Integrated Geotechnical-Hydrogeological Field Programs in Open-Pit Mining – A Win-Win Situation?

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Abstract

The requirement for hydrogeological input into geotechnical mining studies and vice-versa has always required a close collaboration between these two disciplines. An integrated approach to field investigations for multi-disciplinary studies can often be adopted whereby a combined field program is designed by the project geotechnical and hydrogeological teams, in partnership, to cater for both team’s data requirements. This approach usually has considerable cost savings associated with it, particularly when incorporating the drilling of shared holes. However, do the inevitable compromises inherent in this approach adversely affect data quality? This paper examines the authors’ experience with both integrated and non-integrated feasibility study geotechnical and hydrogeological field programs and looks at the technical benefits and drawbacks of integration. A variety of case studies are considered which incorporate a wide range of both novel and commonplace techniques within a variety of geotechnical and hydrogeological settings. It is found that, in almost all cases, collecting data from combined investigations brings some significant advantages over data collected from independent, discipline-specific studies. These advantages far outweigh the disadvantages associated with the compromises that must be made. When cost (and often time) savings are then considered on top of this, surely this approach to geotechnical and hydrogeological data gathering represents a win-win situation?

1 Introduction

Groundwater plays a critical role in geotechnical slope stability, reducing the shear strength of potential failure surfaces, whilst geotechnical parameters such as fracture properties or particle size are often the main physical parameters controlling groundwater flow and distribution. It follows, therefore, that close interaction is regularly called for between geotechnical and groundwater disciplines working on multi-disciplinary investigations. In open-pit mining studies, this interaction often culminates in the input of pore water pressure grids into slope stability analyses and optimisation of depressurisation options where improved factors of safety or slope angles might bring financial and/or operational benefits. Modelled slopes are frequently sensitive to groundwater, with a reduction in pore water pressure of just a few hundreds of kPa (tens of metres hydraulic head) increasing stable slope angles by enough to significantly reduce the amount of waste to be mined. Through this type of optimisation it is not unusual to save tens of millions of dollars in mining costs. It follows that geotechnical data is often an important input into hydrogeological analysis, for example the integration of borehole scale structural data into hydrogeological models in fractured rock environments is often essential in order to adequately reflect the anisotropy of the rock mass. If the interaction between geotechnical and hydrogeological studies can be extended to the data collection phase then a coordinated effort can be made to ensure that the right data is collected, in the right locations, for maximum cost efficiency; an approach that we argue will ultimately benefit both disciplines.

This paper seeks to provide a practical overview to the major benefits and inevitable limitations associated with an integrated geotechnical-hydrogeological field program. It uses a range of illustrative case studies from a variety of geological settings including examples of how some limitations have been addressed in the past.
Although it focuses mainly on hard-rock open-pit mining investigations, the same philosophy applies equally to soft-rocks and soils as well as non-mining situations, for example other large-scale excavations or tunnelling projects. To some, an integrated approach is nothing new, yet this paper will hopefully be beneficial in providing some useful case studies and practical experience. However, it is not uncommon for geotechnical and hydrogeological disciplines to be considered in partial or complete isolation during many stages of mine investigation and the advantages and disadvantages summarised herein seek to highlight the applicability of an integrated approach as well as some of the pitfalls to look out for.

2 Cost

Perhaps the most obvious advantage to an integrated geotechnical-hydrogeological field program is the cost savings associated with the sharing of drilling data and borehole infrastructure. Drilling observations, for example water strikes, rest water levels, penetration rate, loss of drilling fluid, and blow yield, are not just incidental sources of data for a hydrogeological investigation, but critically important data streams which often represent the sole justification for drilling. For example, hydrogeological boreholes are often continued well below the depth required for piezometer or pumping well installation in order to collect hydrogeological drilling observations from deeper water-bearing units. Thus, if this data can be collected opportunistically as part of another investigation programme, then hydrogeological drilling metres can be reduced and costs saved. Almost any borehole can yield useful hydrogeological data, with the exception perhaps of those drilled with a very heavy mud which suppresses the natural characteristics of the rock. The cost, and in many cases time savings, associated with recording of groundwater observations during non-groundwater specific drilling programs are significant, yet are often neglected (Connelly, 2008).

Geotechnical holes may also provide a suitable opportunity for hydrogeological testwork to be undertaken, reducing and in some cases even negating the requirement for hydrogeology-specific drilling. In low permeability hydrogeological settings where rock quality is good, it may be possible to use geotechnical cored holes, most commonly drilled at NQ or HQ diameter, as both open-hole pumping wells and unsealed (non-discrete interval) piezometers. In this way, a number of cross-hole pumping tests can be undertaken without the need for a hydrogeology-specific drilling program. Such an approach was used as part of a recent open-pit feasibility study into a generally competent metasedimentary and skarn hosted iron deposit in Northern Scandinavia. Geotechnical drilling was undertaken at 76mm hole diameter which was sufficient to install a 42mm (OD) electrical submersible pump used for a number of cross-hole pumping tests, where water levels were monitored in several nearby holes. A simple geological sequence and unconfined conditions meant that, in this case, unsealed piezometers were sufficient and no hydrogeology-specific boreholes needed to be drilled.

If this approach is taken, however, particular attention must be given to the development of the borehole (i.e. continuous flushing with clean water) in order to remove drilling mud often present in the form of a “mudcake” on the borehole wall (a deliberate phenomenon which the driller uses to their advantage to reduce water loss in the system), which can mask the true characteristics of the aquifer. Borehole development is often a long winded and hence costly process and is often neglected if the importance is not clearly understood. Furthermore, development of the borehole may in some cases only be partially successful and it can be difficult to confidently access the extent of its success. The use of geotechnical holes as pumping and observation wells with no subsequent modification is also limited by the hydrogeological properties of the units being investigated – only a relatively small pump with a correspondingly small pumping rate is likely to fit in a geotechnical borehole and multi-layer aquifers cannot be investigated separately given that pumping wells and piezometers will be open throughout the saturated thickness.

In-situ testing of hydraulic properties as part of a mine hydrogeological investigation, which may consist of single or double packer testing or downhole impellor flowmeter (spinner) testing, is almost always undertaken in geotechnical or resource boreholes as the requirement to drill boreholes solely for the undertaking of in-situ hydrogeological testing would likely make this form of testing prohibitively expensive in the majority of cases. However, there are some significant disadvantages to hydraulic testing in such holes, which are mostly drilled by
way of diamond coring using a mud flush. In the case of such as packer testing, where water is injected into the
surrounding rock, drill cuttings in the hole may be forced into the formation resulting in a permeability estimate
which is unrepresentative. When undertaking spinner testing, the presence of mudcake on the borehole wall may
artificially reduce the measured permeability unless sufficient development of the borehole is undertaken upon
completion of drilling.

Once any downhole logging has been completed, diamond drilled geotechnical boreholes can be suitable for the
installation of a permanent standpipe or piezometer for monitoring of groundwater head, and in some cases
groundwater quality. This can be achieved in a number of ways varying from a) relatively simple and cheap
installation of a standpipe to monitor hydraulic head across the entire saturated thickness, to b) more complex
and costly installation of a discrete interval piezometer with gravel pack and bentonite seal, to c) installation of
vibrating wire piezometers linked to a continuous datalogger. In this way hydrogeological drilling costs can be
significantly reduced although this may be offset in some instances where installation in a narrower, deeper or
inclined hole is more complicated and costly. On a recent multidisciplinary feasibility study undertaken in
Northern Scandinavia, a combined geotechnical-hydrogeological field program was devised comprising 13
diamond drilled geotechnical boreholes, three of which were converted to standpipes and paired with a pumping
well and piezometer drilled using down-the-hole hammer resulting in three pumping test sites. Even in this case,
where relatively few geotechnical borehole were used for hydrogeological installations, it was estimated that the
cost of drilling an additional three standpipe holes would have added around 25% to the cost of the
hydrogeological field program. This saving was on top of additional cost savings obtained from the sharing of
results from geotechnical laboratory testing.

Where the borehole diameter is too small to meet the requirements for a groundwater installation, reaming the
borehole out to a larger diameter may offer a financially advantageous alternative to drilling a completely new
borehole. This has the added advantage that a preliminary assessment of groundwater conditions can be made
before committing to the installation of groundwater monitoring infrastructure i.e. the drillhole can be used as a
pilot hole. For example, during a recent scoping/pre-feasibility level multi-disciplinary study of a limestone-
hosted metal deposit in Eastern Europe vertical diamond-drilled boreholes drilled up to 800mbgl at NQ diameter
for resource and geotechnical purposes were reamed out to between 101 and 190mm diameter, where suitable
groundwater conditions were encountered, into which screened pumping wells or multi-level piezometers could
be installed. The reduction in hydrogeological drilling budget saved the project over half a million US dollars.

3 Data quality

Cost savings from scope reduction are a false economy if they are accompanied by a reduction in data quality.
In hard-rock mining environments, acquisition of data in shared holes in fact brings some distinct advantages in
that hydrogeological testing is undertaken on structures that have been logged and measured geotechnically. For
example, Figure 1 shows a log of lithological, geotechnical and hydrogeological data from a diamond cored
borehole drilled as part of an integrated open-pit investigation in a geological sequence mainly comprising
fractured granites, phyllites, schists and skarns. During drilling, the drillers were under instructions to notify the
supervising hydrogeologist in the event of a significant increase in penetration rate or loss of drilling fluids. This
was the case from 258mbgl to 262mbgl and drilling was temporarily stopped at 262mbgl to insert a single packer
within competent rock at 256mbgl in order to undertake a single packer test. The orientated core was logged
geotechnically at the drilling site to minimise breakages during transportation and, upon completion, a downhole
acoustic televiewer (AT) survey was undertaken in order to confirm parameters such as fracture frequency, infill,
dip and azimuth, and also to measure parameters that cannot be accurately measured ex-situ such as apparent
fracture aperture at the borehole face. Geotechnical core logging identified a number of large fractures at around
258 to 259mbgl as being generally clean fractures with some carbonate infill. This zone was reflected in the
RQD, fracture frequency, fracture aperture and infill estimates from the AT data. Finally, an impellor flowmeter
(spinner) log of the completed hole was undertaken under pumped conditions, which logged a significant flow
anomaly of more than 70% of the total flow from the hole at around 258mbgl. This flow anomaly was then
converted to a fracture transmissivity.
Figure 1.  (a) Example geotechnical and hydrogeological log for a diamond drilled borehole where hydraulic properties have been derived for structural features identified during geotechnical logging, in this case using downhole impellor flowmeter (spinner) logging and single-packer tests. (b) Acoustic televiewer and caliper log for a specific fracture logged at 258.0 to 258.2mbgl.

Although geotechnical parameters such as RQD or fracture aperture can be indicative of hydrogeological properties such as transmissivity, they rarely correlate closely - a demonstration of the complexity of fractured aquifers where permeability is a function not only of the fracture properties at the borehole face but also the properties and interconnectivity of the wider fracture network. For example in the case of Figure 1, some large aperture fractures were identified in the top 110m of the borehole which produced significantly lower flow anomalies than the narrower fracture identified at 258mbgl. If geotechnical and hydrogeological data had been collected from different boreholes, the physical and hydraulic properties of discrete fractures could not have been compared. In this case, however, the geotechnical core logging, in-situ AT data, flowmeter and packer results all combined to give a very convincing picture of the hydrogeological conditions in this borehole. Once the geological and structural setting was better understood, these data could then be used to identify other similar potentially highly permeable flow horizons and ultimately enable the conceptual hydrogeological model to be better constrained for the site. Scaling of geotechnical and hydrogeological properties gathered at the borehole scale to a more regional scale suitable for the prediction of groundwater flow must then be undertaken within the context of a regional structural understanding (Bellin et al., 2010).

The benefits of data collection in shared drillholes do not only apply to the hydrogeological program. Information, albeit qualitative, on fracture persistence or fracture interconnectivity is a useful input into slope stability analyses. For the geotechnical characterisation of rock mass, definition of pit slope parameters such as joint persistence is of great importance, especially where slope instabilities are predominantly structurally
controlled. However, joint persistence is difficult to obtain at early stages of ground investigations such as feasibility studies, where there may be limited outcrop available and limited or no access to the rock mass at depth, unless sophisticated and costly methods such as downhole radar surveys are used which do not work in all ground conditions. In those cases an indirect approach, such as in-situ hydrogeological testing, can provide an indication of persistence as higher permeabilities are likely to indicate either more persistent structures or structural interconnectivity with the potential to reduce rock bridges and thus rock mass stability.

Although both packer and spinner testing are useful in this regard, spinner testing has the added advantage of being able to more precisely pin-point inflows which relate to structural features, whereas packer testing relies on the operator to define a specific interval to be tested based on review of the drill core, which may be misleading.

4 Borehole location and orientation

The biggest compromise that must be made in any integrated drilling program is usually that of borehole location and orientation. Both programs are driven by data requirements which in some cases differ and this will almost certainly result in the requirement for some concessions on both parts. Table 1 summarises some of the key considerations that drive the decision over borehole location for both geotechnical and hydrogeological open-pit mine investigations.

Table 1. Key considerations in deciding where to drill for the hydrogeologist and geotechnical engineer in an open-pit mine study.

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<tr>
<th>Key considerations for the hydrogeologist:</th>
<th>Key considerations for the geotechnical engineer:</th>
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<tbody>
<tr>
<td>Good coverage across the pit and surrounding area</td>
<td>To target the rock mass which will form the critical pit slopes</td>
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<td>Holes should be drilled in all of the key hydrogeological units</td>
<td>Holes should be drilled in all of the key geotechnical zones</td>
</tr>
<tr>
<td>Vertical holes preferred for ease of piezometer and pump installation</td>
<td>Holes generally inclined so as to intersect and allow orientation of predominant rock mass fabric (bedding, jointing, or foliation)</td>
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<tr>
<td>Intersection of hanging wall and footwall rocks</td>
<td>Intersection of hangingwall and footwall rocks</td>
</tr>
<tr>
<td>Intersection of key structural features</td>
<td>Intersection of key structural features</td>
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<tr>
<td>Pumping well should be grouped with two nearby (10-100m) obliquely positioned observation wells</td>
<td>A range of borehole azimuths and dips can help to reduce the risk of biased intersection of structures</td>
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A key difference between the two programs is that of coverage. Most mine geotechnical studies look at gaining adequate coverage in key geotechnical zones across the area of the proposed pit and marginally beyond; whereas’ most hydrogeology studies must consider groundwater flow within the proposed pit footprint as well as the surrounding area. Sharing of holes is, therefore, often limited to those locations in the immediate vicinity of the pit and the more distal monitoring locations must be drilled specifically to meet the hydrogeological objectives.

A second commonplace conflict is that of the preference for vertically drilled holes for traditional piezometer installation i.e. an installation comprising a slotted pipe interval isolated in a gravel pack and sealed with bentonite. This type of installation is by far the most common form of piezometer installation as it is relatively low cost and can be undertaken using widely available materials. Traditional piezometers can often be adapted
to deep and steeply dipping holes by using methods for the emplacement of materials that help prevent bridging of materials in the annular space e.g. use of a tremmie pipe and mud pump for emplacement of the bentonite seal. However, it gets increasingly difficult to prevent bridging and to ensure a centralised piezometer pipe in a shallow dipping hole. As a general rule, 45° is the practical lower limit for installation of a piezometer with gravel pack and bentonite seal, although it is possible to overcome some of these problems with the use of more complex installation techniques involving the use of packers or grout traps. Vibrating wire piezometers may also offer a solution to this problem, although they can be more fragile over time and they negate the possibility of groundwater quality monitoring or sampling. However, even in situations where exclusively shallow dipping geotechnical boreholes are required, the cost savings of shared boreholes often outweigh the additional costs of vibrating wire piezometers if shallow groundwater sampling wells can be drilled separately using a relatively cheap drilling method. Furthermore, sub-vertical structures are often of more interest to open-pit hydrogeological investigations as they play an important role in controlling horizontal anisotropy, which in turn controls the dominant direction of groundwater flow to the pit. Inclined boreholes; therefore bring the added advantage that they are more likely to insect sub-vertical structures than vertically drilled boreholes.

The majority of considerations outlined in Table 1 are similar for both hydrogeological and geotechnical field data requirements. For example, target geotechnical zones often coincide with target hydrogeological horizons, for example, faults and fractures which control both hydraulic properties and slope stability. In an open pit environment both disciplines require information on the properties of the pit wall rocks rather than the material that will be mined out. In the case of the location of observation wells for pumping tests, the relatively large degree of flexibility with regards to location of pumping wells can mean that the hydrogeological drilling program can to a certain extent work around geotechnical requirements. For example, Figure 2(a) shows the configuration of hydrogeological holes drilled using down-the-hole hammer with air flush (shown in red) and geotechnical holes drilled using diamond coring (shown in yellow) for an integrated open-pit feasibility study investigation. The hydrogeological holes comprised one 150mm open hole pumping well (PPW4) and two discrete interval piezometers - PPW1 screened in the bedrock and PGP1 screened in the overlying glacial till. Both piezometers were installed with HDPE pipe, isolated in a gravel pack and sealed with bentonite. The geotechnical hole was converted to a discrete interval piezometer, screened in the bedrock, using HDPE pipe, sand pack and bentonite slurry emplaced using a mud pump. Figure 2(b) is a rosette plot of orientated fracture intersections logged from orientated core logging and AT surveys in the same geotechnical domain. Data show a predominance of NW-SE striking sub-vertical structures following the orientation of the main structural fabric – the foliation. PPW4 was located along strike from GT2, whilst PPW1 was located oblique to the strike of the main structures from PPW4. In this way anisotropy in the hydraulic properties of the bedrock could be quantified: one might anticipate the response in PPW1 to be less marked than in GT2 (i.e. enhanced permeability along the strike of the main structures), which indeed was found to be the case.

The benefits of shared borehole infrastructure are particularly pertinent to ground investigations for highly soluble commodities. Potash deposits are usually mined underground due to their high solubility. The ore and other soluble salt minerals are usually overlain by cap rocks comprising an aquitard horizon which in turn may be overlain by more permeable rock masses such as jointed limestones. Perforation of the aquitard increases the risk of groundwater flowing from overlying aquifers into the salt horizons which may result in dissolution of the salts, creating potholes and stability issues. To avoid this all boreholes need to be sealed with grout above the salt horizons which is costly, time consuming and may not always be fully achievable. Reducing the number of boreholes by using boreholes for both geotechnical and hydrogeological purposes significantly reduces not only costs but also the risk of groundwater ingress which would otherwise sterilise a large area of mineable ore.
Figure 2.  (a) Example layout of hydrogeological and geotechnical holes at a pumping test site, where PPW4 is a pumping well, PPW1 and PGP1 are piezometers and GT2 is a piezometer installed in a geotechnical borehole.  (b) Rosette plot of open structures of the same geotechnical domain in which this pumping test site is located.  PPW1 has been located oblique to the strike of the main fracture set from PPW4, whilst GT2 and PGP1 are located along strike from PPW4.

5 Scheduling

Another limitation to an integrated field program relates to the scheduling constraints of having two work programs operating in the same borehole.  For example, in-situ testing which is undertaken during drilling such as single packer testing is likely to slow the overall drilling rate of the geotechnical program.  Although this poses a hindrance to the geotechnical program, it brings a distinct advantage to the hydrogeological program in that well-informed decisions on piezometer target intervals can be made during drilling thus allowing piezometer installation to commence immediately upon completion of the hole.

Hydrogeological holes are often drilled with down-the-hole hammer or rotary methods, which are rapid compared with the rate of diamond coring.  If mobilisation distances allow, the slower drilling rates involved in the geotechnical program can often be off-set by drilling holes ear-marked for hydrogeological testing and installations first.  If the number of geotechnical holes required for the hydrogeological program is few compared with the number of hydrogeology specific boreholes which need to be drilled, then the scheduling impacts of an integrated program can be negated.  However, in the more common case where a significant proportion of the geotechnical holes are earmarked for hydrogeological testing and installation, then the hydrogeological schedule and subsequently the geotechnical data analysis may be impacted.

For a typical open-pit multi-disciplinary feasibility study, hydrogeological analysis would ideally be available to input into the geotechnical analyses after preliminary data collation and analysis has been completed; usually around one month after completion of geotechnical drilling.  Given that hydrogeological analysis and predictive modelling may take significantly longer than this, depending on complexity of the rock mass properties, this is usually only achievable if the hydrogeological field program is completed ahead of geotechnical drilling.  Where both programs finish at a similar time, the data analysis portions of both investigations must run concurrently with geotechnical analyses using preliminary hydrogeological data analysis in the initial slope stability calculations and vice-versa.  This brings the need for subsequent iterations of work undertaken by both disciplines and the potential for duplication of effort and delays.

Most of the scheduling conflicts relating to integrated field programs can be solved by way of devising a well thought out schedule during the planning phase of the works.  It is obviously critical that both hydrogeological
and geotechnical teams input fully into this and it is likely that it will be the focus of some discussion and deliberation. There can be upsides to the data analysis tasks being run concurrently as it ensures appropriate dialogue between the two disciplines and sharing of data following on from the site investigation phase. Furthermore, concurrent field programs mean that ongoing data from one program can be used to make running changes to the other in order to better target key features of interest. For example, intersection of a major fault zone during one program might lead to a change of proposed borehole locations in the other in order to investigate this.

6 Knowledge and skills sharing

Although perhaps not a justification in itself, one positive off-shoot from the integration of geotechnical and hydrogeological field programs is that of the opportunity to share knowledge, experience and provide cross-disciplinary training for staff. In turn multi-disciplinary staff may provide an opportunity for cost sharing. For example, hydrogeological field programs often require only minimal supervision during drilling but require sporadic extended periods of supervision during piezometer installation or hydraulic testing. If geotechnical logging duties can be flexible, resources can be switched between geotechnical logging and hydrogeological supervision to even out the workload and minimise the number of staff required on-site. However, there are drawbacks to this approach as complications with one field program might mean knock-on delays to the other. For example, it is not unusual for a protracted piezometer installation to be delayed by 6-12 hours or more, which may have an associated knock-on effect on the geotechnical logging schedule.

7 Developer perspective

Some project developers, in our experience, do not always recognise the benefits of an integrated program at scoping through feasibility stage of a mining project, in some cases perhaps due to a lack of guidance from the technical teams responsible for coordinating the study. There is often a bias towards the geotechnical program as the immediate priority is seen as derivation of pit slope angles and subsequent pit shell modelling. The detailed groundwater characterisation can lag behind as a result and the synergies of the integrated approach promoted here may not be fully realised. Maximum value is attained when the developer recognises the value of an integrated geotechnical, hydrogeological and structural geology assessment where data sharing and knowledge building of the project from this perspective enables an aligned engineering model incorporating pit slope stability and dewatering management to be developed and refined.

8 Summary and Conclusions

The key advantages and disadvantages of an integrated geotechnical-hydrogeological field investigation program discussed in this paper are summarised in Table 2.
Table 2. Summary of key advantages and disadvantages of integrated geotechnical-hydrogeological field programs.

<table>
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<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>Cost savings relating to; collection of groundwater observations during drilling; opportunity for in-situ hydraulic testing; use of geotechnical holes as open pumping and/or observation wells; use of geotechnical holes for installation of standpipes/piezometers; and shared on-site supervision.</td>
<td>Poorly developed diamond drilled holes can lead to artificially low permeability during in-situ testing or if geotechnical holes are used for subsequent installation of standpipes/piezometers.</td>
</tr>
<tr>
<td>Direct comparison of geotechnical and hydrogeological data for the same structures possible.</td>
<td>Geotechnical borehole locations usually limited to areas located close to the pit rim whereas hydrogeological program requires cover of the pit and the surrounding area.</td>
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<tr>
<td>Indirect and qualitative information on joint persistence in rock mass available prior to mining.</td>
<td>Shallow dipping geotechnical holes may not be suitable for installation of traditional piezometers.</td>
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<tr>
<td>In-situ hydraulic testing followed by piezometer installation in geotechnical holes allows for more informed placement of piezometer interval.</td>
<td>Single packer testing during geotechnical drilling may slow drilling progress.</td>
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<tr>
<td>Concurrent field programs means field results from one program can be used to make running changes to the other.</td>
<td>Slow rate of diamond coring may slow hydrogeological program.</td>
</tr>
<tr>
<td>Encourages integration between two disciplines and gives opportunity for sharing of knowledge and experience.</td>
<td>Delays in one program may have knock-on delays in the other.</td>
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<tr>
<td>More availability of mutually beneficial data during the data analysis phase in the more usual case where this is also undertaken concurrently.</td>
<td></td>
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<tr>
<td>Opportunity for cross-training of staff.</td>
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The examples provided herein show that there is often a significant technical advantage to combining geotechnical and hydrogeological site investigation programs. Moreover there is also the added benefit of reduced costs. Limiting factors to an integrated program usually relate to project specific conditions, which can often be overcome by careful upfront planning, good communication and a knowledge of the potential pitfalls and how best to avoid them. The list of pros and cons outlined here is by no means exhaustive and each specific project site will be subject to its own set of specific constraints. However, in the authors’ experience, the integration of field programs almost always brings a net benefit to the project. For some, this will come as no surprise as integration of these two disciplines is standard practice. However, geotechnical and hydrogeological disciplines are often considered in isolation with emphasis typically given to the geotechnical program by many developers at pre-design stage of mining projects. The challenge, then, is to show the value of an integrated field program at the earliest stages of a project to ensure the win-win outcome.
References
