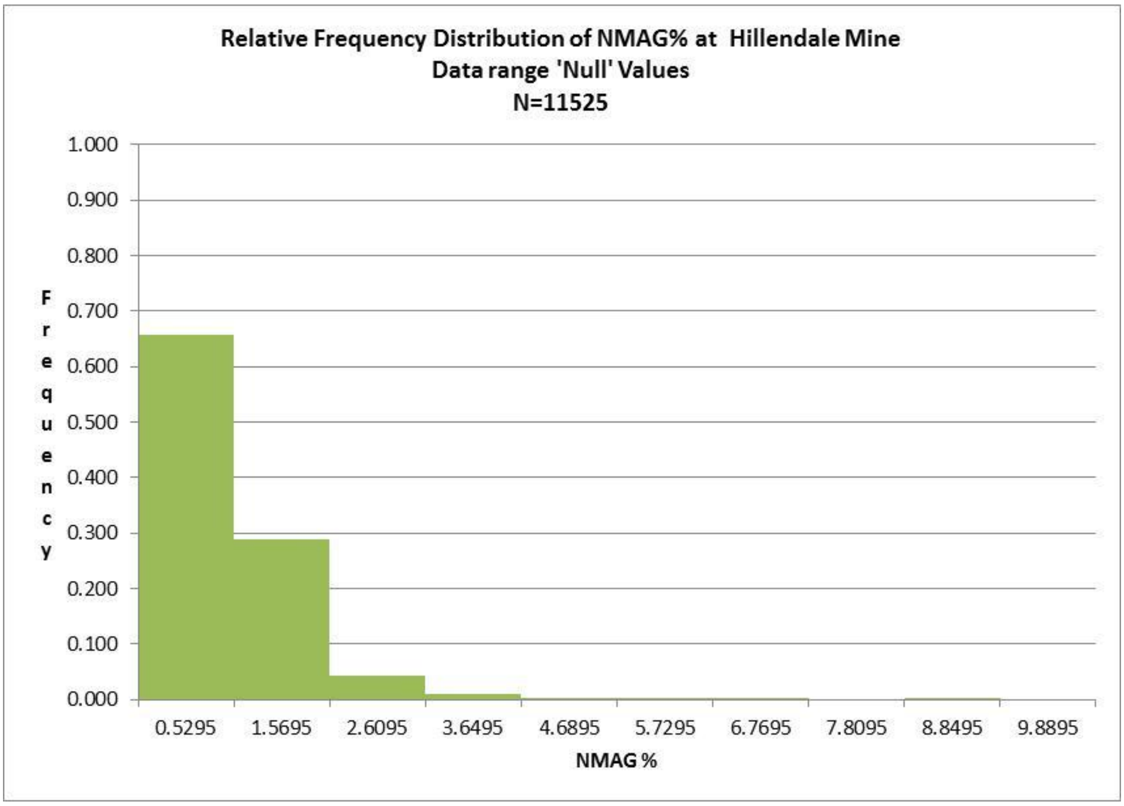


Figure 29. Relative Frequency histogram of ‘nmag’% for ‘null’ values at Hillendale Mine

Comparing the mineral assemblage of the ‘zero’ and ‘null’ values Table 9 there is an upgrade in all the fractions when the ‘zero’ values are replaced by ‘null’ values.

For the ‘null’ dataset, only the THM values with a corresponding magnetic susceptibility fraction analyses was used for the calculation. All the THM values are however used for the resource estimation. Calculating the percentage difference with Equation 1 in the analysed THM compared to the calculated THM the ‘zero’ borehole dataset differs with almost 2% less, whereas the ‘null’ dataset differs with < 0.2%

Table 9. THM and mineral fractions description for 'zero' and 'null' values

	THM	MAGN	MAGS	MAGO	NMAG	THM (Sum)	Percentage Difference
ZERO	5.40	0.53	3.00	0.97	0.81	5.30	1.78%
NULL	6.33	0.63	3.57	1.16	0.96	6.32	0.16%

Equation 1. Percentage difference for the individual datasets

$$Percentage\ Difference \left(\frac{sum\ (thm) - \ THM}{THM} \right) x\ 100$$

Calculating the percentage difference between the THM of the two datasets, there is almost 17% percentage difference for the ‘null’ values compared to the ‘zero’ values as calculated in Equation 2.

Equation 2. Percentage difference between the ‘zero’ and ‘null’ dataset

$$Percentage\ Difference \left(\frac{zero\ (THM) - \ null(THM)}{zero(THM)} \right) x\ 100$$

3.2.3 Summary of basic statistics

Comparing the basic statistics of the ‘zero’ and ‘null’ datasets the general data spread as indicated by the mean, range and standard deviation is similar for each of the individual fractions. Almost 25% of the ‘silt’% are around 18%, 30% of the ‘THM’% are around 2 – 5%, 35% of the ‘magn’% are around 0.29%, 40% of the ‘mags’% are around 3.71%, 85% of the ‘mago’% are around 0.81% and 65% of the ‘nmag’% is around 0.5%.

3.3 Geostatistics

3.3.1 Block model

A single geological block model for Hillendale Mine is created. Only WAC drilling data is used. SURPAC geological software is used for modelling. The original geological information is extracted from SABLE data warehouse to SURPAC. A geological block model of 50 x 50 x 9 metres is created. Subcell splitting of 6.25 x 5.25 x 1.125m is done. The block model is not rotated. The drillholes are composited in 3 metre intervals using the ‘Composite Downhole’ function in SURPAC. No grade constraints are used. The ore body is defined by the digital terrain model (DTM) of the original surface topography and ‘floor’ contours defined as 1.5% ‘mags’ cut-off.

3.3.2 Search Ellipsoid

For the purpose of the study a single pass search strategy is used for the Resource Estimation and kept similar for both datasets. The major axis is defined at 45° with a maximum horizontal search radius of 1000m on the major axis. A maximum of 30 samples is to be used and a minimum of 5. A maximum of 9 metre search radius is defined for the vertical axis. Anisotropy factors for the semi-major axis to the minor axis is defined as 2:1.

3.3.3 Relative Density determination

The average relative density of the Hillendale Mine deposit has been determined to be 1.70 g/cm^3. Sand replacement studies during 2003 determined the density between 1.68 g/cm^3 and 1.72 g/cm^3. Cross validating the tonnage mined with the tonnage estimated using the average value, there is a good correlation within 10% of the actual tonnages and therefore the 1.70 g/cm^3 value is deemed acceptable.

3.3.4 Variograms

For this study, variography is done on the individual units of the heavy mineral deposit namely silt%, THM%, 'magn%, 'mags'%, 'mago'% and 'nmag'%. Each individual fraction is used in variagraphy since each of the fractions has individual characteristics on which they are identified by the magnetic susceptibility analyses and classified.

3.3.4.1 Variograms for 'zero' dataset

Table 10 lists the various properties of the individual variograms for the 'zero' dataset. Variography is done for all fractions, but the focus of the estimation and reconciliation is on the economic fractions (i.e. 'mags' and 'nmag'). The aim is to have a calculated % error of less than 10% for the economic fractions and 95% of errors within two standard deviations.

Looking at the variogram parameters in Table 10 the range of the fractions are between approximately 150 and 302m. Silt% and the 'nmag' fractions have the longest range of 275 and 265m respectively. The THM% for the 'zero' dataset has the longest range with 362m. The 'magn', 'mago' and 'nmag' fractions have relatively low nuggets, while THM and 'mags' have a high nugget. As with the null dataset, the high nugget for THM is expected since it is the package of the individual minerals with their inherent properties.

Table 10. Variogram properties for 'zero' dataset

ZERO DATASET	silt	thm	magn	mags	mago	nmag
LAGRANGE MULTIPLIER	0.757	0.383	0.005	0.097	0.069	0.008
TRUE VALUE	16.430	2.060	0.200	1.330	0.160	0.370
ESTIMATED VALUE	12.973	2.400	0.198	1.361	0.156	0.400
ESTIMATED ERROR	-3.457	0.340	-0.002	0.031	-0.004	0.030
STD_DEV	5.651	3.448	0.403	1.744	1.449	0.516
VARIANCE	91.763	8.206	0.106	2.937	1.245	1.800
AVG KRIG VARIANCE	33.670	11.910	0.163	3.075	2.130	0.265
TWO STD. DEVIATIONS	85.110	96.550	97.090	95.040	96.820	97.330
SILL	129.345	19.2716	0.193	5.154	3.669	0.355
NUGGET	24.5389	10.4572	0.066	2.628	1.813	0.237
C	104.806	8.814	0.127	2.526	1.849	0.128
RANGE (m)	201	362	150	2.66	275	302

Reviewing the percentage of the nugget versus the sill for the 'zero' values as listed in Table 11. For the 'zero' dataset THM, 'mags' and 'nmag' have a nugget to sill ratio of more than 50 while 'mago' is just below 50.

Table 11. Nugget versus Sill – 'zero' values

DESCRIPTION - ZERO	silt	thm	magn	mags	mago	nmag
Nugget vs. Sill	19%	54%	34%	51%	49%	67%

Figure 30 to Figure 35 are the individual variograms as produced for the 'zero' dataset.

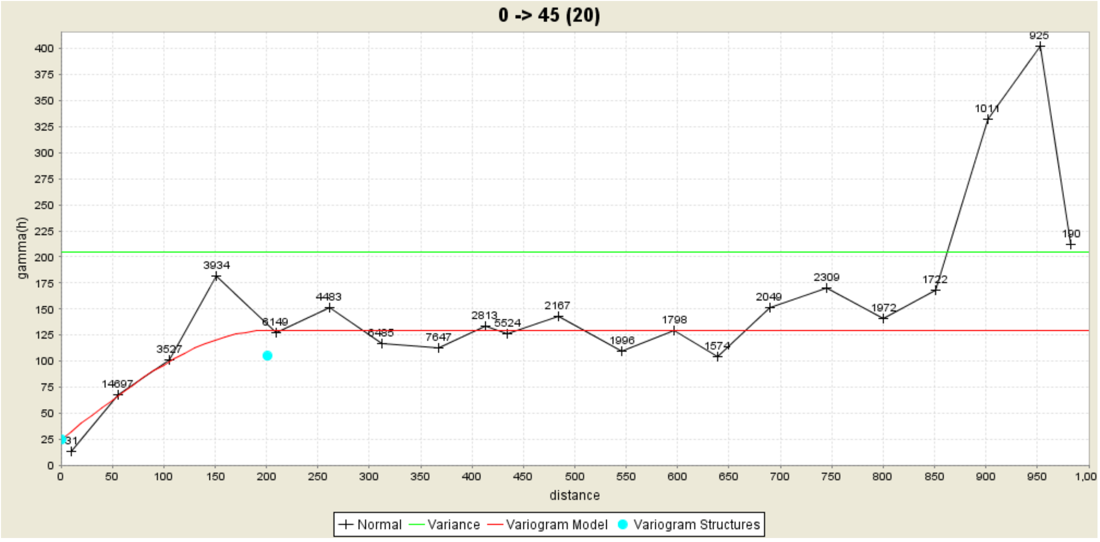


Figure 30. Variogram for silt% - 'zero' dataset

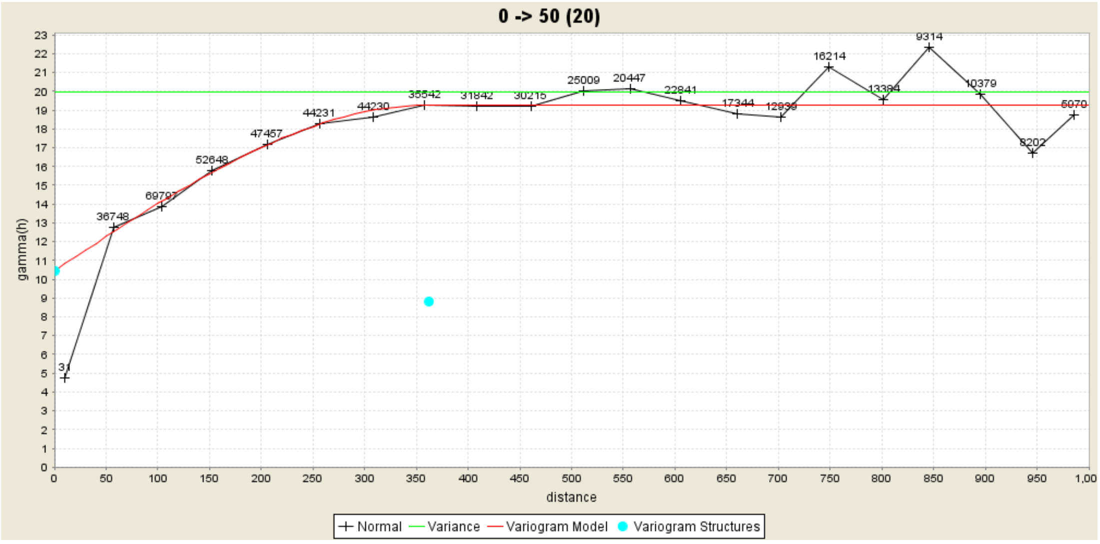


Figure 31. Variogram for THM % - 'zero' dataset

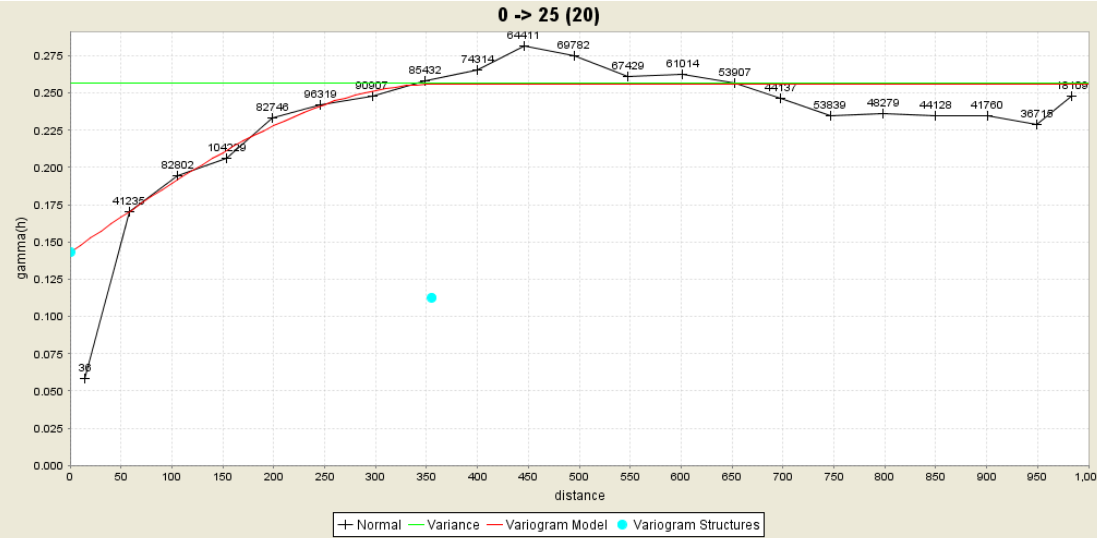


Figure 32. Variogram for 'magn'% - 'zero' dataset

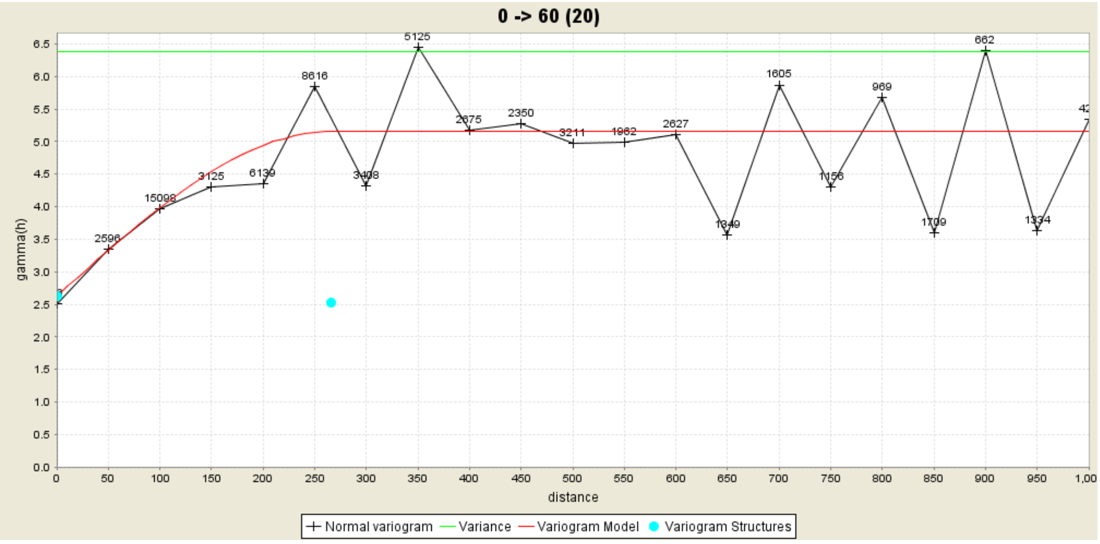


Figure 33. Variogram for 'mags'% - 'zero' dataset

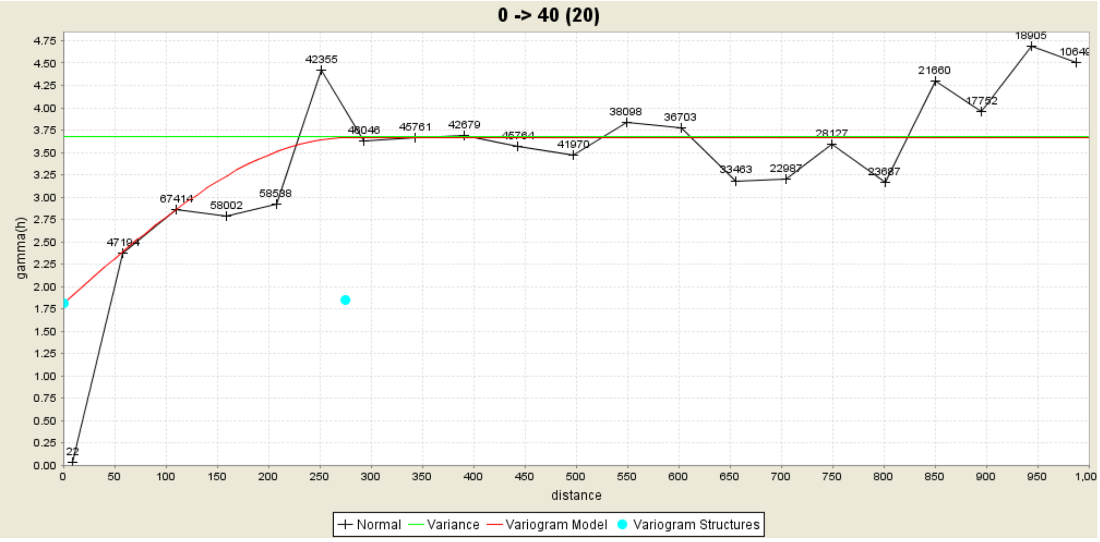


Figure 34. Variogram for 'mago'% - 'zero' dataset

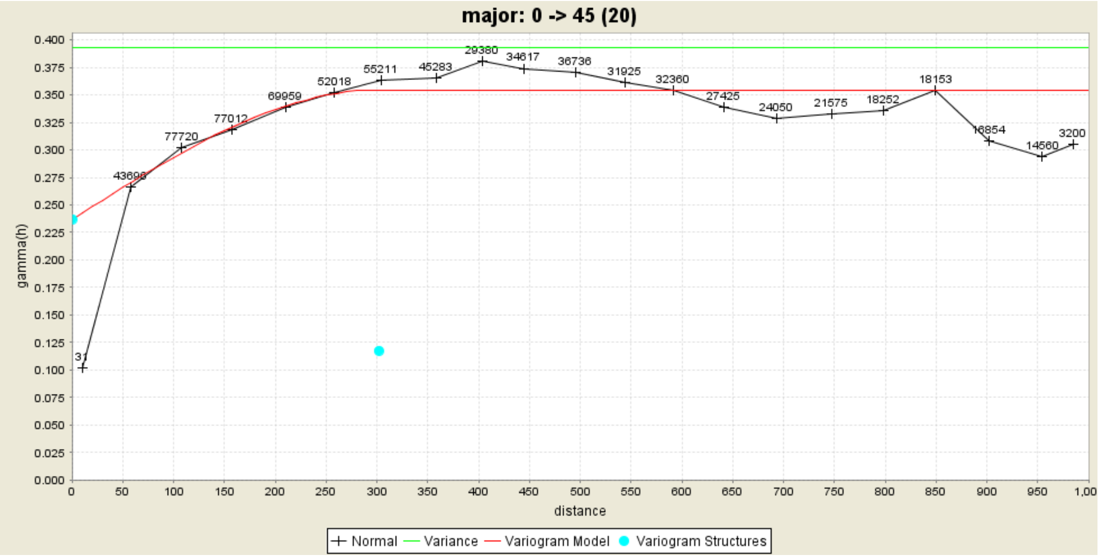


Figure 35. Variogram for 'nmag'% - 'zero' dataset

3.3.4.2 Variograms for 'null' dataset

Table 12 lists the various properties of the individual variograms for the 'null' dataset. Variography is done for all fractions, but the focus of the estimation and reconciliation is on the economic fractions (i.e. 'mags' and 'nmag'). The aim was to have a calculated % error of less than 10% for the economic fractions and 95% of errors within two standard deviations.

Looking at the variogram parameters the range of the fractions are between approximately 120 and 150m. Silt% and the 'nmag' fractions have the longest ranges of 275 and 265m respectively. The THM% has a range of 153m.

The 'magn', 'mago' and 'nmag' fractions have a low nuggets, while 'THM' and 'mags' have a high nugget. The high nugget for THM is expected since it is the package of the individual minerals with their inherent properties.

Table 12. Variogram properties for 'null' dataset

NULL DATASET	silt	thm	magn	mags	mago	nmag
LAGRANGE MULTIPLIER	0.339	0.085	0.002	0.066	0.008	0.003
TRUE VALUE	16.430	2.060	0.200	1.330	0.160	0.370
ESTIMATED VALUE	13.474	2.207	0.227	1.672	0.203	0.458
ESTIMATED ERROR	-2.957	0.147	0.027	0.342	0.043	0.088
STD_DEV	5.631	2.791	0.325	1.800	1.050	0.412
VARIANCE	83.396	7.396	0.095	2.912	0.966	0.173
AVG KRIG VARIANCE	32.150	7.991	0.104	3.202	1.072	0.168
TWO STD. DEVIATIONS	86.070	95.210	95.040	95.340	95.310	95.130
SILL	58.5477	12.5713	0.168	4.577	2.606	0.330
NUGGET	25.3263	5.8297	0.067	2.407	0.498	0.126
C	33.221	6.742	0.101	2.170	2.108	0.204
RANGE (m)	275	153	118	151	121	265

Reviewing the percentage of the nugget versus the sill for the 'null' values as listed in Table 13, it can be seen that the nugget is in general less than 50% of the sill except for the 'mags' fraction. This is expected because the 'zero' (introduced) values are not included.

Table 13. Nugget versus Sill – 'null' values

DESCRIPTION - NULL	silt	thm	magn	mags	mago	nmag
Nugget vs. Sill	43%	46%	40%	53%	19%	38%

Figure 36 to Figure 41 are the individual variograms as produced for the 'null' dataset.

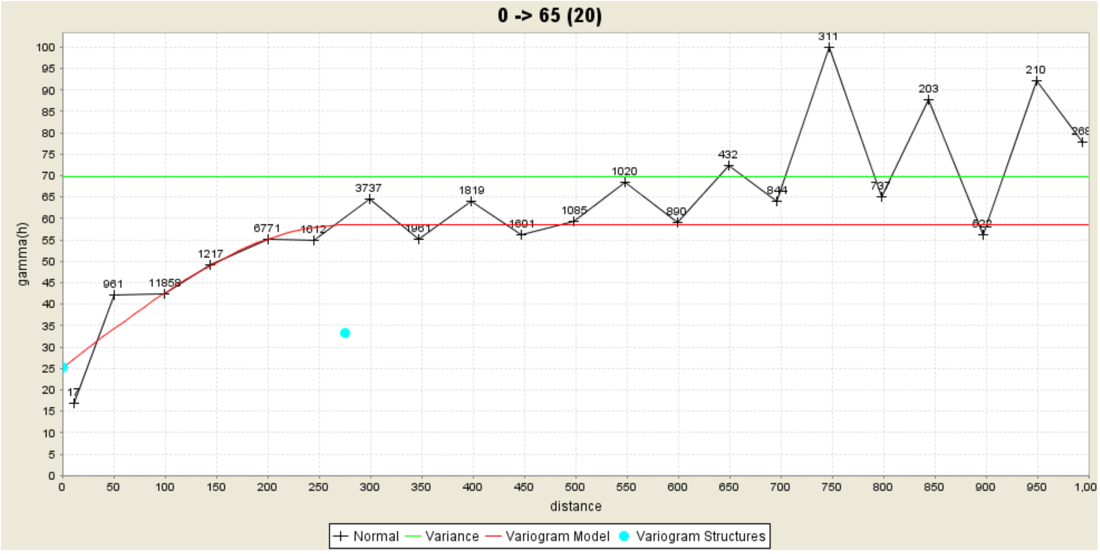


Figure 36. Variogram for silt% - 'null' dataset

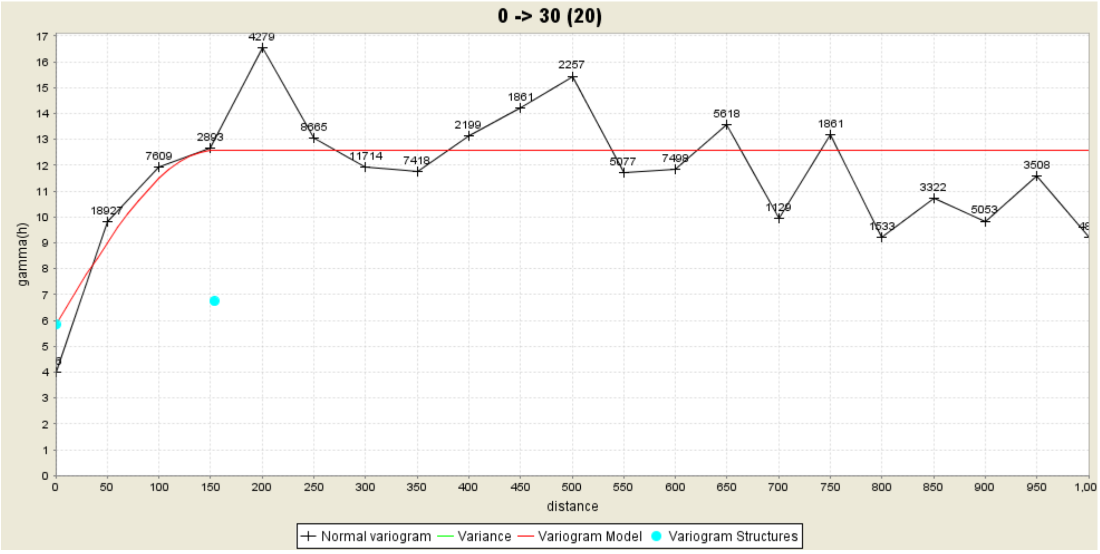


Figure 37. Variogram for THM% - 'null' dataset

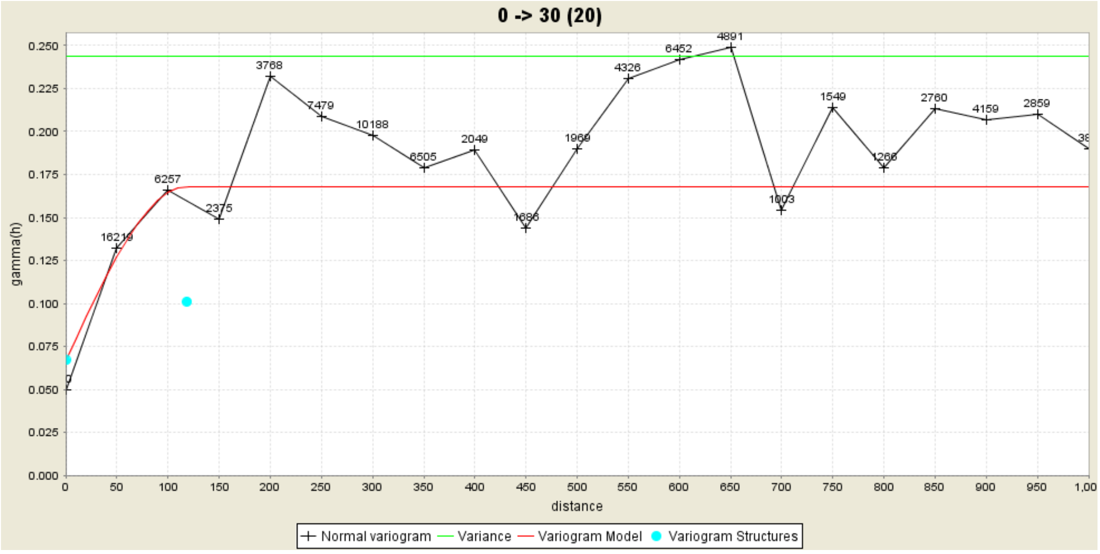


Figure 38. Variogram for ‘magn’% - ‘null’ dataset

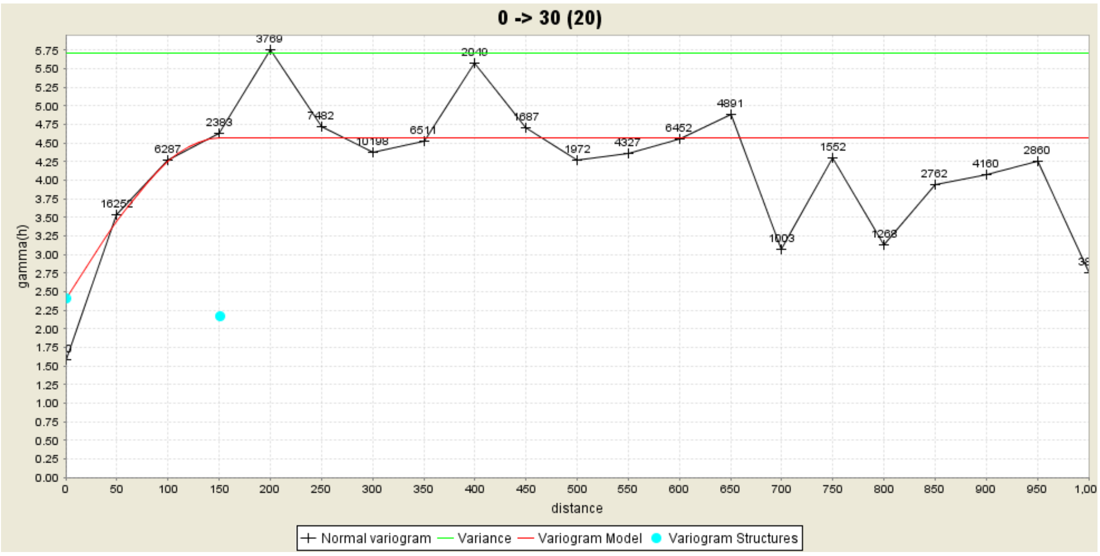


Figure 39. Variogram for ‘mags’% - ‘null’ dataset

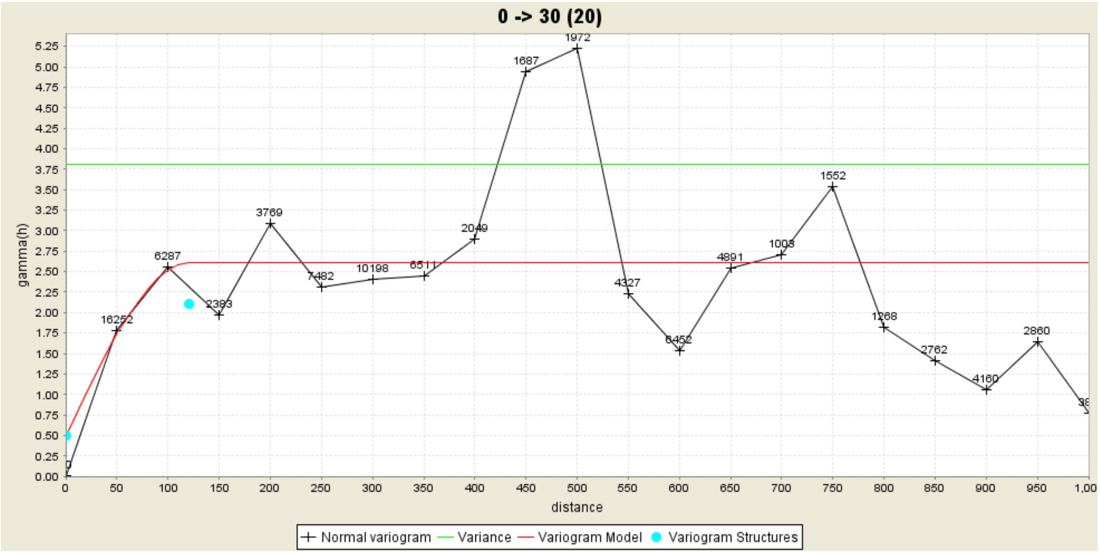


Figure 40. Variogram for 'mago'% - 'null' dataset

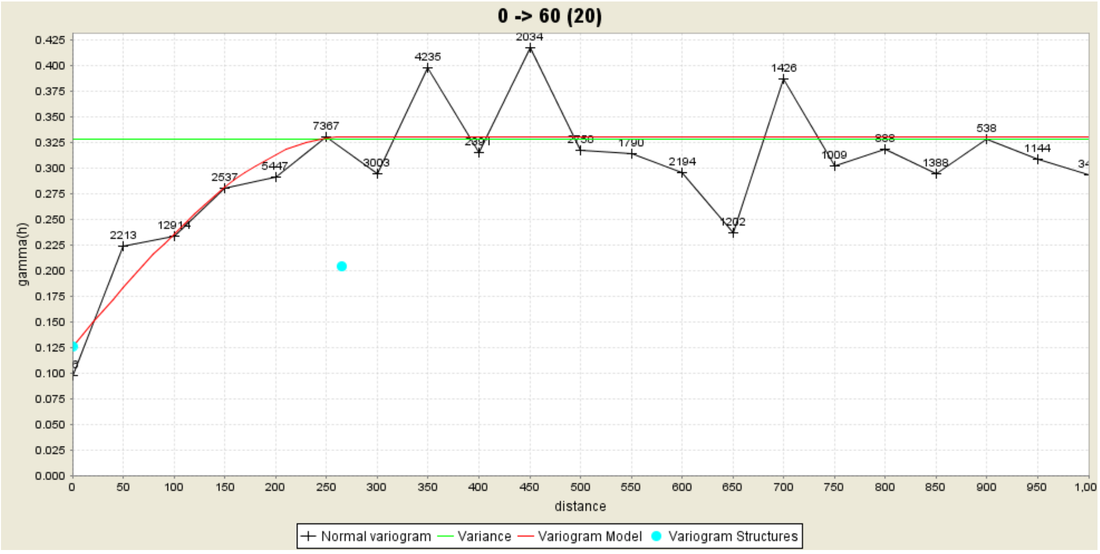


Figure 41. Variogram for 'nmag'% - 'null' dataset

Table 14 compares the variography done for the 'null' dataset against the variography for the 'zero' dataset, the parameters such as the Lagrange multiplier, estimated error, variance and average kriging variance for the 'null' dataset is considerably lower than for the 'zero' dataset. This relates to an average around 64% lower for the Lagrange multiplier and on average between 13% and 26% for the other parameters.

The sill, nugget and range for the ‘null’ datset are on average approximately 26% lower for the ‘null’ dataset compared to the ‘zero’ dataset.

Table 14. Variography comparative table between the 'zero‘ and the 'null' datasets

DATASET	DESCRIPTION	silt	THM	magn	mags	mago	nmag
Zero	LAGRANGE MULTIPLIER	0.757	0.383	0.005	0.097	0.069	0.008
Null	LAGRANGE MULTIPLIER	0.339	0.085	0.002	0.066	0.008	0.003
Zero	ESTIMATED ERROR	-3.457	0.340	-0.002	0.031	-0.004	0.030
Null	ESTIMATED ERROR	-2.957	0.147	0.027	0.342	0.043	0.088
Zero	VARIANCE	91.763	8.206	0.106	2.937	1.245	1.800
Null	VARIANCE	83.396	7.396	0.095	2.912	0.966	0.173
Zero	AVG KRIG VARIANCE	33.670	11.910	0.163	3.075	2.130	0.265
Null	AVG KRIG VARIANCE	32.150	7.991	0.104	3.202	1.072	0.168

3.4 Block model validation

There are a number of validation methods used at Hillendale Mine to compare the estimated block model values with the original input data. These validations include:

- Visual comparisons of the boreholes compared to the block model estimate.
- Comparing the global average of the raw sample data with the block model estimate.
- Histograms of the raw sample data compared to histograms of the block model estimate.
- Trend analysis
- Checking the comparisons of estimated THM against the estimated sum of the various fractions (est (THM) = sum(est) (‘magn’+’mags’+’mago’+’nmag’)

3.4.1 Block model validation – ‘zero’ dataset

3.4.1.1 Comparing global average

The average of the estimated values as listed in Table 15 compare to the original input data shown in Table 7. All other parameters such as maximum, range, variance, standard deviation, skewness, kurtosis and coefficient of variation have decreased with the block model estimation. This is expected since the data is globally smoothed.

Table 15. Global summary statistics of Hillendale block model - ‘zero’ estimate

SUMMARY STATISTICS FOR HILLENDALE MINE - ZERO ESTIMATE BLOCK MODEL						
	SILT %	THM %	MAGN %	MAGS %	MAGO %	NMAG %
N	190978	190976	190976	65517	65517	65517
Min	0.00	0.00	0.00	0.29	0.04	0.09
Max	68.30	18.52	2.11	9.69	8.57	2.21
Average	21.01	5.85	0.51	3.42	1.26	0.91
Range	68.30	18.52	2.11	9.40	8.53	2.12
Mode	0.00	0.00	0.44	0.00	0.00	0.00
Median	20.08	5.58	0.46	3.25	0.41	0.86
Variance	91.22	8.51	0.08	2.41	1.82	0.12
Std. Dev	9.55	2.92	0.28	1.55	1.35	0.34
Skewness	0.61	0.82	1.01	0.73	1.81	0.50
Kurtosis	2.57	3.61	4.65	3.02	6.26	2.50
CoV	0.45	0.50	0.55	0.45	1.07	0.38

Looking at Figure 42 the total heavy mineral assemblage for the ‘zero’ dataset estimate is very similar to the original input data, with the ‘mago’ fraction gaining one percent and the ‘magn’ fraction losing one percent. The mineral fractions of economic interest namely the ‘mags’ and the ‘nmag’ has the same representation in the total heavy mineral assemblage. The original input data includes the ‘zero’ values.

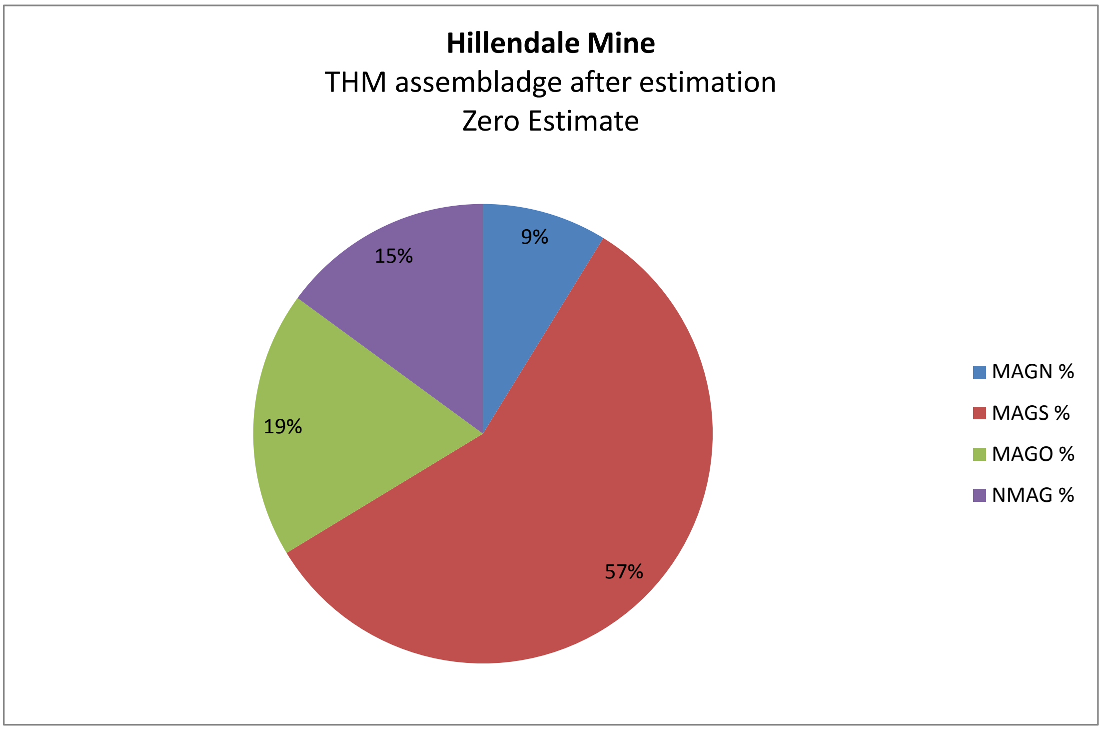


Figure 42. THM assemblage with 'zero' dataset estimation

3.4.1.2 Histograms

From the histograms as indicated in Figure 43 to Figure 48, the basic structure for silt%, 'magn'% and 'mago'% is similar to the histograms from the original input data. The relative percentage of the values has decreased from the input data due to the smoothing with estimation. The 'mags'% and the 'nmag'% histogram distributions have changed. This is expected since there is an economic cut-off applied to the 'mags'% in the geological block model. The geological block model is constrained and not the input data.

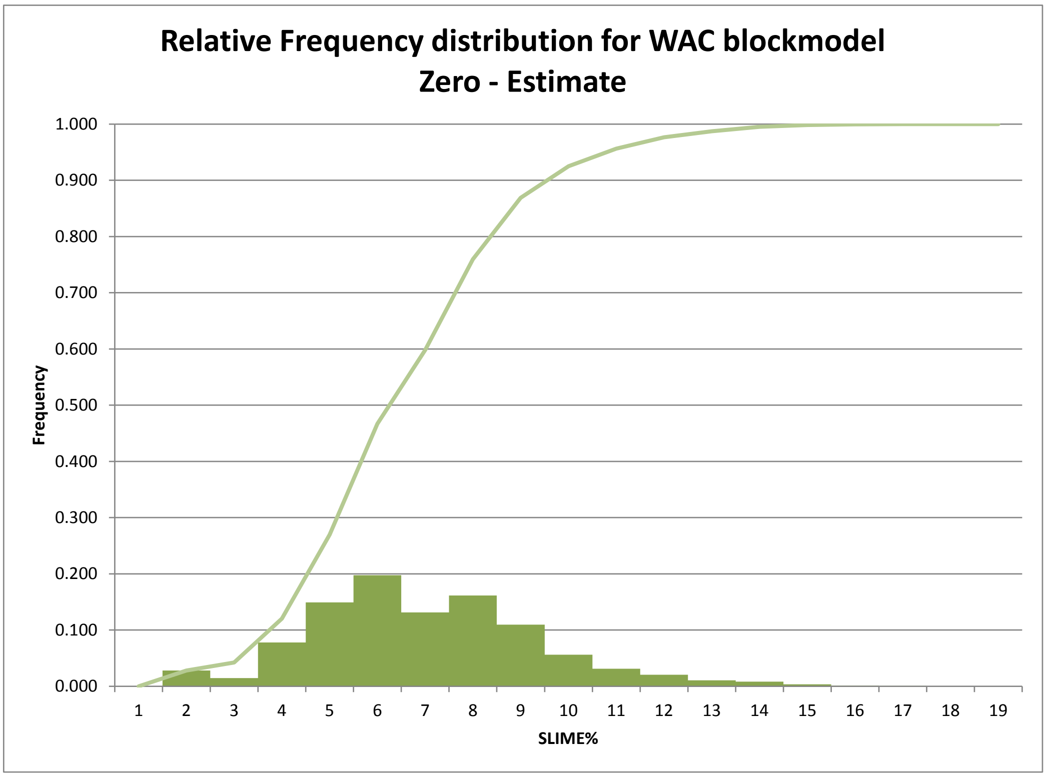


Figure 43. Relative frequency histogram for ‘zero’ estimates - silt %

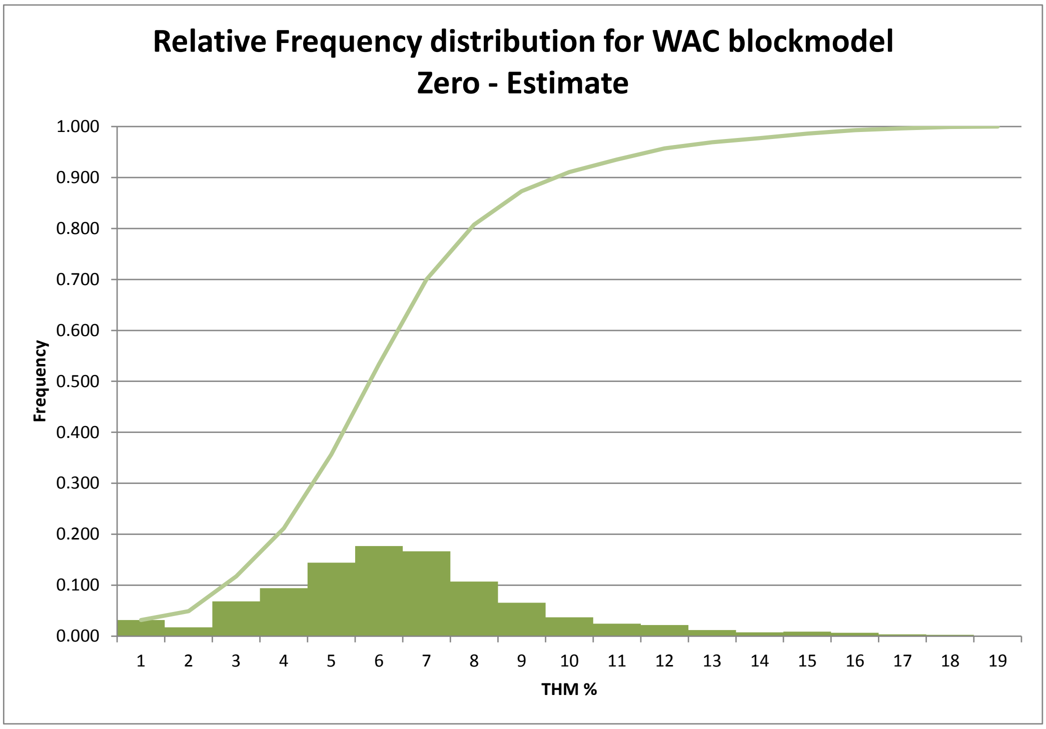


Figure 44. Relative frequency histogram for ‘zero’ estimates - THM %

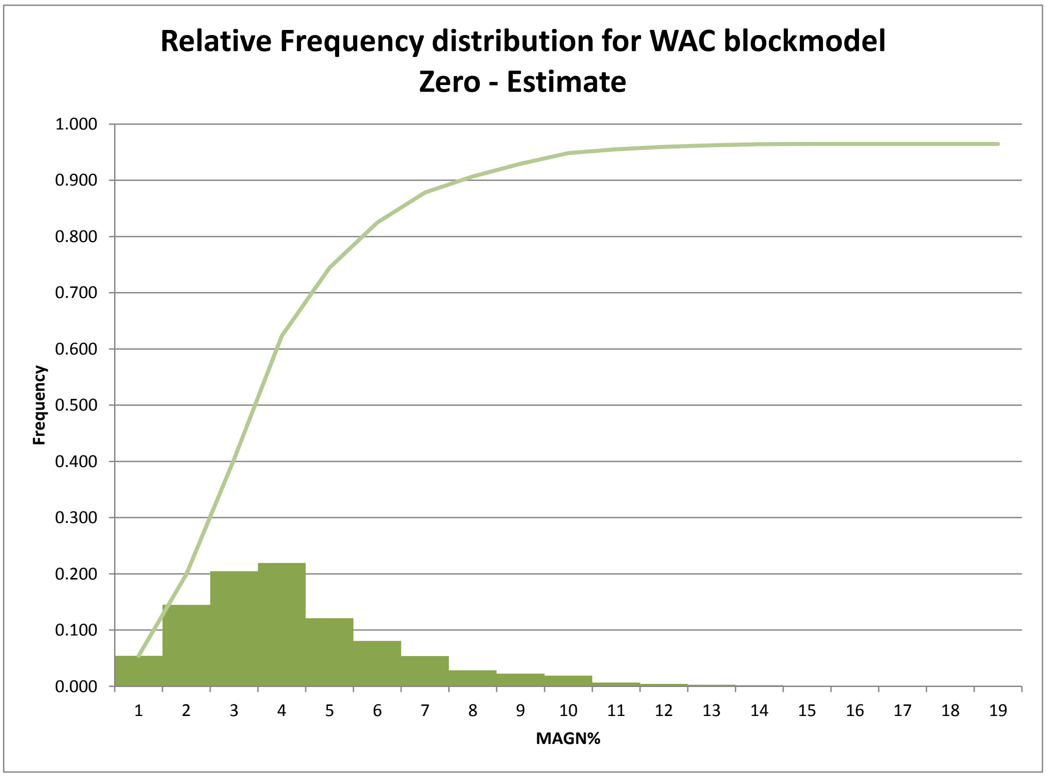


Figure 45. Relative frequency histogram for 'zero' estimates – 'magn' %

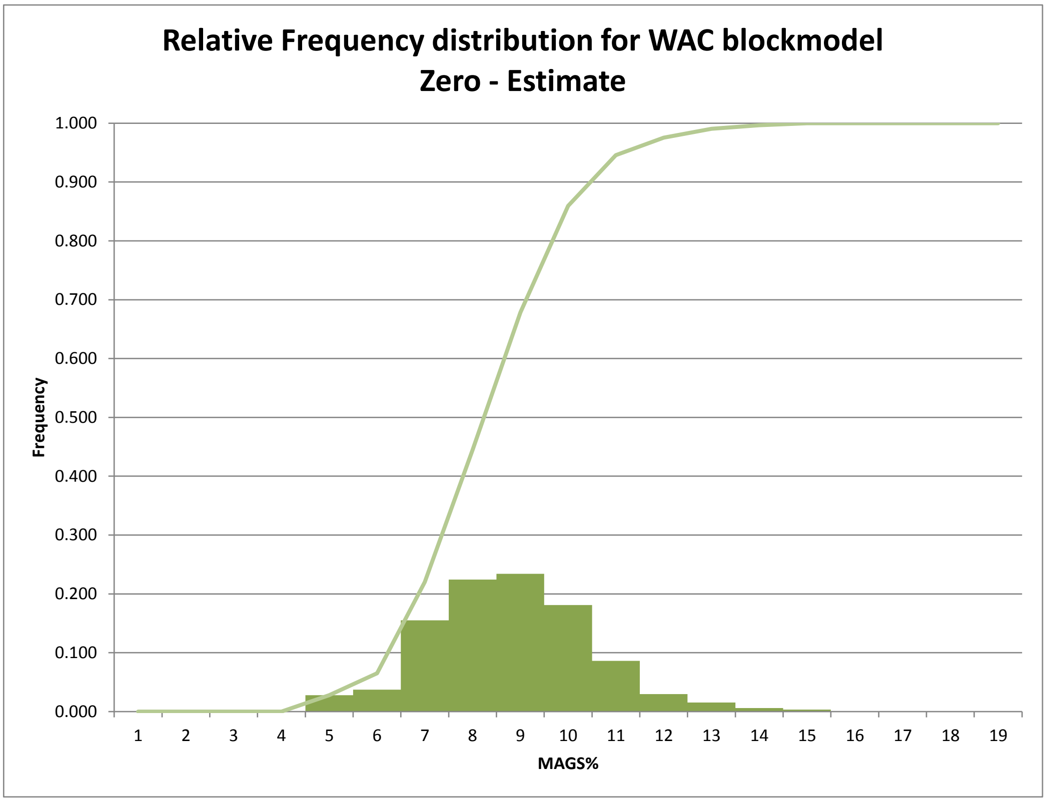


Figure 46. Relative frequency histogram for 'zero' estimates – 'mags' %

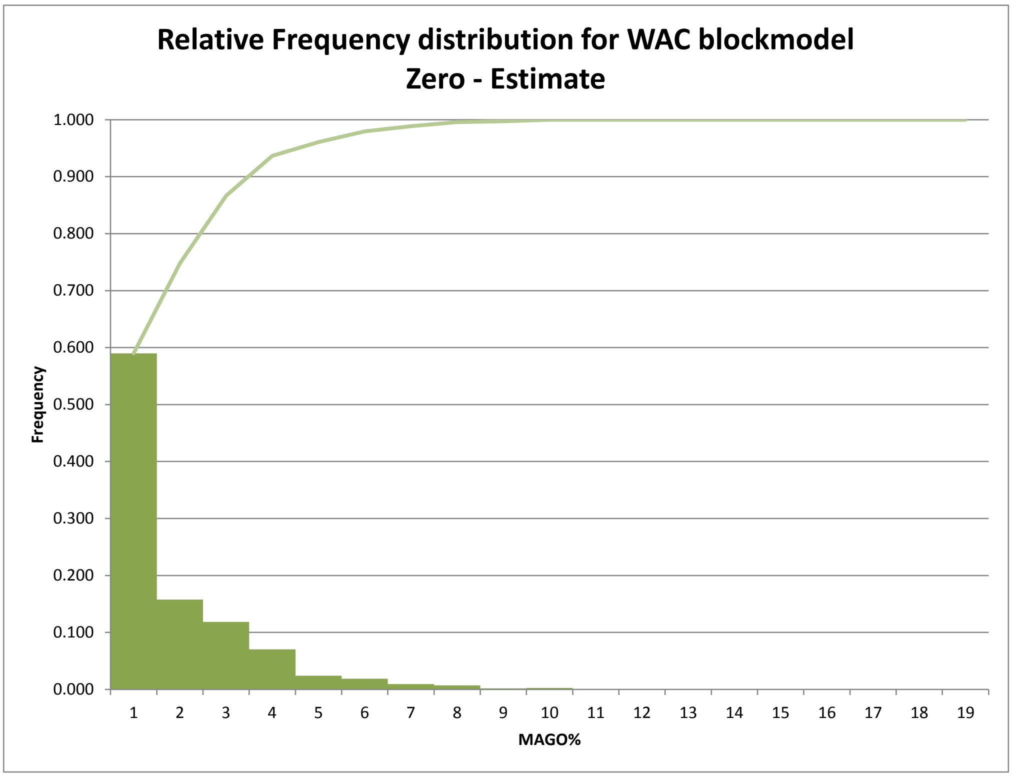


Figure 47. Relative frequency histogram for 'zero' estimates – 'mago' %

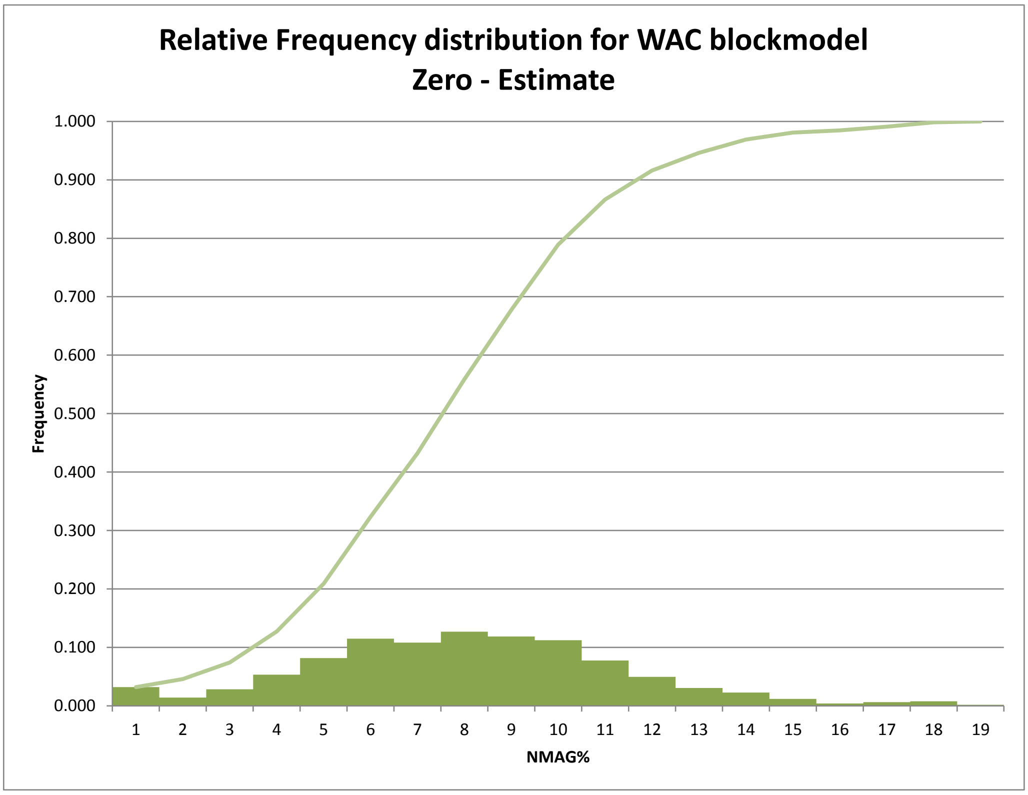


Figure 48. Relative frequency histogram for 'zero' estimates – 'nmag' %

3.4.1.3 Trend Analyses

Figure 50 to Figure 55 represents the trend analyses of the geological model compared to the original input data for the 'zero' dataset. The data is divided into 50 metre intervals north – south and east – west. From the trend analyses it can be seen that the estimated data follows the same trend than the original input data. The block model tends to be overestimated in areas with less data.

Figure 49 is the legend applicable to the trend analyses.

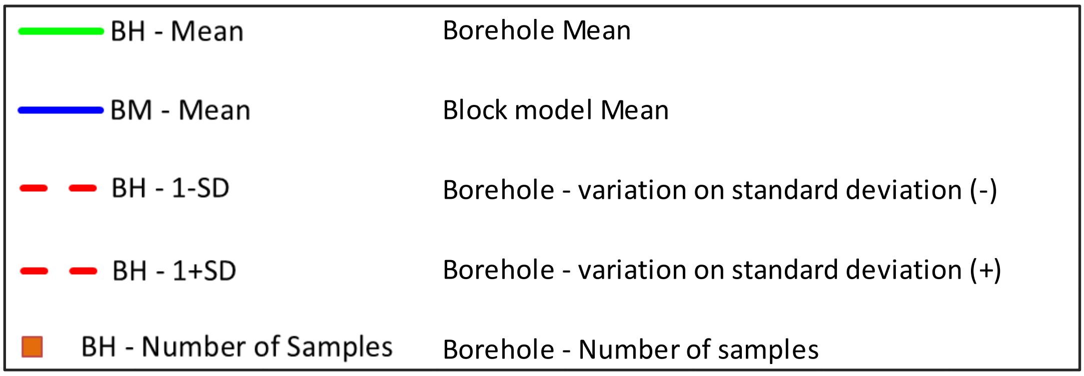


Figure 49. Trend analyses legend

ADDENDUM 1 contains the additional sections trend analyses not included in the text.

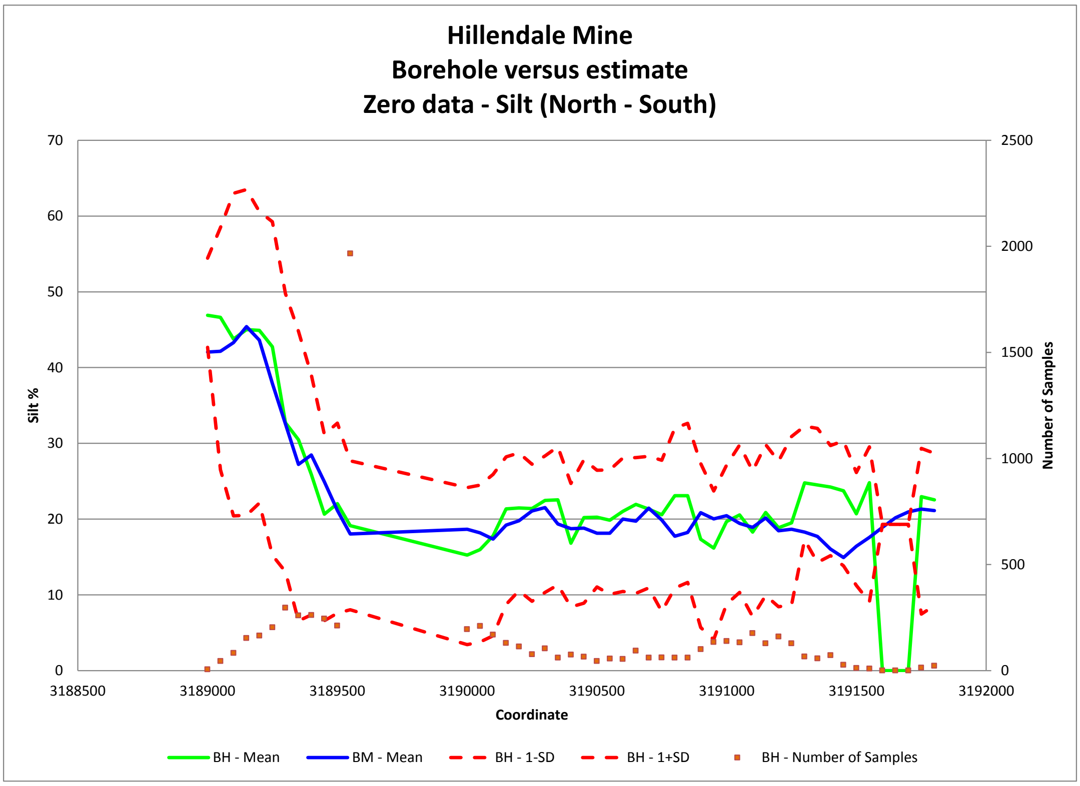


Figure 50. Block model Validation - 'zero' dataset, Silt% (N-S)

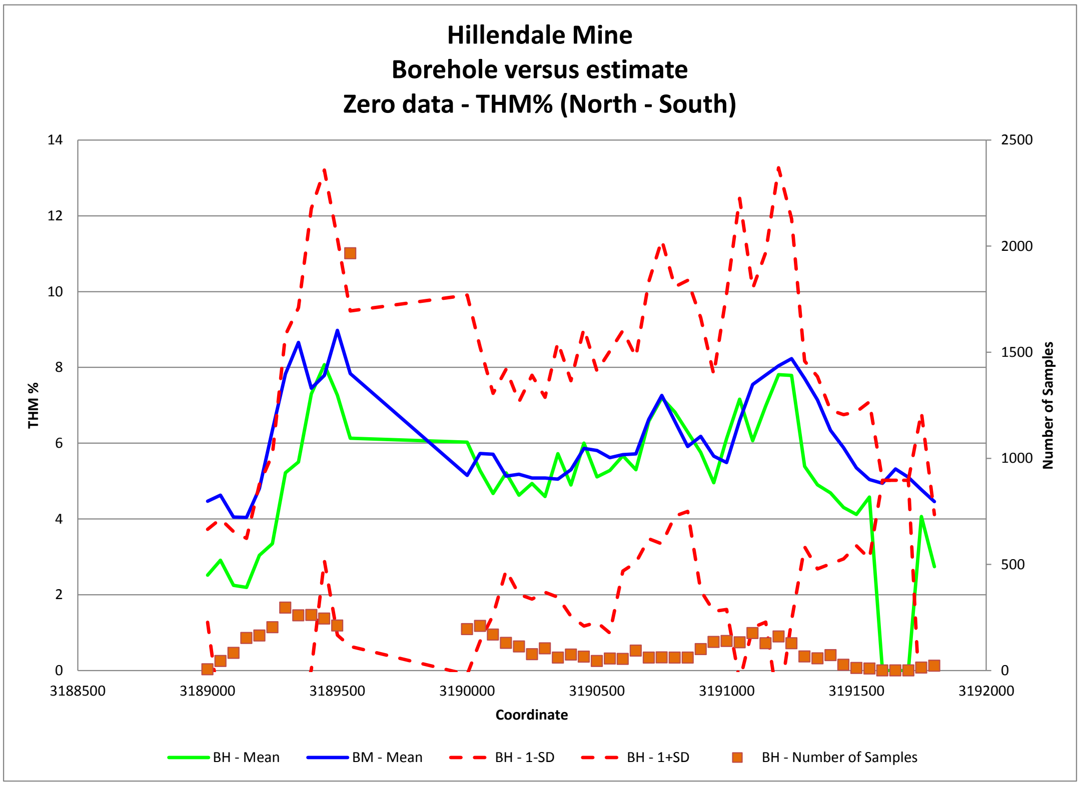


Figure 51. Block model Validation - 'zero' dataset, THM% (N-S)

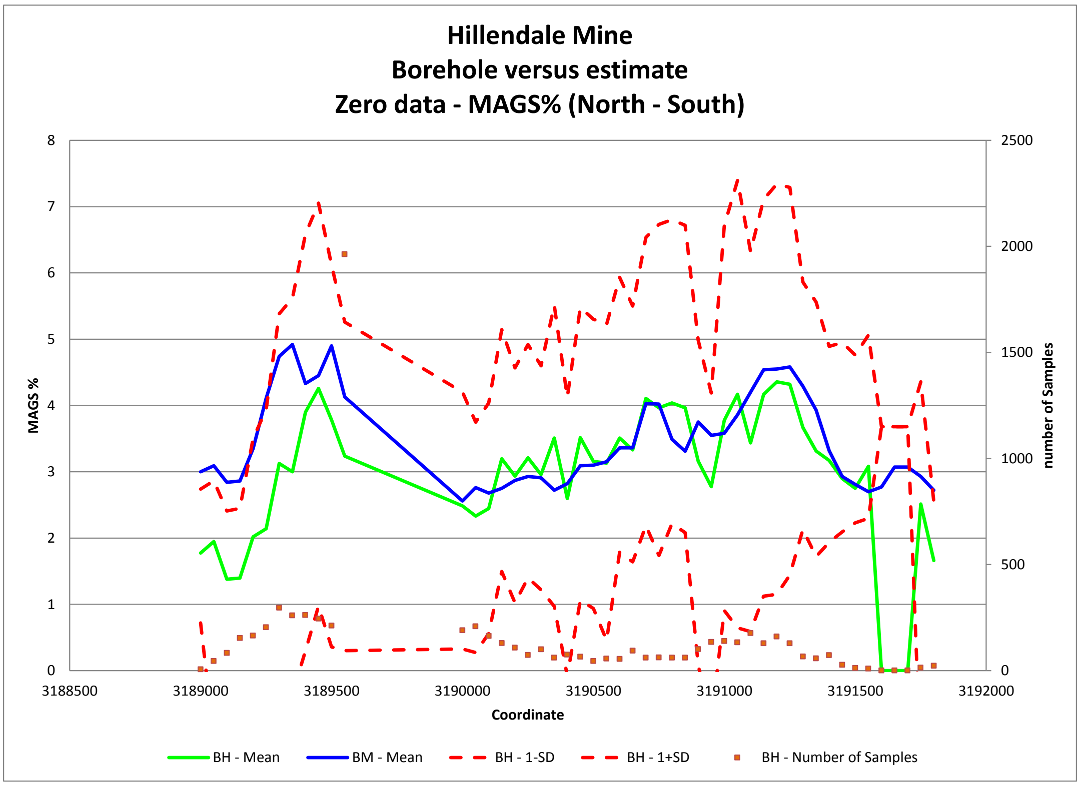


Figure 52. Block model Validation - 'zero' dataset, 'mags'(N-S)

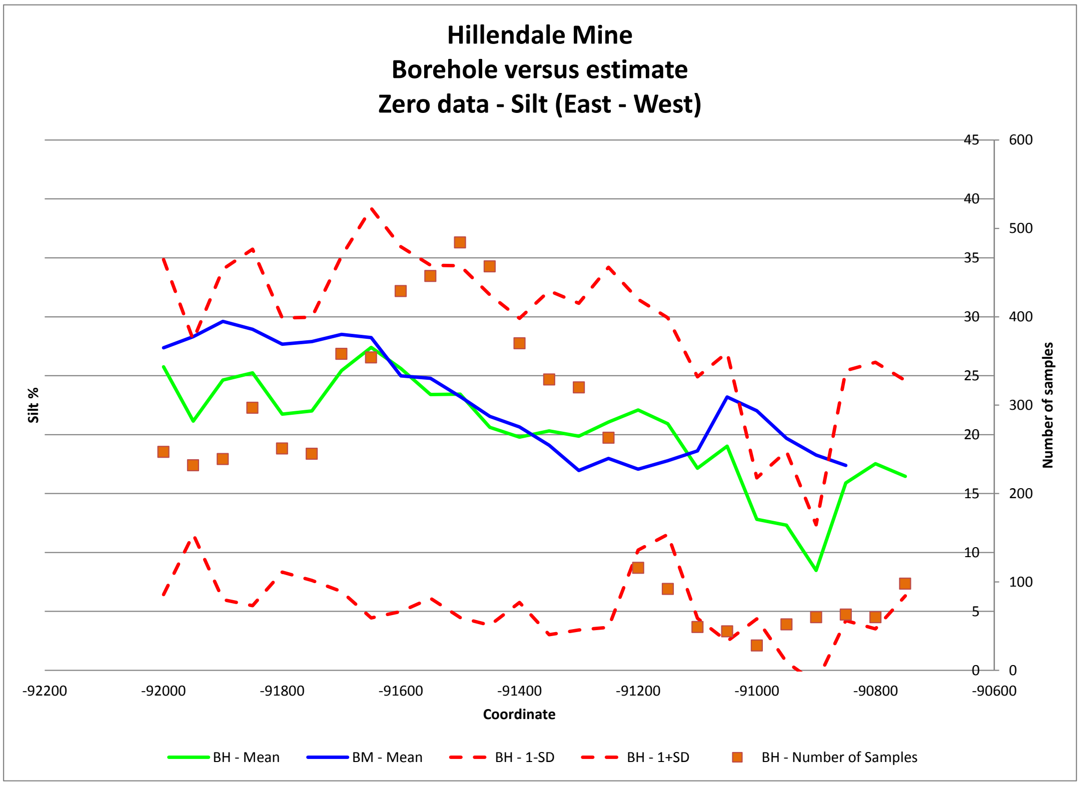


Figure 53. Block model Validation - 'zero' dataset, Silt% (E-W)

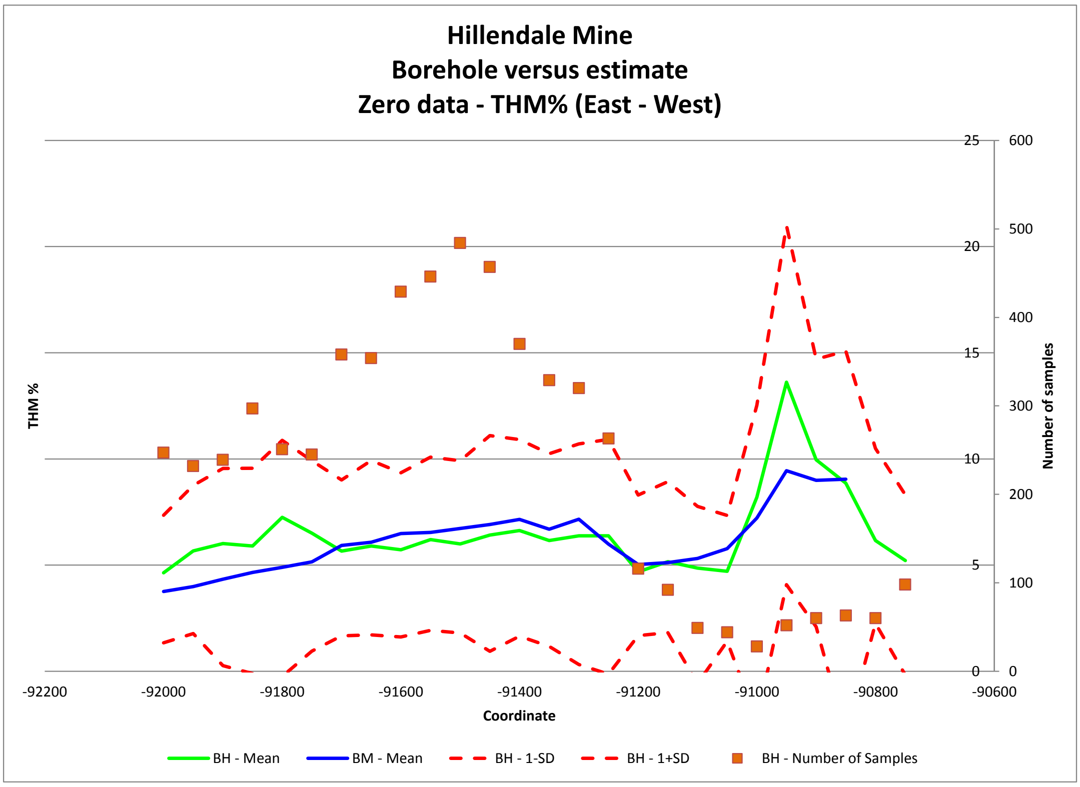


Figure 54. Block model Validation - 'zero' dataset, THM %(E-W)

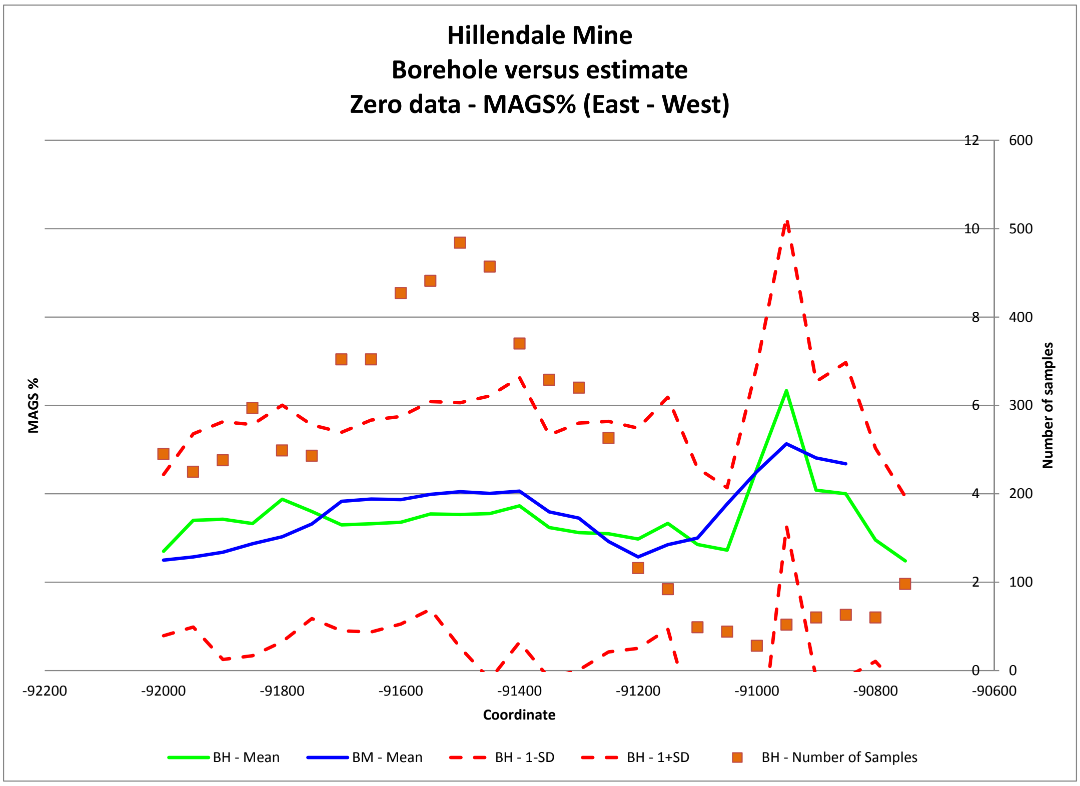


Figure 55. Block model Validation - 'zero' dataset, ‘mags’% (E-W)

3.4.2 Block model validation – 'Null' Dataset

3.4.2.1 Comparing global average

Comparing the block model statistics as listed in Table 16 with the original input data Table 8, the average value for silt% and 'mago'% has decreased while THM%, 'magn'%, 'mags'% and 'nmag'% has increased. The changes in the silt and THM are due to estimation in the block model. Similar to the 'zero' dataset all parameters such as maximum, range, variance, standard deviation, skewness, kurtosis and coefficient of variation have decreased with the blockmodel estimation.

Table 16. Global summary statistics of Hillendale Block model – 'Null' Estimate

SUMMARY STATISTICS FOR HILLENDALE MINE - NULL ESTIMATE BLOCKMODEL						
	SILT %	THM %	MAGN %	MAGS %	MAGO %	NMAG %
N	190978	190976	190976	190976	190976	190976
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	68.77	18.98	2.30	10.21	10.89	2.53
Average	21.00	5.84	0.56	3.65	1.10	0.95
Range	68.77	18.98	2.30	10.21	10.89	2.53
Mode	0.00	0.00	0.54	0.00	0.30	0.00
Median	20.03	5.60	0.52	3.60	0.44	0.93
Variance	89.51	8.52	0.07	2.33	1.85	0.13
Std. Dev	9.46	2.92	0.27	1.53	1.36	0.36
Skewness	0.61	0.89	0.62	0.81	1.89	0.60
Kurtosis	2.59	3.84	2.94	3.22	6.74	2.65
CoV	0.45	0.50	0.49	0.42	1.24	0.38

Looking at Figure 56 the total mineral assemblage for the block model has all decreased in from the original input data. The sum of the average of the fractions is 6.26% compared to the estimated average of 5.84%. Looking at the median of the THM in the dataset is 5.60% while the sum of the median equals to 5.49%.

The median in used since the dataset does not have a normal distribution. Using the sum of the median compared to the estimated median is therefore a more appropriate method to use based on the above calculation.

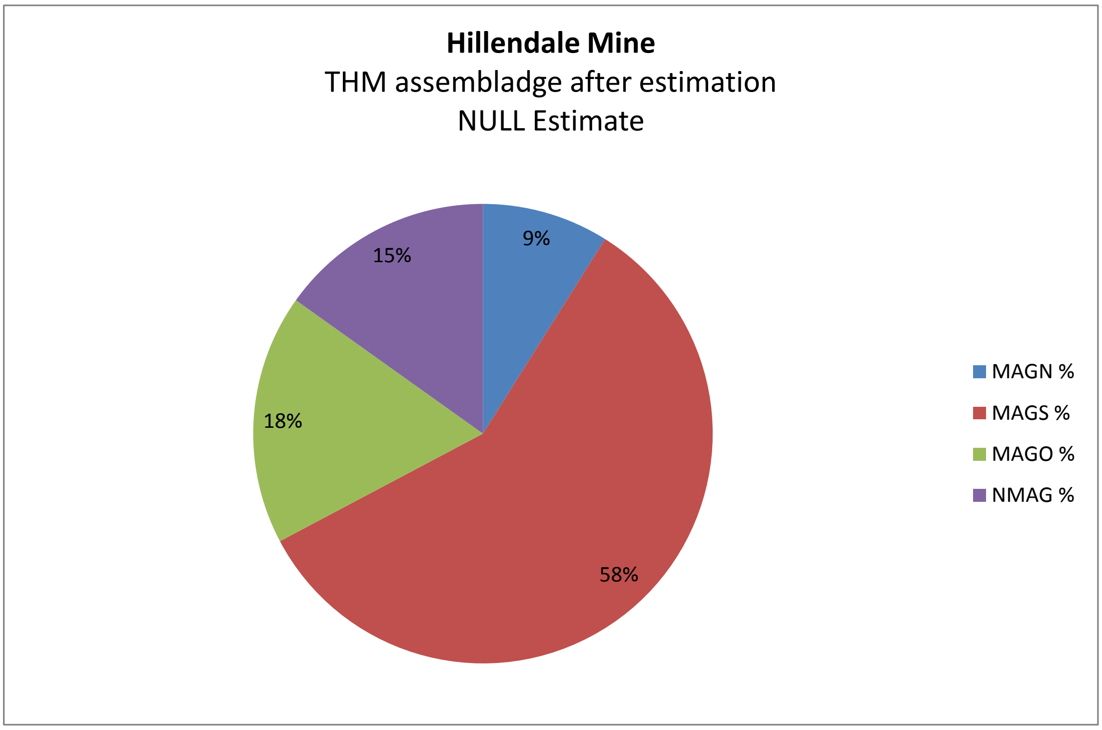


Figure 56. THM assemblage with 'null' dataset estimation.

3.4.2.2 Histograms

From the histograms as indicated in Figure 57 to Figure 62 the basic structure for the estimated values are similar to the original data. There is however not a continuation of the lower estimates of the 'mags'% and the 'nmag'%. This needs to be further investigated.

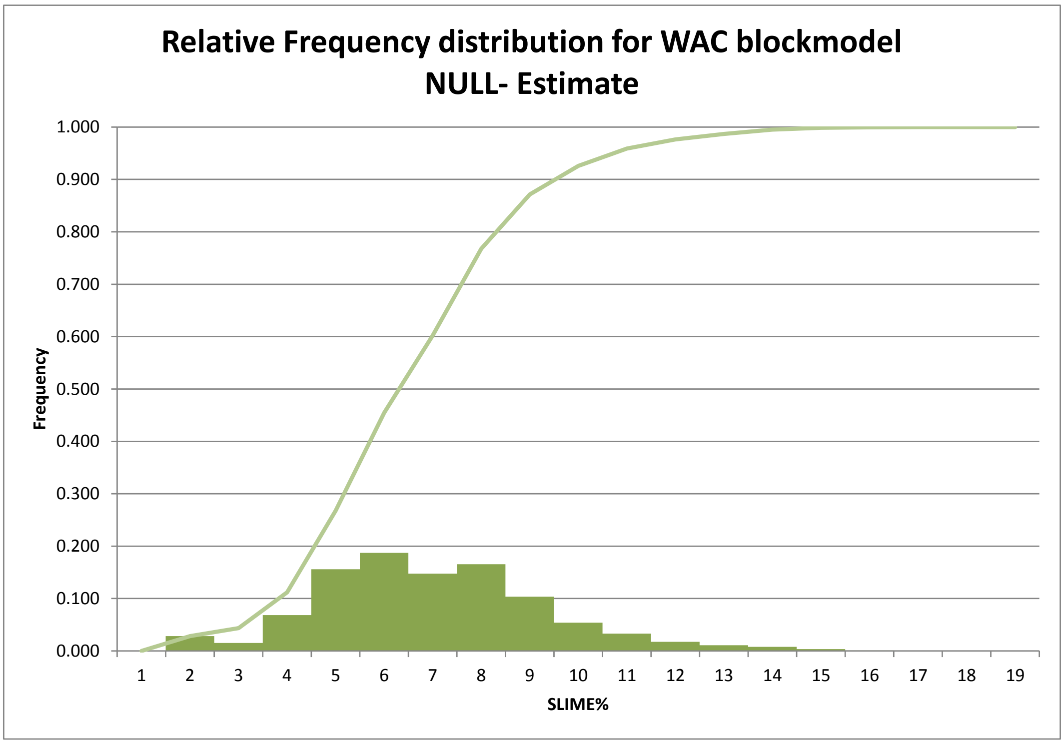


Figure 57. Relative frequency histogram for 'null' estimate - silt %

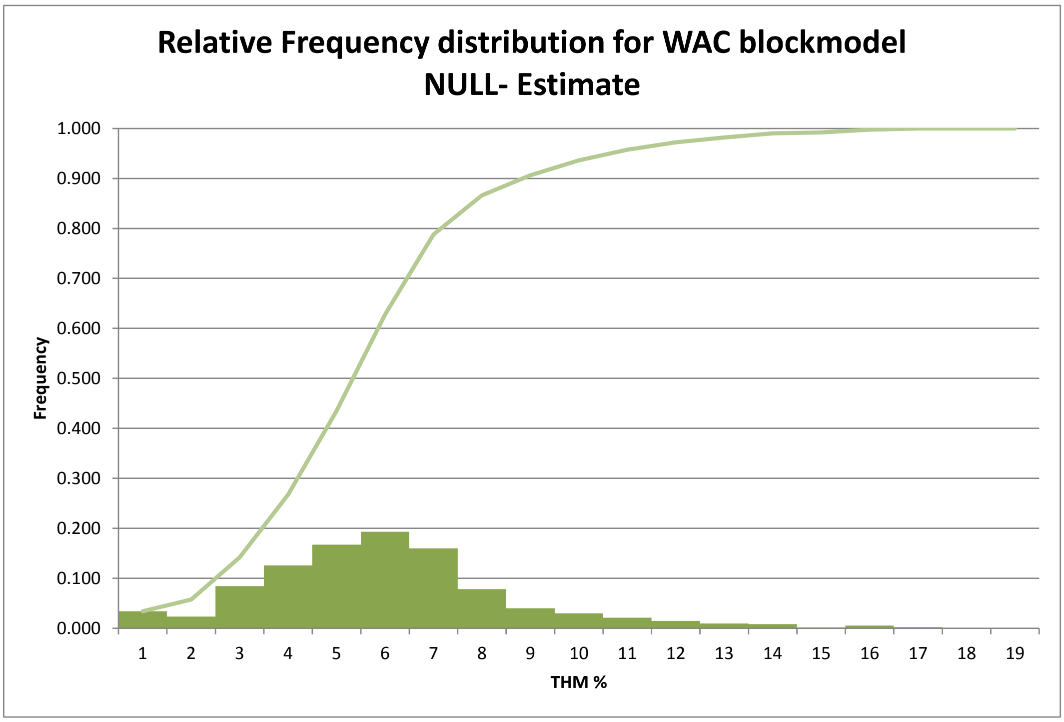


Figure 58. Relative frequency histogram for 'null' estimate - THM %

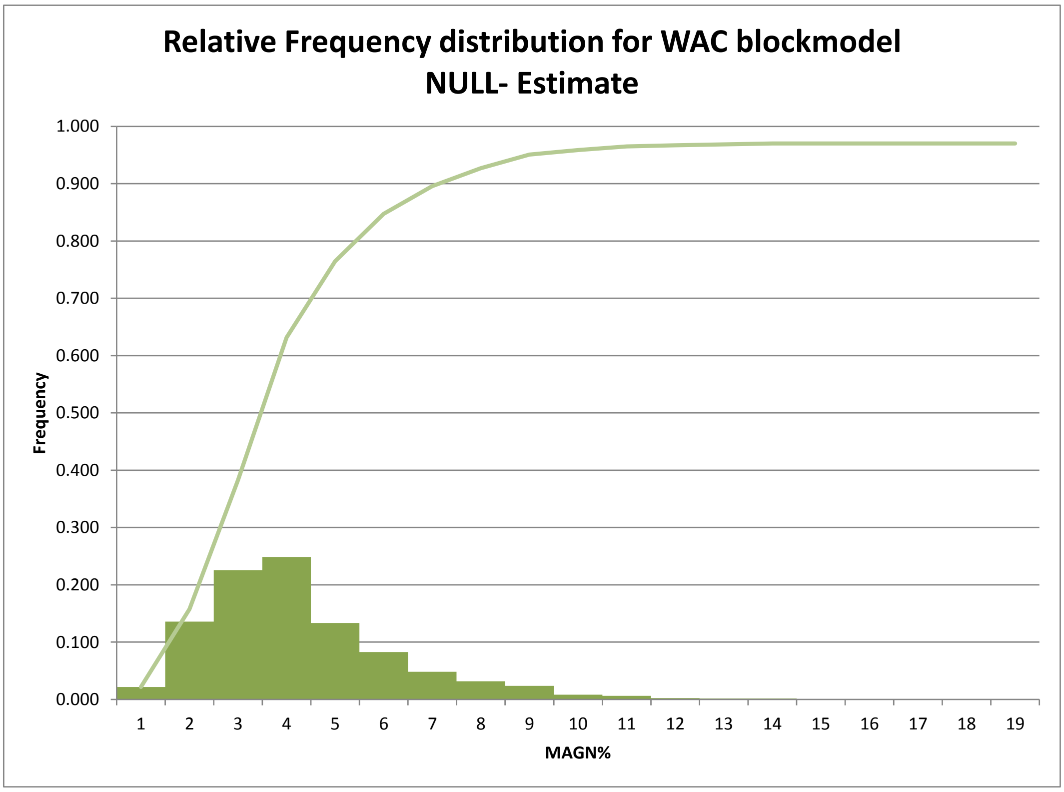


Figure 59. Relative frequency histogram for 'null' estimate – 'magn' %

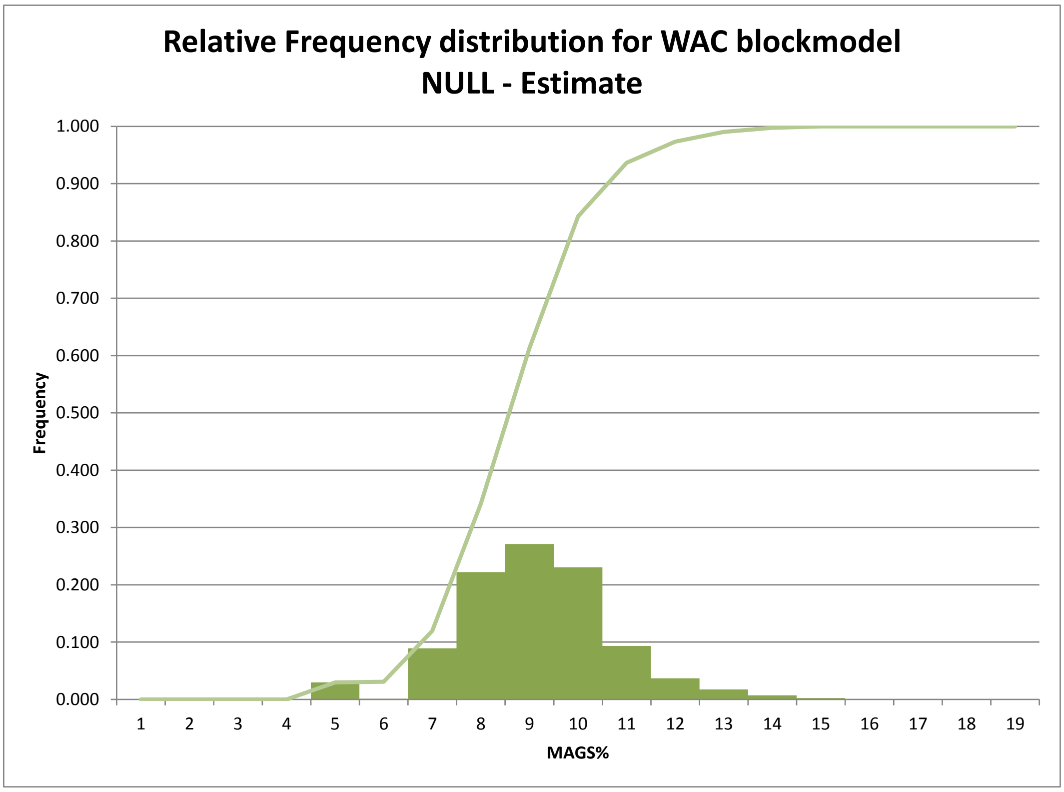


Figure 60. Relative frequency histogram for 'null' estimate – 'mags' %

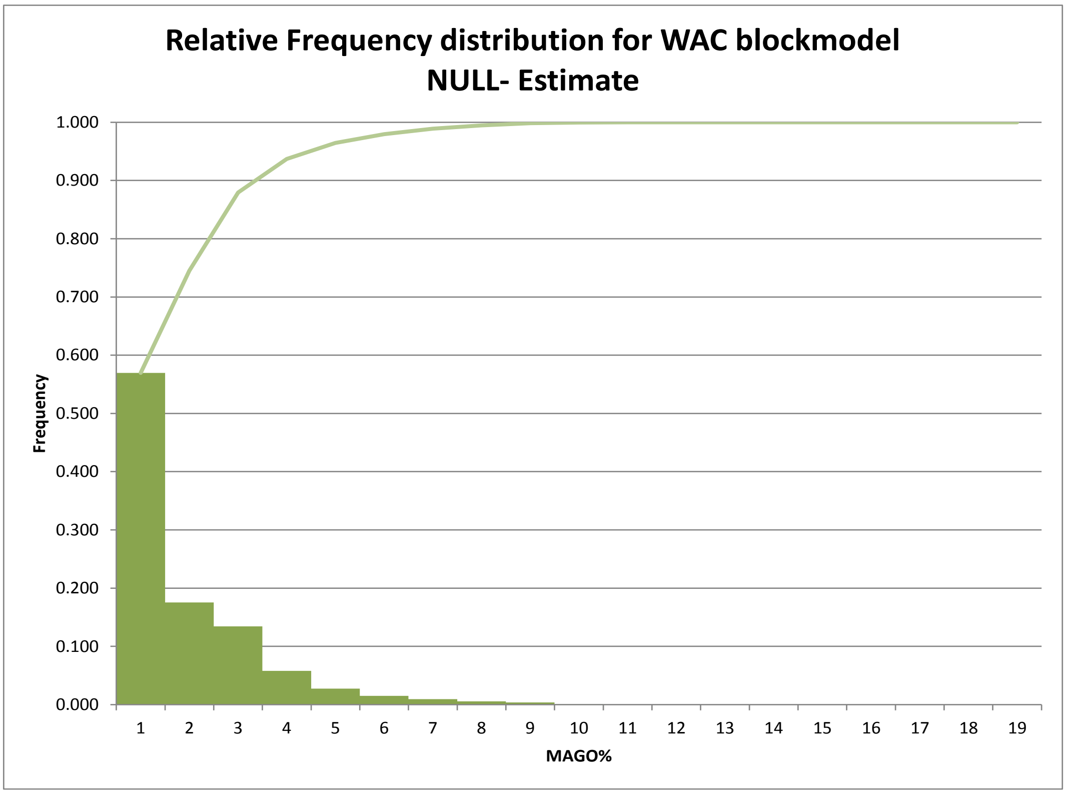


Figure 61. Relative frequency histogram for 'null' estimate – 'mago' %

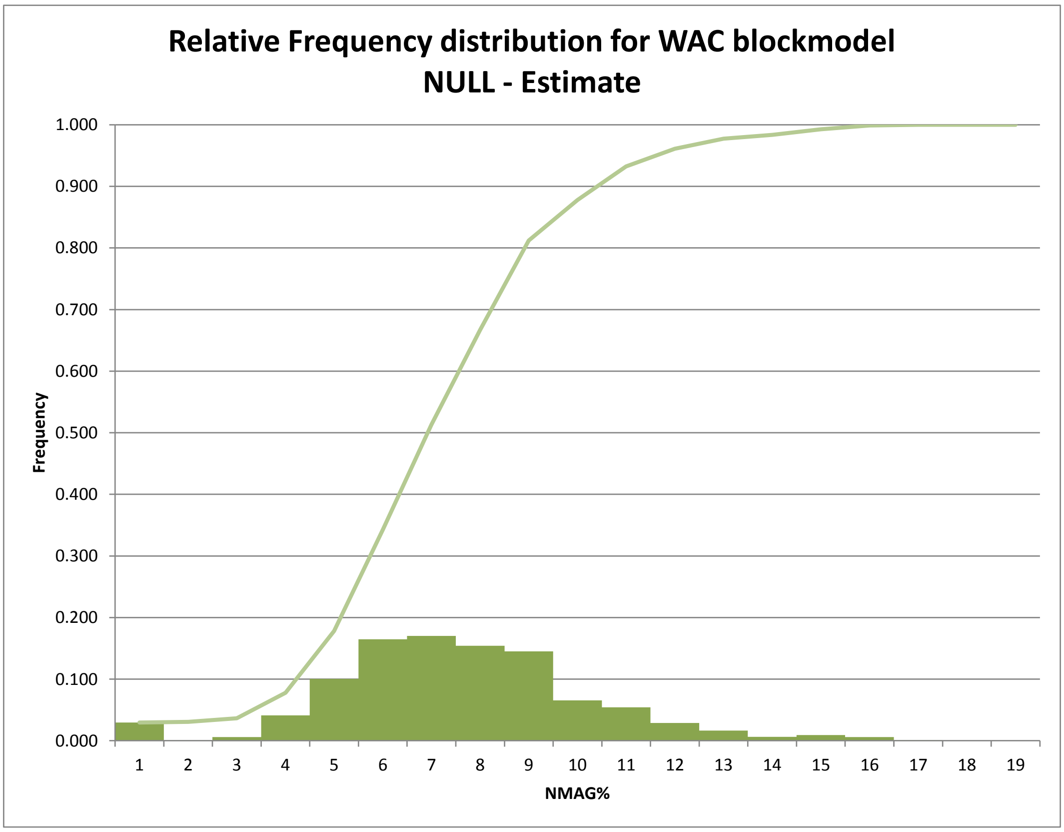


Figure 62. Relative frequency histogram for 'null' estimate – 'nmag' %

3.4.2.3 Trend Analyses

Figure 64 to Figure 69 below represent the trend analyses of the geological model compared to the original input data for the 'null' dataset. The data is divided into 50 metre intervals north – south and east – west. From the trend analyses it can be seen that the estimated values follows a similar trend than the original input data. Areas with less data tend to overestimate the geological block model.

Figure 49 is the legend applicable to the trend analyses.

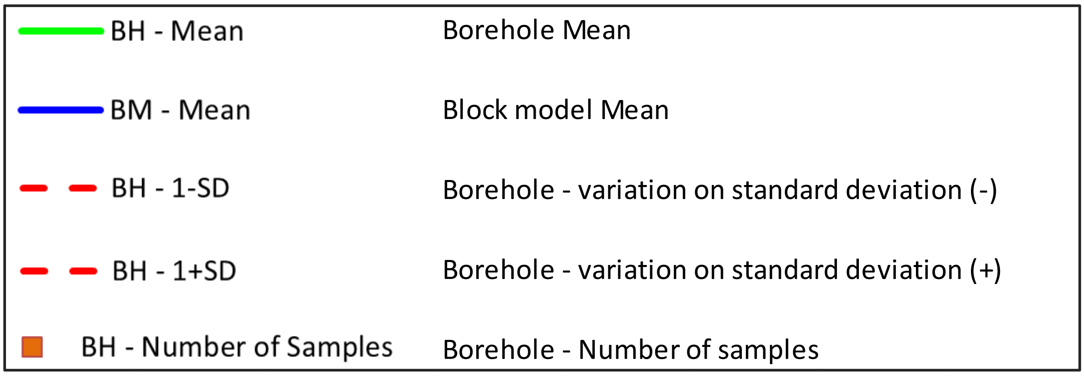


Figure 63. Trend analyses legend

ADDENDUM 1 contains the additional section trend analyses not included in the text.

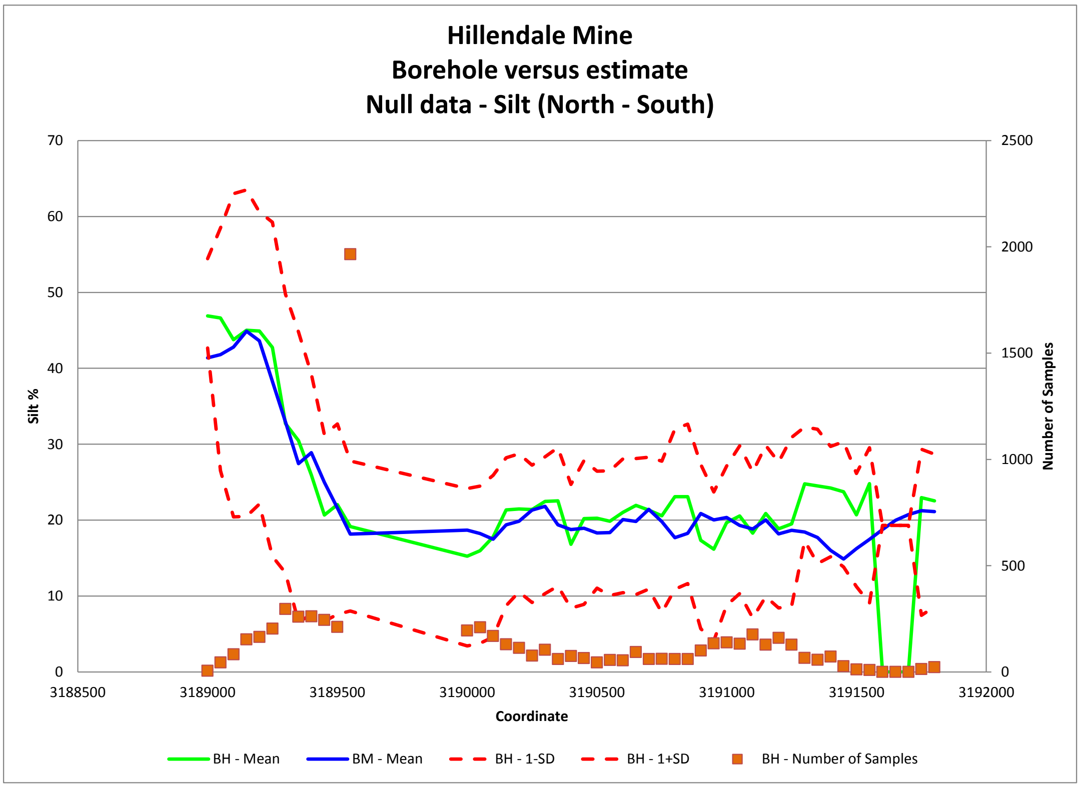


Figure 64. Block model Validation – 'null' dataset, silt% (N-S)

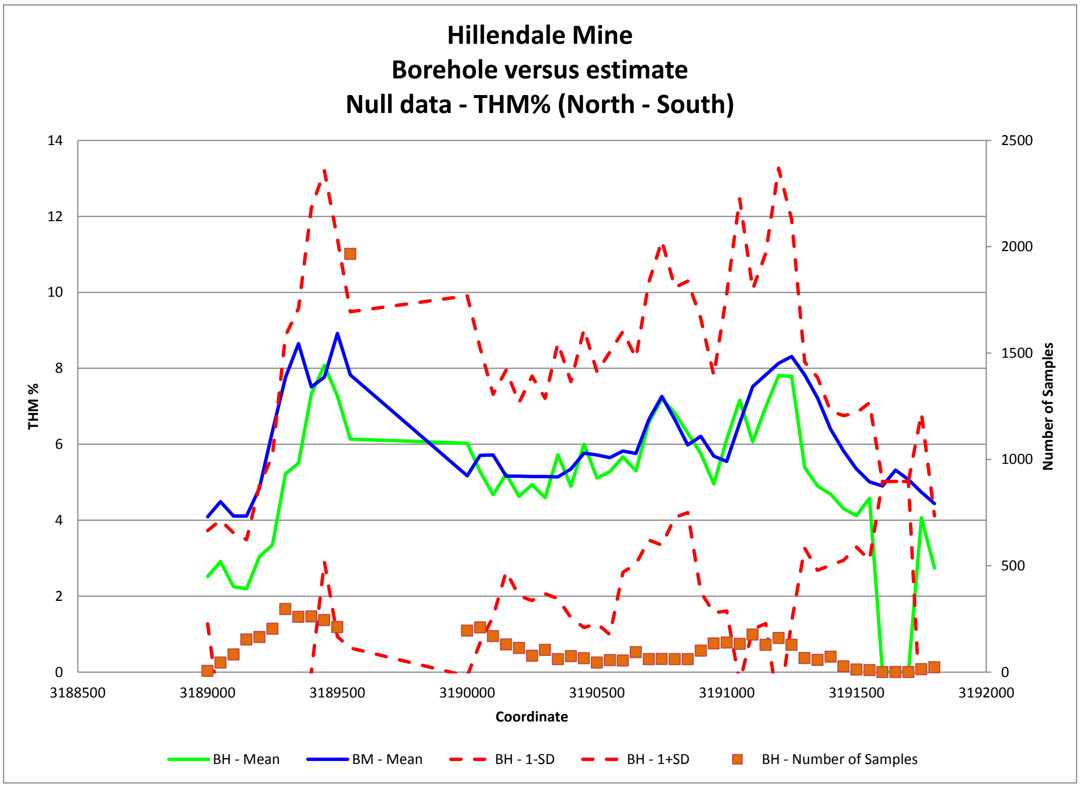


Figure 65. Block model Validation – 'null' dataset, THM% (N-S)

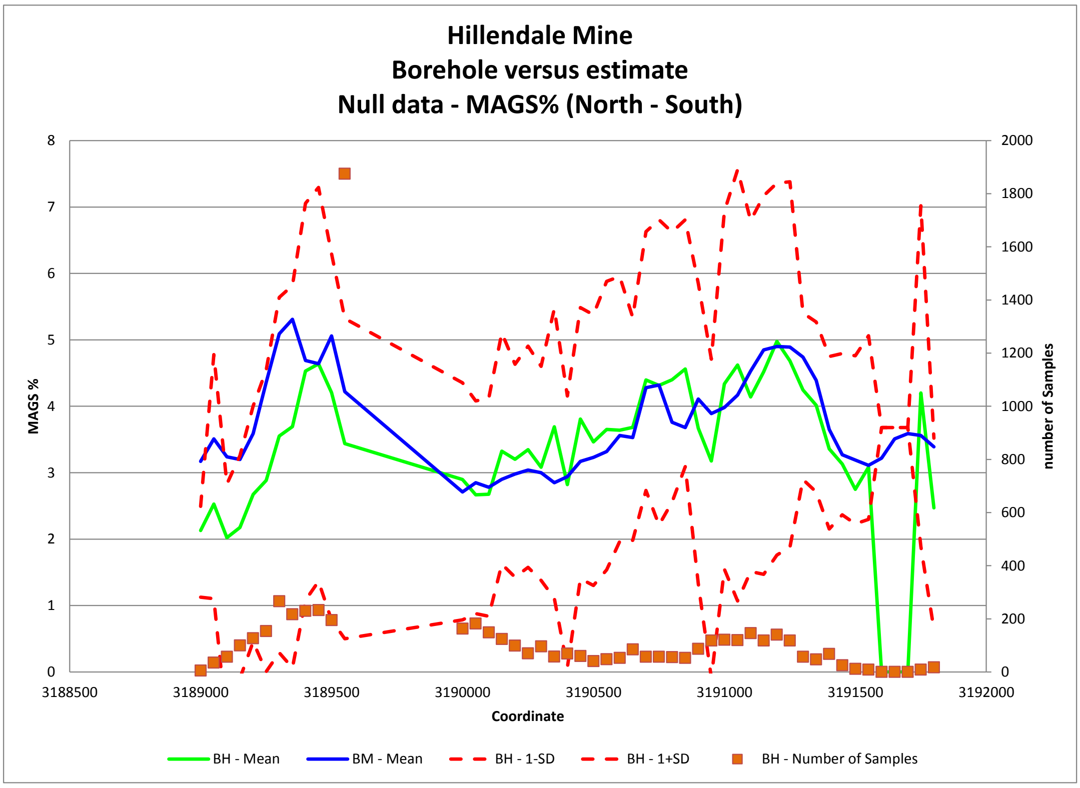


Figure 66. Block model Validation – 'null' dataset, 'mags'% (N-S)

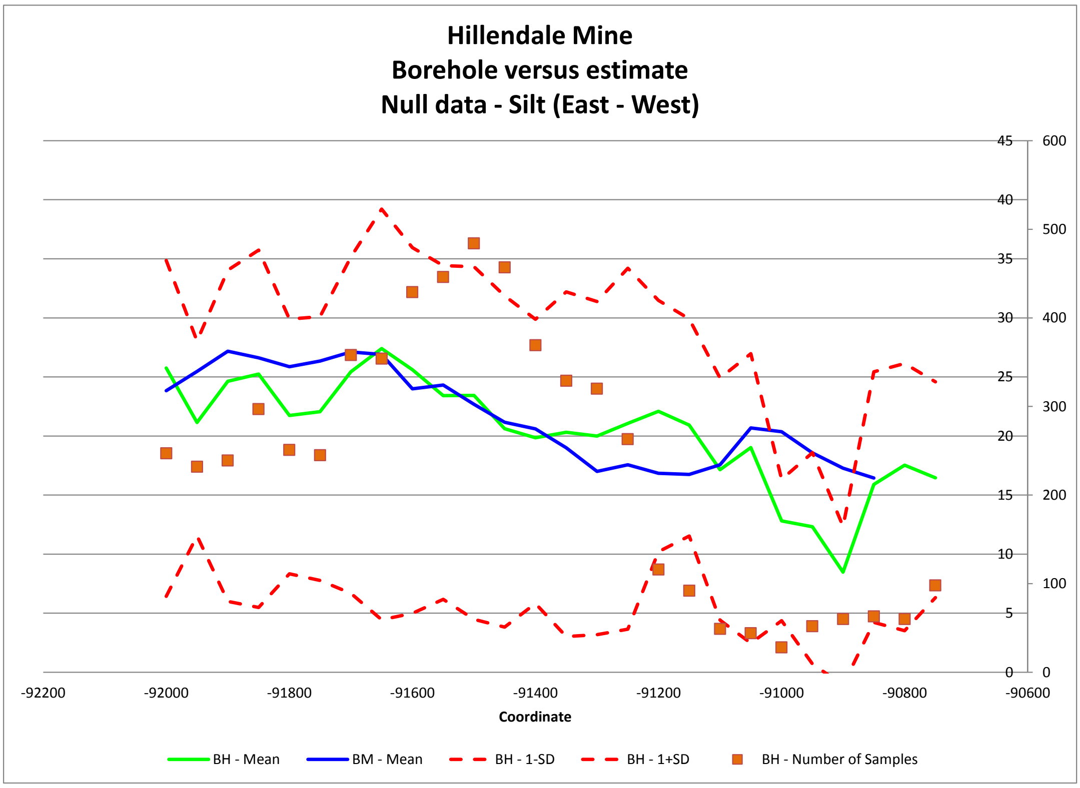


Figure 67. Block model Validation - 'null' dataset, silt% (E-W)

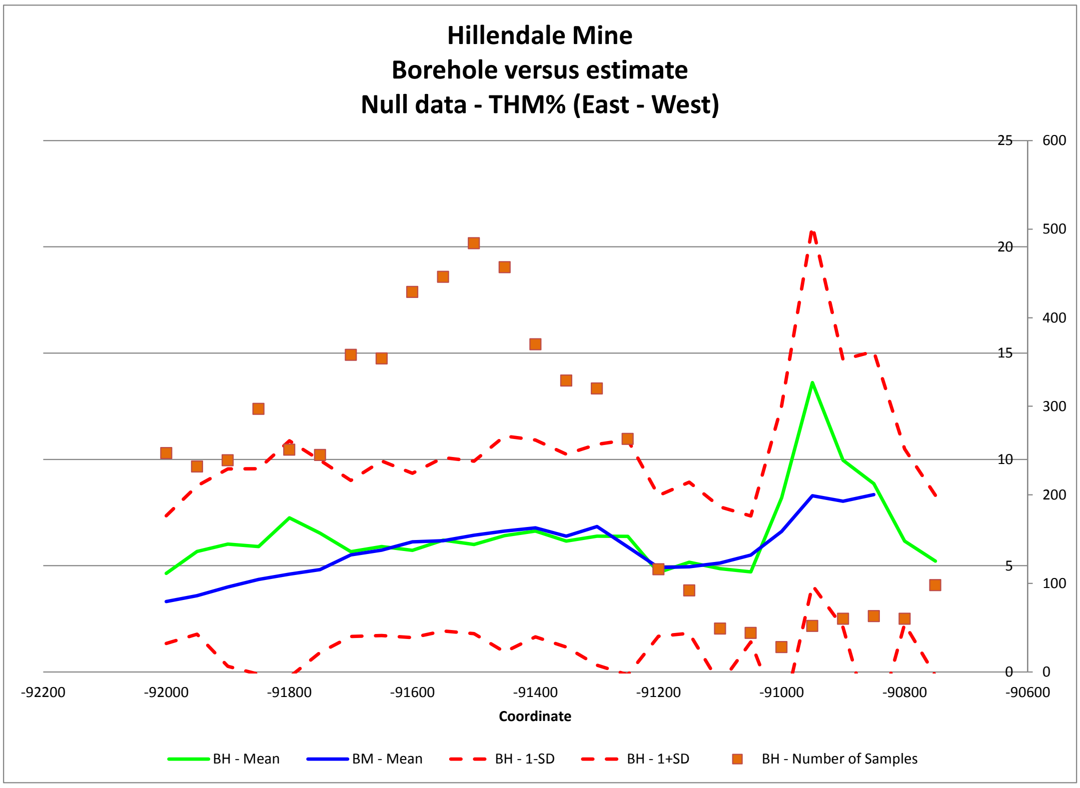


Figure 68. Block model Validation - 'null' dataset, THM% (E-W)

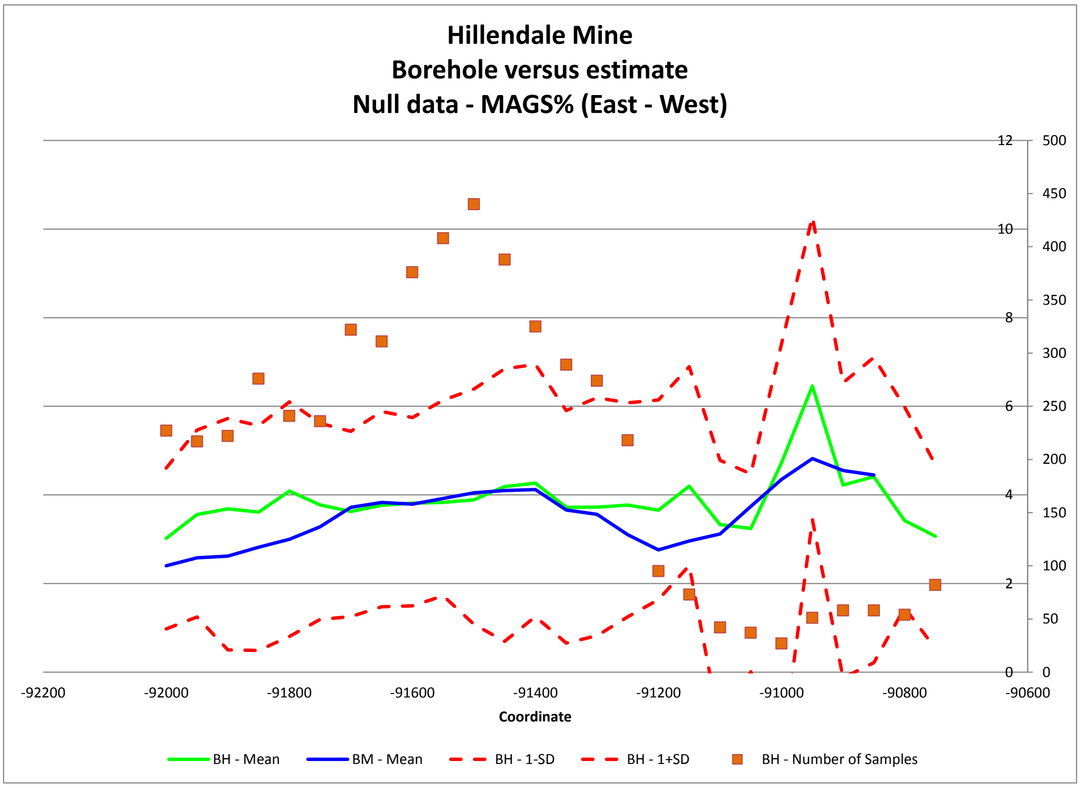


Figure 69. Block model Validation - 'null' dataset, 'mags'% (EW)

3.5 Resource Block model

All borehole information is used for the estimation of the block model. The block model is assigned an ‘’ore category’’ which is defined as the area below the surface topography and a 1.5% ‘mags’ cut-off value. This ‘’ore category’’ is considered to be the mineral resource for Hillendale Mine.

4 Resource Classification

Mineral resources are classified focussing on three different aspects namely geological continuity, data quality and technical feasibility (Dominy et al., 2002). There are various approaches to classify a mineral resource into the various categories.

In the SAMREC code mineral resources are classified in three categories depending on the increasing level of geoscientific knowledge and confidence (SAMREC, 2009), this and is illustrated in Figure 70.

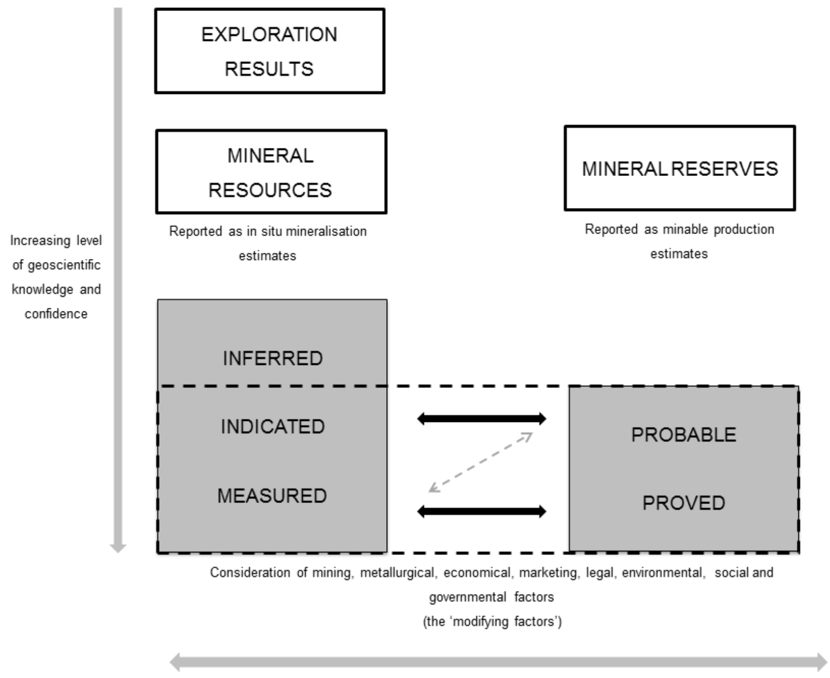


Figure 70. SAMREC Classification (after SAMREC, 2009)

For Hillendale Mine, the resources are classified according to nine classification conditions (van der Schyff, W. Shaw, B., 2006). These include drilling density, survey control, drilling methods, analyses technique, density factor, estimation method, block fill parameter, and number of samples used in estimation. The classification parameters are listed in Table 17. The parameters should be used in combination to derive a classification. Blocks with the highest confidence are classified as 'measured'.

Table 17. Resource classification parameters

Criteria	Range	Measured	Indicated	Inferred
Drilling Density (metres)	50 x 50	√		
	200 x 100		√	
	400 x 200 / 200x200			√
Survey Control	Total Station	√		
	Orhophoto (±1m acc)		√	
	Orhophoto (±5m acc)			√
Drilling Method	WAC	√		
	RCN	√		
	Other			√
Sampling Method	Riffle of dry	√		
	Rotary of dry	√		
	Coning and Quartering		√	
Analysis	Lab	√		
	Field		√	
Density Factor	Sand Replacement (Global)	√		
	Core drilling density	√		

Criteria	Range	Measured	Indicated	Inferred
	calculation			
	Geophysical survey		√	
	Inference from similar deposits			√
Estimation Methodology	Inverse distance	√		
	Ordinary Kriging	√		
Block Fill	2/3 variogram	√		
	1.5 variogram		√	
	Nearest Neighbour			√
Number of Samples	‘>11	√		
	5-10		√	
	1-4			√

For this exercise all the resource parameters such as drilling density, survey control, drilling method are within the measured resource category.

5 Reserves

Mineral reserves are derived through applying discount and modifying factors to the geological block model. Due to the method of mineralisation, only a mineralogical cut-off value of 1.5% ‘mags’ is used. The other reserve modifying factors are geohyrological and legal and are not important for this work.

Once the grade block models are received, geographical boundaries are applied so that all areas associated with infrastructure (including the appropriate exclusion zones) are excluded from the in situ grade block model in order to produce the mining model. Infrastructure includes inter alia roads, railways, houses and pipelines.

Other boundaries applied are those of the geological footwall and those associated with various flood events specified in the environmental management plan (either the 50-year or 100-year). Although the geological floor for ‘ore’ is defined in the grade block model as >3% THM (>1.5% ‘mags’), it is incorporated into the mining model so that additional random checks can be done on the data and so that the mine planner can familiarise himself with the potential ore reserve volume (Sibiya et al., 2005).

The remaining blocks, once all ‘boundaries’ have been applied, constitutes the ‘optimised pit’ in the mining model, since there is no overburden and everything within the ‘ore volume’, which has already been defined as >3% THM or >1.5% ‘mags’, is considered ‘payable’ (Sibiya et al., 2005).

6 Financial Modelling

Financial models take into consideration the capital and operating cost, commodity price forecasts and the choice of discount rate to determine the project viability (Morley et al., 1999).

Resources and Reserves are critical for the financial model. Estimated grades and tonnages that are produced within the LOM are incorporated with economic assumptions to determine the NPV, IRR and payback period for the potential deposit or mine. The financial model in turn is the basis of the yearly financial budgets and forecasts. Incorrect input data, either under or over estimation of the potential resources an impact on the financial model. Production can be off target which in turn has an influence on the client contract.

The Reserve model, as well as mining to plan is therefore essential in combination with the financial model to achieve a successful mining business.

7 Reconciliation

Reconciliation in this context is the process of comparing the plant performance with the predicted geological resource model. The actual grade as supplied by the PWP for a specific time period is compared to the geological block model for the corresponding period. Reconciliation is the process which compares predicted values versus the actual values obtained. The actual values can only be measured after mining.

7.1 Reconciliation process

Reconciliation is done by constraining the geological block model with the specific DTM files for the yearly and monthly mine production surveyed faces. The DTM is the surface obtained from the actual mining faces for the corresponding time period. The tonnages, silt%, THM% and Carpco® fractions as determined by the estimation process for the geological model are extracted for the corresponding time period. The extracted values are compared against the actual tonnages as processed by the plant and actual plant SILT%, THM% and Carpco® fractions.

7.1.1 Yearly reconciliation

Reviewing the reconciliation of the silt% from 2007 to 2010, the block model estimation is almost similar for both the ‘zero’ and the ‘null’ datasets. Both estimates underestimate the actual achieved silt% compared to the plant actuals with more than 10%. Although the silt does not form part of the thesis topic, it is important for mining purposes and therefore reconciled and monitored. If the estimated silt is not achieved, the actual mining might be influenced since there is a risk to not create the required slurry.

The reconciliation of the 'mags'% for the same years, both the 'null' dataset and the 'zero' dataset follow the same trend with over and under estimating during similar time intervals. The 'zero' dataset however underestimate 'less' than the 'null' dataset as seen in 2007, 2008 and 2009, while it 'overestimates' more than the 'null' dataset as seen in 2010.

The similar over and under estimation of both datasets can maybe be explained by the regression effect and information effect (effect of support). The regression effect is where low grade areas are underestimated from the actual grades, while high grade areas are overestimated. This is due to actual mining having different distributions than the sample grades. (Thomas, M., and Snowden, V. 1990). A regression line between the sample and the block may therefore not reflect a 1:1 relationship.

The regression effect is caused by the change in variance of the data. The samples may therefore have a higher degree of variance compared to the actual mining block. A larger block will have lower variance compared to a smaller block. For this reason it is important to standardise the support between exploration samples and grade control (Thomas, M. and Snowden, V. 1990)

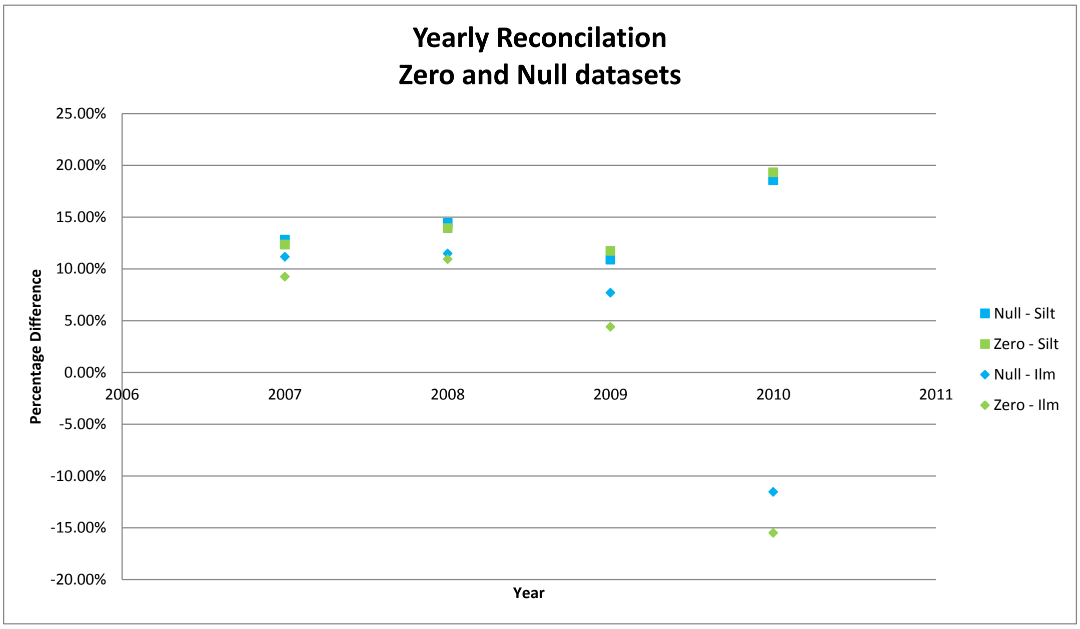


Figure 71. Yearly reconciliation for 2007 to 2010 at Hillendale mine. Silt% and 'mags'%

7.1.2 Monthly Reconciliation

Monthly reconciliation of the PWP plant figures compared to the geological block model is done from January 2010 to July 2010 with the two different geological block models.

For the monthly reconciliation, both the silt% is consistently underestimated for both geological block models varying from close to 0% to almost 20%.

The monthly reconciliation for the 'mags' percentage is again varying with the 'null' dataset 'underestimating' more than the 'zero' dataset and overestimating less than the 'zero' dataset. There is a large deviation for the month of March (3). A potential problem during March was the mining of an area with high 'mago'. The high 'mago' has an influence on the plant recovery.

Consistent with the yearly reconciliation, the regression effect and the support effect can have an influence on the consistent over and under estimation of both datasets.

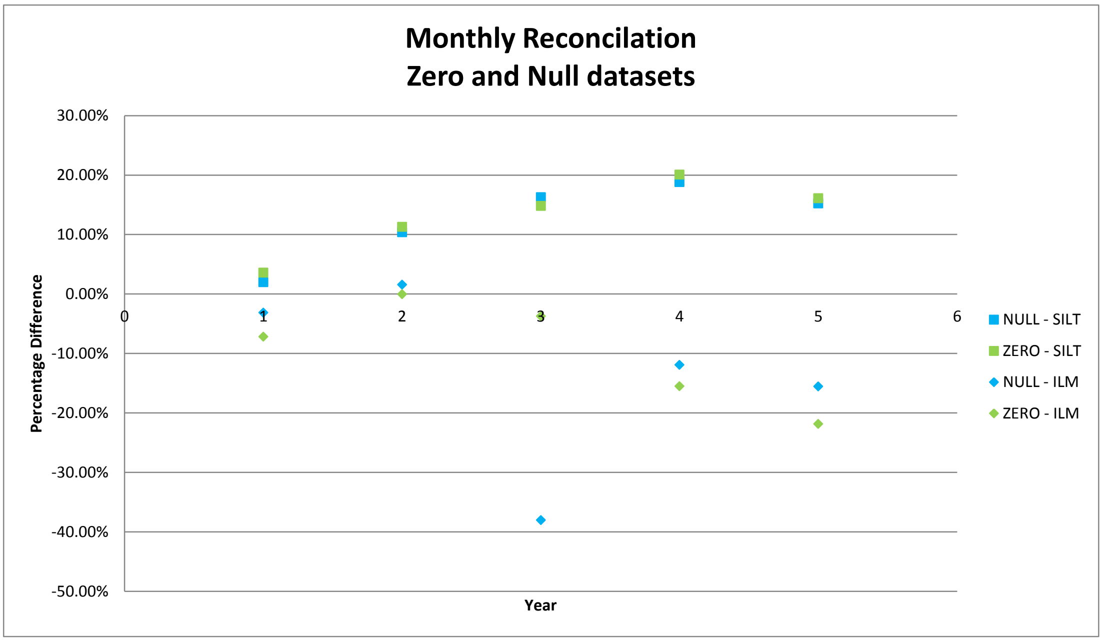


Figure 72. Monthly reconciliation for January to July 2010 at Hillendale mine. Silt% and 'mags'%

8 Summary and Conclusion

The thesis reviewed the differences in the final output of the geological model compared to the actual plant data at Hillendale Mine for two datasets.

Heavy mineral sands are different to many other commodities since it combines geological as well as geochemical parameters with a specific marketable product. Reliable resource estimation is of utmost importance to ensure that the client's needs can be met. Resource audits suggest the replacement of the 'zero' value currently in the geological database with 'null' values. This will to lower kriging variance of the estimate.

Hillendale Mine uses the WAC drilling method. The sampling and sample preparation methodology has throughout the current mining operation been constant. The analytical method for Hillendale Mine is similar to other heavy mineral deposits with final mineralogical and chemical analyses. The difference in analytical methodology if compared to Namakwa Sands is that the original sample is firstly separated into four fractions with different physical characteristics with magnetic susceptibility analyses using magnetic susceptibility. Namakwa uses the complete sample for mineralogical and chemical analyses.

The Carpco® fractions are also consistently measured with similar processes throughout the mining and beneficiation process from the PWP to the MSP. The continuous measurement of similar physical characteristics as used during the downstream processes gives a good representation of the expected mineral resource and potential final products.

The resource estimation process was done for two similar datasets. The one dataset contained the ‘zero’ values as reported by the laboratory for THM<1.5%. The second dataset replaced the ‘zero’ values to ‘null’ values as suggested by external consultants. The global average of both datasets is similar. The biggest difference in the data is that the sum of the fractions does not add to the laboratory THM in the null dataset. This can be misleading since the THM has a non-normal distribution.

The estimation methodology for both datasets where kept similar. Using variography the null dataset has a lower nugget and smaller range than the zero dataset. Variograms for both datasets are acceptable in terms of validations.

The basic statistics and histograms for both datasets are similar for the estimate and the original data. Due to the use of a cut-off value in the blockmodel the ‘mags’ and ‘nmag’ fraction vary from the original histogram.

Inputs into the financial model are received from the scheduled resource and subsequent reserve schedule. The grade and tonnage estimates inputs into the financial model can subsequently have a large impact.

The resource estimate is reconciled with yearly and monthly production figures from the PWP and for monthly production figures. The reconciled values behave similarly for the year on year comparison as well as for the monthly reconciliation. On average the resource estimate overestimate the actual plant data irrelevant of the dataset.

For the yearly reconciliation the ‘null’ dataset overestimates more than the ‘zero’ dataset. The underestimation for the ‘null’ dataset is closer to acceptable limits than for the ‘zero’ dataset. There is a lot more variation between the actual plant data compared to the estimated values with the monthly reconciliation. Both datasets have larger variations, ranging from 0% to 20% over and underestimating due to the effect of volume variance. As with the yearly reconciliation, the ‘null’ dataset overestimates more than the ‘zero’ dataset, while the underestimation of the ‘null’ dataset is better than the ‘zero’ dataset. The similar over and underestimation can be due to the regression effect and support effect.

As mentioned the heavy mineral sand industry is market driven. In general both datasets overestimate the mineral resource on a long term basis (yearly) compared to the actual plant data. The ‘zero’ dataset has an improved reconciliation value for the overestimation compared to the ‘null’ dataset. The improved reconciliation ensures greater confidence in market determination.

Underestimation of the mineral resource occurs in the short term. This should be considered as a constraint in the short term as well. On the long term with market contract negotiation the overestimation of the mineral resource should the prevailing consideration when negotiating product.

Due to the amount of historic data, the laboratory procedure and setup for the mine at current, the additional simplistic cross validation of the sum of the fractions as well the similarity of the resource estimation result, this limited study shows that estimation of the mineral resource using ‘null’ values does not significantly increase the accuracy of the resource estimate.

Heavy mineral sands negotiates markets looking at long-term schedules of which the ‘zero’ dataset provided less variation and therefore more accurate predictability comparing to the actual plant data using reconciliation.

9 Recommendation

From the limited investigation the following is suggested for future work:

- Addition of a protocol in the QAQC to test homogeneity
- Further evaluation on best dataset in terms of statistical distribution and effect cut-off grade.
- Re-evaluating the process using a more appropriate median rather than the average.
- Re-evaluating the outcomes with search and estimation parameters as used by the mine, rather than the single pass search strategy as used with the thesis.
- Establishing the best estimation method for long term contracting.
- Further investigation on discontinuation of block model estimates in the ‘null’ dataset by means of domainin.
- Looking at improving the estimates by evaluating the regression effect and volume variance.

- Reviewing the actual mining and plant recovery in terms of reconciliation.
    - Mining in plan
    - Mining of ‘floor’ material
    - Plant recoveries and standing times.

10 References

Dominy, S. Noppe, M.A., Annels, A. E. (2002). Errors and Uncertainty in Mineral Resource and Ore Reserve Estimation: The Importance of Getting it Right. Expl. Mining Geol., Vol. 11, Nos. 1-4, pp. 77–98.

De-Vitri (undated). A Geologist's Guide to Destroying Shareholder Value and a Business Improvement Model to Insure Against it (undated).

Eggbert, R.B. (2010). Mineral exploration and development: Risk and Reward. Prepared for the International Conference on Mining, "Staking a Claim for Cambodia," Phnom Penh, Cambodia, 26-27 May 2010.

Maud, R. R. 1968. Quaternary geomorphology and soil formation in coastal Natal. Annals of Geomorphology 7, pp. 155 – 199 GAB 876.

Macpherson, M. H., Masters, B. K. 1983. Exploration for Mineral Sands. MMIJ/AusIMM Joint Symposium 1983, Sendai. Chief Executive and Senior Geologist Westeralian Sands Limited, Capel, Western Australia. pp 177 -191.

Morley, C., Snowden, V., Day, D. (1999). Finacial impact of resource/reserve uncertainty. The Journal of The South African Institute of Mining and Metallurgy. OCTOBER–DECEMBER 1999. pp 293 - 302

Noppe, M. (2004). Reconciliation: importance of good sampling and data QAQC. Mining and Resource Geology Symposium. XYZ, EGRU Contribution No 62,

Jones, G. (2009). Mineral Sands: An Overview of the Industry. Iluka (unpublished)

Patersons Australian stockbroker, 2011, Mineral Sands Industry Report.

Philander, C and Rozendaal, A. (2009). Mineral intricacies of the Namakwa Sands mineral resource. The 7th International Heavy Minerals Conference 'What next', The Southern African Institute of Mining and Metallurgy. pp99 – 106.

SAMREC Code. (2009). The South African code for the reporting of exploration results, Mineral Resources and Mineral Reserves – Prepared by the South African Mineral Resource Committee.

Shabala, S., van der Schyff, W. (2010). Review of the Estimation of the Fairbreeze Mineral Sands Deposit. Report No. 12875-10070-1

Sibiya, D. van Graan, J. Botha, B.W. (2005). Ticor South Africa, Heavy Mineral Operations, Reserve and Resource Statement. (unpublished report)

Snowden. V (1996). Practical interpretation of resource classification guidelines. AusIMM 1996 Annual Conference "Diversity, the Key to Prosperity".

Spring, V., Leroux, D.C., Berezowski, M.G.S., Dumouchel, J. (undated). Placer Deposits Guidelines. Canadian Institute of Mining, Metallurgy and Petroleum.

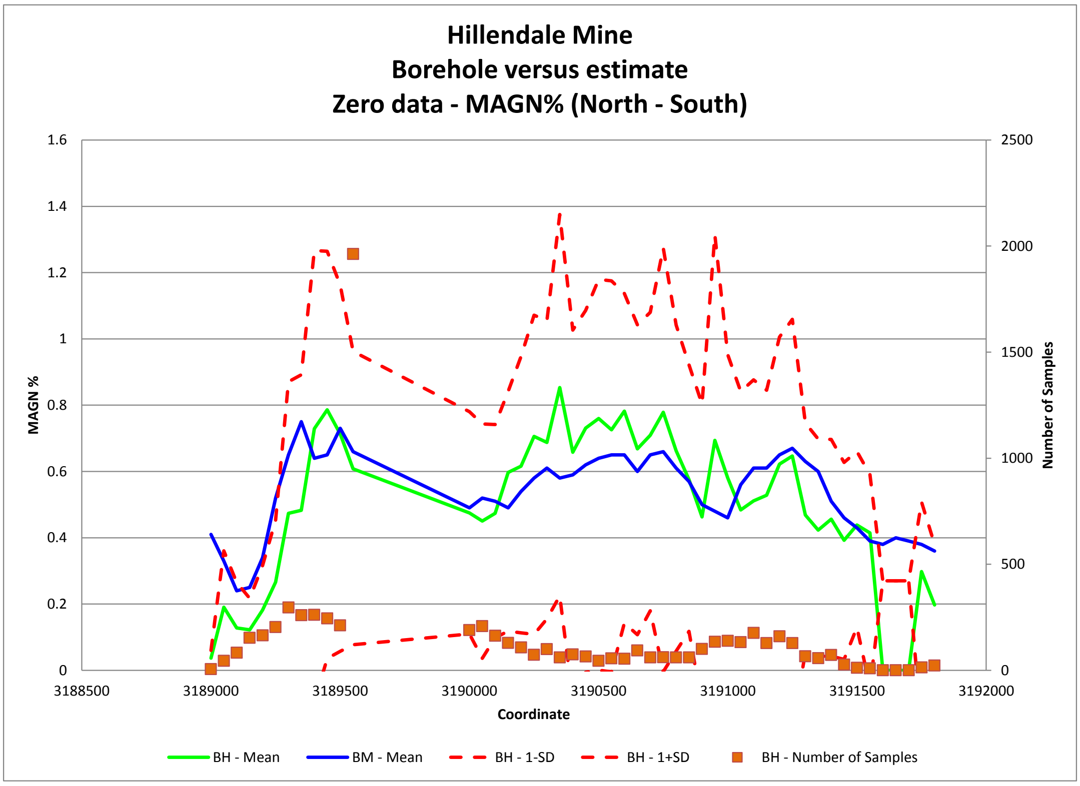
Thomas, M., Snowden, V., (1990) Improving Reconciliation and Grade Control by Statistical and Geostatistical Analysis. Strategies for grade control, AIG Bulletin 10, 1990, PAGES 49-59.

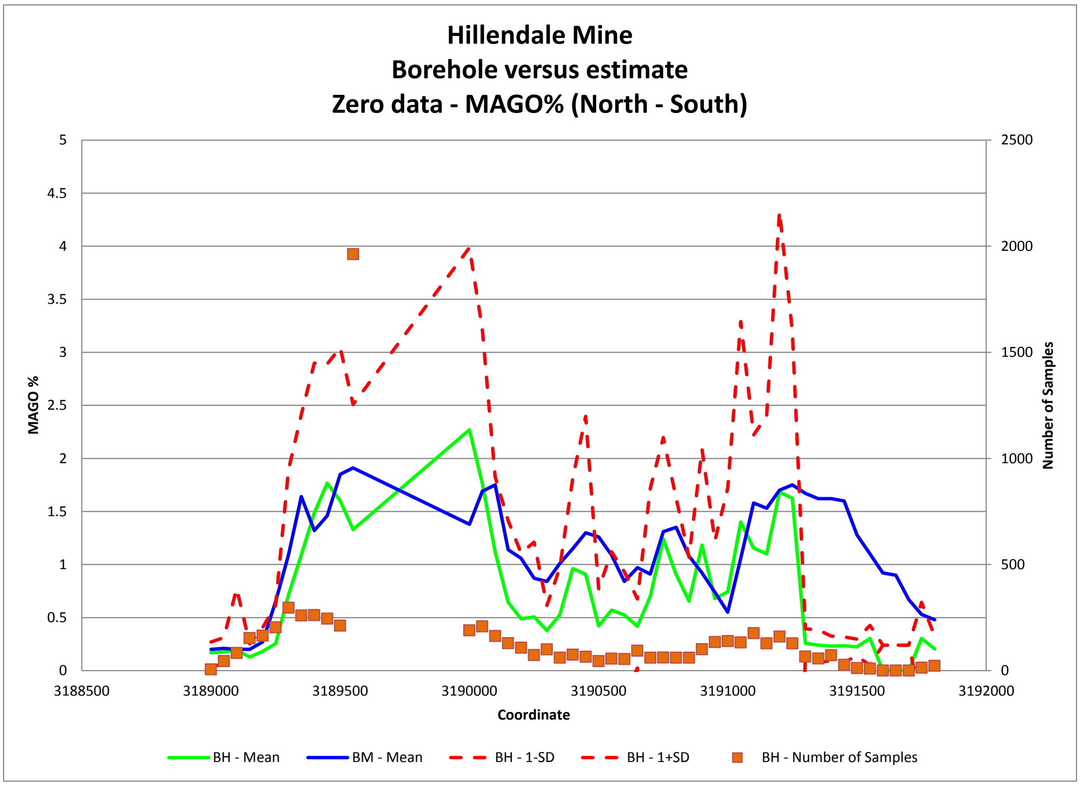
University of Vermont, (2006). Carpco model MIH(13)111-5 Laboratory high-intensity induced-roll magnetic separator. Revision: 03-2, SERIAL NUMBER, 221-06., pp. 47

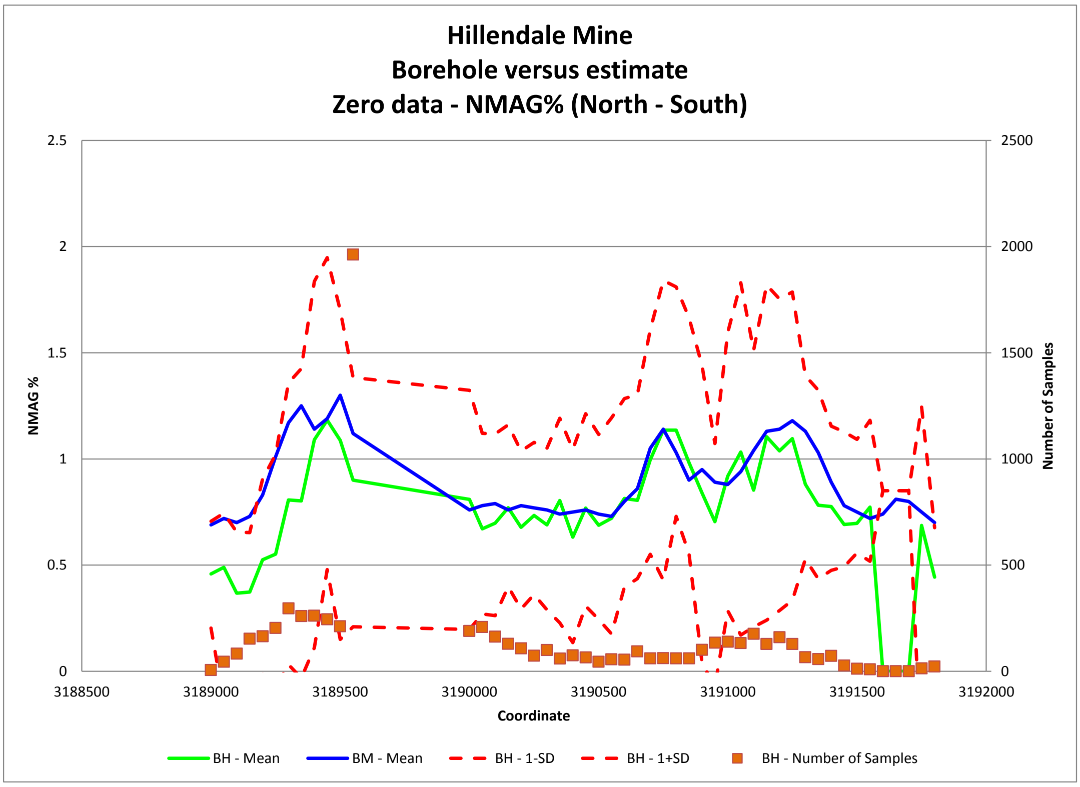
Van der schyff, W., Shaw, B. (2006), Mineral resources and mineral reserves audit of Hillendale and Fairbreeze. Report No. 7882/8196/3/G.

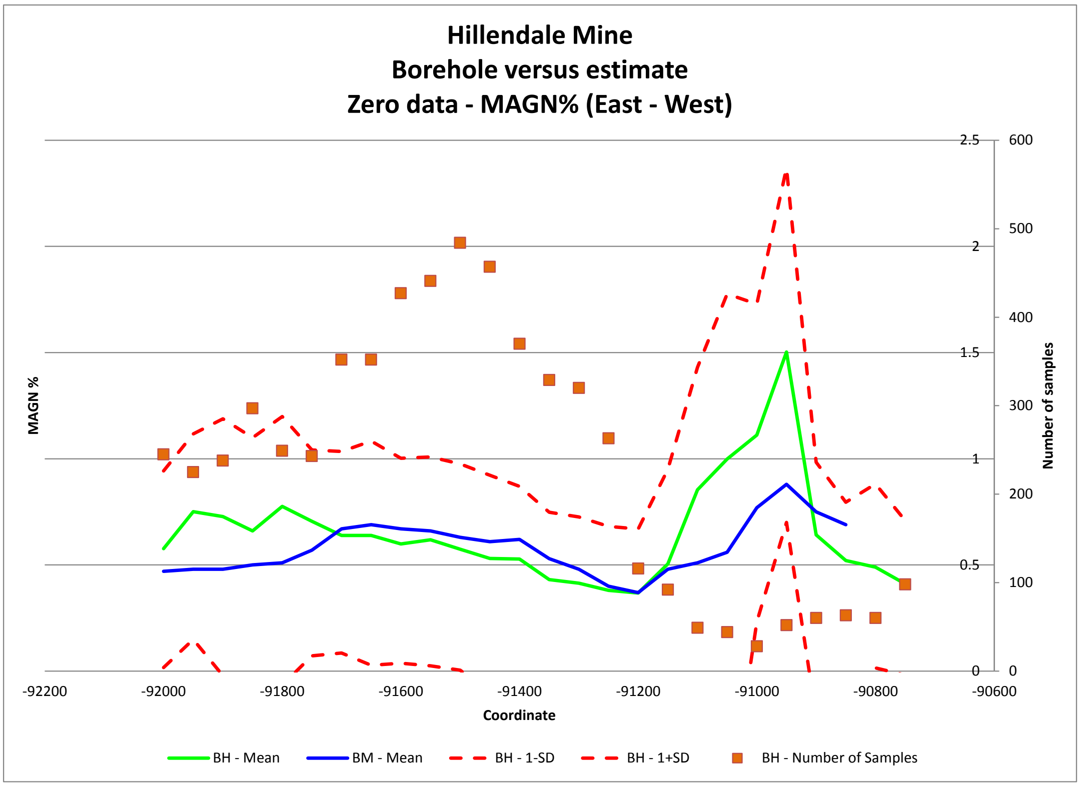
Ware, C. Whitmore, G. Uken, R. (2002). A weathering model for the northern Kwa-Zulu Natal coastal dune cordon, South Africa. South African Institute for Mining and Metallurgy. Pp 229 – 235

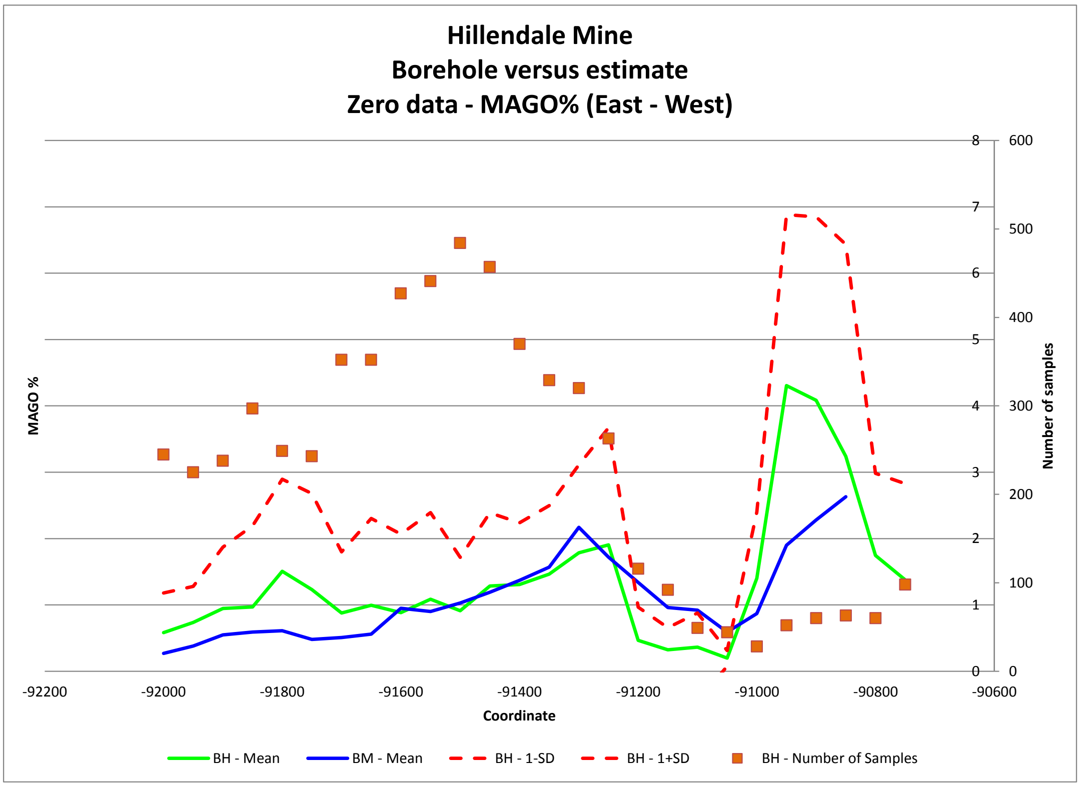
ADDENDUM 1

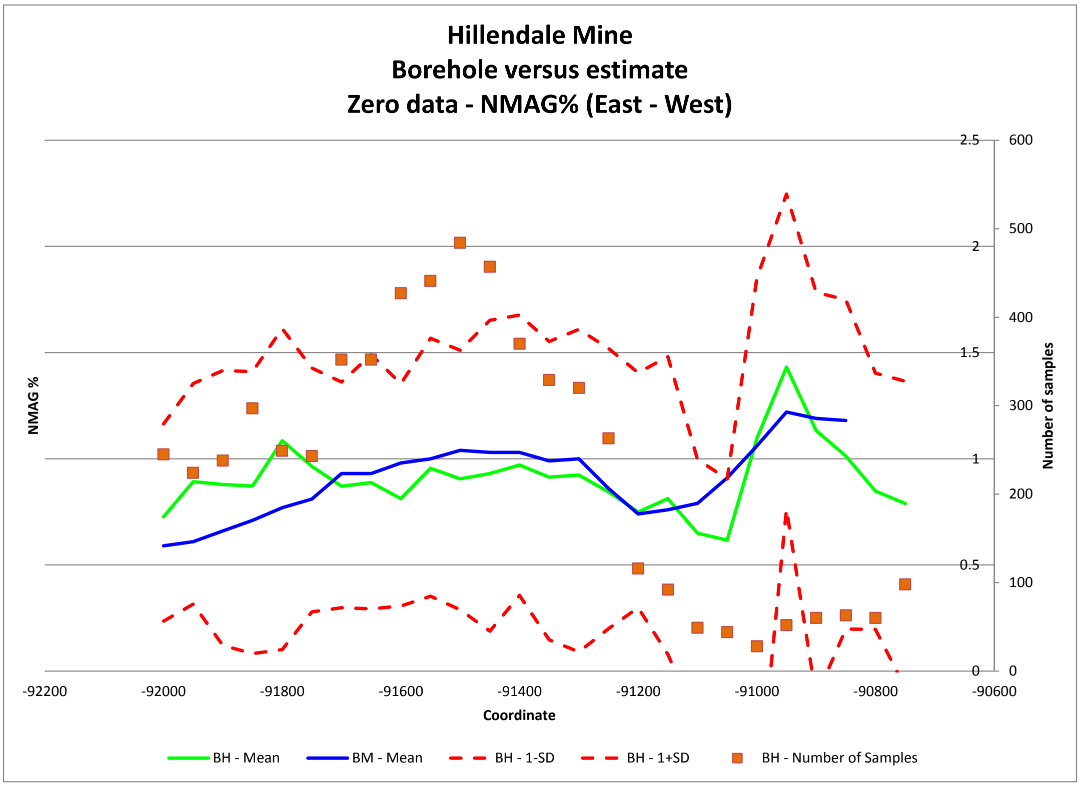

Hillendale Mine
Borehole versus estimate
Zero data - MAGN% (North - South)
MAGN %
Number of Samples
Coordinate
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2500
2000
1500
1000
500
0
3188500
3189000
3189500
3190000
3190500
3191000
3191500
3192000
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples

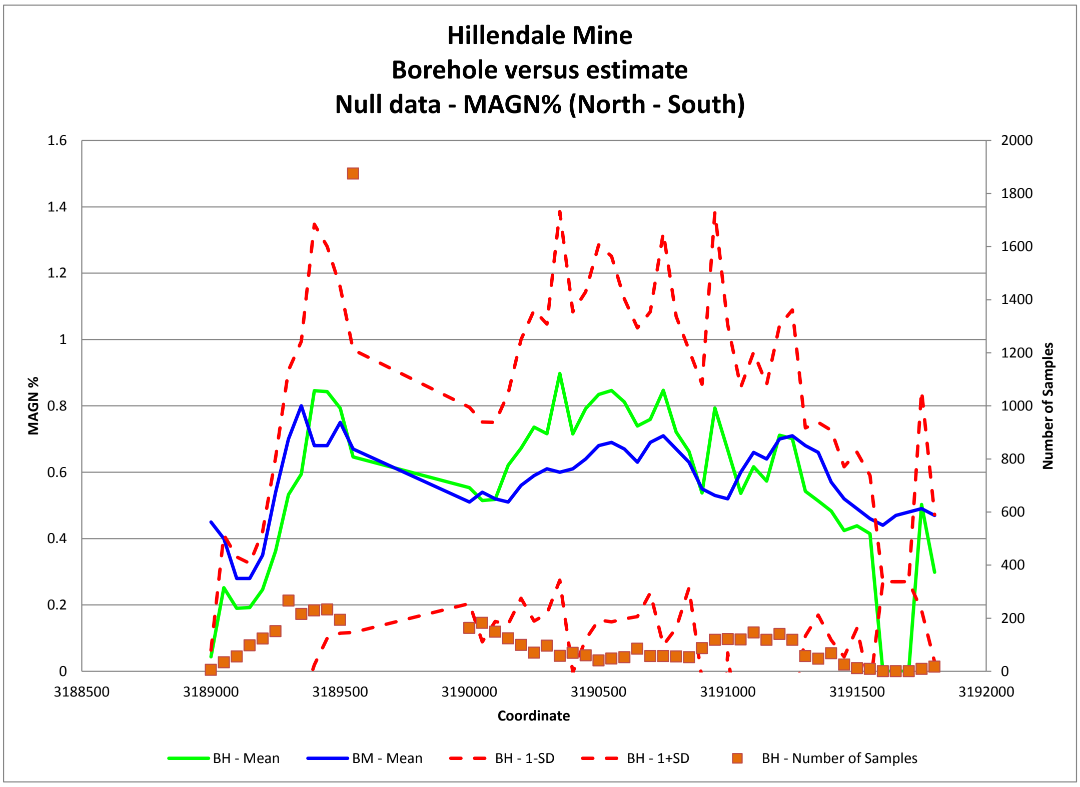

Hillendale Mine
Borehole versus estimate
Zero data - MAGO% (North - South)
MAGO %
Number of Samples
Coordinate
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2500
2000
1500
1000
500
0
3188500
3189000
3189500
3190000
3190500
3191000
3191500
3192000
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples

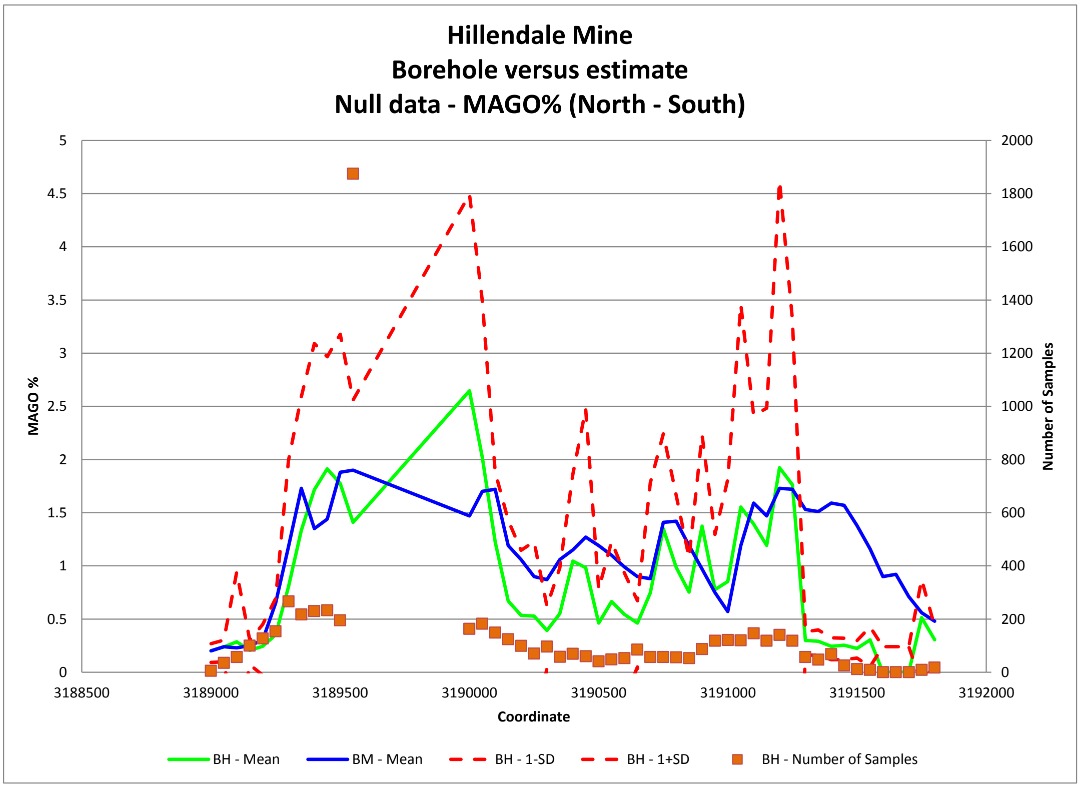

Hillendale Mine
Borehole versus estimate
Zero data - NMAG% (North - South)
NMAG %
Number of Samples
Coordinate
0
0.5
1
1.5
2
2.5
0
500
1000
1500
2000
2500
3188500
3189000
3189500
3190000
3190500
3191000
3191500
3192000
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples

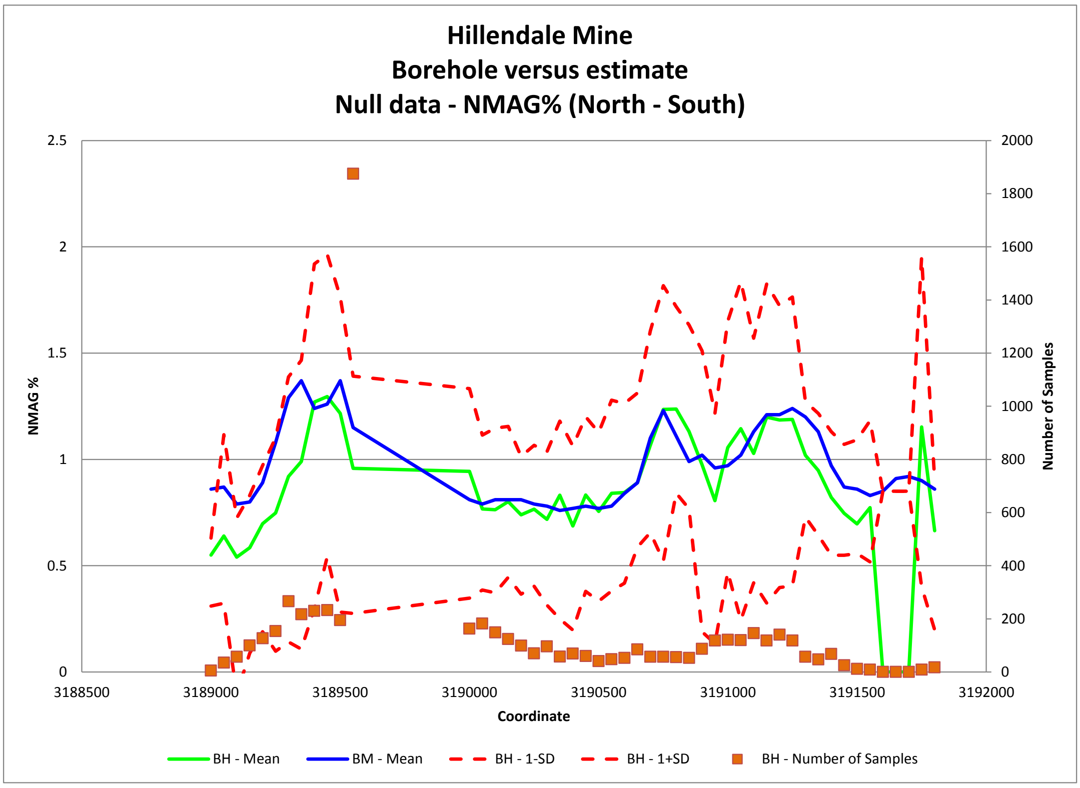

Hillendale Mine
Borehole versus estimate
Zero data - MAGN% (East - West)
MAGN %
Number of samples
Coordinate
0
0.5
1
1.5
2
2.5
0
100
200
300
400
500
600
-92200
-92000
-91800
-91600
-91400
-91200
-91000
-90800
-90600
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples


Hillendale Mine
Borehole versus estimate
Zero data - MAGO% (East - West)
MAGO %
Number of samples
Coordinate
-92200
-92000
-91800
-91600
-91400
-91200
-91000
-90800
-90600
0
1
2
3
4
5
6
7
8
0
100
200
300
400
500
600
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples


Hillendale Mine
Borehole versus estimate
Zero data - NMAG% (East - West)
NMAG %
Number of samples
Coordinate
-92200
-92000
-91800
-91600
-91400
-91200
-91000
-90800
-90600
0
0.5
1
1.5
2
2.5
0
100
200
300
400
500
600
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples


Hillendale Mine
Borehole versus estimate
Null data - MAGN% (North - South)
MAGN %
Number of Samples
Coordinate
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples


Hillendale Mine
Borehole versus estimate
Null data - MAGO% (North - South)
MAGO %
Number of Samples
Coordinate
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples


Hillendale Mine
Borehole versus estimate
Null data - NMAG% (North - South)
NMAG %
Number of Samples
Coordinate
2.5
2
1.5
1
0.5
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
3188500
3189000
3189500
3190000
3190500
3191000
3191500
3192000
BH - Mean
BM - Mean
BH - 1-SD
BH - 1+SD
BH - Number of Samples