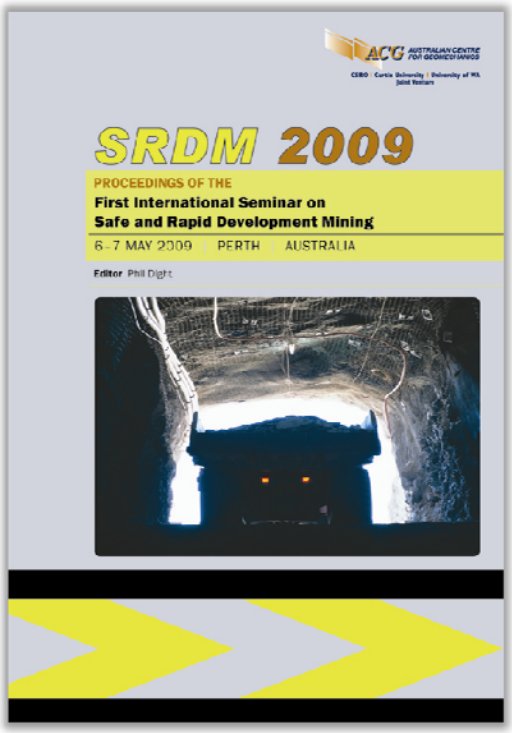
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Hydroscaling technology for rapid drift development

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Abstract

Rapid drift development is still a high priority for many mining companies, as it can reduce costs and also access orebodies faster to increase net present values significantly for any operation. Hydroscaling (water jet scaling) trials have been conducted at various mine sites in Canada and also at Perseverance Mine, Western Australia, Australia, to evaluate this as a potential technology to enhance rapid drift development. The technology in each of these cases removed most of the loose rock within the different rock mass conditions experienced. The success of hydroscaling was measured by either checking the scaling manually or monitoring the shotcrete spraying activity afterwards to monitor rockfalls. During shotcreting, prior to the trials, rockfalls always occurred, whilst there was minimal rockfall after hydroscaling. Monitoring of the shotcrete spraying process prior to trials, and after hydroscaling, has demonstrated an improvement in reduced rock and shotcrete fall out, with commensurate reduction in re-work required. This paper proposes that hydroscaling is now ready for implementation as a technology across a wide range of rock mass conditions and summarises the role for technology within a rapid drift development context.

1 Introduction

Scaling accounts for up to 22% of the total drift development cycle time, whilst support installation time represents about 36–46% of the cycle time. This paper discusses ways in which the scaling and support components, within the drift development advance cycle can speed up tunnel advance.

Escalating mining costs are driving many companies towards faster drifting methods in an attempt to improve profitability of mining operations. Hydroscaling technology combined with an appropriate support strategy offers the possibility of achieving faster drift development advance rates whilst improving the quality of support. In conventional scaling operations, expensive equipment such as development rock drills are used for removing loose rocks from the freshly exposed rock surfaces with the attendant risk of injury to personnel or damage to equipment by falls of ground during the process of scaling. Such damage leads to poor equipment availability. The technique also offers other benefits including:

- Added safety through potential automation.
- Improved equipment availability (reduced down time on machines utilised, but not designed to be used, for scaling).
- Improved shotcrete adhesion strengths.

The development of a hydroscaling technique may also offer more flexibility in replacing certain tasks, e.g. washing of the face.

Hydroscaling works by applying water under high pressure to remove loose material with minimal new fractures induced in the rock mass. By so doing, the damage caused by conventional mechanical scaling techniques is eliminated and the self-supporting capabilities of the excavations are maintained. This means that rock that it is fractured but is still performing some support function across the drift profile can be left in place rather than typical conventional practice of removing all that are loose. A possible side benefit of hydroscaling is reduced wastage of liner support product (e.g. membrane liners or shotcrete) and reduced spraying time (as a result of reduced re-work).

Field trials were carried out in Sudbury, Ontario, Canada during 2002–2003 and Perseverance Mine, Western Australia, Australia during 2005 to evaluate the hydroscaling technique in different rock conditions (Dunn et al., 2005; 2003; 2002).

The aims of these field trials were to:

- Record the performance of hydroscaling under differing rock mass conditions.
- To quantify the potential benefits of the hydroscaling technique in drift advance rates.

2 Hydroscaling in varying ground conditions

A total of 29 hydroscaling tests during drift development advances were conducted at the Fecunis Adit, Sudbury Mine, Canada and the Perseverance Mine at Leinster Nickel Operations in Australia. Various pressures and flowrates have been trialled, typically of 14–12 MPa (2000–1750 psi) and flowrates of between 200–250 L/min. Hydroscaling at high flowrates (> 150 L/min) has advantages over low flowrate high pressure applications in that the jet is more coherent and loses less velocity with distance to the target rock face. Hence, larger stand-off distances can be used — this is an advantage in hydroscaling from under supported ground and using a forward looking angle, thereby removing the possibility of rockfalls on the boom or fly rock damage.

The times recorded for hydroscaling at Perseverance Mine varied from 2–16 min with the bulk of the hydroscaling times 4–8 min. Reasons for the wide ranges of scaling times related principally to operator judgement and experience and the different scaling paths undertaken during each hydroscaling test. There was little doubt that most of the rock was scaled in the first 2–4 min and the remaining time was spent in either making sure nothing else would come down or in attempting to profile the drift development walls. The operators also trimmed the shotcrete (where shotcrete was used) from the previous cut that gave considerable advantages in making a smooth transition from one drift development cut to the next. Small pieces of rock were still removed with further hydroscaling but, in general, after four minutes there was very little additional rock removed. It was envisaged that when an automation (or semi-automation) strategy was introduced, the rate (area covered in unit time = 6 m^2/h) of the hydroscaling would be under 10 m^2/h and designed principally to ensure that the entire drift development surface is covered by the water jet.

(a)

(b)

Figure 1 Hydroscaling in the development headings: (a) Fecunis Adit in Sudbury mine, Ontario, Canada; (b) Perseverance Mine, Western Australia, Australia

The total drift development cycle time (baseline) was calculated to be 12.5 hours for advancing a 5 x 5 m heading by three metres at the Perseverance Mine. Hydroscaling demonstrated the potential to save 20 min from the cycle time. Typically (at Perseverance Mine), the development heading was washed down two or three times during the cycle. The first washdown was after the blast and prior to mucking (to minimise dust generation), the second was normally by the geotechnicians after the heading had been mucked out (for rock mass evaluation and characterisation) and a final wash, if needed, prior to applying shotcrete.

Shotcrete spraying times measured during the trials varied from 20–40 min, excluding the setup and clean up time for the spraying rig. The typical range for the shotcrete spraying activity, including setup and clean up, were given as 30–120 min with a nominal spraying time, including setup and clean up, of 72 min per heading

(Figure 2). Typically five headings (5 m^3 of shotcrete per drift development cut) were sprayed within a 12 hour shift.

Hydroscaling the rock walls prior to shotcreting reduced the degree of variability in the shotcrete spraying times observed by minimising the re-work required. This benefit was somewhat specific to the Perseverance Mine situation and it was envisaged that when hydroscaling is applied at other sites, additional benefits such as reduction in scaling times and less damage to equipment would be obtained, (Dunn et al., 2006; Jenkins et al., 2005).

Scaled rock volumes (measured by laser scanning) were more highly influenced by blasting quality and rock type than the time actually spent hydroscaling. The average scaled thickness increased clearly with poorer rock mass quality. From the results it appears that a constant scaling time was required across similar rock and blasting conditions, to achieve a similar scaled result. In poor rock mass conditions the scaling time has to be set at some level otherwise you are essentially mining the rock.

Automated hydroscaling was used in the Canadian trials (Dunn el al., 2002; 2003) but not in the Australian underground trials. An advantage of the manual hydroscaling conducted at the Perseverance Mine operation was that profiling and trimming work could be undertaken. Previous drift development cuts (advances) typically left prominent brows in the backs and subsequent blast damage (rubble behind shotcrete and damage to shotcrete edges) tended to make the spraying of the next cut more difficult. With hydroscaling, both shotcrete trimming and removal of some of the loose rock material behind the shotcrete was undertaken. In some situations, rock which had not been completely excavated from the required drift profile was removed. If the rock could not be hydroscaled it was obviously left in place and shotcrete was sprayed over it. The benefits of this in terms of time (in spraying up to the previous liner support edge) and shotcrete consumption were not expected to be large, but generating a smooth drift profile is important from a ventilation and drilling (of the next cut) perspective.

Prior to the hydroscaling trials at Perseverance Mine significant rockfalls occurred during shotcreting operations in 75% of the drift development headings monitored. In the hydroscaling trials, only minor rockfalls (minimal impact on shotcreting functions) were recorded in roughly one third of the drift development headings tested.

An estimate of the hydroscaled tonnage was made at the end of each test. Tonnage estimates from the scaling tests were in the order of 0.5 – 3 t. The largest single rock piece scaled was approximately 0.5 t. Although no trend could be observed between the scaled rock volumes versus the total half-barrel length observed in each heading, there was clearly reduced volume scaled in the better-blasted areas. In situations where there were half-barrels remaining after the blast, these were always left intact after hydroscaling. In other words, hydroscaling did not initiate any new fractures or damage to the surrounding rock. At the water pressures and flowrates used, new fracturing (generally initiated through pressurising existing fractures in the rock mass) was minimised and certainly did not induce new fracturing within intact rock. In zones where a high degree of fracturing exists, significant rockfalls were observed during testing. Judgement is therefore required in weak rock mass zones (even in a partial section of a heading) and this is sometimes better achieved through manual operation of the hydroscaling operation (bypass automated control).

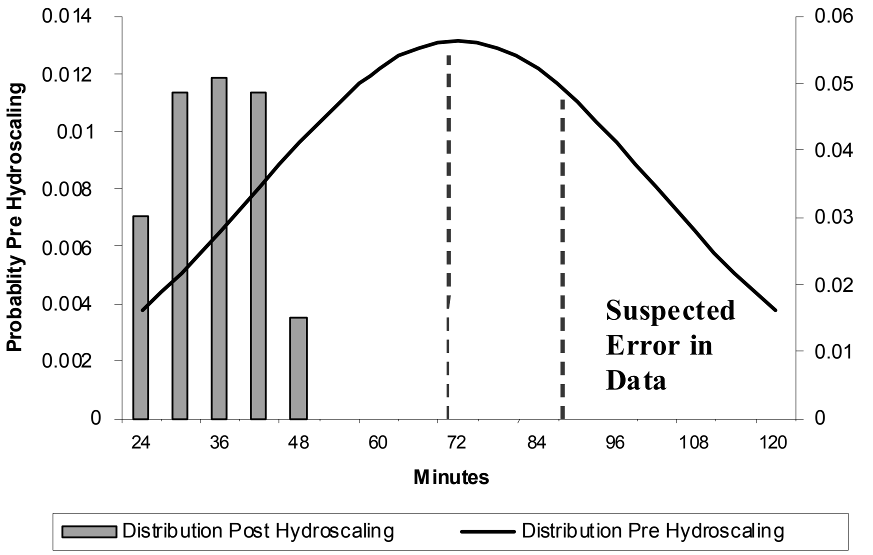


Figure 2 Comparison of shotcrete spraying durations

Improved blasting practices assisted in reducing the scaling requirements and in improving the integrity of the drift development support installed later and so the observations made during this trial should be considered in light of the variable blasting conditions observed on-site.

Working from already supported ground towards the face, i.e. scaling ahead of the boom and nozzle, proved to be a successful approach. No rocks fell on the booms and no equipment damage was reported during the entire trials. In the baseline operation for conventional drift development with mechanical scaling, there were a couple of occasions where rockfalls damaged hoses on the boom and this resulted in downtime for that equipment. Utilising equipment for scaling not designed for the purpose, e.g. drilling jumbo or a bolting machine, had already been highlighted as causing excessive downtime.

Earlier hydroscaling trials by Jenkins et al. (2005) identified a considerable potential to reduce downtime on drilling development jumbos if hydroscaling could replace the scaling function performed. At one mine, a recent internal cost comparison of jumbos exclusively used for blast hole drilling and those used for scaling and bolting showed that the cost per drill metre was almost ten times higher for jumbos used for scaling. The major cause of cost differential was determined to be equipment damage from rock fall-off during scaling. This is estimated to be several millions of dollars per year. There was little doubt that hydroscaling, if implemented correctly, would have a significant impact in reducing downtime on various equipment items depending on the particular drift development cycle and practices adopted.

3 Discussion

In a previous rock scaling study (Dunn et al., 2002; 2003) it was found that scaling times within the industry varied from 0.5 – 2 min/m^2 scaled. Figure 3 indicates hydroscaling rates of around 0.2 – 0.25 min/m^2 (with some variation for blasting quality) should be adequate across a wide range of rock mass conditions. For the 33 m^2 (estimated) scaled in the Perseverance Mine waste headings this would equate to a saving of 6.5 to 8 minutes. For the ore headings (of generally poorer rock mass quality) this would be less due to only 2.5 m advances, compared to 3 m advance within waste headings.

Shotcrete rebound might also be reduced on cleaner rock surfaces but this would also have to be evaluated further. In specialised rapid drift development situations, more novel ways of utilising the hydroscaling technology, e.g. over the top of the blasted muck pile, could be considered to reduce the cycle time further.

A forward lookout angle (no less than 5°) of the nozzle should be used to ensure the jet is scaling ahead of the boom. A minimum stand-off distance (distance of nozzle to drift wall) of two metres should be used. A shorter stand-off distance can be used in certain circumstances. However, the lookout angle should be increased to reduce potential fly rock damage to equipment. Although the main scaling path can be automated, hydro-trimming of the previous shotcrete and loose rock might be better performed manually.

Due to the relatively short-time required to bring down the loose rock material, most scaling was performed during the first four minutes across the rock conditions tested, it was recommended that three different automation settings be used to cover the different rock and blast conditions encountered. These three settings would control the scaling speed and therefore time (and water consumption) to perform the loose rock removal. The estimated water capacity required to cover all situations per heading is approximately 2.5 m^3. The amount of water used during the trial did not provide any operational problems for the drift development cycle.

Hydroscaling produces minimal fly rock; very small rock fragments. A full helmet face shield (like those used during normal shotcreting operations) was found to be sufficient in addition to the normal personal protective equipment. Automation of hydroscaling would allow the operator to be removed completely from operations and allow other tasks, e.g. setting up of subsequent shotcrete operation, geotechnical mapping, to be performed in parallel.

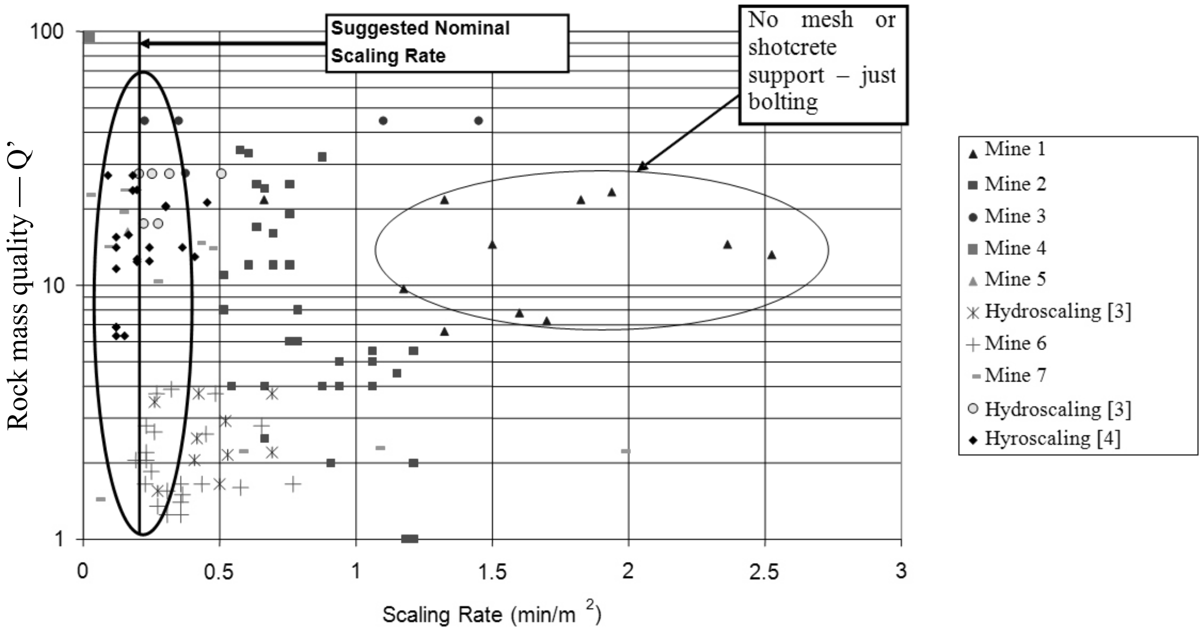


Figure 3 Scaling rate (min/m^2) and rock mass quality (Q)

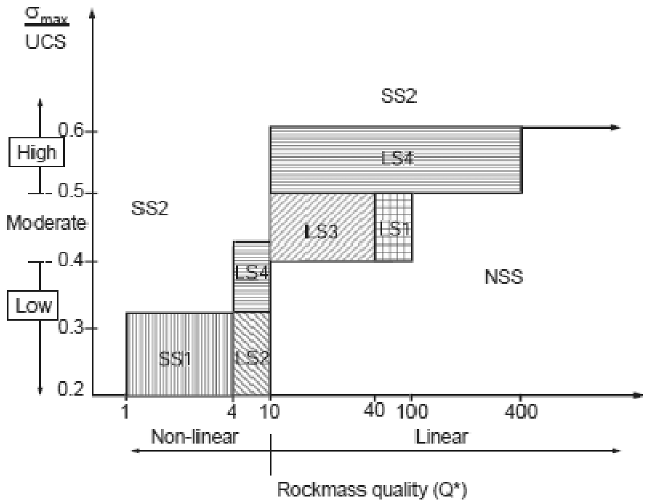
Depending on the requirements at the mine, waterscaling technology could be fitted to a wide range of carriers such as existing jumbo drill rigs, shotcrete machines or service trucks.

Hydroscaling has proven itself across a wide range of rock mass conditions and is currently being implemented by Xstrata Nickel in Canada and BHP Billiton Nickel West in Australia in various mines.

To recap, scaling accounts for up to 22% of the cycle time and support installation time represents about 36–46% of the total development cycle time. The role of scaling can not be assessed in isolation. Figure 4 compares the time required for various support systems and provides a systematic way of assessing support requirements for different rock mass conditions (Suorineni and Kaiser, 2006). Although a fixed hydroscaling rate is suggested here, this should be reviewed in light of the subsequent support system requirements and not purely as an additive time component within the cycle. It is suggested that, if support systems and scaling technology are looked at synergistically within the goals of the development cycle, advance rates can be improved.

4 Conclusions

Rapid drift development is still a high priority goal for many mining companies as it can reduce costs and also access orebodies faster, thereby increasing the net present value significantly for any operation. Two trials were conducted in Canada and Australia to evaluate hydroscaling as a potential technology to enhance rapid drift development. Hydroscaling has proved its ability to remove loose rock in all different rock mass conditions encountered in the 30 or so tests that have been conducted. The performance of the technique in loose rock removal was evaluated by manual check scaling and monitoring the shotcrete spraying operations after hydroscaling and comparing this to rock and shotcrete fall-out with no hydroscaling. In the case of the Perseverance Mine, Australia, the benefits were found to be a reduction of 20 minutes in the average shotcrete spraying times and a reduction in wastage of shotcrete product, as no scaling was typically performed prior to the hydroscaling trial. Benefits to mines currently utilising some form of mechanical scaling were expected to be greater, as they would achieve most of the benefits above and, in addition, replace existing scaling and washing times with roughly eight minutes of hydroscaling time. There should also be a large increase in drill equipment availability, where drills were used to bring loose rock down in the drift development.



(a)

Support System Code	Description	Normalized Installation time
NSS	Scaling only	22%
LS1	Tendons only, ultra wide pattern	37%
LS2	Boltless, TSL fast	40%
	Boltless, TSL slow	202%
	FrSC	247%
LS3	Tendons only	67%
LS4	Sparse Bolted Membrane, TSL fast	55%
	Sparse Bolted Membrane, TSL slow	217%
SS1	Tendons and WWM	70%
	Tendons and TSL fast	74%
	Tendons and TSL slow	236%
SS2	Tendons and WWM	100%
	Tendons and TSL fast	85%
	Tendons and TSL slow	247%
	FrSC with tendons	297%

(b)

Figure 4 (a) Ground condition-based support matrix; (b) Comparison of support systems installation times with mesh plus systematic bolting as base (after Suorineni and Kaiser, 2006)

The hydroscaling technology has proven itself over a wide range of rock mass conditions (Q values of 0.7 – 11) and a single scaling rate (0.2 min/m^2) would seem to be sufficient over the wide range of rock mass conditions evaluated to date. This would provide an initial scaling rate to base automated scaling, although fine tuning for the specific site conditions is expected. Variations in scaling time will inevitably be required to account for blast quality issues and different site characteristics, however, the technology is easily automated and this should be used where possible to limit water wastage. Profiling and face scaling will need manual override of the automated functions. It is suggested that a semi-automatic system is best which can be left in automatic mode to ensure complete coverage of the drift walls and then manual override for other functions. In good rock mass conditions, where no shotcrete clean up work or profiling issues are expected, the entire scaling operation could be automated.

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