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Dilution rating system (DRS)

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ABSTRACT

Unplanned dilution directly adds cost to production from mining, milling, tailings disposal and administration. Additionally, unplanned dilution decreases the productivity, profitability and may affect the planned life of mine. Identifying and quantifying the potential for unplanned dilution allows optimisation of the mining plan and mining practices to minimise the adverse impact on productivity and the cost of production.

The Dilution Rating System (DRS) has been developed to more accurately predict dilution thickness and the variable potential for dilution, from individual stopes to life of mine planning.

The DRS utilises the methodology developed for the Mining Rock Mass Model (Seymour et al 2007, Jenkins et al 2009) to generate a three-dimensional dilution rating model, which is then calibrated against stoping performance. Dilution can be predicted more accurately and the parameters affecting dilution can be determined and minimised through improved mining techniques, for example blasting and ground support design. Potential high dilution areas can be identified in the planning stages of the mine and systems put in place to mitigate the risk of excessive dilution.

This paper presents the methodology used to develop the DRS and then successfully predict dilution for both the hangingwall and footwall of stopes at the Gara Gold Mine. This has enabled the expected dilution to be more accurately predicted and mitigated where possible thus reducing unplanned dilution.

INTRODUCTION

There are many factors that cause dilution in underground mining operations as illustrated Figure 1.

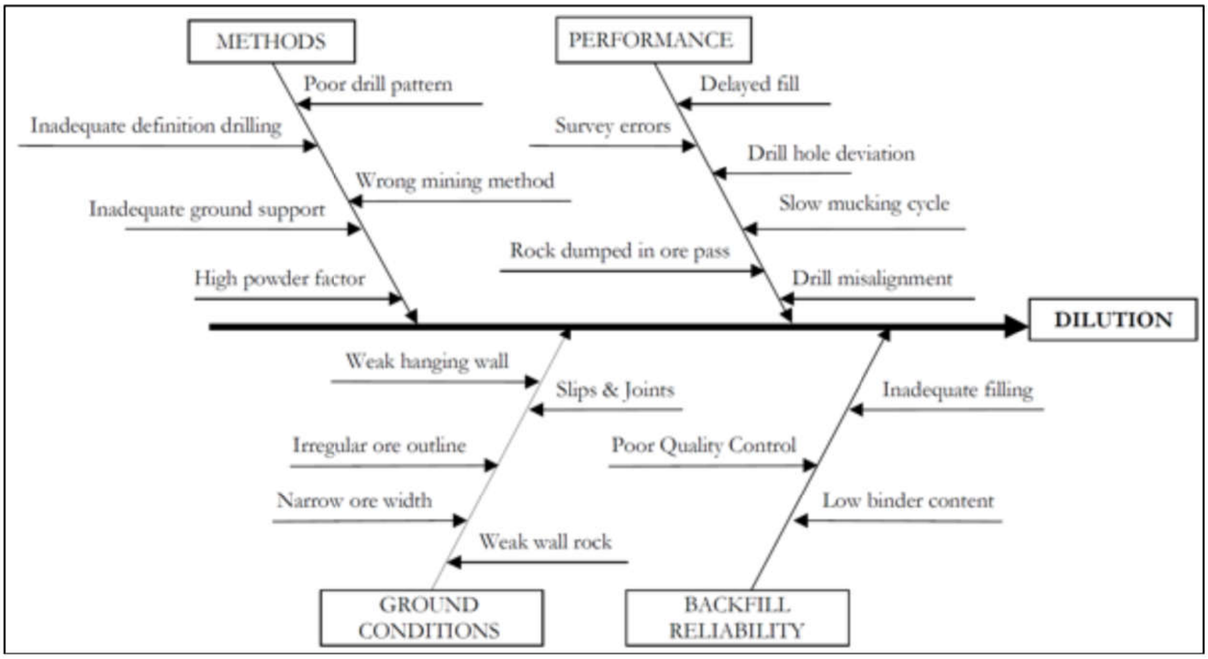


FIG 1 - Fishbone chart of dilution inducing causes (de la Vergne 2014)

The causes due to Mining Methods, Performance and Backfill Reliability can be engineered and controlled as they are functions of the mining system and with good mining control, the resulting dilution can be estimated and planned. However, causes due to Ground Conditions are difficult to predict and often result in unplanned dilution.

The DRS focuses on the causes due to Ground Conditions using a ranking method that takes cognisance of the rock mass properties, structure and stope orientation, thereby enabling a relationship between rock mass characterisation, stope behaviour and dilution potential to be established. The geotechnical properties that affect dilution are unique to each mine site. These parameters are derived from the Mining Rock Mass Model and include: Rock strength, Joint orientation, Shear strength (Joint roughness and Joint infill), Fracture frequency, Block size (RQD and Number of Joint sets) and In-situ Stress. The DRS model is calculated and calibrated for the individual mine site to develop a design chart that is then used to predict dilution volume and thickness.

GARA GOLD MINE

The Gara Gold Mine is located in western Mali, 350km west of the capital city of Bamako. The mine forms part of the Loulo Gold Mine Complex owned and operated by Société des Mines de Loulo SA West Africa (80% Barrick Gold Corporation, 20% State of Mali). The Gara Mine commenced production in 2011 and currently has a mine life to 2032.

The Gara orebody is hosted within an 800m long tourmaline sandstone/greywacke unit. On a regional scale, the Gara deposit spans the hinge of a broad open fold with a gently-plunging north-south trending axis. On the deposit scale, the upper limb of this fold has a steep westerly dip, whereas the lower limb dips steeply to the east as shown in Figure 2. The convention at Gara with this orebody configuration is the hangingwall is the west orebody contact and the footwall is the east orebody contact. Gold mineralisation is strata-bound and hosted predominantly within the quartz-tourmaline stockwork veins, which are enveloped within footwall greywackes and hangingwall sandstone.

The primary mining method utilises long hole retreat open stoping with paste fill retreating to central accesses in an echelon format. Stope panels are up to 50m in length across the width of the orebody up to 15m with 25m spacing between levels. Dilution at Gara is primarily influenced by local folding of the orebody and the presence of continuous structures / shear zones in the hangingwall and footwall. Prior to the implementation of the DRS, total stope dilution at Gara was up to 30% with planned dilution less than 10%. The aim of the DRS at Gara was to increase the ability to predict dilution and reduce the unplanned dilution figures.

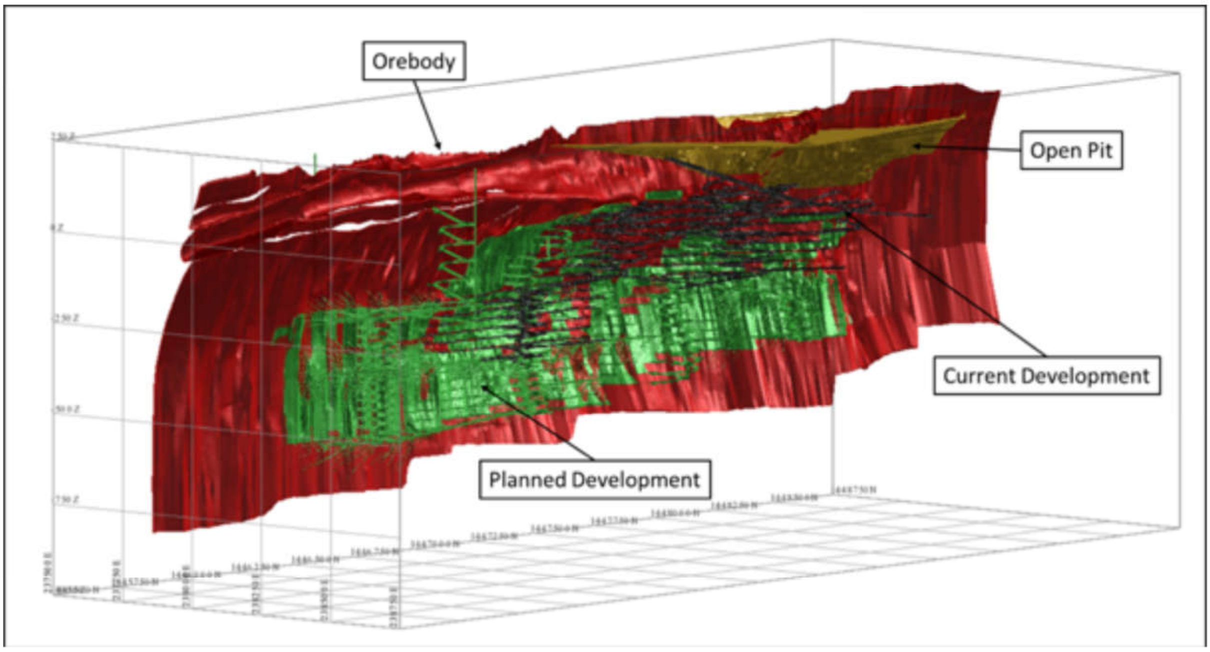


FIG 2 - Isometric view showing the Gara orebody and development

METHODOLOGY

The DRS is based on a ranking method that takes cognisance of the rock mass properties, structure and stope orientation, thereby enabling a relationship between rock mass characterisation, stope behaviour and dilution potential to be established. Each component parameter to the DRS, is rated on a scale of 1 to 5 and weighted depending on the perceived influence of the particular parameter. The individual ratings (typically four or five) are then summed to determine the total DRS rating which is then calibrated with historical stope dilution from the mine. The geotechnical properties that affect dilution are unique to each mine site and these parameters are derived from the Mining Rock Mass Model (MRMM). The MRMM involves creating a number of 3D block models by estimating rock mass values using processed raw data from geotechnical core logs and underground structural measurements. The MRMM block models are analogous to resource block models in that they can be interrogated to determine geotechnical properties for a 3d wireframe. The DRS values are calculated for every block in the model using the individual component values for each block.

The flowchart process of building DRS model is shown in Figure 3.

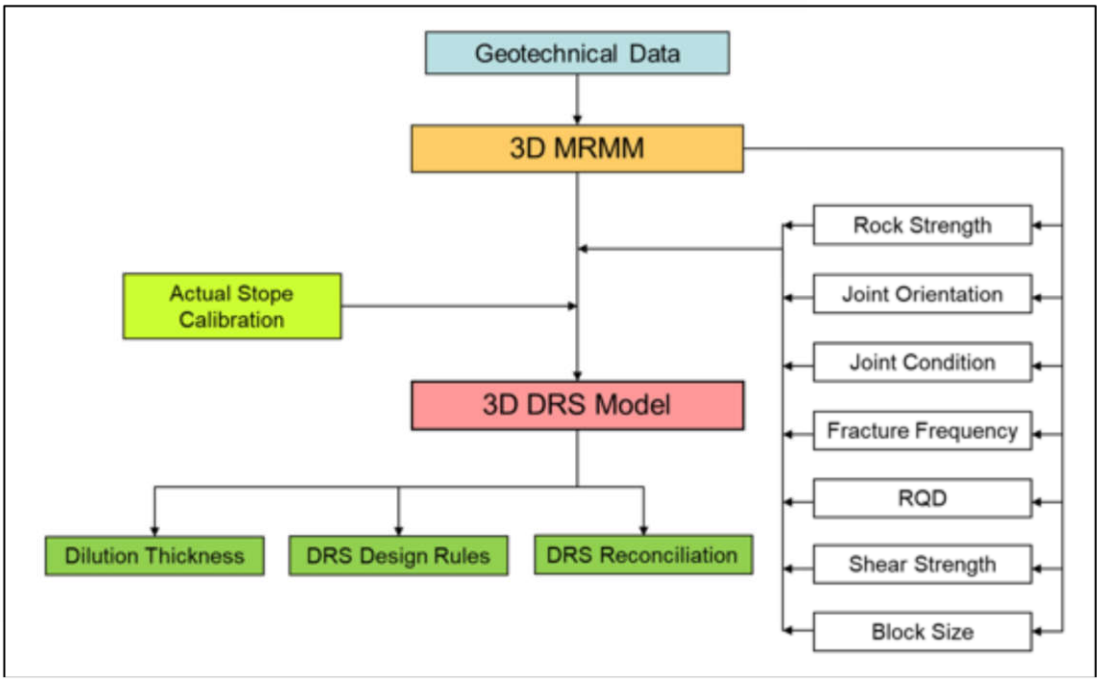


FIG 3 - DRS flowchart

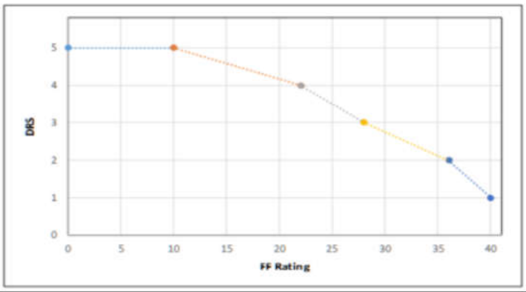
The initial assessment for Gara involved evaluating the geotechnical parameters that could potentially cause dilution. These include:

- The rock mass ratings – RMR, Q', GSI
- Rock hardness/strength
- Joint orientation
- Joint condition – roughness (Jr) and infill (Ja)
- RQD
- Fracture frequency
- Shear strength - Jr/Ja
- Block size RQD/Jn

Each parameter was assessed to select the main controls on dilution at Gara. Following this initial assessment, the DRS for Gara comprises four components, each with a rating from 1 to 5, as shown in Figure 4. Rating values between points are interpolated from the graphs. For example, a logged hardness rating of 2 would have a DRS value of 4.3.

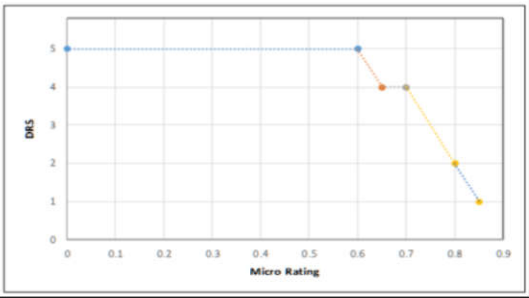
Fracture Frequency

Fracture Frequency Rating	DRS Rating	Fractures per metre
0	5	40/m
10	5	15/m
22	4	3/m
28	3	1/m
36	2	0.3/m
40	1	0.1/m



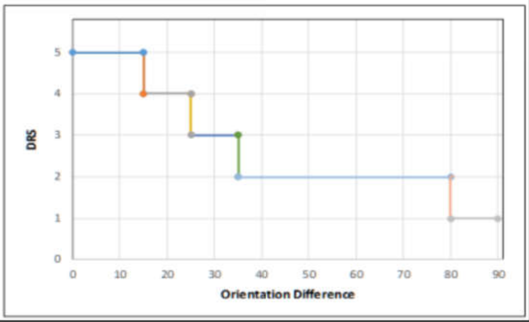
Micro Roughness

Micro Rating	DRS Rating	Description
0	5	Polished
0.6	5	Smooth & Planar
0.65	4	Rough & Planar
0.7	4	Slick & Undulating
0.8	2	Rough & Undulating
0.85	1	Stepped



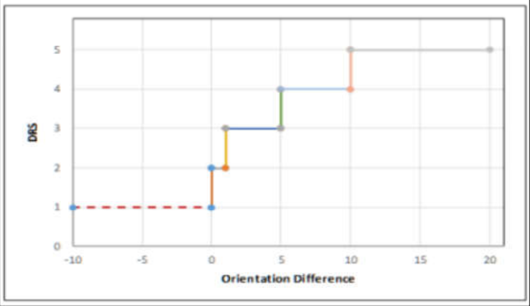
Orientation HW

Difference Hangingwall vs Major Structure	DRS Rating
0	5
15	4
25	3
35	2
80	1



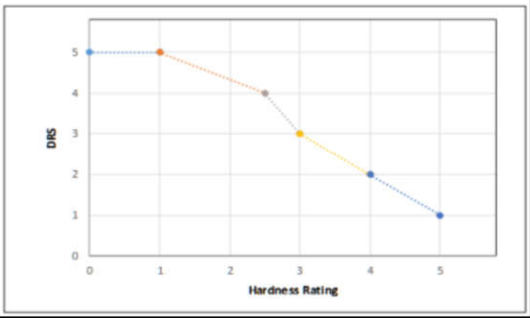
Orientation FW

Difference Footwall vs Major Structure	DRS Rating
<0	1
0	2
1	3
5	4
10	5
20	5



Hardness (QSI)

Hardness Rating	DRS Rating	UCS Mpa
0	5	0
1	5	1
2.5	4	50
3	3	100
4	2	160
5	1	185



Parameter	Rating Range
Fracture Frequency	(1 – 5) * 2
Micro Roughness	(1 – 5) * 2
Hardness	1 - 5
Orientation	1 - 5
Total Rating	**6 - 30**

FIG 4 - Component DRS values

The DRS rating is determined from the sum of the individual components multiplied by a weighting factor:

$$DRS = drs\_hardness*wf^1 + drs\_ori * wf^2 + drs\_ff\_js*wf^3 + drs\_micro*wf^4$$

Weighting factors (wf^1 to wf^4) are applied based on the influence of the individual component on dilution. This is a subjective adjustment based on the knowledge of geotechnical characteristics of the hangingwall and footwall and historical stope performance. For Gara, a weighting factor (wf^1 and wf^2) of 1 was applied to Hardness and Orientation components. Fracture Frequency and Micro Roughness have a larger influence on dilution and a weighting factor (wf^3 and wf^4) of 2 has been applied.

The orientation DRS takes account of the difference between the orientation of the stope wall (hangingwall or footwall) and the orientation of the major structures that occur in the hangingwall and footwall. In the hangingwall as the difference increases i.e. the hangingwall stope wall is steeper than the major structure, the effect on dilution decreases. The converse applies to the footwall i.e. if the footwall stope wall is steeper than the major structure, the dilution increases.

DRS MODEL CALIBRATION

The initial calibration exercise for the DRS involved determining the actual hangingwall and footwall dilution for 35 stopes by clipping the stope design wireframes against the CMS surveyed wireframes. The excess volume (CMS larger than design) for the hangingwall and footwall was considered as dilution. The unplanned dilution thickness for the stope was determined from the dilution volume and the stope wall area (stope length * stope height). The process is illustrated in Figure 5 which shows an isometric view of a stope wall. The sections of the CMS stope that extend beyond the design wireframe are considered as dilution, i.e. the actual mined stope is larger than the design stope. Conversely if the CMS stope does not extend beyond the design stope then this volume is considered as ore loss. A section illustrating dilution and ore loss is shown in Figure 6.

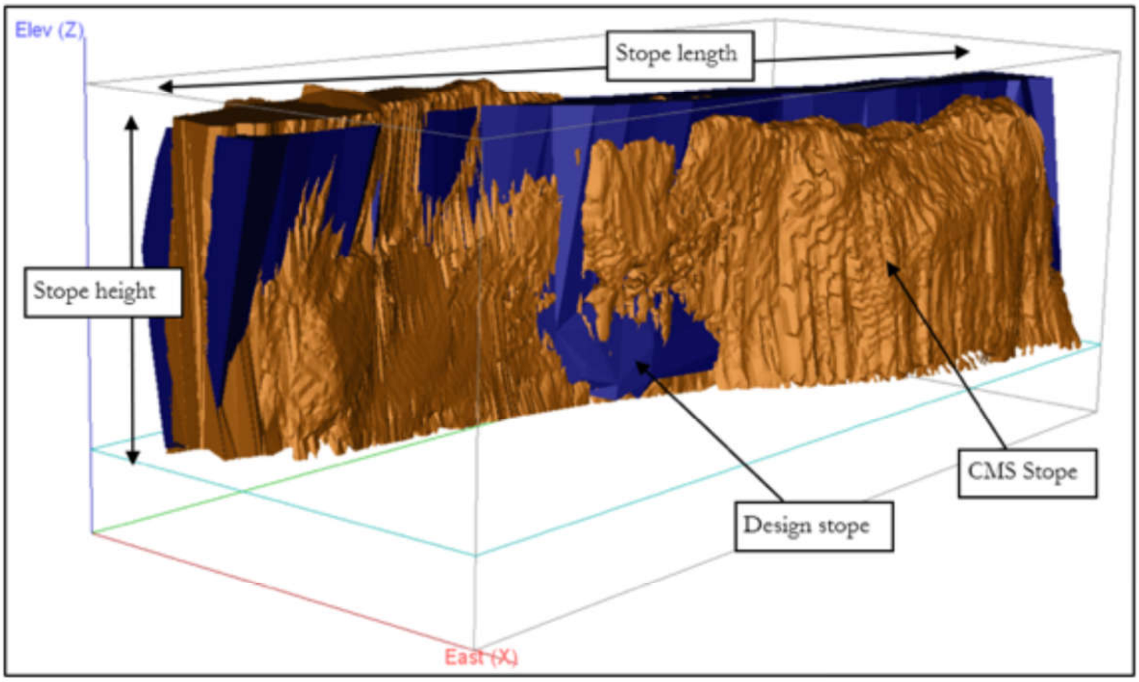


FIG 5 - Isometric view showing the design and CMS stope wireframes

The DRS values were determined for each of the 35 validation stopes by expanding the design stope by 2m and extracting the DRS values within the expanded design stope for the hangingwall and footwall as shown in Figure 7.

Reference to Figure 7 indicates DRS values of approximately 27 for the hangingwall (west wall) between the design stope and the expanded stope. The corresponding DRS values for the footwall (east wall) range between 19 and 21. The DRS values are accumulated in 3D for the full length of the stope.

A number of calibration exercises were completed with the Geotechnical Department at Gara. This process involved evaluating the planned stope design wireframes to determine the DRS rating for the hangingwall and footwall. The actual dilution that occurred during mining was measured with CMS surveys. A summary of the results for the hangingwall and footwall from 64 stopes is presented in Figure 8.

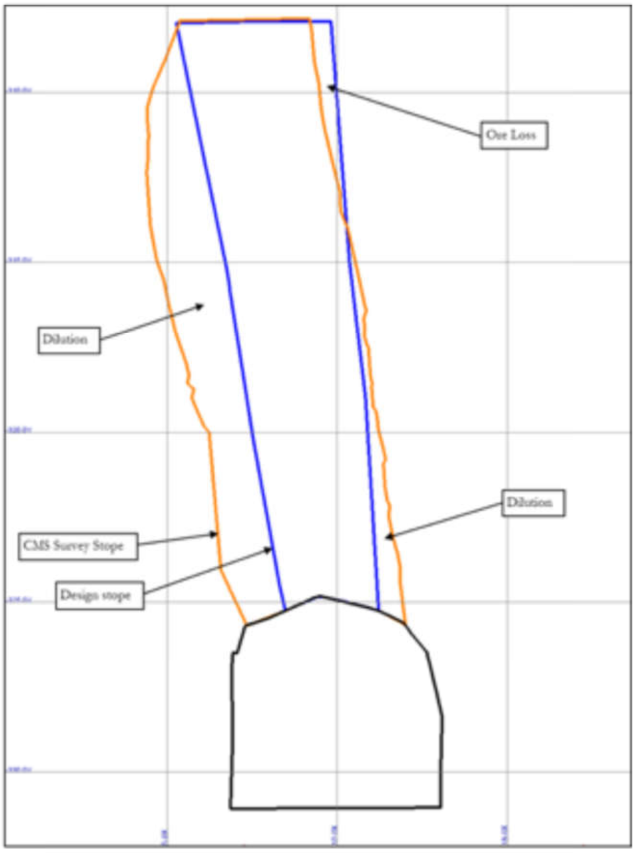


FIG 6 - Section showing Dilution and Ore Loss

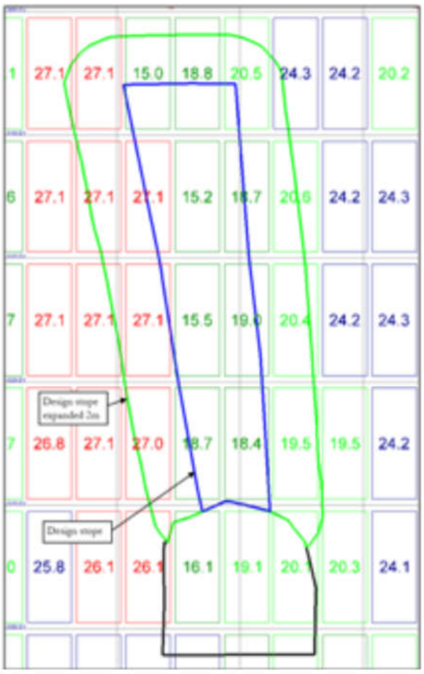


FIG 7 - Section looking north showing the expanded stope with DRS values

Four zones have been identified from the data presented in Figure 8 as follows:

- Zone 1 – High dilution due to mining overbreak or blasting into the hangingwall and footwall structures. Dilution is related to mining practice and not ground conditions.
- Zone 2 – High DRS zone > 26 but the actual dilution thickness ranges from 0.2m to over 2m. The stopes within this region were investigated further and stopes that did not have cable bolt support yielded higher dilution with an average thickness of 1.5m. The dilution reduced

significantly with the installation of cable bolts and an average dilution thickness of 0.6m. For DRS values greater than 26, cable support will significantly reduce dilution.

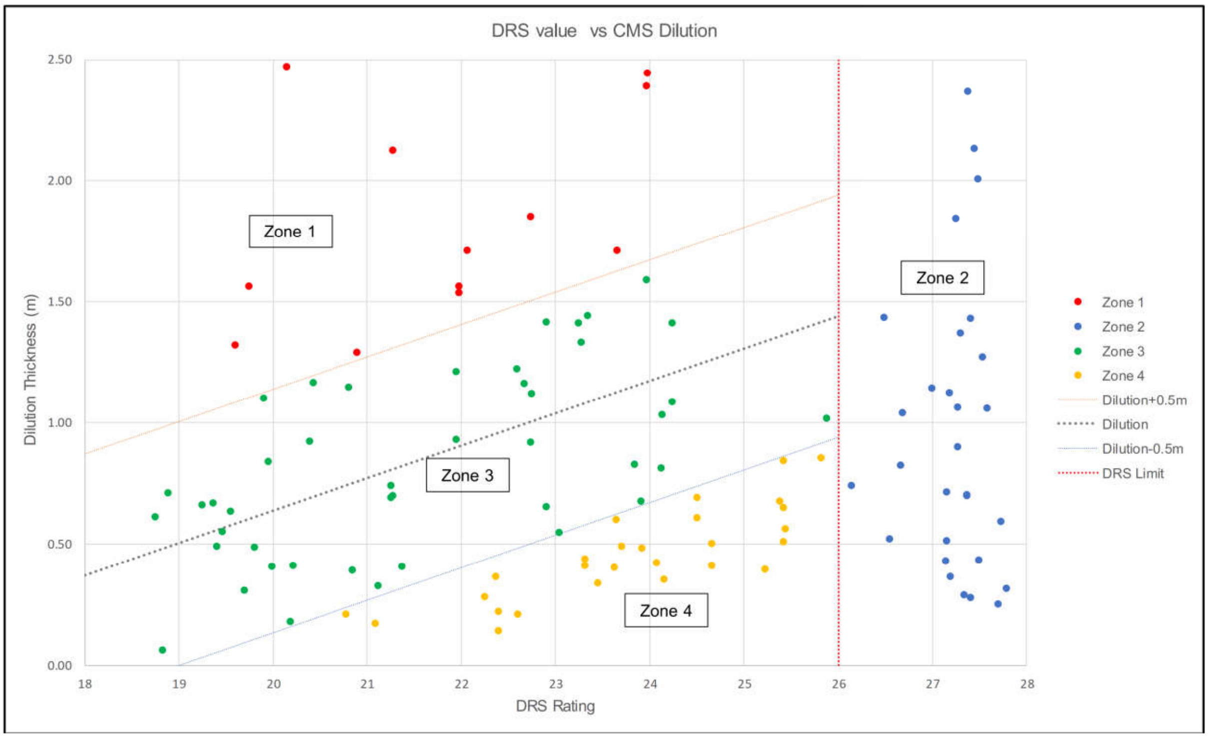


FIG 8 - DRS rating values vs Measured Stope dilution thickness

- Zone 3 – The dilution in this zone follows a linear trend and dilution can be predicted within +/- 0.5m (shown in Figure 8). Cable support will reduce dilution by up 0.5m with DRS values between 22 and 26. For DRS values below 22, cable support has limited effect in reducing dilution.
- Zone 4 – Dilution in this zone is lower than that indicated by the DRS value. The stopes in this zone were investigated and all have significant ore loss i.e the mined stope was smaller than the design stope and hence dilution was minimal.

DRS DESIGN CHART

A Dilution Design chart was developed for Gara based on the calibration data as shown in Figure 9.

The design chart applies to stopes in Zones 2 and 3 (65% of the calibration stope data) and the following design rules are applied:

- DRS Rating <=19 – Nominal dilution thickness is 0.5m
- DRS Rating >19 – Dilution thickness is determined from the design chart or using the following relationship:

  Dilution Thickness (m) = (DRS Rating * 0.13) – 2.04

- DRS Rating 22 – 26 – The dilution thickness can be reduced up to 0.5m with the installation of cable bolts. There is no appreciable reduction in dilution when the DRS rating is less than 22.
- DRS Rating > 26 – The dilution thickness can be reduced by up to 0.9m with the installation of cable bolts.

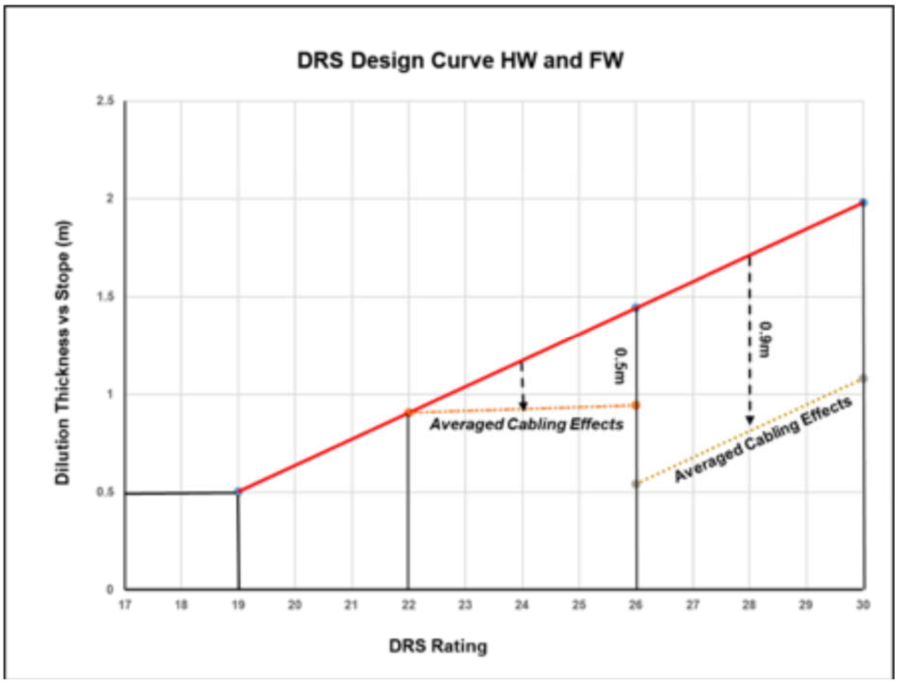


FIG 9 - Gara DRS Design Chart

DRS IMPLEMENTATION

The DRS models have been created for the complete hangingwall and footwall for the Gara orebody allowing dilution to be estimated for any stope at the mine. The models are shown in Figure 10. The DRS models have been incorporated into the mine planning process and all stopes are evaluated against the DRS model prior to mining.

Dilution thickness is estimated using the DRS for all stope designs at Gara based on the Dilution Design chart. Once the stope has been mined the estimated dilution figures are compared to the actual dilution measured from CMS stope surveys. Sixty percent of the reconciled stopes have performed according to the Gara dilution design chart. The remaining stopes (40%) were not predicted accurately due to mining overbreak or ore loss. Current reconciliation between the DRS predicted dilution and actual dilution is presented in Figure 11.

Total dilution has been determined at 30% for the initial 35 stopes that were used to calibrate the DRS model. The total monthly dilution for the one-year period after the DRS has been implemented varied between 6% and 22% with the annual average reduced to 15%. In addition, the DRS has enabled more accurate and reliable prediction of dilution. Unplanned monthly dilution has reduced from 11% to 2% with an average of 5% for the period. The results are summarised in Figure 12.

Examples of stope dilution that has been estimated using the DRS with the corresponding CMS measured dilution are given in Figure 13 to demonstrate DRS model reliability and precision.

Cable bolt patterns can be designed to target areas within stopes that have high DRS values and hence high potential dilution. The actual dilution during mining is reduced due to the mitigating action. For example, Stope 435L Block 12, the DRS model predicted a dilution thickness of 2.4m. Dilution control cable bolts were installed on the hangingwall and footwall of the stope from both the top and bottom ore drives. As a result of the installation of the dilution control cable bolts, the actual dilution thickness was 1.20m. There was a 50% reduction in dilution in this stope due to cable bolt installation.

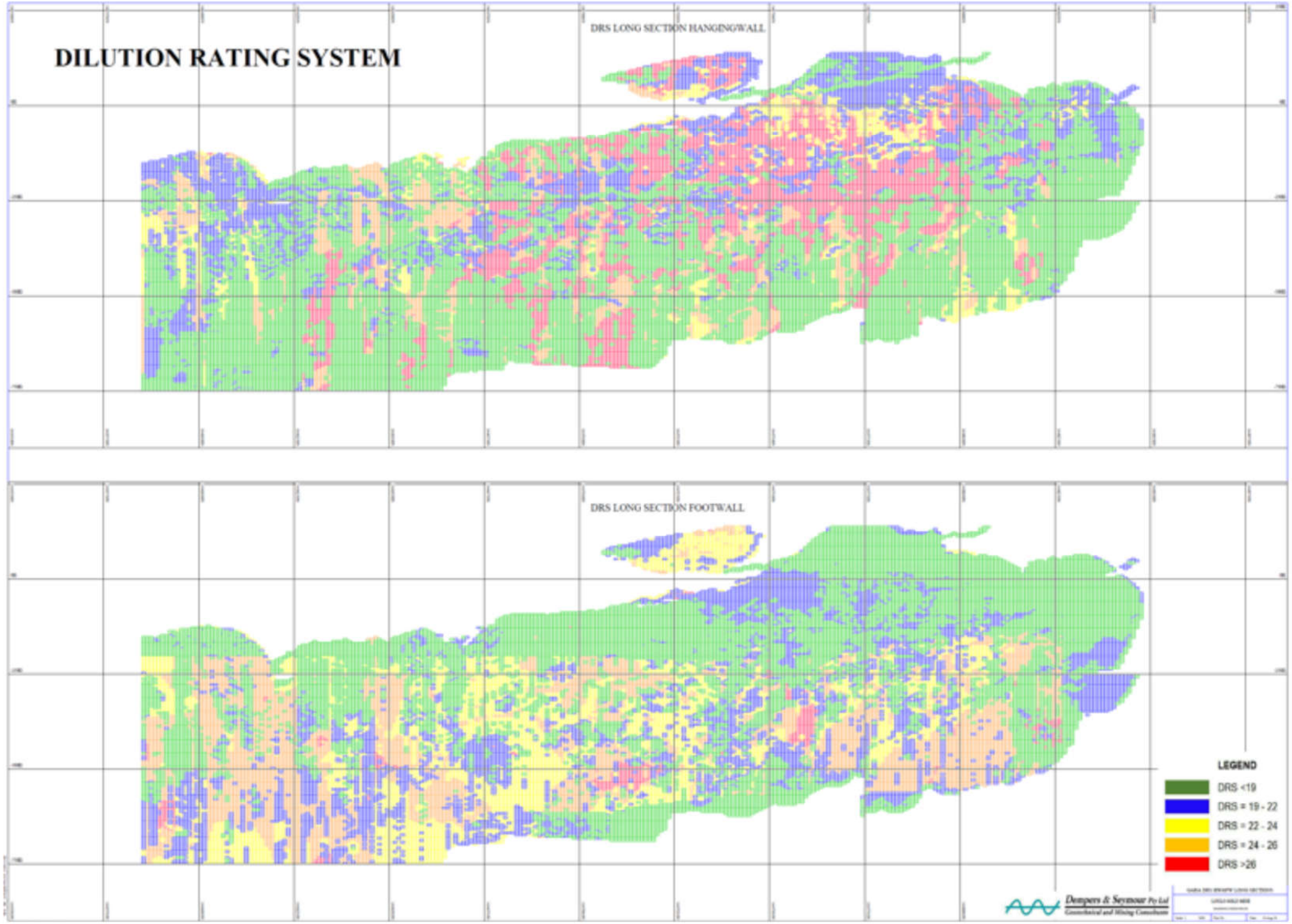


FIG 10 - Long section looking west showing the DRS models for the hangingwall and footwall

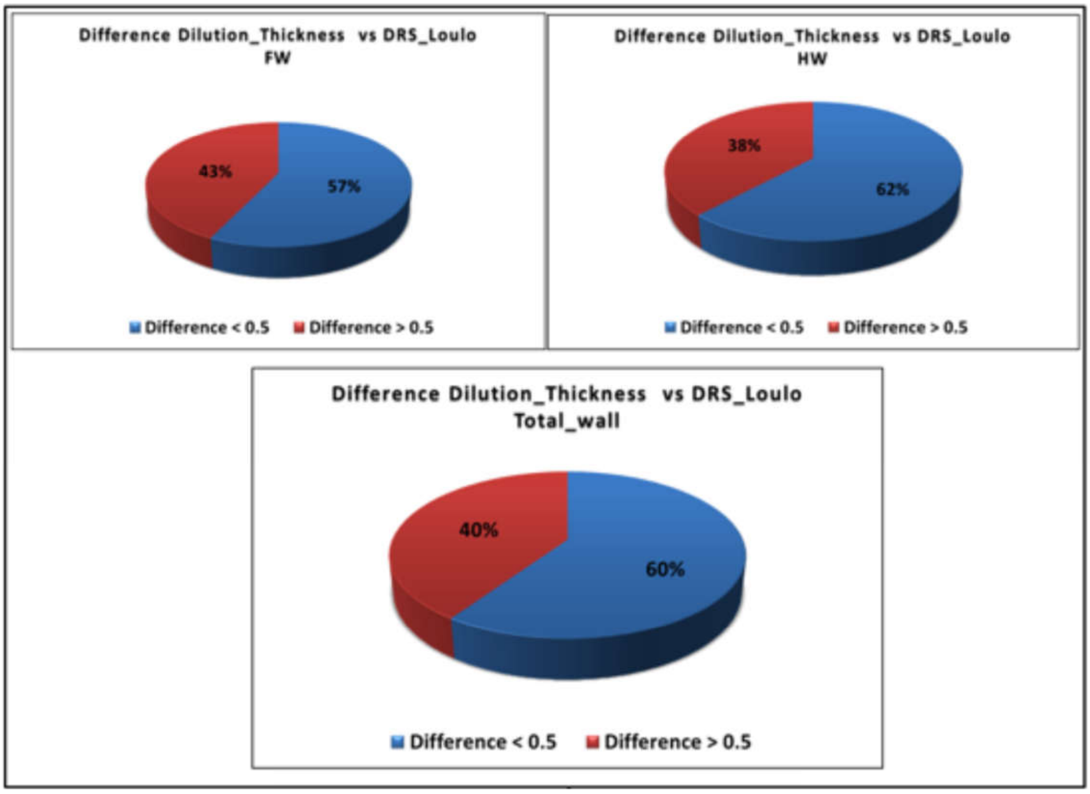


FIG 11 - Current DRS Reconciliation

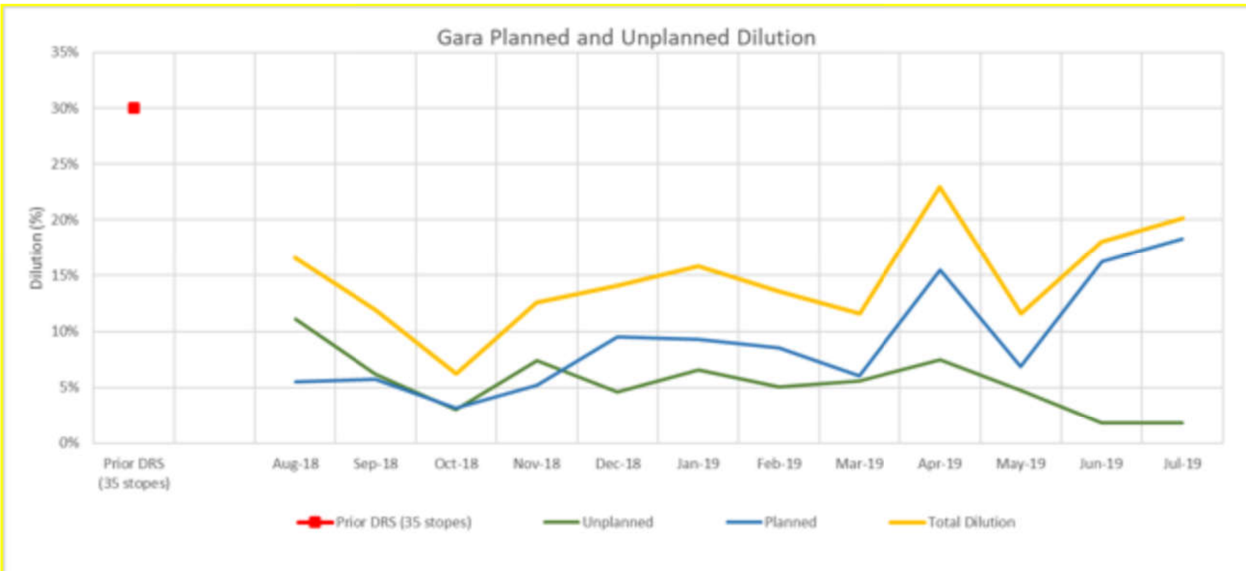


FIG 12 - Summary dilution results

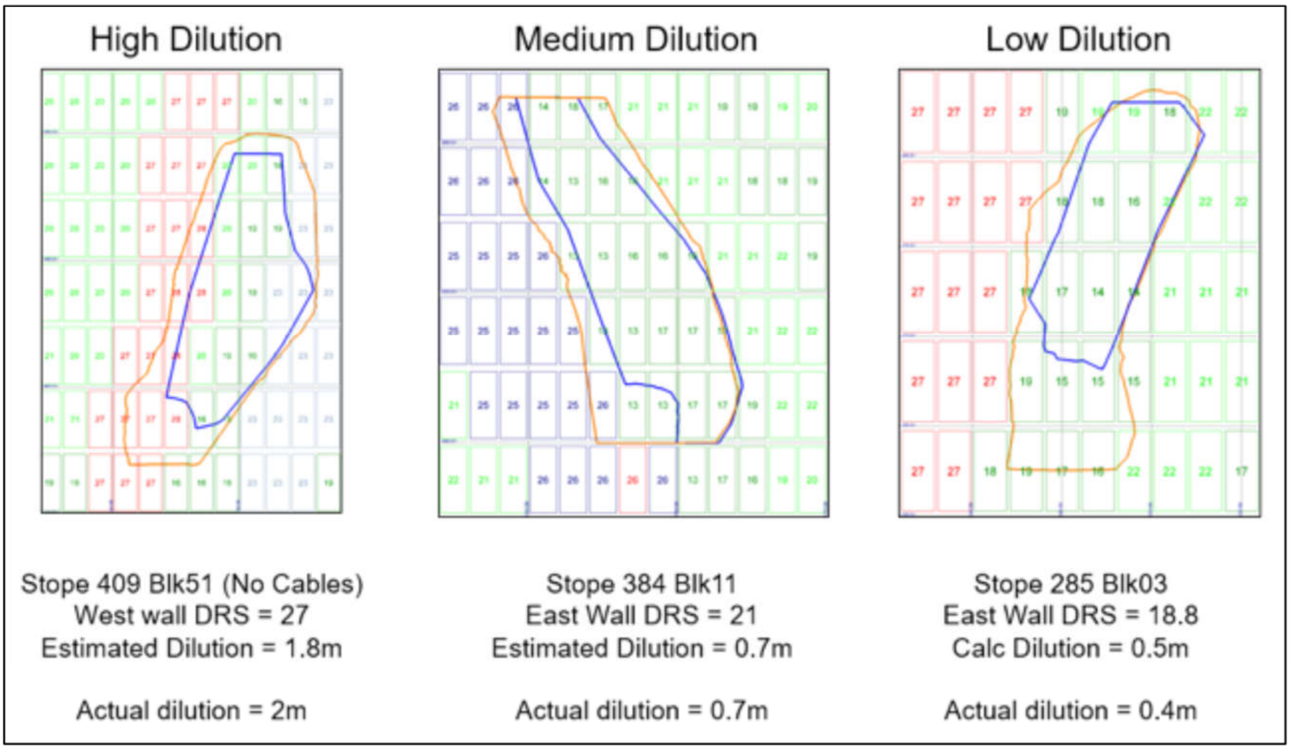


FIG 13 - DRS estimated dilution vs measured CMS dilution

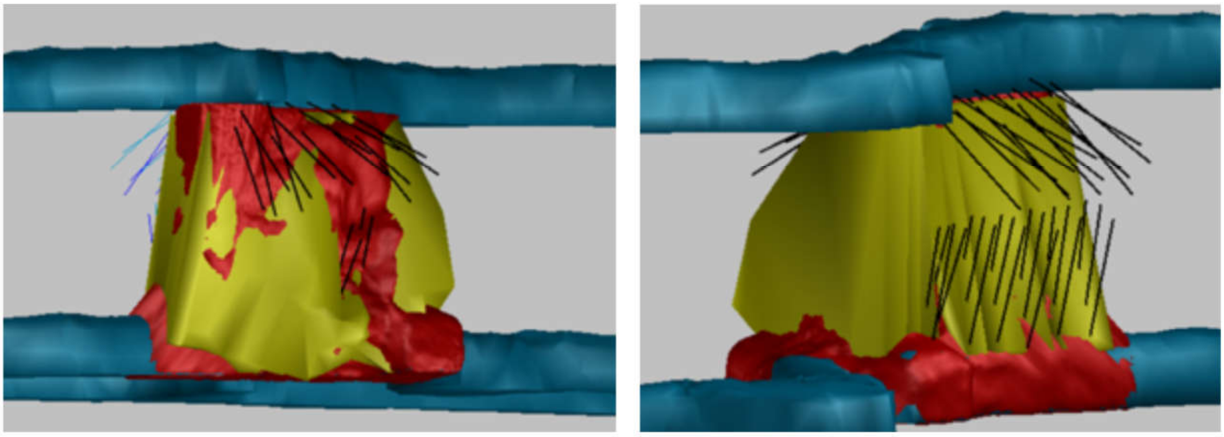


FIG 15 - Isometric views showing 435L Block 12 cables installed from the top & bottom ore drives

CONCLUSIONS

The mine is able to predict dilution for all of the mined stopes using a three-dimensional DRS model based on measured rock mass geotechnical characteristics. The majority of the stopes where the difference between predicted DRS values and actual values exceed 0.5m are due to either mining overbreak (Zone 1) or ore loss (Zone 4). The accuracy of dilution predictions has increased and unplanned dilution has been reduced. Overall dilution has also been reduced from up to 30% to 15% since the implementation of the DRS model.

Gara has been able to control and limit dilution with cable bolt support patterns that have been specifically designed to target areas of the stope walls where high dilution is predicted with the DRS model. The mine has been able to plan for stopes that have a high potential for dilution using the DRS model. Additional ground support and modified stope drill and blast designs have also reduced dilution. The mine is also able to plan for stopes that do not require additional support as opposed to applying a general blanket rule for all stoping areas. Each stope is evaluated independently and the support and blasting patterns designed accordingly.

Future development work for the DRS application at Gara involves continuous reconciliation between the DRS models and actual dilution. The model and the design chart can then be updated to reflect current ground conditions at the mine.

The stopes considered for the current DRS model were not affected by in-situ or mining induced stress. As the mine gets deeper, stress effects will become a factor that will influence dilution. Stress and the resultant effects on dilution are currently being evaluated by the mine and will be incorporated into future versions of the DRS models.

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