Qualitative geotechnical hazard and risk assessment

E.C.F. Hamman
AngloGold-Ashanti Australia

Abstract

Reviews of Geotechnical Management Practices on mines are becoming an essential part of the due diligence exercises completed for corporate governance. In general, reviews tend to have a unique style, focussing on the current, visible, critical issues on the mine and issues deemed important by either the reviewer or a third party.
The disadvantage is that certain issues may be overlooked. Whilst a detailed hazard or risk assessment on any specific geotechnical issue is still the best process to understand and manage it, the detailed method cannot provide a comparative assessment for all the mines in a company.
A hazard questionnaire was developed to assess geotechnical hazards on a mine, and to evaluate the associated risk. The checklist methodology employed in this generic hazard questionnaire, facilitates comparison between different underground or open pit operations.
The paper will introduce the concepts of hazard and risk, familiarise the reader with the checklist assessment methodology used for geotechnical risk review, and explain the results obtained from the developed hazard questionnaire.

INTRODUCTION

Reviews of Geotechnical Management Practices on mines are becoming an essential part of the due diligence exercises completed for corporate governance. In general, reviews tend to have a unique style, focussing on the current, visible, critical issues on the mine and issues deemed important by either the reviewer or a third party.

These identified hazards are usually analysed in detail and the individual risk and proposed mitigation options reported to senior management or the board. The disadvantage is that certain issues may be overlooked. Another drawback is that geotechnical hazards and risks are perceived as exclusive events, restricted to one particular mine.

Whilst a detailed hazard or risk assessment on any specific geotechnical issue is still the best process to understand and manage it, this cannot provide a comparative assessment for all the mines in a company. Ideally, a comparative assessment should allow for ranking mines against one another and itself, highlighting improvement or decline of geotechnical management over time. The reporting format should be simple, with substantial backing data to validate the ranking results.

Consequently, a hazard questionnaire was developed to assess geotechnical hazards on a mine, and to evaluate the associated risk. The checklist hazard assessment methodology (Naismith, 1998) was employed to create a generic, geotechnical hazard questionnaire.

A reporting format was developed that could calculate the "one number" managers are so fond of, representing the Geotechnical status of a mine. This number could then be used to rate mines against each other or against itself, to see whether the geotechnical management has improved or not. However, it was found that to fully understand the "one number", certain refinements needed to be made.

TERMS RELATING TO HAZARD IDENTIFICATION AND RISK ASSESSMENT

Most of the terms and definitions relating to hazard identification and risk assessment in this paper, have been defined in a number of publications (3,4). New terms will be explained as they are introduced. Generally, these terms refer to concepts or groups of geotechnical issues listed in the compiled questionnaire or calculated values.

The publicised terms used are:

- Harm – The negative effect on personnel, a process or equipment.
- Hazard – Something with the potential to cause harm; any geohazard in this paper.
- Likelihood – Potential or probability of a hazard occurring.
- Impact – Socio-economic result of a hazard occurring.
- Risk – Likelihood that harm with a certain impact may occur from a specific hazard. (Mathematically - the product of likelihood and impact.)
- Qualitative Risk Analysis – The relative measure of risk, based on ranking or descriptive categories such as low, medium, high; or on a scale from 1 to 10.
- Quantitative Risk Analysis – The use of measurable and verifiable objective data to determine the probability of associated risks.
- Risk Management – The systematic application of management policies, procedures and practices to the tasks of analysing, evaluating, controlling and communicating risk issues.

Using these definitions, a risk assessment involves identifying hazards and calculating the risk, for example:

Consider a slope in terms of geometry, geotechnical fabric and adverse dipping faults that form a wedge. This wedge is an instability that exhibits an accelerating rate of movement due to heavy rainfall over the past 72 hours. This instability is a hazard that has a potential to fail due to the geometry and geotechnical characteristics. Now consider location of the slope. In one scenario, the slope is a sidewall in an abandoned open pit, and in another it is a road-cutting above a highway. The socio-economic impact of the hazard in the road-cutting is much greater than the hazard in the abandoned pit, therefore, the associated risk is greater.

This example also illustrates the concept of qualitative risk analysis vs quantitative analysis. In a qualitative analysis, the reader can intuitively make an assessment on hazards, contributing factors and alternate scenarios. In a quantitative analysis the reader will require exact measured and calculated data on rainfall, porewater pressures, rate of movement, shear strength properties, geometries, traffic flow, lane widths and instability volume to name but a few of the unknowns.

The geotechnical hazard questionnaire, employing the checklist methodology, was developed to facilitate a qualitative risk analysis, making use of a ranking system for likelihood and impact.

THE CHECKLIST METHODOLOGY

The checklist methodology used to assess a hazard, comprises of two phases. First, a series of questions are generated pertaining to the hazard(s). Secondly, individual scores or ratings are determined for each question, thereby providing an overall hazard score to assess the importance of a hazard (3).

Naismith (3) found that, whilst not satisfying all of the requirements for a hazard identification methodology, a checklist approach does provide an appropriate methodology where limited geotechnical engineering resources are available. General criticisms levelled at this checklist methodology include:

- Any checklist depends on the experience of the compiler and may not be comprehensive. However, omissions should become fewer over time as the checklist is used and updated.
- A checklist cannot cover every conceivable situation, therefore its relevance to the situation it is applied, or to any changing situation, must be questioned.
- A checklist tends to induce mechanical responses to items which feature on the checklist and suppresses consideration of anything which may have been omitted or may have changed.

In developing the geotechnical risk review questionnaire, geotechnical hazards (or geohazards) were identified and questions devised from literature, accident reports, personal experience of several industry specialists and analysing geotechnical activities. The questionnaire introduces hazards that may exist, query their likely consequences and promote thought on action that can be taken to ameliorate their effects.

Referring to the previous example, Table I illustrates typical questions that can be asked, using the checklist methodology, to define the hazard.

	Checklist Methodology Hazard Question	Y Score	N Score	Category	Class
1	Has there been rainfall in the last 72 hours?	20	0	Groundwater	A
2	Are pore pressure measurements taken?	0	20	Groundwater	B
3	Has there been any increase in pore pressure?	20	0	Groundwater	B
4	Is drainage/depressurisation in place?	0	20	Groundwater	C
5	Are there any major structures (faults/dykes)?	20	0	Geology	A
6	Are the geometries known for the major structures?	0	20	Geology	B
7	Do these structures contain fault gouge?	20	0	Geology	A
8	Has shear strength testing been completed on fault gouge?	0	20	Geology	B
9	Is a slope monitoring system in place?	0	20	Monitoring	C
10	Is there an alarm system in place?	0	20	Monitoring	C
11	Are catch fences installed?	0	20	Monitoring	C
12	Is access to the area controlled?	0	20	Monitoring	C

Table I *- Checklist Methodology Questions to Define and Score a Geotechnical Hazard*

HAZARD CLASSES AND CATEGORIES

The review questionnaire does not assess specific hazards (ie tailings dam, San Andreas fault or a specific support unit), it assesses the group of geotechnical issues pertaining to the physical aspects of a site, the database, understanding of geotechnical hazards, and procedures and strategies in place for effective geotechnical management on a mine. All the geotechnical hazards are consigned to descriptive classes and categories that facilitate reporting on the hazards and risks recognized during the review.

Categories are based on geotechnical characteristics, such as geology, geotechnical setting and groundwater, or on geotechnical management practices, such as monitoring, databases and procedures (1, 2). In the questionnaire, each category has a catalogue of questions, in which the hazards pertaining to that category are described and rated.

Referring to Table I, questions 1 to 4 could form part of a category on Groundwater, questions 5 to 8 a Geology category and questions 9 to 12 a Monitoring category.

The question catalogue is set up to distinguish different classes, whilst covering all the generic aspects of the said category. There are three main classes, each consisting of a number of categories (Table I). These classes are described below.

Class A - Site Characteristics

Site Characteristics aims to assess the physical geotechnical hazards within the mining area. These are permanent hazard, such as annual rainfall, fault orientation, rock types and existing infrastructure. In the questionnaire this class includes categories such as geology, rock mass properties, groundwater regime, surface water, surface features, surface infrastructure and underground infrastructure. Results from this class can be used to evaluate the base risk for geohazards, what Mother Nature provided, and existing infrastructure on all mines.

Class B - Site Knowledge

Site Knowledge assesses whether sufficient and relevant data is available for each of the physical geotechnical hazards. The understanding and information available on a hazard can change between reviews. Therefore, it can be seen as a measure of "awareness" and progress on a site for a specific hazard. Site knowledge consists of the same categories as Site Characteristics.

Class C - Site Controls

The last class aims to assess the strategies and procedures that a mine has in place to manage all the physical geotechnical hazards identified in the previous two classes. Changes in this class can be expected with each review, and indicate whether the geotechnical management on the mine is improving or declining. In the questionnaire, categories for this class include database, monitoring, reporting, design, failures, access roads, personnel, ground support and code of practice.

GEOTECHNICAL RISK REVIEW

A geotechnical risk review can be completed in three steps using the developed geotechnical hazard review questionnaire (1,2):

- Step 1 (Likelihood rating) – Assess the likelihood of identified geotechnical issues being hazards.
- Step 2 (Impact rating) – Evaluate the impact of the geotechnical hazards.
- Step 3 (Risk rating) – Calculate the associated risk.

Likelihood Rating

Likelihood rating is best explained using the previous slope example. Table II provides a Possible and Rated Score for all the relevant questions from Table I. Note, not all questions from a checklist are applicable, hence their scores are omitted in the totals. E.g. Blasting related questions for a soil excavation.

Once the questionnaire has been completed, the hazard rating for each catalogue question, category and class is automatically calculated as a percentage (Equation 1) of the possible score for the hazard (3).

	Checklist Methodology Hazard Question	Y Score	N Score	Possible Score	Rated Score	Likeli-hood
1	Has there been rainfall in the last 72 hours?	20	0	20	20	100%
‘’	‘’	‘’	‘’	‘’	‘’	
12	Is access to the area controlled?	0	20	20	0	0%
	Totals			240	180	75%

Table II *- Calculating the Likelihood Rating*

$$Rating_{Likelihood} = \frac{TotalScore_{Rated}}{TotalScore_{Possible}} = \frac{180}{240} = 75\% \qquad (1)$$

Bear in mind that physical geotechnical hazard categories, such as Geology and Groundwater, will contain questions and hazard ratings related to different classes.

Impact Rating

The impact a geotechnical hazard category may have on a mine can be evaluated for the whole category or for each question in the catalogue. The rating is determined from either reference guidelines used in the company, or alternatively using the Turnbull Impact Ranking guidelines set out below (Table III).

Level of impact	Ranking
Very minor or insignificant	1
Minor or insignificant	2
Insignificant	3
Potentially important in a single financial period in the short term	4
Important - potential to cause reasonable damage in the short term	5
Major - potential to cause significant damage in the short and medium term without threatening its survival	6
Could seriously weaken the Company without threatening its short term survival	7
Could threaten the survival of the Company	8
Significant threat to the survival of the Company	9

Table III *- Turnbull Impact Ranking*

The assessment should be done as a group of people, ideally from more than one discipline. It is important to record what the deciding factor is for each impact rating, to facilitate future or comparative assessment.

	Checklist Methodology Hazard Question	Likeli-hood	Impact Ranking	Impact
1	Has there been rainfall in the last 72 hours?	100%	3	33%
‘’	‘’			
12	Is access to the area controlled?	0%	6	67%
	Totals	75%	4	44%

Table IV *- Calculating the Impact Rating*

Table IV illustrates the impact rating calculation using the slope example. As with likelihood, the impact is calculated as a percentage (Equation 2) for each catalogue question, category and class.

$$Rating_{Impact} = \frac{ImpactRanking_{Rated}}{ImpactRanking_{Maximum}} = \frac{3}{9} = 33$$

Risk Rating

Once the likelihood and impact ratings have been calculated for each hazard category, the total likelihood and total impact for the classes can then be calculated as the average of all the assessed hazard categories. These values will then be used to evaluate and rate, the total geotechnical management risk of the whole mine.

Since risk is the product of likelihood and impact, Risk Rating can now be calculated (Equation 3) using the Hazard Rating and Impact Rating. Risk Rating can also be presented as a comparative graph, plotting Hazard Rating and Impact Rating on the Y and X axis' respectively. Table V illustrates calculating the risk rating as a percentage for the slope example.

	Checklist Methodology Hazard Question	Likeli-hood	Impact	Risk
1	Has there been rainfall in the last 72 hours?	100%	33%	33%
‘’	‘’			
12	Is access to the area controlled?	0%	67%	0%
	Totals	75%	44%	34%

Table V *- Calculating the Risk Rating*

$$Rating_{Risk} = Rating_{Likelihood} \times Rating_{Impact} = 75 \times 44 = 34\% \quad (3)$$

INTERPRETING RESULTS

The results from the geotechnical risk review need to be presented in a uniform format, to allow comparison between mines and reviews. Graphs and tables are good visual aids that enable a quick assessment or comparison, to identify critical areas. The reporting format uses a data-delving approach over three levels, starting with the final overall result in Level 1. The results of a completed review on an existing mine is used as an example to illustrate the concept.

Level 1 – Overall and Class Risk Rating

Figure 1 illustrates the final risk rating for the three classes, the total mine and the comparative total results for other mine sites. Management can now see how this mine relates to the other mines, and how the three classes contribute to the overall mine risk rating.

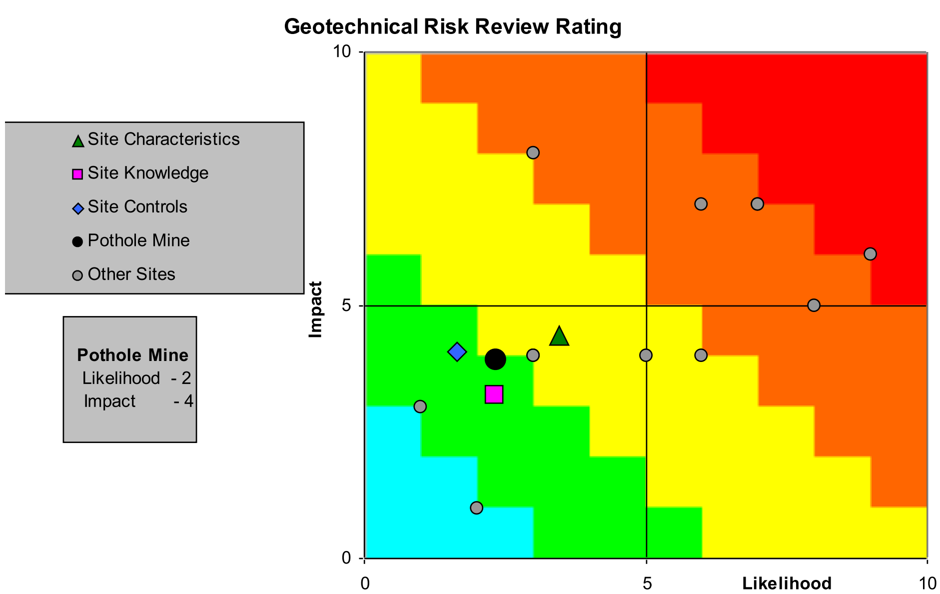

Figure 1 *- Comparative geotechnical risk review rating graph*

The Risk Rating graph can be divided into quarters depicting the level of Control and Manageability of the hazard (Figure 2). A lower likelihood denotes better control, and a lower impact denotes no extra management of the hazard.

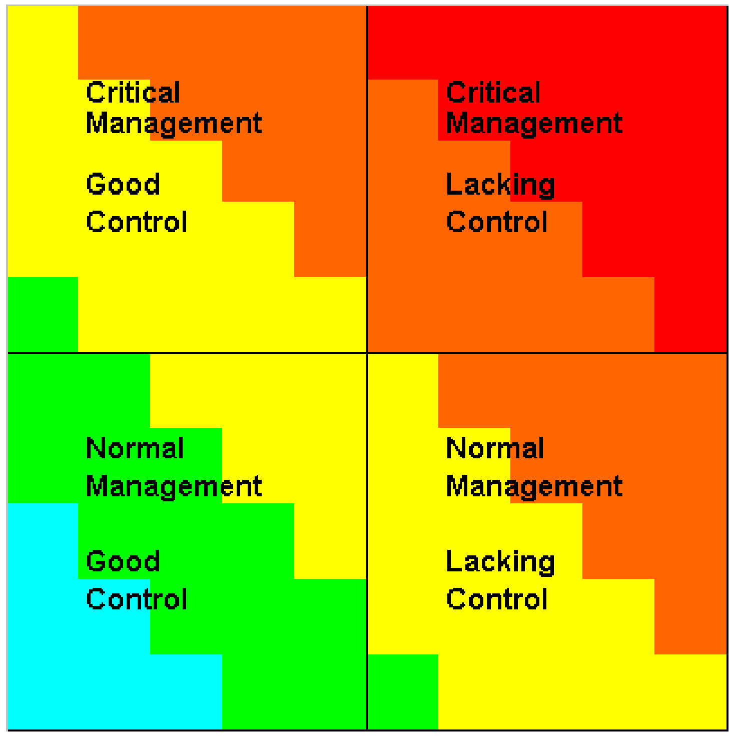

Figure 2 *- Control and Management required for the geotechnical hazard*

This means that the management and control for geotechnical risk on a mine can be expressed as a combination of the likelihood and impact ratings. For this example, the Risk Rating of 2/4 (Figure 1), means that there is a likelihood of 2 (20% likelihood) as calculated from the questionnaire and an impact of 4 (High cost, possible fatalities and reputation damage) as evaluated from the Turnbull impact ranking tables (or company impact ranking tables). Thus, the mine has Good Control on the overall geotechnical hazards and only requires Normal Management.

Level 2 – Category Risk Rating

As seen in Figure 1, Site Characteristics has the highest risk, and when the hazard categories for each class and their calculated likelihood ratings are investigated, the Groundwater category, within Site Characteristics, is the hazard with the highest risk rating (Figure 3). As discussed earlier, the Site Characteristics are representative of the physical environment or geohazards on a mine, therefore risk ratings for categories in this class will stay unchanged.

The higher the risk rating, the higher the level of control required to manage the hazard. Mines should aim for a likelihood rating of 10% for Site Knowledge and Site Controls as these classes are a measure of the knowledge, data and controls on a mine.

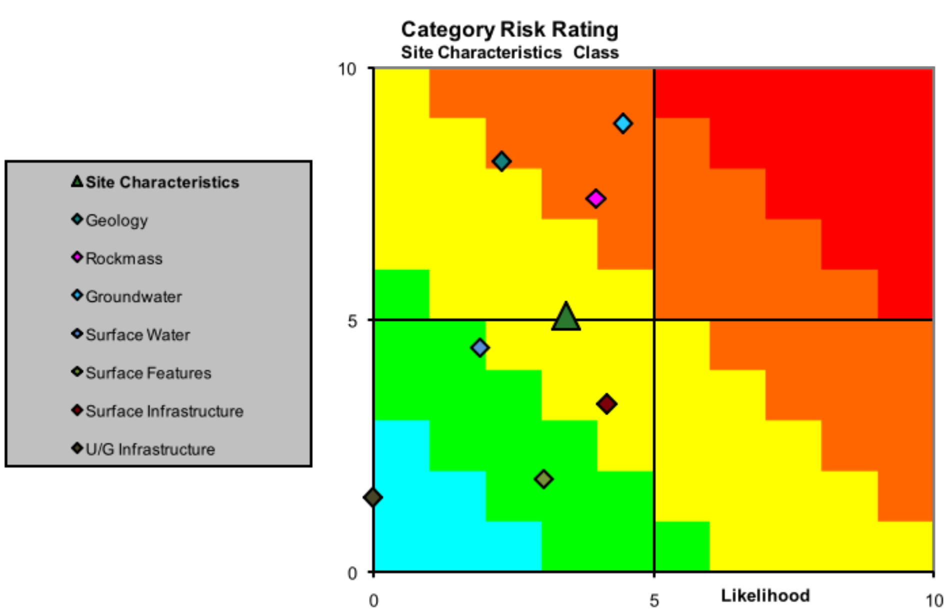

Figure 3 *- Geotechnical Risk Rating graph for categories*

Level 3 – Question Catalogue

The Groundwater category has been identified having the highest risk rating for the Site Characteristics class. By assessing the question catalogue for Groundwater, more insight can be gained on causes for the likelihood, impact and risk rating. Figure 4 is show the question catalogue of Groundwater category for the example.

NR	CHECKLIST QUESTIONS	Option	Score	Comment
1	Could mine workings intercept any permeable horizon or aquifer?	y	15	
2	What is the depth of natural groundwater? (Low, Moderate, High)	m	15	
3	Does the existing or planned mine workings intercept a surface water feature (river channel, lake, dam)?	n	0	
4	Does the existing or planned mine workings intercept the area of influence from a surface water feature (river channel, lake, dam)?	y	15	Drainage channel in the north of the pit.
5	Does a conduit (borehole, dyke or fault) exist, which could allow the passage of water from any permeable horizon/aquifer to mine workings?	y	15	
6	What is the potential inflow from any permeable horizon/aquifer in relation to the size of mine workings? (LMH)	m	15	
7	Could water inflow from a permeable horizon/aquifer become significant within one working period?	n	0	
8	Could the presence of groundwater give rise to pore-pressures?	y	15	
9	Could the presence of groundwater cause any reduction in intact rock strength through chemical or mechanical action?	n	0	
10	Do old workings, which may contain accumulations of water, lie above or adjacent to the existing or planned mine workings?	y	15	Water accumulation in old satellite pit.
11	Do any other accumulations of water lie above or adjacent to the existing or planned mine workings?	n	0	
12	Could the groundwater level rise significantly with rainfall recharge?	n	0	
13	Is the groundwater flow structurally controlled?	y	15	
14	Is water present in joints, bedding planes or within strata in the slope?	y	15	
15	Could circular failure occur in rockmass (high percentage soil) due to groundwater?	y	15	
16	Could groundwater flow cause liquifaction within rockmass (high percentage soil, fault gauge)?	y	15	
17	What is the estimated flow rate? (LMH)	y	15	
18	Could significant water pressures develop in joints, bedding planes or within strata in the face, hanging- or foot-wall?	y	15	
19	Would the current watertable contribute to circular failure?	n	0	
20	Could groundwater flow cause cavitation within the rockmass (high percentage soils, major fault gauge)?	n	0	
21	What is the "relative" porosity of the rockmass (LMH)?	l	0	
22	Could the groundwater regime be considered "homogenous" around the pit?	n	15	Fracture flow - never homogenous.
23	Will dewatering pumping be required?	y	15	
24	Has a hydrogeological study been completed for the area?	y	0	Will require an update in 1 year.
25	Has the permeability of the rockmass been established? (LMH)	l	0	
26	Has the current storage of the rockmass been established? (LMH)	l	0	
27	Has the annual recharge rate of the rockmass been established? (LMH)	l	0	
28	Has it been determined if any perched aquifers exist or form?	n	15	Perched acquifers has been found on neighbournig sites.
29	Has it been determined if closed compartments of groundwater exist along the mine workings (pit) perimeter?	y	0	
30	Has the required dewatering pumping been determined?	y	0	
31	Has yield test pumping been done?	na	0	
32	Has the transmissivity been calculated?	na	0	
33	Has the storage been calculated ?	na	0	
34	Have these results been incorporated into the design?	na	0	
35	Does a system exist which is capable of monitoring the groundwater level and inflow?	y	0	
36	Are records kept of the groundwater levels and inflow?	y	0	
37	Does a system exist to handle the groundwater and associated inflow?	y	0	
38	Are there weepholes in the slopes?	y	0	
39	Do procedures exist for instating, maintaining and monitoring the system?	n	15	Procedures in place for piezometer installations.
40	Are records kept of the pumping, storage and inflow?	y	0	
41	Are the groundwater procedures adhered to?	y	0	
42	Are water-bearing features identified and mapped on an ongoing basis?	n	15	
43	Are there any measurements/modelling of the current inflow/recharge?	n	15	
44	Is it known what the current dewatering system potential are?	n	15	
45	Could any inflow from a permeable horizon/aquifer be accommodated easily by existing water handling equipment/systems?	y	0	
46	Would additional water handling equipment/systems be needed to handle any increased inflow?	y	15	Monsoon rainfall events during rainy season.
47	Does the groundwater serve as a source of water to the mine?	n	0	
48	Is there a groundwater management plan?	n	15	
49	Is the groundwater management plan adhered to?	na	0	

Site Characteristics Hazard Score =	**240**
Total Possible Score for Site Characteristics =	**540**
Site Characteristics Hazard Rating =	**44%**
Site Knowledge Hazard Score =	**90**
Total Possible Score for Site Knowledge =	**285**
Site Knowledge Hazard Rating =	**32%**

Figure 4 *- Question Catalogue for Groundwater with Likelihood Calculation*

CONCLUSION

The questionnaire technique is a suitable qualitative risk assessment tool for a corporate office, or any reviewing entity, to evaluate geotechnical management and identify problem areas on a mine. However, due to the nature of detailed comments and review of each checklist question, it can take a long time, and as such is best conducted on an annual basis. In addition, some issues will either not be addressed fully, but through the continuous development of, or site specific additions to the questionnaires, these can be addressed over time.

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