Manual **017**

Alberta Energy Regulator

Coal Mine Pit Wall Abandonment

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1 Introduction

This manual provides guidance on the submission requirements, application process, and evaluation criteria for coal mine pit wall abandonment under the *Coal Conservation Rules* (*CCR*). The goal is to help industry assess the long-term safety and stability of pit slope features and reduce risks to acceptable levels.

An operator applies to abandon a coal mine pit wall either as a standalone application or as part of larger coal mine abandonment application.

This manual does not address conservation, closure, and reclamation requirements that are regulated under the *Environmental Protection and Enhancement Act* (*EPEA*) or the *Public Lands Act* (*PLA*).

2 Application Process and Evaluation

There are two applications involved in abandoning all or part of a coal mine:

1) The operator first applies for AER consent to carry out its proposed abandonment activities (as per section 12(2) of the *CCR*).
2) After the activities are complete, the operator then applies for an abandonment approval (as per section 12(3) of the *CCR*).

If the recommended processes outlined in this manual are followed, then both applications should be able to be processed and decided on within the defined timelines.

- The operator is encouraged to have a preapplication meeting with us to ensure that they understand the application requirements and that their proposed abandonment activities comply with the approved mine reclamation plan, the Alberta Environment and Parks (AEP) and AER end land-use requirements, and that the risk criteria and proposed factors of safety are appropriate and acceptable.
- Applications should be sent by email to coal.applications@aer.ca.
- We will first conduct an administrative review to ensure the application is complete.
- The application will be posted on the AER Public Notice of Application page.
- Anyone who believes they may be directly and adversely affected by an application may file a statement of concern. If we receive one, the standard process will be followed.
- Then we will complete a technical review of the application. Additional information may be requested.
- We will then decide to approve or deny the application. If we deny it, the applicant may file an appeal through the regulatory appeal process.

- We will provide the applicant with a link to the decision letter, which is accessible through the Integrated Application Registry. We will also share our decision on our Publication of Decision page and will send it directly to any statement-of-concern filers.

We will accept pit wall abandonment applications either on their own or as part of an overall coal mine site abandonment application.

We will evaluate pit wall abandonment applications considering all factors, such as rockfall assessment results, mitigation measures, factor of safety, performance history, seismic analysis results, and approved land use. We are not setting prescriptive values for these factors with the exception of the acceptability criteria for estimated risks.

3 Guidance on Submission Requirements

This chapter provides guidance on submission requirements for both of the applications outlined in section 2. The information supplements the requirements outlined in sections 12(2) and 12(3) of the *CCR*.

3.1 General Information

The operator should provide the following information. All maps should be submitted in DXF/DWG format and NAD 1983 coordinates.

3.1.1 Regional Map

Provide a regional map that shows and describes the following:

- mine location and lease boundary
- urban centres
- other industrial operations and lease boundaries, such as *EPEA*, *PLA*, *Water Act* boundaries
- other operations (i.e. O&G development, forestry operations, etc.)
- water bodies
- road, rail, pipeline, power and utility corridors, and other public works

3.1.2 Mine Layout

Provide maps and descriptions of the mine project area, including the following:

- approval boundary
- mine lease boundary and adjacent lease boundaries
- water bodies

- mine pits
- coal processing plants
- coal stockpiles
- coal reject/refuse and waste rock stockpiles defined as external discard mine dumps
- water dams and coal tailings dams
- site roads, rail, pipeline, power and utility corridors, and other site infrastructure

3.1.3 Coal Mine Pit Wall

Provide maps and descriptions of the coal mine pit walls to be abandoned, including the following:

- active mine operations
- what infrastructure has/is planned to be decommissioned for abandonment and when
- the pit slopes for which abandonment is requested
- "as built" plans and representative cross-sections of the pit slopes to be abandoned
- any previous approvals received for the pit slopes to be abandoned
- comparison of previously approved abandonment plans versus the currently proposed abandonment and the reasons and justifications for deviations (e.g., changes occurred through mine amendment)

3.1.4 Geology

Provide an overview of the regional and mine-scale geology, including the following:

- stratigraphy
- depositional setting
- any geological structures or features

An overview of regional geology and mine-scale geological controls should be included with representative cross-sections across the site. The geology and structural geological controls for each pit slope to be abandoned should be provided and indicated in the "as built" plans and cross-sections described in section 3.1.3.

3.1.5 Hydrogeology/Hydrology

Provide the general hydrogeology and hydrology conditions for the project area, as well as additional details for each pit wall to be abandoned.

Provide the appropriate water management strategies to isolate the mine wall areas from water impact. These may include control of surface water infiltration, both at the pit perimeters and at the mine wall toes, and drainage systems to mitigate and prevent buildup of pore water pressure. These systems should include a monitoring program and be incorporated into the final surface reclamation water management plan before a reclamation certificate can be applied for and issued.

3.1.6 Land Use

Describe the proposed end land use and any deviations from the approved end land use, including the following:

- recreational (camping, fishing, hunting, hiking, skiing, off road vehicles, etc.)
- forestry
- other industrial opportunities
- other land development potential (golf course, residential, commercial, retail)

Potential end land uses should align with AEP's requirements, which may be discussed in the preapplication meeting as outlined in section 2.

3.2 Pit Wall Slope Stability

The operator should include the following unless not applicable:

- slope stability assessment
- seismic analysis
- performance assessment
- rockfall and rockslide hazard assessment

3.2.1 Slope Stability Assessment

A slope stability assessment of the long-term stability of pit walls under a representative range of conditions should be submitted. Kinematically possible failure modes should also be assessed, including the following:

- planar failure
- wedge failure
- toppling failure
- broken rock mass

Assessment of the long-term stability, especially for the abandonment of footwalls, should consider reasonable worst-case scenarios for groundwater conditions at steady-state seepage and the appropriate mitigation to reduce pore water pressures where required.

We recognize that when a pit slope is initially designed, there is limited site-specific data available, especially during the initial mine or site development. Experience gained through observation, geological mapping, and operations should be applied to subsequent assessments of the pits. In order for us to evaluate the pit slope for abandonment, the operator needs to reassess the factor of safety for the slopes and provide the assumptions and input parameters chosen, including the rationale for their selection. The factor of safety reassessment should incorporate the end land use, which may be discussed in the preapplication meeting.

3.2.2 Seismic Analysis

The foothills and mountains of Alberta are mostly classified as low to moderate seismic hazard (http://www.seismescanada.rncan.gc.ca/hazard-alea/simphaz-en.php). Nevertheless, because the sedimentary rocks may have been severely folded and faulted, exposed pit slopes should be assessed under appropriate seismic loading conditions.

The operator should submit a pseudo-static slope stability analysis for the slopes to be abandoned and provide a rationale for the seismic coefficients and minimum factor of safety selected for the analysis.

3.2.3 Performance Assessment

The operator typically monitors pit slopes during mining operations to ensure they are safe for workers and equipment at the toe of the slope. After mining, the operator should continue monitoring the pit wall performance and record instances of rockfall or rockslide. The operator should provide a historical review of the pit wall to be abandoned including historical rockfall and rockslide incidents and an assessment of pit wall performance backed up by a minimum of five years of post-mining monitoring data.

The pit slope performance assessment should include at least the following:

- data from slope monitoring sensors and associated interpretation
- record of visual observations with photographs and associated interpretation
- data from digital imagery, satellite, or other available technology with associated interpretation

3.2.4 Rockfall and Rockslide Hazard Assessment

The operator should submit its assessment of rockfall or rockslide hazards for the pit walls that it requests to abandon. The operator should apply a consistent approach to assessing the rockfall and rockslide.

For the purposes of this manual, the terms “rockfall” and “rockslide” are defined as follows:

rockfall	A rapid movement (falling, rolling, or bouncing) of less than 100 m^3 of rock fragments from a coal mine pit slope.

rockslide — A mass movement of more than 100 m^3 of rock from a coal mine pit slope. Smaller rockslides may start as a large block of rock that fragments quickly and moves like a rockfall. Larger rockslides (greater than 100 000 m^3) may display higher mobility and move as one mass down the slope. The larger rockslides can start as a wedge, planar, or rock mass (circular or bi-modal) failure.

Several rock classification systems have been developed and widely used, such as the rock mass rating (Hoek 1995), the geological strength index (Marinos et al. 2007), and the rockfall hazard rating system (Pierson 1992). We recognize that these systems are typically applied in rock mechanics design and for highway-specific scenarios. The operator may need to tailor the systems or develop their own that is suitable for its own site. We recommend that the operator consider the factors and conditions in appendix 2 and develop a systematic method for rating their pit slopes.

The operator should distinguish the incidence of rockfall *after* mining from that *during* mining. Operational incidents may not reflect the frequency of rockfall of rockslide after mining because safety controls are implemented to reduce worker exposure to rockfall and rockslide, and not all incidents are necessarily reported.

3.3 Risk Assessment

We have adopted a quantitative risk-based approach based on the following landslide risk management practices and guidelines: Australian Geomechanics Society 2000, Fell et al. 2005, Fell and Hartford 1997, and ERM-Hong Kong Ltd. 1998. This section outlines a consistent way for mine operators to assess the risk to end land users resulting from rockslides and rockfall and to evaluate if desirable safety targets are achieved and if additional risk reduction measures are required.

For the purpose of evaluating rockfall and rockslide risks in the pit wall abandonment design, only the public safety impact is considered.

The operator should include the following three components:

- hazard identification
- risk analysis
- risk evaluation and criteria (including risk reduction measures)

Appendix 3 provides additional guidance to operators on assessing rockfall and rockslide risks in their pit wall abandonment applications.

3.3.1 Hazard Identification

Hazard identification requires an understanding of the slope-forming processes and the relationship of those processes to geomorphology, geology, hydrogeology, climate, and vegetation. The operator should

- identify the types of potential rockslide and rockfall;
- assess the physical extent of each potential rockslide and rockfall being considered, including the location, overall extent, and volume involved;
- assess the likely initiating events, the physical characteristics of the rocks involved, and the mechanics for rockslide or rockfall;
- estimate the resulting anticipated travel distance and velocity of movement; and
- address the possibility of fast-acting processes such as flows and falls, from which it is more difficult to escape.

There could be multiple potential hazardous events identified for a site. The operator should provide rationales and evidence to support their selection of hazardous events.

3.3.2 Risk Analysis

The risk of loss of life can be estimated from two perspectives:

- Individual risk is generally described as the risk to a single person exposed to a hazard.
- Societal risk is generally described as the risk to groups of people who might be affected by hazardous events.

The operator should estimate both individual risk and societal risk. The societal risk should consider the end land-use types described in section 3.1.6.

Because of the danger that the estimated risk numbers could be used in a simplistic and mechanical way without recognition of the uncertainties, sensitivity analyses are useful to evaluate the effect of changing assumptions or estimates.

The operator should clearly state assumptions used in the risk analysis and the resulting sensitivity (i.e., variations in the estimated risk) in the submission. If a sensitivity analysis is not carried out, the operator should explain some of the limitations and uncertainty in the risk estimates.

3.3.3 Risk Evaluation and Criteria

Risk evaluation involves comparing estimated levels of risk (see section 3.3.2) with AER-adopted risk criteria (see figures 1 and 2); and identifying existing risk reduction measures and consider whether any further risk reduction measures should be implemented.

Risks cannot always be completely eliminated, but they should be reduced at least to a level that is “as low as reasonably practicable,” meaning they are tolerable only if it can be demonstrated that all reasonable and practicable measures have been taken commensurate with the level of assessed risk (Canadian Standard Association 2017).

The "as low as reasonably practicable" principle divides risks into three bands

- an upper band called "intolerable," where risk cannot be justified except in extraordinary circumstances;
- a middle band called "as low as reasonably practicable," where risk is tolerable only if it can be demonstrated that all reasonable and practicable measures have been taken; and
- a lower band called "broadly tolerable," where risk needs to be maintained to assure it remains at this level.

The "as low as reasonably practicable" risk region is bounded by an upper tolerability limit and a lower tolerability limit. Organizations worldwide developed their own risk tolerability limits based on societal values supported by historical data (Macciotta and Lefsrud 2018). The AER adopted the following tolerability limits for evaluating risks to public safety from rockfall and rockslides in pit wall abandonment planning and designs

- for individual risk, the upper tolerability limit is 1 fatality per 10 000 years, and the lower tolerability limit is 1 fatality per 1 000 000 years (see figure 1); and
- for societal risk, the upper tolerability limit and lower tolerability limit are specified in figure 2.

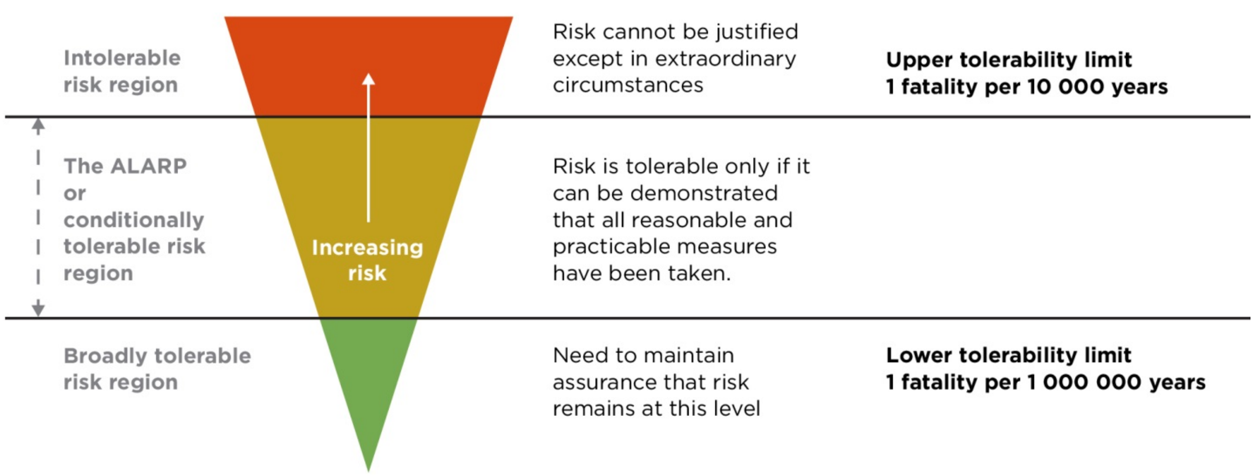

Figure 1. Individual risk evaluation criteria using the "as low as reasonably practicable" principle (modified from Canadian Standard Association 2017)

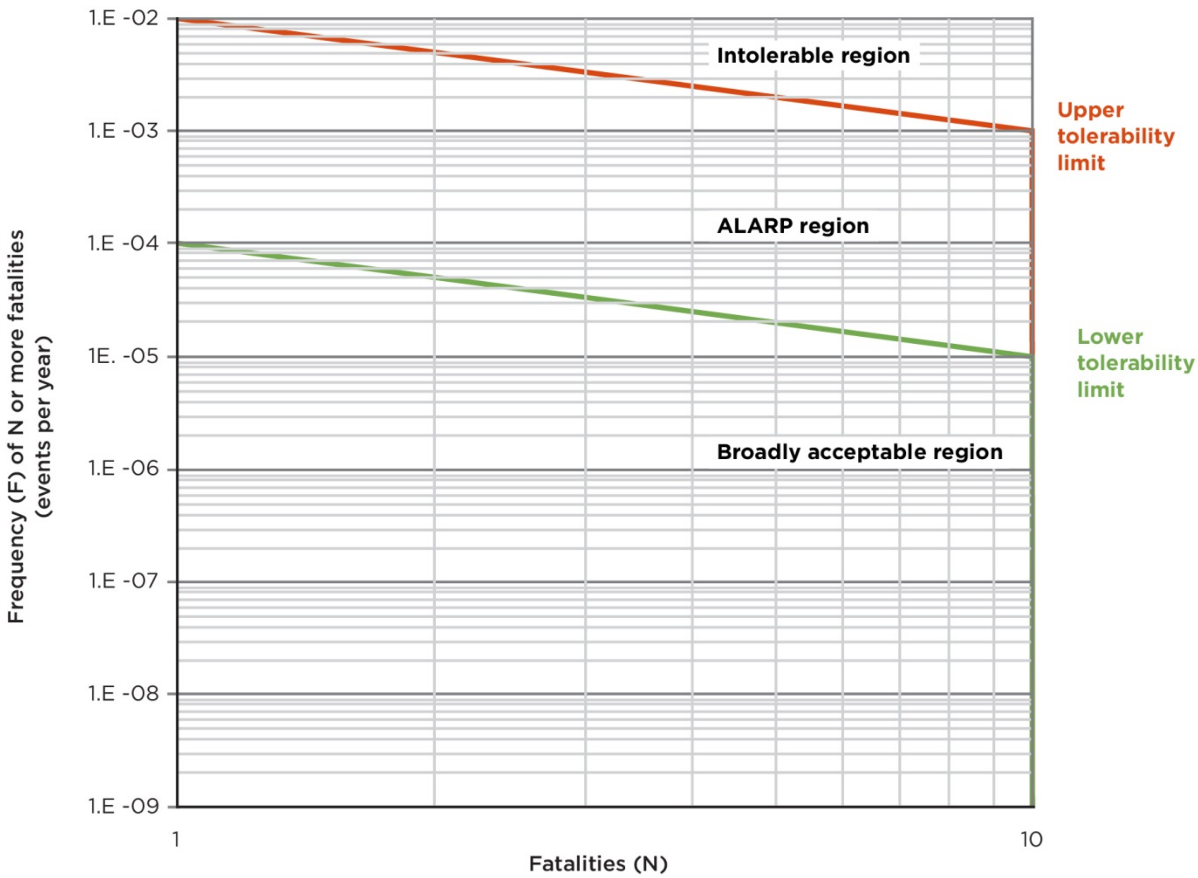

Figure 2. Societal risk evaluation criteria using the “as low as reasonably practicable” principle

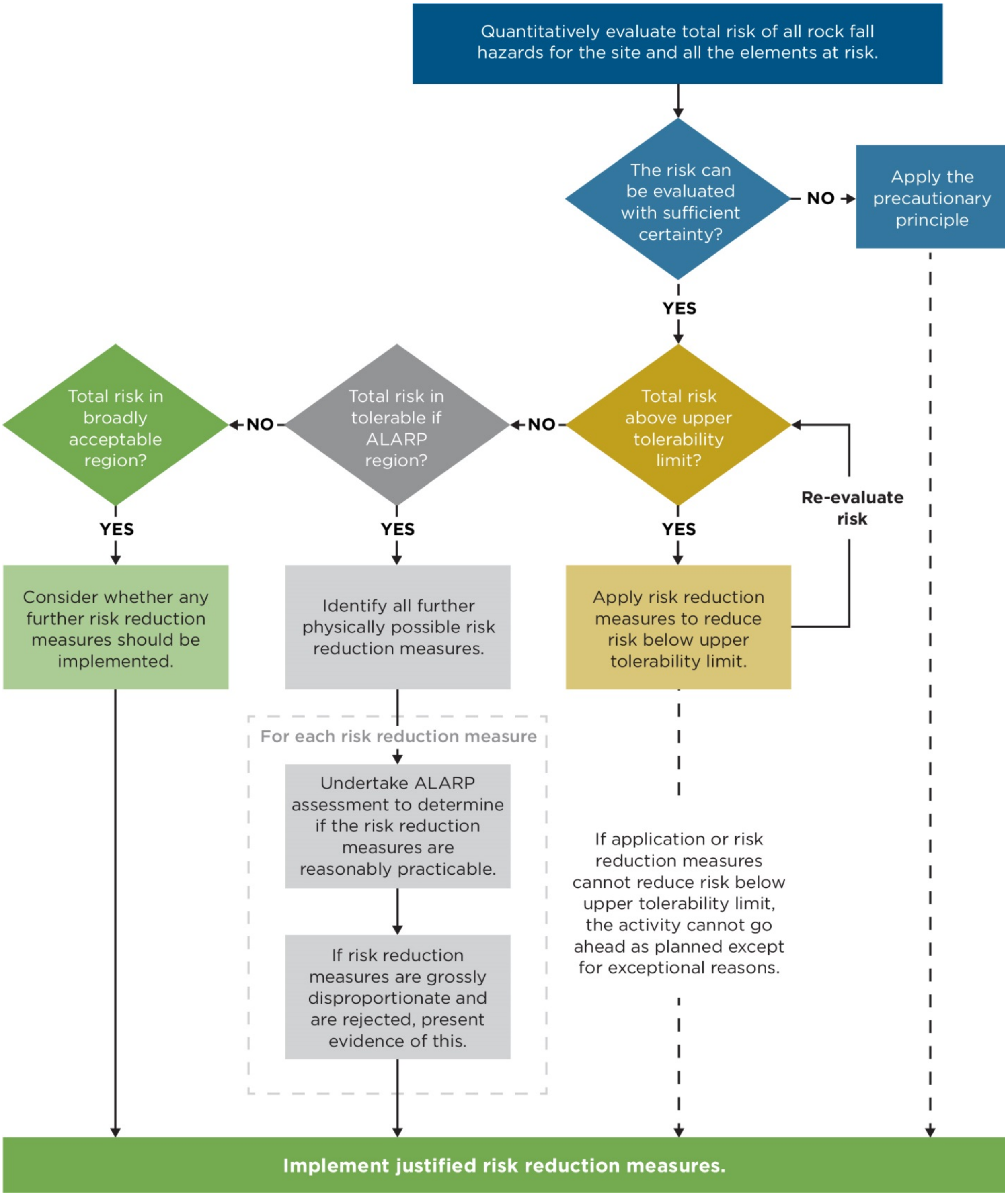

Figure 3. How to apply the "as low as reasonably practicable" principle (modified from Commission for Energy Regulation 2013)

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Appendix 1 Glossary

as low as reasonably practicable	The concept that risk is tolerable only if it can be demonstrated that all reasonable and practicable measures have been taken commensurate with the level of assessed risk (Canadian Standard Association 2017).
endwall	The pit wall created in a surface coal mine that connects two main pit walls together, usually a footwall to a highwall.
footwall	A pit wall created in a surface coal mine by the strata underlying a coal seam once it is mined.
highwall	The pit wall created in a surface coal mine by an unexcavated face of exposed overburden and coal.
individual risk	It is generally described as the risk to a single person exposed to a hazard. In this manual, it is expressed as the total annual chance that a person at some distance from the abandoned pit wall slope might die due to all potential hazardous events at the slope.
pit wall	Either a footwall, highwall, or the endwall of a surface coal mine pit.
rockfall	A rapid movement (falling, rolling, or bouncing) of less than 100 m^3 of rock fragments from a coal mine pit slope.
rockslide	A mass movement of more than 100 m^3 of rock from a coal mine pit slope. Smaller rockslides may start as a large block of rock that fragments quickly and moves like a rockfall. Larger rockslides (greater than 100 000 m^3) may display higher mobility and move as one mass down the slope. The larger rockslides can start as a wedge, planar, or rock mass (circular or bi-modal) failure.
societal risk	It is generally described as the risk to groups of people who might be affected by hazardous events. In this manual, it is expressed as the expected number of deaths per year due to potential hazardous events at the abandoned pit wall slope.

Appendix 2 Rock Slope Characterization Example Factors and Conditions

Possible factors and conditions for rock slope characterization are described here. A mine operator may adjust as necessary for their specific needs. It is paramount that the assessment be applied consistently and be clearly rationalized.

Discontinuities

There are three important factors for discontinuities:

- Orientation
- Spacing
- Roughness

The discontinuities in sedimentary rocks may include bedding planes, two orthogonal joint sets, and tectonic faults (thrust, strike-slip). Bedding planes are pervasive and continuous, joints sets are pervasive and not continuous, and faults are typically discrete and continuous. The orientation has a large influence on the occurrence of rockslides and rockfall. Unfavourable orientation of discontinuities permits rocks to slide-fall and topple-fall from the pit slope. Similarly unfavourable orientations permit larger wedge and planar failures to initiate rockslides.

Other things being equal, when joint sets and bedding are closely spaced, rockfall should be more frequent, although blocks of rock are smaller and have less destructive energy. Widely spaced joints and beds create larger blocks of rock and would dislodge less frequently, although they may bounce and roll further. A larger rock is more destructive. Considering probabilities, smaller, more frequent rockfall may generate a higher risk for individuals.

Roughness of bedding, joint, and fault surfaces influence the ease with which rocks can be dislodged by freezing and thawing and affects the angle at which rocks will slide. A rough discontinuity may add several degrees of resistance to the friction angle compared to a planar, slickensided, or weak infilled discontinuity. Bedding planes are rougher than joint sets, which tend to be more planar and smoother. Because beds are pervasive and continuous, the friction resistance is very important. Joints sets are pervasive and not continuous, and larger wedge or planar failures that require shearing through intact rock are less likely to occur.

Weathering

Weaker or softer, thinly bedded mudstone and shale weather and erode faster than siltstone, quartzite, and sandstone. When mudstone and shale beds are exposed in a final pit wall and weather faster than overlying rock, blocks will fall in response to loss of support. Similarly, a toppling failure mechanism is accelerated when weaker beds weather and erode faster than adjacent stronger beds.

Seepage

Classify the influence of seepage on a sedimentary rock slope based on the following premises:

- Coal mine pit slopes are well drained at and behind the slope face because of bedding and joint sets. The discontinuities are more open and free draining near the slope face in response to blasting and excavation with large mining equipment.
- Seepage is a normal response to rainfall and snowmelt and has no adverse effect in these situations.
- Seepage that appears throughout the spring thaw indicates a seasonally higher groundwater table and will have no adverse effect in most cases. However, should the duration of the seepage become longer or become more widespread, a change in groundwater conditions is occurring behind the slope and may affect slope performance. It is important to understand what is affecting the increase in groundwater.
- Seepage accelerates the weathering and erosion of weaker shale or mudstone beds. Seepage may support vegetation growth on the rock face. Roots, especially of trees, wedge rock loose.
- Seepage that is present on the pit slope much of the year indicates a higher groundwater table that exits in the slope. Soft rock weathers and erodes faster in the presence of water.
- Winter seepage freezes and forms ice sheets and ice in discontinuities. Ice in discontinuities exerts high physical forces that loosen rock on the slope.

Freeze-Thaw Cycles

Freeze-thaw cycles are common for all coal mines in Alberta. They occur in the fall and spring and have more influence in the spring because diurnal temperatures vary more and more water is available to expand and contract when it freezes and thaws.

Evidence of Rockfall

Rockfall accumulation (talus) at the base of pit slopes is strong evidence of rockfall. The challenge is to distinguish rock that has fallen *after* completion of mining from rock that has fallen *during* mining in direct response to the disturbance of the mining operation. The incidence of rockfall may be artificially inflated if post-mining rockfall cannot be distinguished from rockfall during active mining. The operator should assess the rockfall after mining is finished in the pit and annually for five years to provide evidence of trends after mining. Photographs, videos, and digital imagery taken from the same place over time are useful in this regard.

Appendix 3 Assessing Rockfall and Rockslide Risk

Hazard Identification

Methods for hazard identification include geomorphological mapping and gathering of historic information on rockfall and rockslide in similar topography, geology, and climate. When identifying possible hazards, considerations should be given to hazards located both on and off site. It is important that the analysis includes the full range of hazardous events (from small, high-frequency events to large, low-frequency events). The effects of additional development on the slope should also be considered, as these effects may alter the nature and frequency of possible hazardous events (Fell et al. 2005).

Annual Frequency of the Hazardous Event

The annual frequency of the hazardous event *H* (rockfall or rockslide) is expressed as

- the number of rockfall or rockslide that may occur in a particular slope per year,
- the probability of a particular slope experiencing rockfall or rockslide in a given period (e.g., a year), or
- the probability of driving forces for a rockfall or rockslide exceeding the resistance forces.

The operators may choose to apply any number of methods to assess and estimate the frequency, depending on what information is available and the specific-site conditions. Upon receiving the application, we will review and assess the appropriateness of assessment methods and reasonableness of the estimated probability. The following provides a few examples of estimating frequency:

- field inspection and observation
- historical data on the number of rockfalls in time and space, using predicted relative frequency
- mapping and interpretation of the geological, hydrogeological, geomorphological, and engineering history of the site and environs to form appropriate models
- data on site history, movement, occurrence, seismicity, rainfall, etc. using sources such as historical records, previous survey plans, published data, and reports

Temporal-Spatial Probability

Risk estimation requires considering people who either live or may spend some time in the area affected by rockfall and rockslide. The operator should include factors such as

- the number and geographic distribution of the population,
- the population type (e.g., residential, school, industrial), and
- the likelihood of people being present (i.e., including the number of hours a day people are present).

The temporal-spatial probability is the probability that a person will be in the area affected by the rockfall or rockslide at the time of its occurrence (Fell et al. 2005). Factors that should be considered in relation to temporal-spatial probability include whether

- the affected person occupies or frequents the areas where rockfalls and rockslides may occur,
- there is varying occupancy of the area (e.g., night vs. day, week days vs. weekends, summer vs. winter); and
- the person will have sufficient warning to evacuate the area.

Vulnerability

The operator should discuss and calculate the "vulnerability" (probability of loss of life of an individual given an impact from a rockfall or rockslide) of affected persons. Influential factors include the following:

- size of rocks
- mechanism, initiation, and velocity of rockfall or rockslide
- whether the persons are in the open or enclosed in a vehicle or building
- whether the vehicle or building collapses when impacted by debris
- the type of collapse if the vehicle or building collapses

Individual Risk

Individual risk is expressed as annual probability that a specific individual (i.e., a person who lives or spends some time in the area affected by rockfall and rockslide from the abandoned pit wall slope) might die due to a hazardous event *H*. It can be calculated as follows:

$$IR = f(H) \times P(S|H) \times P(T|S) \times V(L|T)$$

IR	annual probability that a specific individual might die due to a hazardous event H
$f(H)$	annual frequency of a hazardous event H
$P(S\|H)$	probability of a specific individual is on the path of rockfall or rockslide given a hazardous event H
$P(T\|S)$	probability of a specific individual is in the area affected by rockfall or rockslide at the time of its occurrence
$V(L\|T)$	probability of loss of life to a specific individual given the person is on the path of rockfall or rockslide at the time of its occurrence

Total individual risk is expressed as the total annual probability that a specific individual might die due to *all* potential hazardous events at the slope.

Societal Risk

Societal risk is expressed using plots of cumulative frequency (F) of rockfall and rockslide per year causing N or more fatalities, versus the number of fatalities due to rockfall and rockslide. These are commonly referred as FN curves.

The construction of an FN curve includes the following four steps:

1) Calculate the annual frequency of fatalities (f_i) for each hazardous event H_i:

$$f_i = f(H_i) \times P(S|H_i) \times P(T|S)$$

$f(H_i)$	annual frequency of a hazardous event H_i
$P(S\|H_i)$	probability of people are on the path of rockfall or rockslide given a hazardous event H_i
$P(T\|S)$	probability of people are in the area affected by a hazardous event H_i at the time of its occurrence

2) Calculate the number of fatalities (N_i) for each hazardous event H_i:

$$N_i = N(H_i) \times V(L|T)$$

$N(H_i)$	number of people in the area affected by a hazardous event H_i at the time of its occurrence
$V(L\|T)$	probability of fatality given people are on the path of rockfall or rockslide at the time of its occurrence

3) Sort the calculated (f_i, N_i) for all hazardous events from the lowest to highest fatalities (table 1)

Table 1. Example list of calculated (f_i, N_i) for all hazardous events, sorted by number of fatalities

H	f_i	N_i
H_1	4.8×10^{-4}	1
H_4	8.0×10^{-5}	1
H_3	7.0×10^{-4}	2
H_2	6.2×10^{-6}	3
H_5	1.2×10^{-6}	4

4) Calculate the cumulative frequency (F) of rockfall and rockslide per year causing N or more fatalities (table 2)

Table 2. Example list of calculated cumulative frequency (*F*) of rockfall and rockslide per year causing *N* or more fatalities

Fatalities	Hazardous events	Sum of f_i for each event causing *N* or more fatalities
1 or more	H_1, H_4, H_3, H_2, and H_5	1.27×10^{-3}
2 or more	H_3, H_2, and H_5	7.07×10^{-4}
3 or more	H_2 and H_5	7.40×10^{-6}
4 or more	H_5	1.20×10^{-6}

5) Plot each F,N pair on a log-log graph (figure 3)

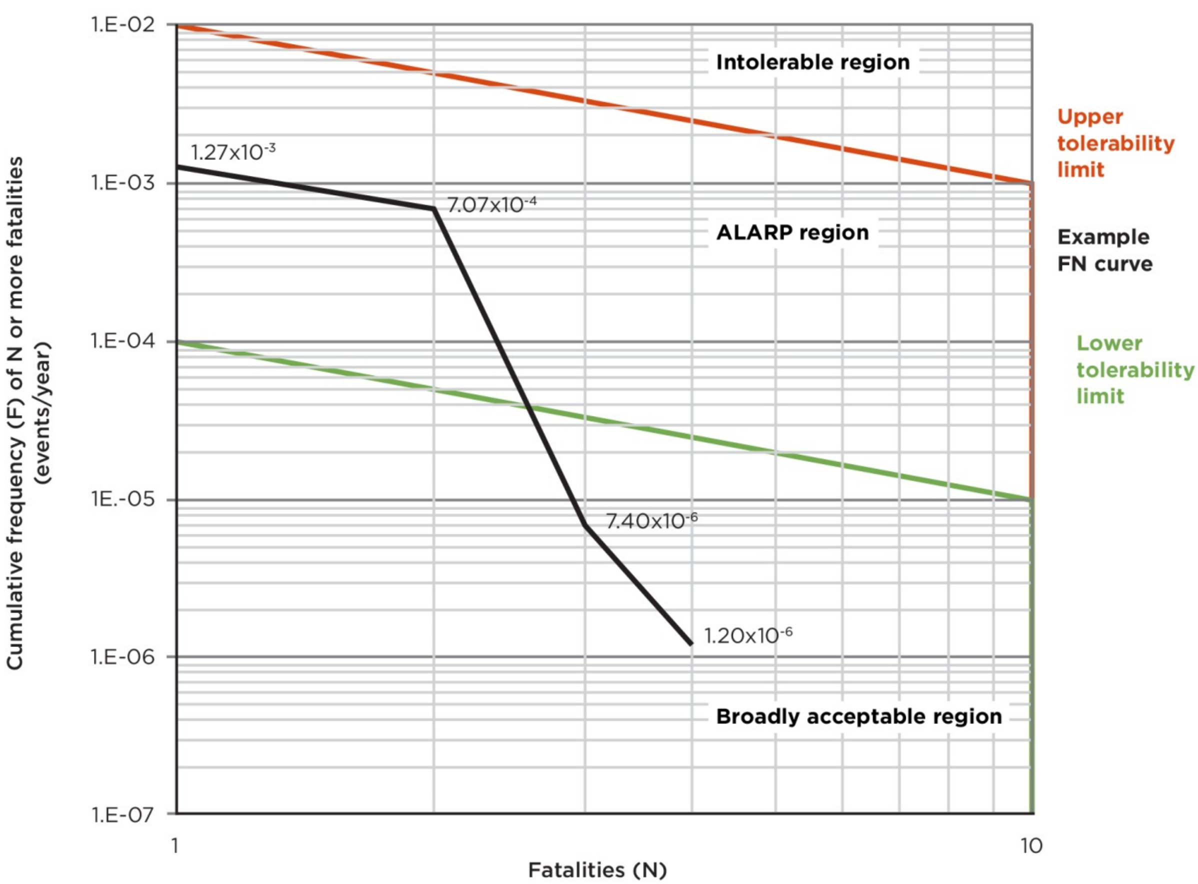

Figure 4. A sample FN curve