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Failure Mode and Effect Analysis at Ely Copper Mine Superfund Site

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Failure Mode and Effect Analysis at Ely Copper Mine Superfund Site

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This document has been prepared by SLR International Corporation. The material and data in this technical report were prepared under the supervision and direction of the undersigned.

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ACRONYMS

bgs	Below Ground Surface
BMP	Best Management Practice
EBOR	East Branch of the Ompompanoosuc River
EMFI	Ely Mine Forest, Inc.
FMEA	Failure Modes and Effects Analysis
FS	Feasibility Study
gpm	Gallons Per Minute
IDF	Intensity Distribution Function
LUGW	Lower Underground Workings
MIW	Mining Influenced Water
MMI	Modified Mercalli Intensity
OU	Operable Unit
pcf	Pounds Per Cubic Foot
PGA	Peak Ground Acceleration
ROD	Record of Decision
RI	Remedial Investigation
RPN	Risk Priority Number
SLR	SLR International Corporation
USEPA	United States Environmental Protection Agency
USGS	US Geological Survey
UUGW	Upper Underground Workings

1. INTRODUCTION

1.1 TERMS OF REFERENCE

This Technical Report presents the Failure Mode and Effect Analysis (FMEA) conducted at the Ely Copper Mine Superfund Site (Ely Mine) by SLR International Corporation (SLR). The FMEA reported in this Technical Report is focused on the underground workings (adits, shafts, stopes, etc.) of the Ely Mine and impacts from potential releases of mining influenced water (MIW) from those underground workings. This FMEA was developed in support of the Operable Unit 2 (OU2) and Operable Unit 3 (OU3) Remedial Investigation and Feasibility Study (RI/FS) and Record of Decision as well as the Operable Unit 1 Remedial Design. The FMEA scope was limited to identifying the potential failure modes that could impact remedial actions planned or proposed for the Ely Mine and what failure modes may remain unresolved as a result of the planned or proposed remedial actions. While this FMEA does discuss mitigation and contingency measures, the assumption is that activity specific FMEAs will be developed in support of the design efforts for each Operable Unit and that the selection and more rigorous evaluation of these measures would be conducted at that time.

The FMEA was performed at the request of Mr. Andy Boeckeler of Nobis Engineering Inc. (Nobis) and under subcontract 15-NH80070-008 between SLR and Nobis.

The FMEA and this Technical Report were prepared by Dr. Tarik Hadj-Hamou and Mr. Ryan Dougherty of SLR and reviewed by Dr. Ian Hutchison, also of SLR.

1.2 FMEA TEAM

The FMEA was performed under the direction of Dr. Ian Hutchison of SLR. The following technical staff participated in the FMEA and the preparation of the Technical Report:

- Dr. Ian Hutchison (SLR) – A civil engineer with 40 years of experience in mining engineering and experience in risk analysis and the performance of FMEA.
- Dr. Tarik Hadj-Hamou (SLR) – A civil engineer with over 35 years of experience in geotechnical engineering including stability analysis of earth structures (tunnels, slopes) and experience in probabilistic, hazard, and risk analysis.
- Mr. Ryan Dougherty (SLR) – A staff geologist with three years of mining engineering experience.
- Mr. Carl Fietze (SLR – Africa) – An engineering geologist with 20 years of experience in underground rock engineering and slope stability. Assisted with the assessment of the adit stability.
- Mr. Andy Boeckeler (Nobis) – Project manager, who managed and oversaw the preparation of the Remedial Investigation Report and Feasibility Study for Operable Units 2 and 3 at Ely Mine.

- Mr. Brett Kay (Nobis) – senior engineer familiar with the closure construction activities to be carried out at Ely Mine and was involved in preparing the Remedial Investigation Report and Feasibility Study for Operable Units 2 and 3 at Ely Mine.
- Mr. Matt Kierstead (Milestone Heritage Consulting) – A mine historian with over 25 years of experience and a deep knowledge of the conditions at Ely Mine and was involved in the writing of the report Historic/Archaeological Mapping and Testing, Ely Mine Site Volume I by PAL.

A working FMEA session was held at the Ely mine during the site visit conducted on December 10, 2015. This working session was attended by Mr. Brett Kay and Chris Adams of Nobis, Dr. Tarik Hadj-Hamou of SLR, Mr. Ed Hathaway of the USEPA Region 1, Mr. Matt Kierstead of Milestone Heritage Consulting. During the working session, the context and overall purpose of the FMEA was established. The working session also included an initial assessment of the potential impacts of a MIW release at the Ely Mine. Those impacts include: potential damage to site and local infrastructure (primarily site access roads and the culvert under South Vershire Road); potential threats to site workers or visitors during a release as well as any equipment in the path of release; ecological impacts to the Ponds, Ely Brook and its tributaries, Schoolhouse Brook, and the East Branch of the Ompompanoosuc River (EBOR). These impacts are summarized in Section 3 and discussed in Section 6 of this Report.

Preparation of the FMEA involved meetings and conference calls with the technical staff listed above.

A draft version of the Report was sent out to Mr. Ed Hathaway (United States Environmental Protection Agency [USEPA] Region 1) who reviewed the Report with the support of the EPA National Mining Team.

2. PURPOSE

The US Environmental Protection Agency (USEPA) requested the performance of the FMEA of the underground workings at the Ely Mine with a focus on the risks associated with the potential release of MIW.

The purpose of the FMEA is to provide the USEPA, contractors, and other agencies that will develop the closure plan for Ely Mine, oversee the closure construction activities, and manage the closed mine with an appreciation of the risks at each stage of the process. This FMEA was not developed to select or provide the rigorous evaluation of the mitigation, contingency, and planning measures that may be required to address the identified failure modes.

The FMEA identifies potential failure modes associated with the underground workings and considers triggering events such as earthquakes, extreme weather, and disturbances induced during the performance of additional investigations such as drilling and exploration and during construction of the remedy such as, excavation in front of collapsed portals, ground vibrations, unloading of waste, etc. The FMEA focuses on potential impacts from the release of MIW on individuals working or visiting the Ely Mine, the facilities at Ely Mine such as the access roads and the culvert under South Vershire Road, and the ecological features including the Ponds, Ely Brook and its tributaries, SHB, and the EBOR.

3. BACKGROUND

3.1 ELY MINE

The Ely Mine is an abandoned copper mine near Vershire, Orange County, Vermont. Ely Mine lies in the Ely Brook valley north of Schoolhouse Brook, a tributary of the Ompompanoosuc River. The mine was exploited from 1853 to the early 1900's and again sporadically during World Wars I and II. Ely Mine is within a 20-mile long ore deposit that is known as the Vermont Copper Belt. The area was the location of several other mines.

The former Ely Copper Mine was an underground hardrock mine with shafts, stopes, and adits. The main shaft of the mine ("Main Shaft") extends to a depth of approximately 1,400 ft. below ground surface (bgs). The first comprehensive exploration plan was developed by Rittler in 1859 and included a series of adits and shafts that either existed at that time or were being suggested for development. Due to the orientation of the ore body, some of those adits were created. Successive owners and/or operators of the mine developed other plans to better follow the ore body and extract the richest ore. In 1944 the US Geological Survey (USGS) published a report detailing the geology of the area and including a series of plates describing the underground workings (White and Eric, 1944). The layout and associated cross sections developed by USGS (Plates 3 and 4, of White and Eric, 1944) are still considered current. Adits and shafts were named according to the mine engineers, mine managers, or owners and the year of construction. Consequently, with changes of ownership, the adits and shafts have been labelled inconsistently between documents. Nobis (2016) developed a naming convention that will be used herein. The plan view and cross sections of the underground workings currently used with the Nobis naming convention are shown on Figures 3-1 and 3-2 adapted from Nobis (2015a, 2016). A complete and detailed description of the underground workings, their history, and estimated dimensions, as well as a detailed description of other features at Ely Mine are provided in PAL (2005) and Nobis (2015a, 2015b). Information relevant to the FMEA includes:

- Layout of the underground workings;
- Geology of Ely Mine;
- Groundwater regimes as understood in 2016; and
- Proposed remediation because of potential impacts.

This information was obtained from the previously referenced documents as needed for the FMEA. Table 3-1 summarizes the naming convention and status of the mine workings relevant to this FMEA as of June 2016.

3.1.1 SITE OPERABLE UNITS AND PROPOSED ACTIONS

To facilitate the evaluation and implementation of actions to reduce, eliminate, or control actual or potential human-health and ecological risks, Ely Mine has been divided into four Operable Units (OUs).

- OU 1 (OU1) includes all mine waste rock piles, the ore roast beds, and tailing along with all associated surface water and sediment impacts in Ely Brook, Ely Brook Tributaries, and on-site ponds. A remedial investigation (RI) (Nobis, 2011a) and feasibility study (FS) (Nobis, 2011b) were completed for OU1 and a ROD was signed in September 2011 (EPA, 2011). The OU1 cleanup action involves the excavation and consolidation of unconsolidated waste rock, tailings, and mine impacted sediments within an on-site waste repository. The waste areas to be excavated are shown in Figure 3-1. As shown in this figure, several features of the underground workings, including the Deep Adit, Burleigh Shaft, Pollard Adit, West Adit, Shaft 4, Main Adit, Adit A, Pollard Shaft, Shaft 2, and Tyson Adit, are within the limits of the Upper Waste Area excavation zone. Of particular relevance to this FMEA are elements of the OU1 cleanup that may include excavation and heavy machinery operation in the vicinity of the Pollard Adit, Deep Adit and Main Adit, including excavations above the Pollard Adit or Deep Adit and within a short distance (e.g. 5-15 ft) of the Pollard Adit or Deep Adit portals, along with subsurface investigations or remedial actions in the vicinity of and within the Pollard Adit or Deep Adit (e.g. drilling, waste rock excavation, and heavy machinery operation), including penetrating the Deep Adit with boreholes or wells, and unearthing and opening the existing plug that blocks the Deep Adit portal. The OU1 Remedial Design will include an activity specific FMEA to more rigorously evaluate failure modes and to support the development of mitigation measures and contingency plans to minimize the potential uncontrolled release of MIW.

- OU 2 (OU2): OU2 includes groundwater and surface water impacts associated with the underground workings on property currently owned by Ely Mine Forest, Inc. (EMFI). An RI (Nobis, 2015a) and FS (Nobis, 2015b) were completed for OU2 in 2015. The OU2 Proposed Plan includes closure of the Deep Adit, Pollard Adit, West Adit, Burleigh, and Shaft 4 by filling and plugging (USEPA, 2015). Of particular relevance to this FMEA are elements of the OU2 Proposed Plan that require pre-design investigations of the LUGW (i.e. drilling or other heavy machinery operations) to determine the geometry, physical conditions, and volume and pressure head of pooled or dammed water within the LUGW. The OU2 Remedial Design will include an activity specific FMEA to more rigorously evaluate failure modes and to support the development of mitigation measures and contingency plans to minimize the potential uncontrolled released of MIW, including the assessment of the final closure approach for the Deep Adit, Burleigh Shaft, Shaft 4, and Pollard Adit.

- OU 3 (OU3): OU3 includes groundwater and surface water impacts associated with the underground workings on property currently owned by Green Crow Corporation (i.e. the Main Shaft and related stopes north of the crest of Dwight Hill). An RI (Nobis, 2015a) and FS (Nobis, 2015b) were completed for OU3 in 2015. The potential does not exist for the underground workings to discharge directly to the ground surface within OU3 and, therefore, no failure modes for OU3 are presented in this FMEA.

- OU 4 (OU4): OU4 includes the Smelter/Slag source area, surface water and sediments of Schoolhouse Brook (SHB) and Ompompanoosuc River, and groundwater contamination not associated with the Underground Workings. There are no known underground workings within OU4 and, therefore, no failure modes for OU4 are presented in this FMEA.

3.2 FAILURE MODES AND EFFECTS ANALYSIS

FMEA is a systematic methodology to quantify the risk and failure of engineered systems. A FMEA combines the failure modes, the causes of failures, the effects of failures and corrective actions.

By casting the FMEA in a probabilistic framework through a measure of the likelihood of occurrence of each failure mode and a measure of the consequence of each failure mode severity of the effect, the risk associated with each failure mode can be evaluated and the failure modes ranked.

The ranking is based on the Risk Priority Number (RPN) which is the product of the measure of likelihood and severity. An RPN is calculated for each failure mode identified.

Consequently the steps in a FMEA are:

- Identifying the possible failure modes. The list should be exhaustive and include all possible failure modes. Those perceived as not likely to occur or with negligible consequence can be eliminated from further consideration at that stage. For those remaining failure modes, the FMEA process will quantify the risk associated with each failure mode using the RPN. This process will allow for elimination of those failure modes that are considered insignificant;
- Developing the probability of occurrence of each failure mode and the associated likelihood measure scale. The scale of likelihood can be developed based on numbers or quantitative measures such as statistics, as is often the case for qualitative assessment; and
- Developing a scale for severity of the consequences associated with each failure mode. The consequences are based on qualitative (e.g. level of erosion) or quantitative (e.g. cost to repair) metrics.

It is fairly common to assemble a team to identify the failure modes and develop likelihood and severity scales. The purpose of assembling a team is to include those that are familiar with the system, its possible failure modes, and associated consequences, in order to accurately assign probabilities of occurrence and severity ratings. The team assembled for the performance of this FMEA is identified in Section 1.2.

In addition to a table ranking of the failure modes based on their RPN, another convenient representation of the results of the FMEA is a color coded matrix, known as the risk characterization matrix, with likelihood of occurrence as the column heading and consequence severity as the row heading as shown on Figure 3-3. Each failure mode falls in the cell formed by the intersection of the severity of the consequence and the likelihood of occurrence of that failure mode.

A benefit of the FMEA is the ability to assess the potential effectiveness of mitigation, corrective, or remedial actions for each failure mode by reevaluating the probability of occurrence of the mitigated failure mode and the severity of its impact with the assumption of the successful implementation of such measures. A revised RPN can calculated for the mitigated failure mode to allow for a comparison with that of the unmitigated failure modes or the RPN other potential mitigative actions.

It is noteworthy that the RPN can be reduced by lowering either the likelihood or the severity or both. For a natural system, the corrective actions tend to address severity rather than the likelihood of occurrence that may be related to external conditions or natural hazards not under operator control (e.g. landslides, earthquake, rock falls, etc.).

Once the information is generated, the calculations are conducted and the FMEA process lends itself to a systematic spreadsheet approach.

4. FRAMEWORK OF FMEA

4.1 GENERAL CONDITIONS

As described in Section 3.1, Ely Mine is an underground mine. Shafts, adits and stopes were excavated as documented by USGS (White and Eric, 1944), and Nobis (2015a, 2015b). A plan view of the underground workings is shown on Figure 3-1 and a cross section on Figure 3-2. These figures were obtained and adapted from Nobis (2015a). The figures list the adits and shafts that have been identified, and show that there are two networks of underground workings.

The lower network includes the Deep Adit, the Burleigh Shaft and the short Pollard Adit located under the Upper Waste Area waste rock pile. Figure 3-1 shows a west trending adit branching off of the Deep Adit. This adit will be referred to as the West Adit. It is of importance since its conditions are not well known and it could fill up with water in case of a blockage of the Deep Adit, thereby adding to the volume of MIW that could be released in a blow-out.

The upper network includes the Main Adit, the Tyson Adit, Adit A, the Main Shaft, the Pollard Shaft, and Shaft II.

In the FMEA and the balance of this Technical Report the two networks will be treated separately and referred to as the Lower Underground Workings (LUGW) and Upper Underground Workings (UUWG). Figures 4-1 and 4-2 show schematic cross sections through each network. These cross sections do not show stopes and adits such as West Adit that are behind the plane of the cross section. These cross sections are not to scale and were created based on existing historical documents.

It is assumed herein that there are no significant hydraulic connections between the two networks as none are reported in previous studies (USGS, 1944, PAL, 2005, Nobis 2015). Mr. Matthew Kierstead who performed historic/archaeological mapping at the Site (PAL, 2005) further confirmed that there is no documented record of underground workings that connect the LUGW and UUGW (Matthew Kierstead, Personal Communication, 2016). Furthermore, because of the dip in the ore body there would have been no reason from a mining and ore recovery perspective to establish a connection between the LUGW and the UUGW. Other subsurface investigations performed for the OU1 and OU2 RIs documented that bedrock groundwater flow within OU2 is controlled by a low-yield bedrock fracture network and no significant transmissive fractures were observed that connect the UUGW and LUGW. This conclusion is supported by the approximate 100 foot steady-state head differential observed between the Main Shaft and the Deep Adit, as well as distinct geochemical differences observed between the water of the UUGW (i.e. the Main Shaft and Main Adit) and that of the LUGW (i.e. Deep Adit) (Nobis, 2015a). The Main Shaft geochemistry is dominated by iron along with cobalt and manganese whereas the geochemistry of the Deep Adit is more reflective of the drainage from the overlying waste piles with aluminum, cadmium, copper, and zinc as the main constituents. The Main Adit geochemistry is more similar to the Deep Adit than the Main Shaft.

4.2 LIKELIHOOD SCALE

The likelihood scale was established qualitatively following discussion within the FMEA team and the USEPA and a review of the FMEA performed at the Leadville Mine drainage tunnel (BUREC, 2008). Four classes of likelihood have been retained:

- Ruled out or Highly Unlikely;
- Low or Unlikely;
- Moderate or Neutral; and
- High or Likely.

Each class is described in detail Table 4-1 along with an assigned probability of occurrence and likelihood scale. The likelihood and associated probability of occurrence cover the time period considered. Typically, all things being equal, the probability of a failure mode will tend to be equal or higher for a given event if the exposure period is longer. Time periods specific to Ely Mine are discussed in Section 4.5.

4.3 CONSEQUENCE SCALE

The consequence scale is established as a site specific scale based on the potential impact from a failure. At Ely Mine the main potential impacts are related to a large release of MIW and are:

- Economic impact to the downstream population such as loss of roads or access to the property;
- Impact on water quality within the site (i.e. at the Ponds, Ely Brook and its tributaries) or outside the site (Schoolhouse Brook [SHB] or the East Branch of the Ompompanoosuc River [EBOR]) due to elevated aluminum, copper, and zinc for a MIW release from the Deep Adit or Main Adit and from elevated iron for a MIW release from the Main Shaft along with the associated impacts from any suspended mine waste transported along with the release; and
- Impact on aesthetics of the area through erosion due to a large release of MIW.
- Impacts on site workers or hikers visiting the area who could be near an adit portal near Ely Brooks its tributaries during a release.

Four levels of severity have been identified ranging from Level 0 (no significant impact) to Level 3 (maximum impact). These four levels are listed in Table 4-2 with a description of the impact associated and a severity scale for use in the calculation of the RPN.

It is noted that, in addition to the consequences described above, changes to the physical structure, air flow, temperature regime, and/or moisture or standing water conditions may occur within the underground workings as a result of an adit, shaft, or stope collapse. These changes could result in impacts to threatened or endangered species of bats that hibernate within or otherwise occupy the Site underground workings.

4.4 RISK CHARACTERIZATION MATRIX

The risk characterization matrix is obtained by combining the likelihood and the consequence numeric scales. The risk characterization matrix for the Ely Mine underground workings is shown on Figure 4-3. It is a 4 x 4 matrix where the four columns are the four levels of likelihood and the four rows are the four levels of consequence established previously.

One such matrix will be filled out for each network of underground workings. Each of the potential failure modes and their associated consequence will be inserted in the appropriate cell.

4.5 ASSUMPTIONS

In performing the FMEA for the underground workings at Ely Mine the following assumptions were made:

- This FMEA is focused on failure modes that would lead to the release of MIW from the underground workings at Ely Mine that could subsequently impact the environment, the aesthetics of the site post-closure, the community, and/or pose health and safety risks to humans.
- A failure is defined in this FMEA as an uncontrolled release of MIW. Two types of failure can occur:
  a. Catastrophic failure associated with the sudden release of MIW if a blockage in an adit abruptly fails (blow-out).
  b. Limited failure impact when, because of a blocked adit, the low flows currently observed are transferred to a higher elevation adit or shaft but the discharge is similar as previously recorded.
- MIW flows principally out of the Deep Adit and the Main Adit as observed over time and recorded in 2014-2015 by Nobis (2015a). The flows measured are reported in Table 3-1 of Nobis (2015a) and reproduced here in as Table 4-3.
- The maximum discharge rates of 11.1 gpm and 7.9 gpm measured at the Main Adit and Deep Adit respectively are used to estimate the filling rate of the adits and shafts in case of blockage.
- The available information about the dimensions of the underground workings adits, shafts, and stopes was used to determine maximum volumes of water that could be released during a failure. The data and volumes are provided in Table 4-4. Also, the filling rate of these underground workings was calculated using the maximum filling rate reported in (Table 4-3). To be conservative with respect to the potential release volumes, the FMEA assumed that each mine feature could be blocked near its entrance resulting in the maximum potential release of MIW. While this is likely the existing condition for the Deep Adit, it is possible that a blockage could occur further inside the mine features (shafts and adit) or in multiple locations. These additional permutations were not considered since the goal of this FMEA was to identify the potential failure modes and provide general information to support mitigation and planning with the expectation that the remedial design would address the worst scenario. It is also expected that the remedial design

would include an activity specific FMEAs containing much greater detail with respect to mitigation and contingency measures.

- The LUGW and UUGW networks are not connected.
- While it is theoretically possible that a simultaneous release of MIW from the LUGW and UUGW could occur if the UUGW were blocked and susceptible to a release of MIW before the remedial action to address the LUGW is completed, this scenario was not evaluated in the FMEA. The UUGW are not currently blocked which makes this a future risk scenario only. If the LUGW remedial action is not implemented in the short-term, it may be appropriate for long-term contingency and monitoring plans to consider the potential for a simultaneous release from both the UUGW and LUGW in a similar time frame.
- The FMEA considers three Phases at Ely Mine:
  a. **Phase I: Current Conditions and Investigations**, which covers the period until construction begins and is assumed to up to 10 years in duration. This phase also covers the field investigation that may be carried out to collect data about the underground workings. Such investigation may include drilling into the adits from above and removal of the collapsed materials at the portals;
  b. **Phase II: Construction**, which covers the construction period and is assumed to be up to 5 years in duration; and
  c. **Phase III: Post-construction**: Which covers the long-term performance and is assumed to be 100 years in duration after completion of the remedy.
- It is assumed that the basic remedies contemplated would be as described in the OU1 Record of Decision (USEPA, 2011) and the OU2 Proposed Plan (USEPA, 2015).

5. FAILURE MODES

5.1 DEFINITIONS

The main failure modes considered are those resulting in the uncontrolled release of MIW to the environment substantially in excess of the discharge rates currently released from the Main Adit and Deep Adit (11 gpm and 7.9 gpm, respectively). As discussed in Section 5.4, these flows could increase slightly following a winter characterized by a thick snow cover (e.g. in excess of 800 mm) but it is believed that flows would remain within the same order of magnitude (i.e. not experience a 10-fold increase).

For an uncontrolled release from either the Deep Adit or the Main Adit to occur, the following succession of events needs to happen:

1. The adit is blocked.
2. Water accumulates behind the blockage.
3. The blockage ruptures either suddenly (catastrophic release) or is gradually eroded and gives out (slow to fast release) as a result of natural or man-made influences.

Causes for a blockage to occur in an adit include:

- Collapse of the adit due to the geological nature of the rock formation;
- Collapse of the adit induced by outside events such as earthquakes or extreme weather;
- Collapse of the adit induced by construction activities (weight of equipment ground vibrations, and stress relief from unloading the waste piles or other materials); or
- Collapse of the roof or walls of the adit induced by investigation activities such as drilling; or
- Accumulation of precipitates or sediments eventually blocking the adit.

The likelihood of each cause of blockage at Ely Mine is discussed in the following sections of this Technical Report.

Water will accumulate behind the blockage at a rate commensurate with the rates observed and recorded at the Deep Adit and Main Adit (Nobis 2015a) and reported in Table 4-3 or slightly higher if affected by rain and/or snow. Effects of rain and/or snow on infiltration into the mine and flows out of the adits are discussed in Section 5.3.4 and 5.3.5 of this Technical Report.

Rupture of a blockage will occur if:

- The pressure behind the blockage is greater than the combined weight of the blockage (soil and rock) and the resisting shear force developed between the blockage and the roof, floor, and walls of the adit;
- The blockage erodes away due to soil saturation and/or piping; or

- Some activity reduces the weight of the resisting force, such as removal of the material within the blockage (e.g. removal of sloughed materials at the portals) waste rock excavation.
- Exploratory investigations destabilize the blockage.

In addition to the failure mode related to the failure of a blockage in either the Main Adit or the Deep Adit, failure modes specific to exploration and construction activities are discussed in Section 5.3.3

5.2 GEOLOGICAL CONSIDERATION

Two types of blockages are related to the geological nature of the rock formation in which the underground workings of Ely Mine are located. The first type is the sudden collapse of the adit or other underground structure (stopes, shaft) and the second type is more time dependent and is related to weathering and deterioration. Both mechanisms were assumed to be a potential cause of a partial or full blockage at some point in the future.

A review of the geology of the mine and available information was performed by Carl Fietze of SLR Consulting (Africa) (Pty) Ltd. who is a mining geologist specialized in working in stratified underground ore deposits. In a Technical Memorandum, Mr. Fietze concluded that both the likelihood of blockage due to collapse of an adit and of blockage due to weathering of rock were high but would be time dependent and more likely to occur in the long term. The Technical Memorandum prepared by Carl Fietze is included in Appendix A of this Technical Memorandum.

Consequently, it is considered in this FMEA that:

- The risk of collapse of an adit causing blockage during Phase I, which includes investigation activities, is considered to be **Low (Unlikely)**.
- The risk of collapse of an adit causing blockage during Phase II, because of construction activities near the adits, namely in the LUGW may be heightened and the risk is considered **Moderate (Neutral)**.
- The risk of collapse of an adit causing blockage during Phase III has a high probability of occurrence (i.e. considered to be greater than 50% over the exposure time span of 100 years), and therefore the risk is considered **High (Likely).**

It should be noted that the UUGW does not appear to have changed substantially since the 1944 USGS mapping (White and Eric, 1944) suggesting that there is some integrity to the UUGW. As a result, the likelihood of failure for the three phases were based on the assumption that the risks for both adit collapse and weathering will increase with time, therefore assigning a relative risk of **Low** in the short term increasing over time to **High** in the long-term.

5.3 EXTERNAL CAUSES

5.3.1 EARTHQUAKES

Ely Mine is located in East Central Vermont and is on the currently seismically passive eastern margin of the US. The region has a complex tectonic history and there has been significant historical seismicity in the region, though there is a marked absence of mapped Quaternary seismic activity (URS, 2003). A list of historical earthquakes that were felt in Vermont is provided in Table 5-1. Table 5-2 utilizes the Modified Mercalli Intensity (MMI) scale, with experienced ratings local to the Ely Mine ranging from III (weak perceived shaking) to VI (strong perceived shaking).

Using the seismic hazard tool available on the USGS web page[1] the peak ground acceleration (PGA) for the 475, 2,475, and 4,975 year return period earthquake were obtained for Ely Mine, and are reported in Table 5-2. The accelerations ranging from 0.04 (4% of g) to 0.20 g (20% of g) can be associated with perceived shaking (i.e. MMI) using relationships such as those developed by Trifunac and Brady (1975) or Atkinson and Kaka (2006) for the New Madrid Area (i.e. East Coast tectonics). Table 5-3 shows the relationships between PGA and MMI used to relate the PGA calculated at the Ely Mine and equivalent MMI. The expected level of shaking at the Ely Mine under the 4,975 year return period is characterized as strong to very strong with potential damage as light to moderate. This level of seismicity is similar to that historically felt at the Ely Mine (Table 5-1) for which no significant damage has been reported in the literature. There are also no accounts of earthquake damage occurring at the Ely Mine.

Consequently, we will consider that the risk of an earthquake triggering a failure in the underground workings at Ely Mine is **Negligible** and is therefore **Ruled Out**.

5.3.2 CONSTRUCTION

Heavy equipment is likely to be used for removal and transport of the materials from the Upper Waste Area and to excavate the materials that are currently blocking access to the Deep Adit and Pollard Adit. The relationship of the waste material to the LUGW is shown on Figure 1-6 of Nobis (2015a) included herein as Figure 3-1 and in the cross sections shown on Figures 3-2 and 4-1 (adapted from Nobis 2015a) of this Technical Report. Heavy equipment may also be used to bring flowable fill on site and to inject flowable fill in the Deep Adit.

Implementation of the OU1 Remedy requires waste rock excavation in the vicinity of the Pollard Adit and Deep Adit portal, while implementation of the OU2 Proposed Plan requires excavation and opening of the Pollard Adit and Deep Adit portal. As shown on Figure 4-1, it is estimated that the accessible opening of the Deep Adit is 53 ft away from the face of the slope. Consequently any closure construction activity related to the Deep Adit will require removal of these 53 ft of soil and additional soil above and around the portal to prevent potential sliding of overburden material (e.g. soil or other debris from buried portal) or glacial till to provide a safe work place. These construction activities signify that heavy equipment will be near both the portal and roof of the Deep Adit (within 5 ft). The weight of the equipment and the induced ground vibrations may loosen rocks or induce collapse of the roof leading to complete or partial blockage. In the case

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[1] http//:earthquake.usgs.gov/hazards/

of full blockage it is estimated that up to 292,000 gallons of water (Table 4-4) could accumulate behind the blockage in as short a time as 10 days. Consequently, the risk of failure from operating equipment above and around the Deep Adit without mitigating measures is considered **Moderate (Neutral).**

Because the OU2 Proposed Plan includes the removal of the existing Deep Adit plug, mitigation measures should be undertaken prior to heavy machinery operation or excavation in the vicinity of the Deep Adit to ensure the identification and controlled removal of pooled water behind any identified adit blockages. Pre-design investigations should be performed to identify existing adit blockages and standing water conditions, head levels, and volumes within the extent of the LUGW. Pooled adit water should be removed prior to initiating construction activities by pumping or gravity discharge. The Deep Adit discharge flow should be monitored during investigation and construction and proper BMPs installed to control a potential large discharge. The actuals BMPs will be determined as part of the remedial design for the OU2 Remedial Action, which will include a FMEA specific to the activity of closing the LUGW features. Low ground pressure equipment should be used when within 10 ft of the roof at the adit. Consequently, assuming the appropriate BMPs and Site infrastructure necessary to contain and treat the release are developed during the remedial design and implemented during the remedial action, the risk of failure from operating equipment above and around the Deep Adit is considered **Ruled Out (Negligible).**

The short Pollard Adit may also be impacted by the weight of the equipment and by the unloading through removal of the waste materials above and around the adit, altering the stress field in the rock formation. Vibrations induced by the equipment may potentially loosen pieces of rock within the Pollard Adit. There is limited information about the adit; it is thought to be about 19 ft long. The size of this adit is such that, even if full, the consequence of a release would have a moderate impact, with the volume of the Pollard Adit estimated to be approximately 6,000 gallons. (Table 4-4)

At the Pollard Adit, the risk of failure from operating the equipment above and around is considered **Low (Unlikely)** and should be considered prior to beginning construction. Proper stormwater management BMPs should be installed and the waste in the area of the adit removed slowly. The actuals BMPs will be determined as part of the OU2 Remedial Design, which will include a FMEA specific to the activity of closing the LUGW features. The pressure head is expected to be no more than the height of the adit or on the order of 7 ft. assuming that it was excavated to dimensions comparable to those of the Deep Adit. Consequently, the impact from a release of MIW would be limited and considered to be not significant assuming the OU2 Remedial Design identifies the appropriate BMPs and Site infrastructure necessary to contain and treat the release are developed during the remedial design and implemented during the remedial action.

Operating equipment will have a negligible impact on the UUGW with the majority of risk stemming from material falling in the open shafts or causing further collapse of the Main Adit. The actual BMPs will be determined as part of the OU1 remedial design, which will include an FMEA specific to the activity of closing the UUGW features with emphasis on the activities in close proximity to the Main Adit. Assuming the OU1 Remedial Design identifies the appropriate BMPs and Site infrastructure necessary to contain and treat the release and includes appropriate restrictions to limit activities that would induce further collapse of the Main Adit, the overall risk is considered **Negligible** and is **Ruled Out**.

5.3.3 INVESTIGATIONS

Prior to implementation of the remedies at the Deep Adit and Main Adit, additional investigations and explorations will be carried out.

These investigations and explorations will be intrusive and may include drilling above the Deep Adit to delineate the extent of the current blockage and estimate the depth of water. Additional work may include removal of some of the soil and debris accumulated at the portal.

Based on the geologic nature of the rock as described in Appendix A and the risk of undetected voids within the rock mass as was observed when advancing borehole MW-UP1, the risk of roof collapse during drilling may not be ruled out and is therefore considered **Low (Unlikely)**. Partial blockage may also occur when the drilling bit or cutter will punch through the roof of the adit.

If a collapse of the roof is detected during drilling, it should be attempted to estimate the volume of collapsed material to assess if it could block the adit. The consequence level should then be selected based on those observations and estimations. Excavation of the material collapsed at the portal of each adit, even if the water levels in the adits have been established to pose no threat shall proceed carefully. BMPs should be installed to control any release. The actuals BMPs will be determined as part of the remedial design for the OU2 Remedial Action, which will include an FMEA specific to the activity of closing the LUGW features.

The risk associated with excavating some or all of the material from the portal to gather additional data regarding the dimensions and status of the Pollard Adit or Deep Adit should be considered **Moderate (Neutral)**. Any program to excavate the area near the Pollard Adit or Deep Adit will be preceded by activities to identify whether water is impounded and under pressure within each adit. An activity specific FMEA will be developed and the work plans will identify appropriate BMPs and Site infrastructure necessary to contain and treat the releases.

5.3.4 RAINFALL

In 2011, Hurricane Irene generated record rainfall in Vermont. Consequently, the risk that a large rainstorm could impact Ely Mine should be considered. The resulting impact from extreme rainfall would be increased infiltration into the underground workings. Because the Main Adit acts as a fixed elevation decant point for the Main Shaft mine pool, increased infiltration to the UUGW would not raise the mine pool elevation but would result in increased discharge rates from the Main Adit. Increased infiltration in the LUGW could result in flooding of the Deep Adit, West Adit and Pollard Adit and/or increased discharge rates from the Deep Adit.

To assess the likelihood of such impact, the historical precipitation records for the area were reviewed. Two weather stations were retained for their proximity to Ely Mine and their completeness of data. One station is in Union Village, located 10 miles as the crow flies south of Ely Mine, and the other is at the Montpelier Airport, located 25 miles as the crow flies north of Ely Mine. The Union Station covers the period 1950 through 2015, and the Montpelier Station covers the period 1970 through 2015. Throughout the overlapping 45 year period at Montpelier Airport Station and the 65 year period at the Union Village Station, a total of 6 events with rainfall over 3 inches in a 24-hour period were recorded. The maximum 24-hour rainfall, measured at the Montpelier Airport Station, was 5.3 inches on August 28, 2011 (i.e. Hurricane Irene).

This maximum recorded 24-hour rainfall in the vicinity of Ely Mine was compared to that predicted by the Intensity Distribution Function (IDF) recommended for the State of Vermont by the Northeast Regional Climate Center for a 24-hour storm at different return periods. Figure 4-4 shows the IDF curves for return period ranging from one year to 500 years. The 5.3 inch 24-hour rainfall event corresponds to an event with a return period between 50 and 100 years. The 65 year record period available indicates that Ely Mine has not been subjected to a catastrophic rain event such as a 100-year or 500-year period event. Such events could produce 6.8 inches or 8.4 inches of rain in 24 hours. Therefore, the potential impact of such large storm is considered in this FMEA as discussed in the following.

The materials at Ely Mine exhibit relatively low hydraulic conductivities. Average values reported by Nobis (Table 6-4 in Nobis 2015a) are 4.29 10^{-4} cm/s for the overburden material, 1.8 10^{-4} cm/s for the glacial till, and 3.72 10^{-4} cm/s for the bedrock. Infiltration rate of water in the soil and rocks is typically limited to a fraction of the saturated hydraulic conductivity of the material (5% to 20% typically). Therefore, any rainfall greater than 3 inches is not likely to result in a higher infiltration rate than a rainfall of lesser intensity as rainfall will run-off as overland flow especially in sloping terrain.

Further, historical data and anecdotal reports suggest that the pool level in the Main Shaft has remained constant over the years, even after large rain events.

Consequently, we will consider that the risk of large rainfall events leading to an increase in seepage filling the underground workings is **Negligible** and therefore **Ruled Out** for all three Phases.

5.3.5 SNOW COVER

Snowmelt by contrast to rainfall could cause an increase in recharge of the underground workings because of the slower nature of the infiltration process. Slow snow melting from the bottom will penetrate through ground cover, glacial till, and bedrock, and enter the mine workings.

Nobis recorded flows out of the Main Adit and Deep Adit once a month between July 8, 2014 and July 7, 2015. These flows are reported on Table 4-3 and on Figure 4-5 along with the snow depth measured at the Union Village Station. The data shows that the flows out of the adits tend to be highest in the spring after snowmelt. Consequently, the maximum flow rates measured at each adit in the spring can be considered as the maximum flow out of the adits.

Snow depth data at Union Station for the period 1950 through 2015 is reported on Figure 4-6. The data shows that the snow depth in the winter 2014-2015 was in the order of 711 mm or over twice the average of 318 mm. The maximum depth was recorded on February 1, 1958 and was 1,194 mm or about 1.7 times the amount recorded in 2014-2015. It is therefore possible that following a winter when thick snow covered the area, more water could recharge the mine in the spring. This could lead to increased flows out of the adits which is an important variable when considering the time it would take to fill a blocked adit with water.

Looking at historical data and the current climatic trends, we will consider that the risk of large snowfall events leading to an increase in seepage filling the underground workings is **Negligible** and therefore **Ruled Out** for Phase I and Phase II and **Low (Unlikely)** for Phase III.

6. ANALYSIS

6.1 UPPER UNDERGROUND WORKING

6.1.1 FAILURE MODES FOR UUGW

For the UUGW four types of major risk that could lead to uncontrolled release of MIW have been identified:

- Collapse/Blockage of an adit;
- Stope collapse or large rock falling in the mine pools leading to a surge wave;
- Geochemical changes that could result in precipitate blockages most likely in combination with a partial blockage from another mechanism; and
- Slope failure in overburden or glacial till blocking the adit.

For each type of risk, failure modes have been identified and are listed in Table 6-1. For each failure mode, it is also indicated for which of the three Phases it will be a concern. The sixth column on Table 6-1 provides an initial assessment of whether or not each risk needs to be considered further or if it is either negligible and can be ruled out, or addressed through another failure mode with a higher consequence. This initial screening reduces the size of the FMEA and allows it to focus on the dominant failure modes. A total of 13 failure modes were identified and labelled Failure Mode I through II with Failure Modes 1a and 3a to complete the series. The numbering is not describing a sequence or a chronological order.

Rather the numbers were assigned based on identifying the failure modes during the FMEA process.

Consequently, in the balance of this report it may appear that numbers are out of order. To facilitate the comprehension of the numbering and order, the figure describing a failure mode is listed in the last column of Table 6-1.

For the UUGW the geometry of the network is an important factor as failure modes can cascade into each other resulting in a domino effect, as described in the following for the Main Adit:

1. Main Adit is blocked (regardless of cause)
2. Water accumulates behind blockage (Figure 6-1), and the following can happen:

    a. Blockage fails as soon as the Main Adit is full. The amount of water released is at most the volume stored in the Main Adit or approximately 225,000 gallons (Table 4-4). However, the pressure head applied to the blockage is only 7 ft (height of adit). Such a low pressure head is not likely to displace the amount of material needed to block the adit (which needs to be at least 6 ft wide by 7 ft tall (dimensions of the adit) by say 2 to 3 ft thick) or a volume of 84 to 126 ft^3, or approximately 5 to 8 tons of material.

This is Failure Mode 1 on Table 6-1 and is depicted on Figure 6-1.

b. Blockage fails when water has filled up the Main Adit and because Adit A is blocked, the water rises in the Pollard Shaft, Shaft II, and the Main Shaft to the elevation of either the Pollard Shaft or Shaft II. This is the maximum elevation since these two shafts are open, and water reaching that elevation will seep out. This elevation is on the order of 70 ft.

   The volume of water stored is then on the order of 571,000 gallons. Further, the pressure head applied to the blockage will be on the order of 70 ft (Table 6-2). Such a pressure head will generate a force against the blockage of 91 tons (6 ft wide x 7 ft high x [70 ft of pressure head x 62 ft pcf]), or enough force to displace up to 28 cubic ft of material with 20% friction resistance included in calculation.

   This is Failure Mode 1a on Table 6-1 and is depicted on Figure 6-2.

c. Blockage in the Main Adit holds and water rises as the previous case and seeps through Adit A, or eventually blowing the soil/rock plug of that adit.

   This is Failure Mode 2 on Table 6-1 and is depicted on Figure 6-3.

d. Blockage in the Main Adit holds and the soil/rock plug in Adit A holds, water rises to and seeps through Adit A, and seeps through the Pollard Shaft.

   This is Failure Mode 4 on Table 6-1 and is depicted on Figure 6-4.

The location of the blockage within the adit can also affect the failure type, resulting in the development of numerous failure scenarios. Figures 6-5 through 6-9 show the schematics of the other failure modes identified at the UUGW and listed in Table 6-1.

Table 6-2 lists for the blow-out type failure modes the amount of water that can be released and the pressure head associated with the blockage. The pressure with which the water may flow out is an indication of the damage potential of the failure mode.

6.1.2 RESULTS FOR THE UUGW

6.1.2.1 Unmitigated Workings

The FMEA for the failure modes identified in the UUGW are presented in Appendix B and summarized in the Risk Characterization Matrices on Figures 6-16, 6-18, and 6-20 for each of the three Phases. Figures 6-17, 6-19, and 6-21 show the results of the FMEA for the failure modes if corrective, remediation, or mitigation measures are implemented.

Failure Mode 1a is identified as the most critical failure mode because of the volume of water released and the catastrophic nature of the release (70 ft of pressure head). The assessment of the risk associated with it for each phase is detailed below. Based on our knowledge of the geology, geometry of the workings, and the current conditions, the following likelihoods of occurrences and severities of consequences are assigned:

- A low probability of occurrence during Phase I, (i.e. a probability of occurrence less than 10% which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1));
- A low probability of occurrence in Phase II, (i.e. a probability of occurrence less than 10% which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1));
- A high probability of occurrence in Phase III, (i.e. a probability of occurrence of over 50%, which corresponds to a 3 on the likelihood numeric scale (Table 4-1)); and
- The severity or consequence of this mode of failure is irrespective of the Phase and is a Level 3 which corresponds to a 300 on the consequence numeric scale (Table 4-2). The rational for this choice is described in the following:

Stormwater modeling was performed to evaluate the effect of a Main Adit failure (using an assumed discharge of 571,000 gallons occurring over 30 minutes) to the 50-year and 100-year flood stage elevations of Ely Brook at its crossing and culvert with South Vershire Road. These results are summarized in Table 6-4 and indicate that a Main Adit failure would contribute 42.3 cubic feet per second (cfs) to the Ely Brook stream base flow with a resulting increase to the Ely Brook stage elevation of approximately 0.6 feet. Prior Ely Brook stream flow monitoring (at the Ely Brook – Schoolhouse Brook confluence)(URS, 2008; Nobis, 2014) documented a range of stream flow between 0.13 cfs and 13.5 cfs. Consequently, the Main Adit failure could contribute additional stream flow from 3 to over 300 times the observed range of Ely Brook base flow. Based on the downgradient surface topography, the Main Adit discharge would be expected to follow the topographic fall line roughly from north to south, significantly scouring the Upper Waste Area waste rock piles. The adit discharge and mobilized waste rock sediments would likely follow the downgradient Ely Brook tributary EBT-3 as well as the access road located to the east of EBT-3. Significant scouring and erosion of these features are likely. The combined Main Adit discharge and base flow (modeled at the 50-year and 100-year flood stages) would overtop the existing culvert and South Vershire Road by 0.3 and over 0.9 feet respectively during a 50-year and 100-year flood. Damage to South Vershire Road is possible. The adit discharge and waste rock sediment load would enter Schoolhouse Brook. The downgradient extent of observed or measured impacts in both Schoolhouse Brook and the EBOR will be dependent on the flood stage of those receiving streams, and impacts will be propagated further downstream under low flow conditions (i.e. reduced dilution). Prior Schoolhouse Brook stream flow monitoring (at the Ely Brook – Schoolhouse Brook confluence)(URS, 2008) documented a range of stream flow between 3.6 cfs and 33.6 cfs. Consequently, under low flow conditions, the Main Adit failure could contribute additional stream flow to Schoolhouse approximately 12 times greater than the observed Schoolhouse Brook base flow. Under these low-flow conditions, visual, chemical, and physical impacts (e.g. total suspended solids; elevated iron and manganese; and total dissolved solids) would be observed in Schoolhouse Brook and likely observed in the EBOR.

- It is noted that, during the 100-year flood conditions, Ely Brook overtops South Vershire Road without the contribution of the Main Adit failure. It is also noted that, proposed conditions currently contemplated for OU1 Remedial Design includes the reconstruction of the South Vershire Road culvert from the existing 72” diameter CMP to a 14’ (wide) by 6’ (high) box culvert. Under these proposed conditions, the Main Adit discharge does not overtop South Vershire Road during either the 50-year or 100-year floods.

Once the likelihood and severity have been established, the RPN can be calculated for the failure mode:

- Phase I: Failure Mode 1a RPN = Likelihood x Severity = 0.3 x 300 = 90
- Phase II: Failure Mode 1a RPN = Likelihood x Severity = 0.3 x 300 = 90
- Phase III: Failure Mode 1a RPN = Likelihood x Severity = 3 x 300 = 900

The details of the FMEA for Failure Mode 1a during Phase III are shown on Figure 6-10. Details of the calculations for each failure mode identified are shown in the tables included in Appendix B.

6.1.2.2 Mitigation FMEA

Mitigation measures necessary to lower the risk for each identified UUGW failure modes have been considered and summarized in Tables B-2 (Phase I), Table B-3 (Phase II), and Table B-4 (Phase III) in Appendix B.

Because Failure Mode 1a ranks high in risk, mitigation measures that could lower the risk are considered. The mitigation measures include building a water tight or draining plug, plugging all adits to essentially force water out through the Main Shaft, or installing a drain connected to the main pool. Each mitigation measure will carry some residual risks that need to be evaluated and has a cost that needs to be considered.

If a watertight plug is considered, the watertight plug should be designed to resist at least 70 ft of head, and accommodation should also be made to collect the water that will then seep at a higher elevation location such as Adit A, Pollard Shaft, Tyson Adit, Shaft II, or the Main Shaft should all shafts and adits collapse and be blocked. A watertight plug should only be used if the design evaluation concludes that forcing the water to exit at the Main Shaft or other openings is the only viable approach to address the failure mode. Alternatively, a flow-through plug could be constructed to drain the water from the adit. However the residual risk will be drain plugging, or a collapse farther inside the adit directing seepage water towards a higher elevation opening. A flow-through plug would need to include redundancy (i.e. two drains) and be also designed to withstand the 70 ft of pressure head, to reduce both the consequence of a failure and the likelihood of the failure. The flow-through plug failure will be considered to have failed if water stops flowing through the drains for an extended period of time, signaling either clogging of the drains or a collapse behind the plug. Either way, the consequence is considered to be Level 1 since the plug is designed not to fail and water trapped will eventually come out at the Pollard Shaft or another opening, which would require collection and treatment. The probability of the drain to clog or fail will be Low (Unlikely) assuming the necessary inspection and maintenance activities are performed. Consequently the RPN of the drained plug for Failure Mode 1a is calculated as:

- Phase III: Failure Mode 1a RPN (drained Plug) = Likelihood x Severity
  = .3 x 30 = 90

To reduce the consequence to negligible and the likelihood to zero, one solution is to build plugs in the Main Adit and the Tyson Adit at different locations to control seepage and force it out through the Main Shaft. However the cost of such a solution is prohibitive. In addition, this mitigation would greatly increase the magnitude of a release if one of the plugs were to fail. This approach would also alter critical habitat for federal and state threatened and endangered bat species.

Another option considered is the installation of a drain connected to the mine pool to keep the water elevation in the pool at an elevation beneath that of the Main Adit. This could restrict the water from the Main Shaft from contributing to the Main Adit discharge. The residual risk with such option is the risk of clogging or failing with time. Consequently this plan would require the implementation of a maintenance program.

The long term conditions indicates that FMEA Failure Mode 1a is the most critical failure mode with a high likelihood of occurrence and a Level 3 consequence at the UUGW (and is in the 'red zone' on Figure 6-20. It is estimated that over a 100 year period it is likely that (over 50% chance) that the Main Adit will collapse and would get blocked. Failure of the blockage would release up to 571,000 gallons of water under 70 ft of pressure head.

Corrective measures for Failure Mode 1a and other failure modes associated with the UUGW are suggested in the FMEA Calculations included in Table B-4 in Appendix B. The risk for these failure modes was recalculated assuming corrective measures were applied and are shown on Figure 6-21 showing that the risk ranking of a failure mode could be brought down to different levels depending upon the corrective measures implemented (i.e. in the 'green zone' and even the white zone'). The choice of a corrective measure has also an impact on the costs of the measure as shown on the FMEA calculations where order of magnitude of cost have been provided for illustration purposes only.

6.1.2.3 Main Adit Notes

The requirement to prevent impacts to threatened or endangered species of bats that currently (April 2016) hibernate within the UUGW greatly limits the mitigation measures that could be implemented to address a failure of the UUGW features. As a result, the long-term risk associated with UUGW Failure Mode 1a is not currently addressed (as of April 2016) by either the OU1 or OU2 remedies and the threat of this failure mode remains unresolved over the long-term (up to 100 years for Phase III assumptions). The remedial designs for OU1, OU2, and OU3, and the associated long-term site management and monitoring plans should consider whether Site infrastructure could be improved to mitigate a future release from the UUGW. It is unlikely that the passive treatment system to be installed as part of the OU2 Remedial Action could effectively mitigate a sudden uncontrolled release from the UUGW resulting from the failure of an internal blockage. Any long-term monitoring program would need to identify the physical changes that would indicate a blockage in the Main Adit since the current discharge fluctuates seasonally and is relatively low flow, highly variable, and often dry.

6.2 LOWER UNDERGROUND WORKINGS

6.2.1 FAILURE MODES FOR LUGW

For the LUGW, similar to the UUGW, four types of major risks that could lead to uncontrolled release of MIW have been identified:

- Collapse/Blockage of an adit;
- Stope collapse or large rock falling in the mine pools leading to a surge wave;
- Geochemical changes; and
- Slope failure in overburden or glacial till blocking the adit.

Similarly to the mechanism described for the failures related to the Main Adit of the UUGW, a series of events have to take place in the LUGW for failure to occur. For example for the Deep Adit the following sequence of event is would have to occur:

1. Deep Adit is blocked (regardless of cause)
2. Water accumulates behind blockage (Figure 6-11), and the following can happen:

    a. Blockage fails as soon as the Deep Adit is full. The amount of water released is at most that volume stored in the Deep Adit and West Adit is on the order of 278,000 gallons (Table 4-4). However, the pressure head applied to the blockage is equal to the height of the adit (Tables 4-4 and 6-2). Such a low pressure head is not likely to displace the amount of material needed to block the adit (estimates as for the Main Adit vary from 5-8 tons of material).

       This is Failure Mode 12 on Table 6-3 and is depicted on Figure 6-11.

    b. Blockage fails when water has filled up the Deep Adit and risen in the Burleigh Shaft. The volume of water stored is then on the order of 284,000 gallons. Further, the pressure head applied to the blockage will be on the order of 35 ft (Table 6-2). Such a pressure head will generate a force against the blockage of 46 tons (6 ft wide x 7 ft high x [35 ft of pressure head x 62 ft pcf]), or enough force to displace a blockage of up to 14 ft in length with 20% friction resistance included in calculation.

       This is Failure Mode 12a on Table 6-3 and is depicted on Figure 6-12.

    c. Blockage in the Deep Adit holds and water rises and seeps through the Burleigh Shaft or other unidentified openings/connections.

       This is Failure Mode 17 on Table 6-3 and is depicted on Figure 6-14.

All the identified possible failure modes associated with the LUGW are reported in Table 6-3. For each failure mode we have identified the phases to which it applies and determined an initial assessment of risk. Some failure modes have been eliminated from further consideration as they are deemed insignificant, or are addressed by other failure modes.

The dominant failure modes for the LUGW are linked to a blockage of the Deep Adit which would lead to the accumulation of up to 284,000 gallons of water in the Deep Adit, West Adit, and Burleigh Shaft. Failure modes associated with releases from the Deep Adit and Burleigh Shaft are depicted on Figures 6-11, 6-12, 6,14, and 6.15.

Though a small adit, (reported to be 19 ft long) and with limited documentation, the Pollard Adit was included as a potential failure mode. The only identified failure mode associated with the Pollard Adit is the release of MIW when removing the waste rock and uncovering the adit. The volume of water that could be stored was estimated to be on the order of 6,000 gallons (Table 4-4) (if assumed to have same height and width as the Deep Adit). This is Failure Mode 16, depicted on Figure 6-13.

Other identified failure modes exist that may not present as catastrophic a consequence, but need to be considered, as they may affect the selection of the final remedy for the mine. One such failure mode is linked to sporadic outflow surges from the Deep Adit due to partial blockage. Partial blockage could be an indication of the development of full blockage and should therefore be considered and addressed via appropriate mitigations. This is Failure Mode 18 depicted on Figure 6-15.

6.2.2 RESULTS FOR THE LUGW

The FMEA for the failure modes identified in the LUGW are presented in Appendix B and summarized in the Risk Characterization Matrices on Figures 6-16, 6-18, and 6-20 for each of the three Phases. The results show that Failure Mode 12a presents the highest risk at the UUGW through the potential release of up to 284,000 gallons of water.

Failure Mode 12a is identified as the most critical failure mode because of the volume of water released and the potential catastrophic nature of the release. The risk associated with it is detailed below. Based on our knowledge of the geology, geometry of the workings, and the current conditions, the following severities of consequences and likelihoods of occurrences are assigned:

- A low probability of occurrence during Phase I, (i.e. a probability of occurrence less than 10% which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1);
- A low probability of occurrence in Phase II, (i.e. a probability of occurrence less than 10% which corresponds to a 0.3 on the likelihood numeric scale (Table 4-1));
- A high probability of occurrence in Phase III, (i.e. a probability of occurrence of over 50%, which corresponds to a 3 on the likelihood numeric scale (Table 4-1)); and
- The severity or consequence of this mode of failure is irrespective of the Phase and is a Level 2 which corresponds to a 100 on the consequence numeric scale (Table 4-2). The rational for this choice is described in the following:

Stormwater modeling was performed to evaluate the effect of a Deep Adit failure (using an assumed discharge of 284,000 gallons occurring over 30 minutes) to the 50-year and 100-year flood stage elevations of Ely Brook at its crossing and culvert with South Vershire Road. These results are summarized in Table 6-4 and indicate that a Deep Adit failure would contribute 21.3 cubic feet per second (cfs) to the Ely Brook stream base flow with a resulting increase to the Ely Brook stage elevation of approximately 0.3 feet. Prior Ely Brook stream flow monitoring (at the Ely Brook – Schoolhouse Brook confluence)(URS, 2008; Nobis, 2014) documented a range of stream flow between 0.13 cfs and 13.5 cfs. Consequently, the Deep Adit failure could contribute additional stream flow from 1.6 to over 160 times the observed range of Ely Brook base flow. Based on the downgradient surface topography, the Deep Adit discharge and mobilized waste rock sediments would be expected to follow the topographic fall line roughly from north to south along the unnamed Deep Adit drainage, discharging downstream into Pond 5 and following the Ely Brook Tributary EBT-2 to its confluence with the main channel of Ely Brook within the Lower Waste Area. Some portion of this discharged volume may overtop the banks of Pond 5 and/or EBT-2, resulting in overland flow that could scour portions of the Lower Waste Area or Tailing Area. The combined Deep Adit discharge and base flow (modeled at the 50-year and 100-year flood stages) would overtop the existing culvert and South Vershire Road by over 0.9 feet during a 100-year flood. Damage to South Vershire Road is possible. The adit discharge and waste rock sediment load would enter Schoolhouse Brook. The downgradient extent of observed or measured impacts in both Schoolhouse Brook and the EBOR will be dependent on the flood stage of those receiving streams, and impacts will be propagated further downstream under low flow conditions (i.e. reduced dilution). Prior Schoolhouse Brook stream flow monitoring (at the Ely Brook – Schoolhouse Brook confluence)(URS, 2008) documented a range of stream flow between 3.6 cfs and 33.6 cfs. Consequently, under low flow conditions, the Deep Adit failure could contribute additional stream flow to Schoolhouse approximately 6 times greater than the observed Schoolhouse Brook base flow. Under these low-flow conditions, visual, chemical, and physical impacts (e.g. total suspended solids; elevated iron and manganese; and total dissolved solids) would be observed in Schoolhouse Brook and may be observed in the EBOR.

It is noted that, during the 100-year flood conditions, Ely Brook overtops South Vershire Road without the contribution of the Deep Adit failure. It is also noted that, proposed conditions currently contemplated for OU1 Remedial Design includes the reconstruction of the South Vershire Road culvert from the existing 72" diameter CMP to a 14' (wide) by 6' (high) box culvert. Under these proposed conditions, the Deep Adit discharge does not overtop South Vershire Road during either the 50-year or 100-year floods.

Once the likelihood and severity have been established, the RPN can be calculated for the failure mode:

- Phase I: Failure Mode 12a RPN = Likelihood x Severity = 0.3 x 300 = 90
- Phase II: Failure Mode 12a RPN = Likelihood x Severity = 0.3 x 300 = 90
- Phase III: Failure Mode 12a RPN = Likelihood x Severity = 3 x 300 = 900

These combinations of Likelihood and Severity and associated RPN, place Failure Mode 12a in the "yellow zone" for Phase I and II (Figures 6-16 and 6-18) and "orange zone" for Phase III (Figure 6-20).

The details of the FMEA calculations for the other failure modes identified at the LUGW are shown in the tables included in Appendix B.

Mitigation measures necessary to lower the risk for each identified LUGW failure modes have been considered and summarized in Tables B-2 (Phase I), Table B-3 (Phase II), and Table B-4 (Phase III) in Appendix B.

Figures 6-17, 6-19, and 6-21 show the revised relative risk ranking of each failure modes when suggested mitigation measures are implemented. In some instances the likelihood remains the same but the severity of the consequence decreases or vice-versa. The focus of the suggested mitigation measures is to bring the failure mode down to a lower risk ranking.

The suggested corrective actions and the associated FMEA calculations are included in Appendix B.

It is noted that USEPA is actively addressing the risks associated with LUGW Failure Mode 12a and 15a during planned investigation and construction phases (Phase I and II) by incorporating appropriate mitigation measures and best management practices in ongoing plans and designs for future actions at Ely Mine, including the OU1 Remedial Design and OU2 Proposed Plan. Also, the OU2 Proposed Plan for the LUGW closure includes sealing, filling, and plugging of LUGW using flowable fill, thereby eliminating the potential for pooled water within the LUGW and the associated failure modes over the long-term (Phase III) should this Proposed Plan be implemented.

As shown in Tables B-2 through B-4, Failure Mode 12a is brought down from Level 2 to Level 1 or even a Level 0 through the combination of a reduced consequence and a decreased probability of occurrence with the effect of the contemplated mitigation measures.

7. SUMMARY CONCLUSIONS

7.1 SUMMARY

A FMEA was performed for the underground workings of Ely Mine located in Vershire, Vermont. The focus of the FMEA was to identify the failure modes that could contribute to a sudden uncontrolled release of mine impacted groundwater from the mine underground workings in excess of the ability of the Site infrastructure to contain and treat the discharge.

The FMEA considered three Phases of the underground working:

- ***Phase I: Current conditions and Investigations***, with a time frame of up to ten years. The Phase I FMEA considered potential MIW release related to pre-design investigations of the LUGW that are currently contemplated as part of the OU1 Remedial Design and/or OU2 Proposed Plan. These pre-design investigations may require drilling or other heavy machinery activities in the immediate vicinity of the LUGW, including penetrating the Deep Adit with boreholes or wells, and removing the existing Deep Adit plug. Consequently, these activities result in an increased likelihood of a MIW release during Phase I. As a result, the planning for the pre-design investigations for the LUGW will include an activity specific FMEA and additional work plan development to assess internal conditions within the LUGW prior to any activities that could cause a release of MIW and to also include the installation of Site infrastructure that could contain and treat a release that could result from the pre-design investigations.
- ***Phase II: Construction***, with a time frame of less than five years. The Phase II FMEA considered potential MIW release related to the OU1 cleanup, which includes excavation of the Upper Waste Area, where several features of the underground workings are located. Furthermore, the OU1 cleanup requires that several currently buried underground workings be partially unearthed and exposed, including the Deep Adit and Pollard Adit, requiring excavations and other associated heavy machinery activities in the immediate vicinity of these workings. Consequently, these activities result in an increased likelihood of MIW release during Phase II. As a result, the planning for LUGW Remedial Action will include an activity specific FMEA and additional work plan development to assess internal conditions within the LUGW prior to any activities that could cause a release of MIW and to also include the installation of Site infrastructure that could contain and treat a release that could result from the implementation of the remedial action.
- ***Phase III: Post-construction***, with a time frame of 100 years. The Phase III FMEA considered potential MIW release that could occur over a time period of 100 years or more following the completion of the remedy construction activities and identified failure modes that could be of concern over that period. The implementation of the OU1, OU2, and OU3 cleanup actions will substantially change the site conditions. A FMEA will be prepared after the completion of all cleanup activities to assess any long-term conditions that could release MIW in excess of site infrastructure. This information will support the development of the plans for and implementation of long-term monitoring, operations and maintenance activities.

A likelihood scale and a consequence scale were established based on the potential causes for failure and their associated consequences. Because of different exposure times, the likelihood of one particular failure mode will vary across Phases.

For each failure mode and Phase, corrective action, remediation, or mitigation measures have been suggested, such as those measures currently contemplated in the OU2 Proposed Plan (USEPA, 2015), and the risk re-evaluated for each failure mode assuming implementation of those measures.

The FMEA results demonstrate the presence of three significant failure modes:

- UUGW Failure Mode 1a (Phase I, II, and III): This failure mode is associated with the formation of a blockage in the Main Adit, regardless of its origin, and its subsequent rupture. Failure Mode 1a would result in the sudden and uncontrolled release of up to 571,000 gallons of adit discharge water under approximately 70 ft of pressure head, potentially causing significant erosion, scouring, and damage to site features such as the Ely Brook channel and tributaries, the culvert under South Vershire Road, and South Vershire Road itself. Under low-flow conditions, visual, chemical, and physical impacts resulting from this release would be observed in Schoolhouse Brook and likely observed in the EBOR. Without mitigation measures, Failure Mode 1a represents the most critical failure mode for all three Phases. It is particularly critical in Phase III (post-construction) when there is a greater than 50% probability of occurrence with a maximum estimated RPN = 900. Mitigation measures to reduce the risks associated with Failure Mode 1a are suggested in the FMEA calculations included in Tables B-2 through B-4 (Appendix B) and the resulting risk for Failure Mode 1a was recalculated assuming corrective measures were applied (Figure 6-21). These results demonstrate that some mitigation or corrective measures could reduce the long-term RPN for Failure Mode 1a from 900 to 0.

  It is noted that USEPA is actively addressing the risks associated with UUGW Failure Mode 1a during planned investigation and construction phases by incorporating appropriate mitigation measures and best management practices in ongoing plans and designs for future actions at the Ely Mine, including the OU1 Remedial Design and OU2 Proposed Plan. However, the requirement to prevent impacts to threatened or endangered species of bats that currently hibernate within the UUGW will prevent implementation of certain mitigation measures that could alter or influence the physical condition of these features. Regardless, the long-term risk associated with UUGW Failure Mode 1a is not currently addressed (as of June 2016) by either the OU1 or OU2 remedies and the threat of this failure mode remains unresolved over the long-term (up to 100 years for Phase III assumptions).

- LUGW Failure Mode 12a and 15a (Phase I, II, and III): These failure modes are associated with the Deep Adit and result when either a blockage forms in the future (Mode 12a), or a blockage currently exists (Mode 15a), regardless of its origin, and this blockage subsequently ruptures. Failure Modes 12a and 15a would both result in the sudden and uncontrolled release of up to 284,000 gallons of adit discharge water under approximately 35 ft of pressure head, potentially causing significant erosion, scouring, and damage to site features such as Pond 5, EBT-3, and Ely Brook. Under flood stage conditions, these failure modes may also result in damage to the South Vershire Road culvert and South Vershire Road itself. Under low-flow conditions, visual, chemical, and physical impacts resulting from this release would be observed in Schoolhouse Brook and may be observed in the EBOR. These failure modes are particularly critical in Phases I and II where the Site measures currently contemplated for OU1 and/or OU2 (e.g. drilling and construction) result in an increased likelihood of failure. Corrective or mitigation measures to reduce the risks associated with Failure Modes 12a and 15a are suggested in the FMEA calculations included in Tables B-2 through B-4 (Appendix B) and the resulting risks for Failure Mode 12a and 15a were recalculated assuming corrective measures were applied (Figures 6-17 and 6-19). These results demonstrate that some mitigation or corrective measures could reduce the Failure Mode 12a and 15a relative risk rankings for current and construction phases from RPN = 30 to RPN = 9.

It is noted that USEPA is actively addressing the risks associated with LUGW Failure Mode 12a and 15a during planned investigation and construction phases (Phase I and II) by incorporating appropriate mitigation measures and best management practices in ongoing plans and designs for future actions at Ely Mine, including the OU1 Remedial Design and OU2 Proposed Plan. Also, the OU2 Proposed Plan for the LUGW closure includes sealing, filling, and plugging of LUGW using flowable fill, thereby eliminating the potential for pooled water within the LUGW and its associated failure modes over the long-term (Phase III) should this Proposed Plan be implemented. Most notably, the risk associated with catastrophic Failure Modes 12a and 15a would be eliminated. Summary sheets for each phase of these three Failure Modes (1a, 12a, 15a) are included in Appendix C.

7.2 CONCLUSION

The following conclusions are drawn from FMEA conducted at the underground workings of Ely Mine:

- Under current conditions, both the risk of catastrophic failure and associated MIW release at the Deep Adit and Main Adit are low.
- Prior to construction, it is recommended to investigate further the conditions near the portal of the Deep Adit.
- During construction, it is recommended to anticipate and develop contingency plans and possibly add site infrastructure to manage and treat a possible release of larger volumes of water than currently measured should a portal blockage present in either the Deep Adit or Main Adit retain a pool of water.
- During construction, low ground pressure equipment should be considered when near the portal or roof of the Deep Adit.
- Under long term conditions, without the implementation of corrective action the risk of a catastrophic release at the Deep Adit is high but implementation of corrective measures identified in the OU2 proposed plan for remedial action will lower the risk level to low.
- In the Phase III long term conditions phase, the potential failure modes associated with the LUGW should be low or negligible assuming the successful implementation of the remedial action and the performance of inspection and maintenance activities.

- Because of concerns about causing disturbance to endangered bat habitats, the remedy proposed for the Main Adit does not address the risk of a blockage forming with the associated risk of a blow out with damaging consequences. As a result, the risk associated with a future MIW release from the Main Adit will not be reduced as a result of the currently planned remedial actions at the Ely Mine. As a result, long-term site management and contingency planning should consider whether Site infrastructure could be modified to mitigate a future release of MIW from the UUGW.

8. REFERENCES

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TABLES

Table 3-1: Ely Copper Mine Superfund Site FMEA Underground Workings Naming Convention and Statuses

Mine Workings Type	Current Name used in FMEA	Alternate/Previous Alias	Current Status and Information
Lower Workings	Deep Adit	Adit I	• Portal collapsed to unknown extent • Unknown extent of collapse within adit • Unmeasured seepage from adit enters Ely Brook Tributary 2
	Pollard Adit	1850s Pollard Adit	• Portal blocked by waste rock piles • Unknown condition of inner adit • Unmeasured seepage from waste rock piles
	West Adit	-	• Unknown condition of adit
	Burleigh Shaft	Shaft III	• Portal open • Unknown condition of inner shaft
Upper Workings	Adit A	1850s Pollard Adit A	•
	Main Adit	1861 Pollard Adit	• Portal partially collapsed • Unknown condition of inner adit • Endangered bat species habitat in inner adit • Measured outflow from adit of 7.9-11.1 gpm enters Ely Brook Tributary 2 and/or Ely Brook Tributary 3 (Nobis 2014-2015)
	Tyson Adit	1834 Tyson, 1854 Pollard Adit	• Portal collapsed to unknown extent • Unknown condition of inner adit
	Main Shaft	Shaft I	• Portal open • Unknown condition of inner shaft
	Pollard Shaft	1850s Pollard Shaft	• Portal open • Unknown condition of inner shaft • Endangered bat species habitat in inner adit
	Shaft II	-	• Portal open • Unknown condition of inner shaft
	Shaft II Connector	-	• Unknown condition of shaft; assumed to be open, acting as connection from the Tyson Adit to the Main Adit

Table 4-1: Likelihood Definitions and Scale

LIKELIHOOD	DESCRIPTIONS	PROBABILITY OF OCCURRENCE FOR PERIOD UNDER CONSIDERATION	LIKELIHOOD NUMERIC SCALE
Ruled Out (Negligible)	The physical conditions do not exist for its development or the likelihood is so remote as to be non-credible.	<0.1%	0
Low (Unlikely)	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred in the past or that a condition or flaw exists that could lead to its development in the future.	>0.1% and < 10%	0.3
Moderate (Neutral)	The fundamental condition or defect is known to exist or indirect evidence suggests it is plausible, but evidence is not weighted toward likely or unlikely.	>10% and <50%	1
High (Likely)	There is direct evidence or substantial indirect evidence to suggest it has occurred and/or is likely to occur.	>50%	3

Table 4-2: Consequence Definitions and Scale

CONSEQUENCE LEVEL	DESCRIPTION	CONSEQUENCE NUMERIC SCALE
Level 0 - No Significant Consequences	No significant economic consequences or impacts to the downstream population. Any release will be of a volume and chemistry within the range of what is currently taking place under current site conditions.	0
Level 1	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality within Site (Ponds, Ely Brook and Tributaries) may experience degraded water quality for a limited period of time but no significant impacts to Schoolhouse Brook or EBOR. Minor erosion may occur and access road or other repair may be necessary.	30
Level 2	No significant economic impacts to the downstream population (loss of road use or damage to property); water quality with Site and downstream in Schoolhouse Brook and EBOR is adversely impacted to an extent greater than current impacts for a short period of time. Extensive visual/aesthetic impacts for a short period of time. Minor risk to people on site in path of releases. Moderate erosion on-site requiring substantial repair, possible short-term loss of use of Site access roads.	100
Level 3 – Maximum Impact	Economic impacts to the downstream population (loss of road use due to culvert damage or washout at South Vershire Road); water quality within Site and downstream in Schoolhouse Brook and EBOR is adversely impacted to an extent greater than current impacts for an extended period of time. Extensive visual/aesthetic impacts. Danger to people on site in path of releases. Major erosion on-site requiring substantial repair, possible extended loss of use of Site access roads.	300

Table 4-3: Flows Out of Deep Adit and Main Adit

Date	Main Adit (gpm)	Deep Adit (gpm)
7/8/2014	4.0	2.6
8/1/2014	0.8	2.8
9/10/2014	0.8	7.0
10/22/2014	0.2	1.5
11/10/2014	0.0	1.2
12/18/2014	0.0	1.2
1/30/2015	0.0	1.6
2/18/2015	0.0	1.4
3/23/215	0.0	1.9
4/22/2015	11.1	5.6
5/26/2015	2.5	7.9
7/7/2015	6.3	2.1

Table 4-4: Estimated Volumes of Ely Mine Underground Workings

Location	Feature Name	Dimensions (ft)[1]			Diameter (ft)	Total Volume (gal)	Recharge Rate[2] (gpm)	Time to Fill[3] (days)
		Length	Width	Height				
Lower Workings	Deep Adit	600	7	6	-	188,496	7.9	6.6
	Burleigh Shaft	17	7	10	-	8,901	0	0.3
	West Adit	285	7	6	-	89,536	-	3.1
	Pollard Adit	19	7	6	-	5,969	2	0.8
Upper Workings	Main Adit	715	7	6	-	224,624	11.1	5.6
	Adit A	48	7	6	-	15,080	0	0.4
	Pollard Shaft	-	-	50	9	23,781	-	0.6
	Shaft II	-	-	10	13	9,923	0	0.2
	Shaft II Connector	-	-	45	10	26,423	-	0.7
	Tyson Adit	250	7	6	-	78,540	0	2.0
	Main Shaft	200	30	10	-	448,800	-	11.2

Notes:

1. Based on available information (Nobis, 2015a and Nobis, 215b) and approximated from mine drawings.
2. Maximum value recorded by Nobis in 2014-2015.
3. Total Volume/Discharge Rate.

Table 5-1: Large Earthquakes Felt in Vermont

YEAR	LOCATION	MAGNITUDE	MMI RANGE IN VERMONT
1732	Montreal, Quebec	5.8	VI-IV
1925	La Malbaie, Quebec	6.5	IV-III
1935	Timiskaming, Quebec	6.1	IV-III
1940	Ossipee, N.H.	5.5	VI-IV
1944	Massena, N.Y.	5.2	V-IV
1973	Maine-N.H.-Quebec border	4.8	V-III
1982	Gaza, N.H.	4.7	IV-III
1983	Goodnow, N.Y.	5.1	IV-III
1988	Saqueny, Quebec	6.2	V-IV

Table 5-2: Peak Ground Acceleration, Return Period at Ely Mine, and Mercalli Intensity

Probability of Occurrence	Return Period (Years)	PGA (% of g)	MMI	Perceived Shaking	Potential Damage
10% in 50 years	475	4	V	Moderate	Very light
2% in 50 years	2,475	13	VI	Strong	Light
1% in 50 years	4,975	20	VII	Very Strong	Moderate

Table 5-3: Relationships between Acceleration and Mercalli Intensity

Perceived Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very light	Light	Moderate	Moderate-Heavy	Heavy	Very heavy
Peak Ground Acceleration (% g)	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Velocity (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
MMI (Trifunac and Brady, 1975)	I	II-III	IV	V	VI	VII	VIII	IX	X+
MMI (Atkinson and Kaka, 2006)	I-II	III	IV	V	VI	VII	VIII	IX	X

Table 6-1: Identified Failure Modes – Upper Underground Workings

LOCATION	RISK TYPE	N°	FAILURE MODE	PHASES AT RISK	FURTHER RISK SCREENING NECESSARY?	FIGURE
Upper Workings	Adit Collapse/Blow-out	1	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-1
		1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit and water rise in Pollard Shaft	All Phases	YES	6-2
		2	Blow-out of Adit A due to rising pressure/water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-3
		3	Blow-out of the Tyson Adit due to rising pressure/water levels behind collapse induced blockage in Main Adit (behind Pollard Shaft)	All Phases	NO - represented by 1a	6-5
		3a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit behind Pollard Shaft and water rises in Shaft II	All Phases	NO - represented by 1a	6-6
		4	Slow discharge from the Pollard Shaft due to rising water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-4
		5	Slow discharge from Shaft II due to rising water levels behind collapse induced blockage in the Main Adit (behind Adit A)	All Phases	NO - represented by 1a	6-7
		6	Slow discharge from the Main Shaft due to rising water levels behind collapse induced blockages in the Main Adit (behind connector/Shaft II in Main Adit) and in Tyson Adit	All Phases	YES	6-8
		7	Sporadic outflow surges from main adit due to partial Main Adit blockage	All Phases	YES	6-9
	Stope Collapse	8	Stope collapse into mine pool causing surge of water from the mine shaft pool to discharge out of the Main Adit	All Phases	YES	None
	Surface Slope Failure	9	Any surface slope failure resulting in blockage of lower adits	All Phases	YES	None
	Geochemical Conditions	10	Formation and washing out of precipitates	Phase III (Post Remedy)	YES	None
		11	Continual water quality degradation due to evolving geochemistry	Phase III (Post Remedy)	YES	None

Table 6-2: Selected Failure Modes: Discharge Volumes, Heads, and Fill Times

Failure Mode	Volume of Release (gal)	Pressure head (ft)	Time to Fill[1] (days)
1	224,624	7	5.6
1a	571,036	70	14.3
2	15,080	10	14.3
3	78,540	15	13.4
3a	509,018	70	13.4
12	278,032	10	9.8
12a	284,001	35	10.6
16	5,969	10	0.8

Notes:
1. Volume/Discharge Rate.

Table 6-3: Identified Failure Modes – Lower Underground Workings

LOCATION	RISK TYPE	N°	FAILURE MODE	PHASES AT RISK	FURTHER RISK SCREENING NECESSARY?	FIGURE
Lower Workings	Adit Collapse/Blow-out	12	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit	All Phases	YES	6-11
		12a	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft	All Phases	YES	6-12
		13	Blow-out of the Deep Adit due to rising pressure/water levels from an unidentified fracture network supplying water to material	All Phases	NO; Saturation from unidentified fracture networks will not induce mine working collapses. (See Report for further rational)	None
		14	Blow-out of the Deep Adit due to rising pressure/water levels from opening of fractures during construction activities which supply water to material	Phase II (Construction)	NO; Saturation from unidentified fracture networks will not induce mine working collapses. (See Memo for further rational)	None
		15	Blow-out of the Deep Adit due to an unidentified high pressure/water level buildup behind existing blockage	Phase I (Current Conditions) Phase II (Construction)	NO - represented by 15a	None
		15a	Blow-out of existing plug during investigation or construction	Phase I (Current Conditions) Phase II (Construction)	YES	None
		16	Blow-out of the Pollard Adit due to stability disturbances caused by vibrations/release of pressure from construction activities	Phase II (Construction)	YES	6-13
		17	Slow discharge from the Burleigh Shaft due to rising water levels behind collapse induced blockage in the Deep Adit	All Phases	YES	6-14
		18	Sporadic outflow surges from the Deep Adit due to partial blockage within the Deep Adit	All Phases	YES	6-15
		19	Any adit collapse induced blockage during construction from equipment vibration/pressure resulting in lost time/injury	Phase II (Construction)	YES	None
		20	Any adit collapse induced blockage during construction from rebound/pressure release caused by removing stock piles	Phase II (Construction)	YES	None
	Surface Slope Failure	21	Any surface slope failure resulting in blockage of lower adits	All Phases	YES	None
		22	Any surface slope failure during construction from equipment vibration/pressure resulting in lost time/injury	Phase II (Construction)	YES	None
		23	Any surface slope failure during construction from rebound/pressure release caused by removing stock piles	Phase II (Construction)	YES	None
	Geochemical Conditions	24	Formation and washing out of precipitates	Phase III (Post-Construction)	YES	None
		25	Continual water quality degradation due to evolving geochemistry	Phase III (Post-Construction)	YES	None

Table 6-4 Stormwater Modeling Results - Peak Ely Brook Stage Elevation at S. Vershire Rd.

	50-year Storm Event				100-year Storm Event			
Modeled Conditions	Without Adit Discharge	With Main Adit Release	With Deep Adit Release	With Combined Main/Deep Adit Releases	Without Adit Discharge	With Main Adit Release	With Deep Adit Release	With Combined Main/Deep Adit Releases
Existing Conditions: 72" diameter CMP at S. Vershire Rd., road elevation 982	981.7	982.3	982.0	982.6	982.9	>982.9	>982.9	>982.9
Proposed Conditions DURING CONSTRUCTION: 14'W x 6'H box culvert at S. Vershire Rd., road elevation 982	N/A	N/A	N/A	N/A	978.3	978.6	978.5	978.8
Proposed Conditions POST CONSTRUCTION: 14'W x 6'H box culvert at S. Vershire Rd., road elevation 982	N/A	N/A	N/A	N/A	978.1	978.5	978.3	978.6

Notes:

1. Assumed Main Adit release volume = 570,000 gallons and Deep Adit release volume = 287,000 gallons.
2. Assumed discharge duration = 30 minutes.
3. Assumed adit portal dimensions = 7 ft x 6 ft.
4. Assumed Main Adit discharge flow rate = 42.3 cfs and Deep Adit discharge flow rate = 21.3 cfs
5. Elevations results shown in bold red shading indicate that the flow overtops South Vershire Road (road elevation = 982).

FIGURES

Figure 3-1: Plan View of Underground Workings

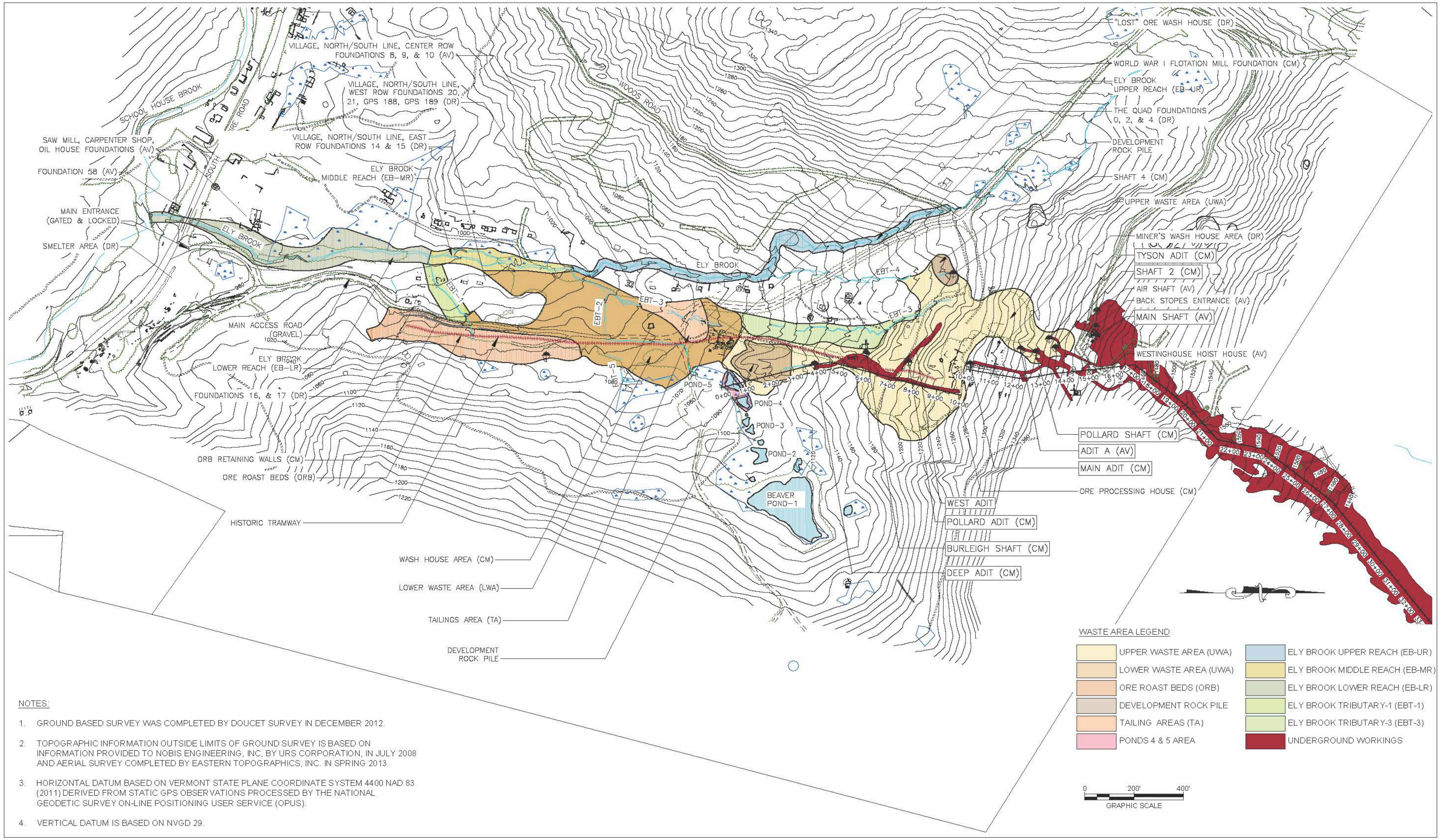


Figure 3-2: Cross Sections of Underground Workings

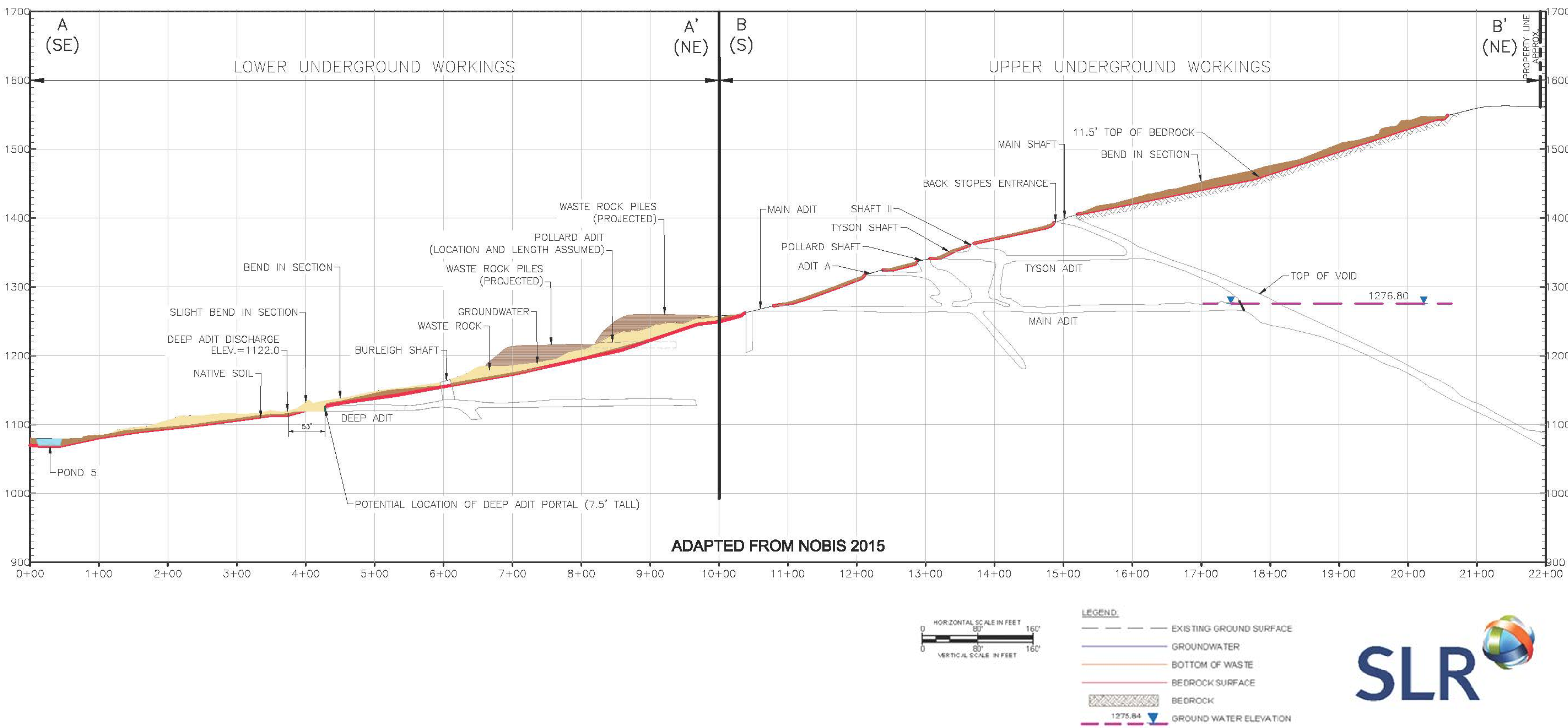


Figure 4-1: Schematic Cross Section of Lower Underground Workings

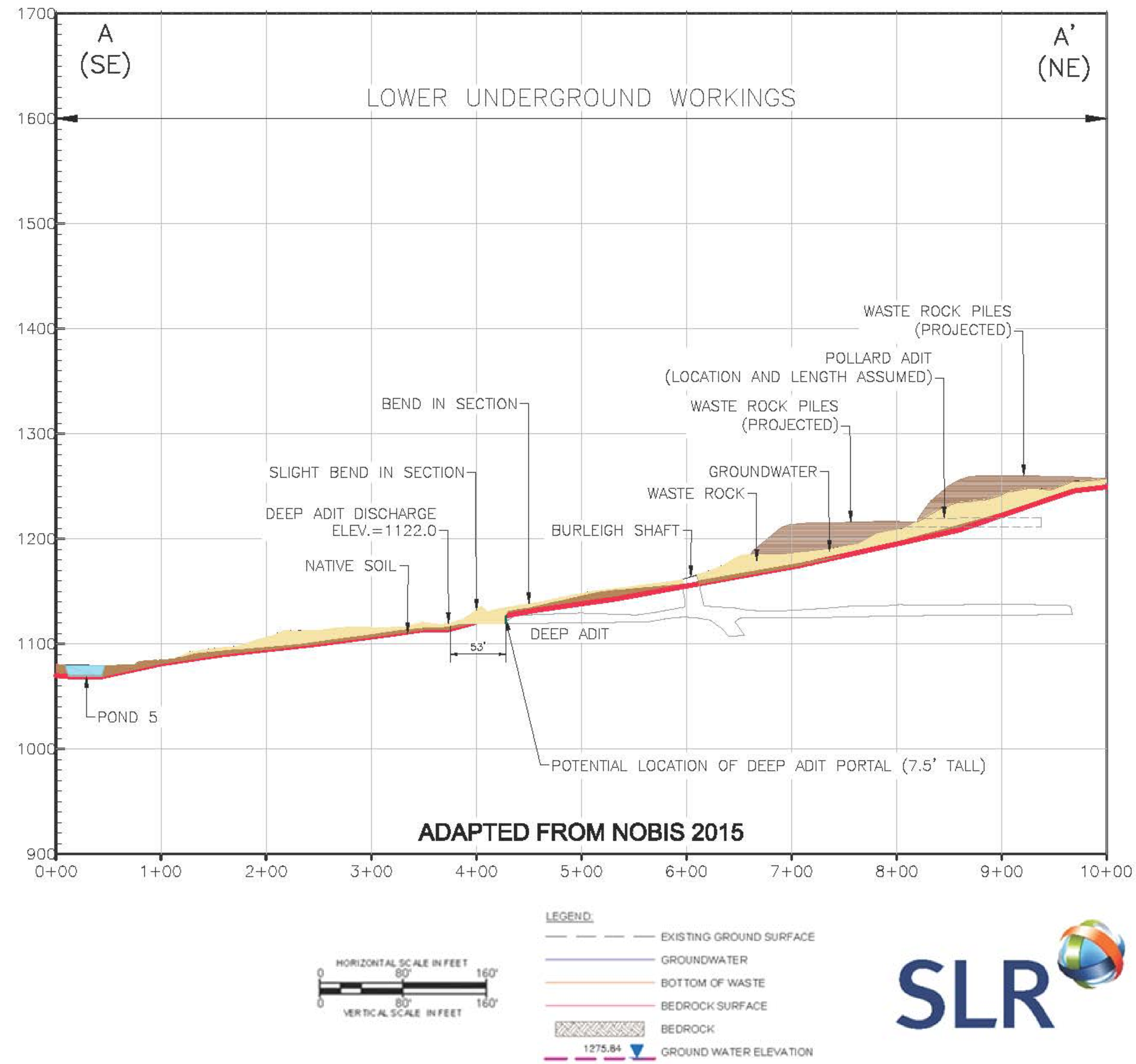


Figure 4-2: Schematic Cross Section of Upper Underground Workings

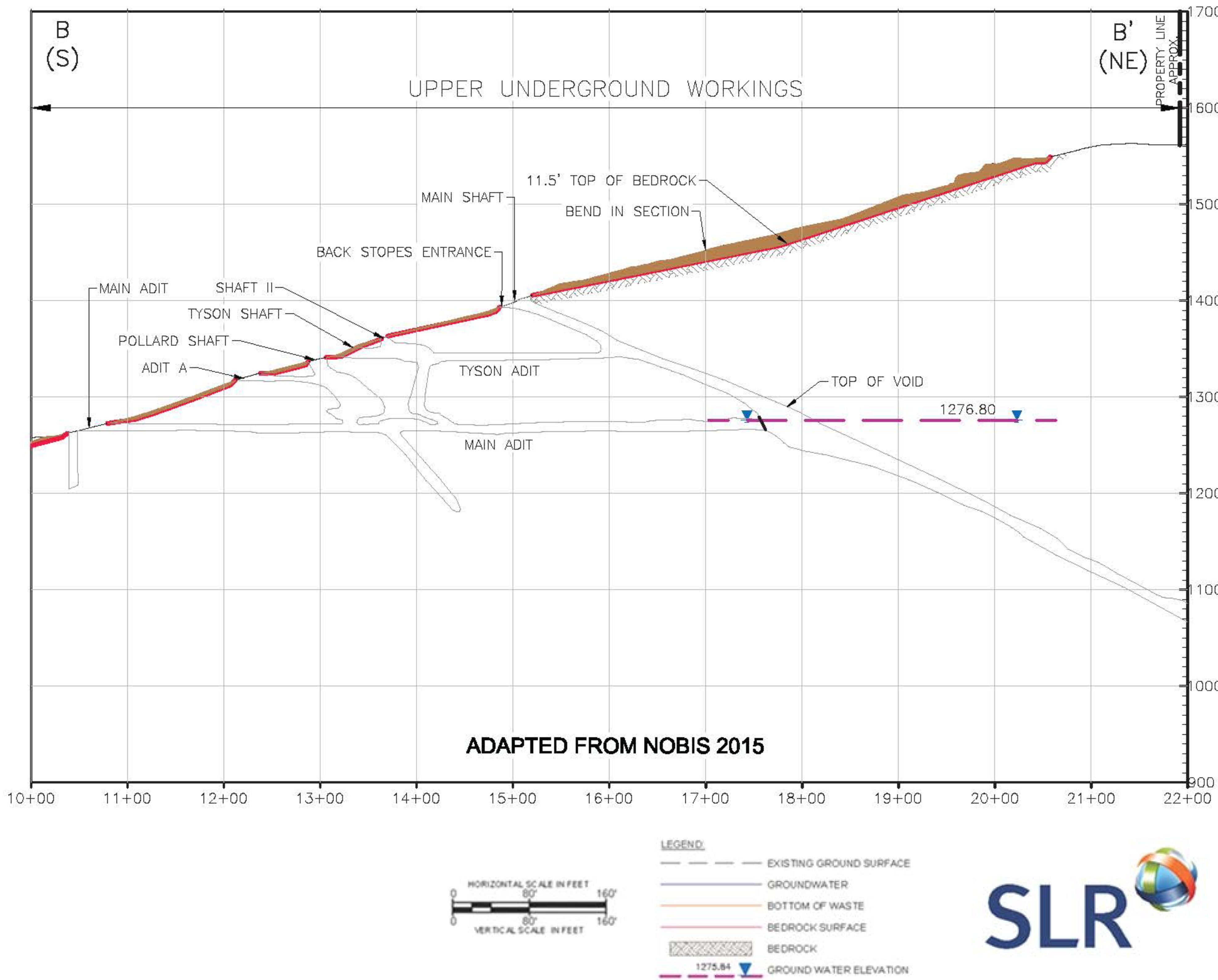


Figure 4-3: Risk Characterization Matrix for Ely Mine Underground Workings

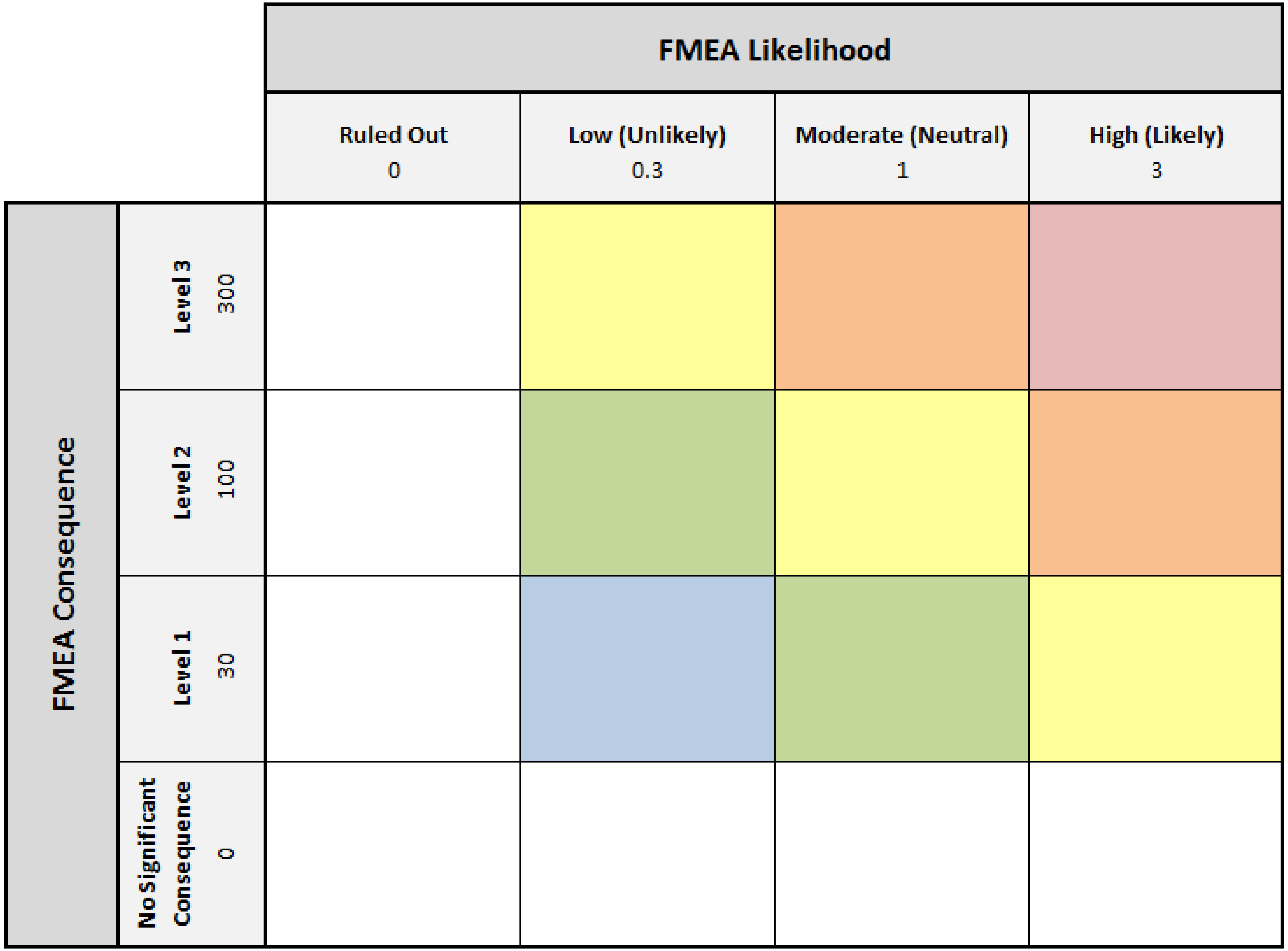


Figure 4-4: Vermont IDF Curves

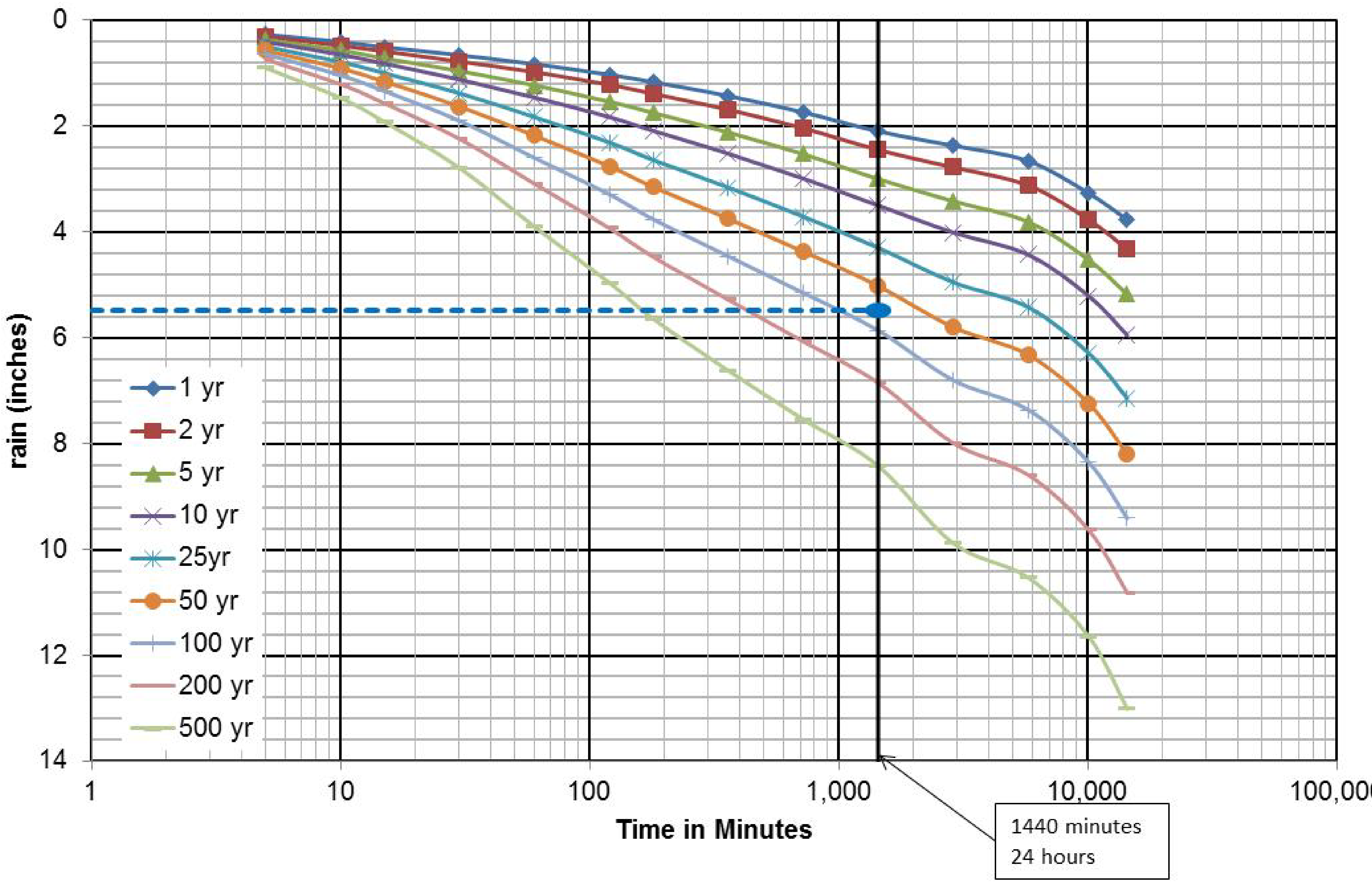


Figure 4-5: Snow Depth and Flow out of Main Adit and Deep Adit (2014-2015)

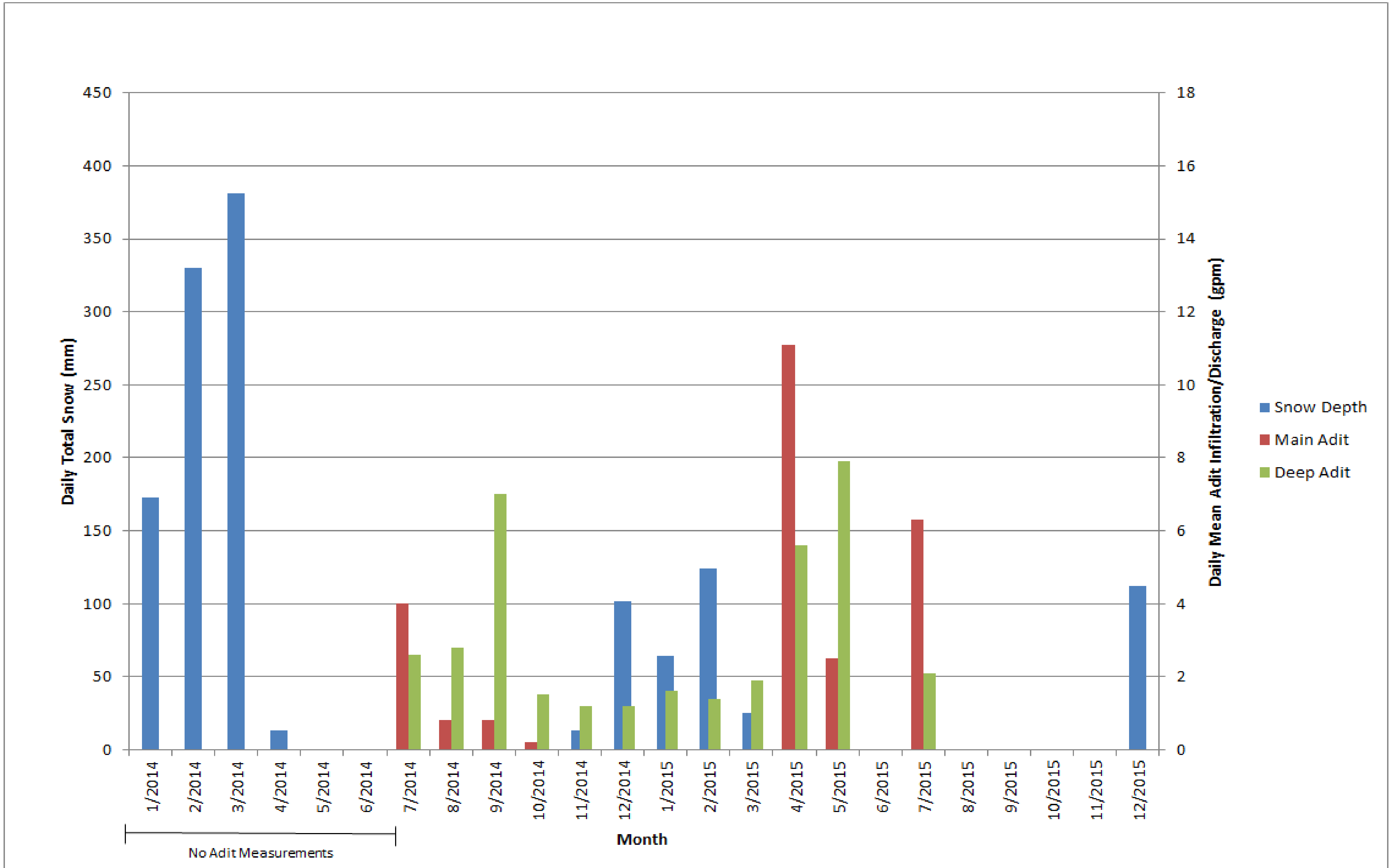


Figure 4-6: Snow Depth at Union Village Station (1950-2015)

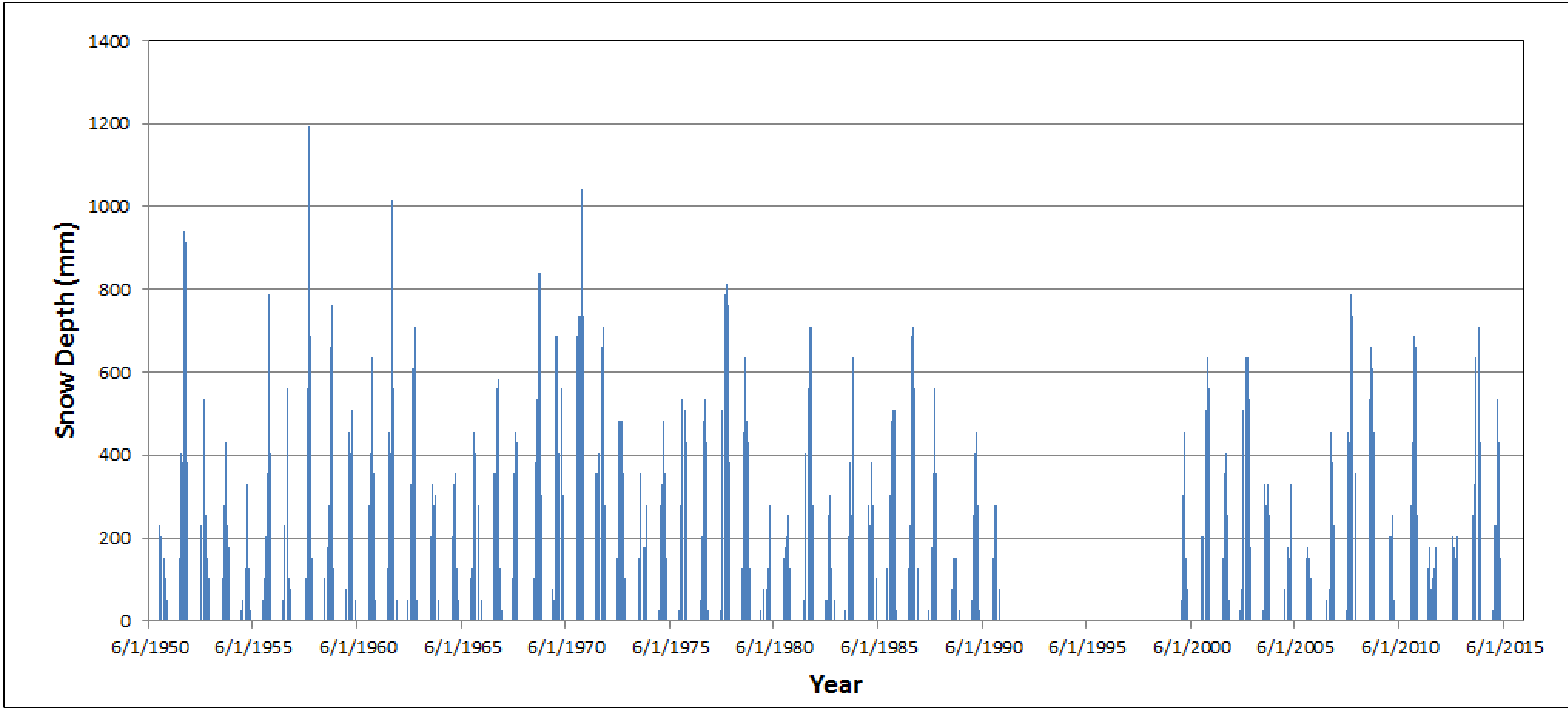


Figure 6-1: Failure Mode 1 Diagram

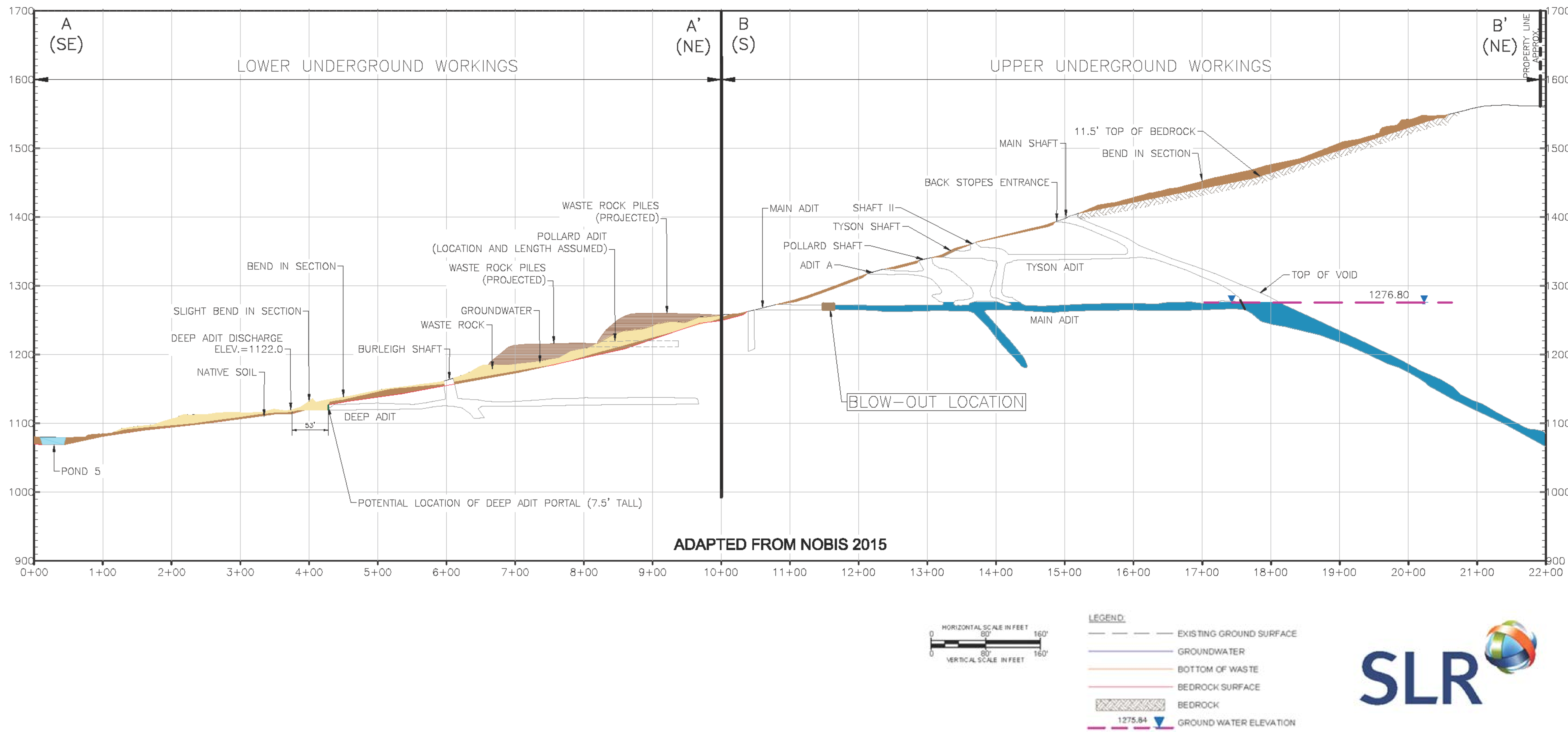


Figure 6-2: Failure Mode 1a Diagram

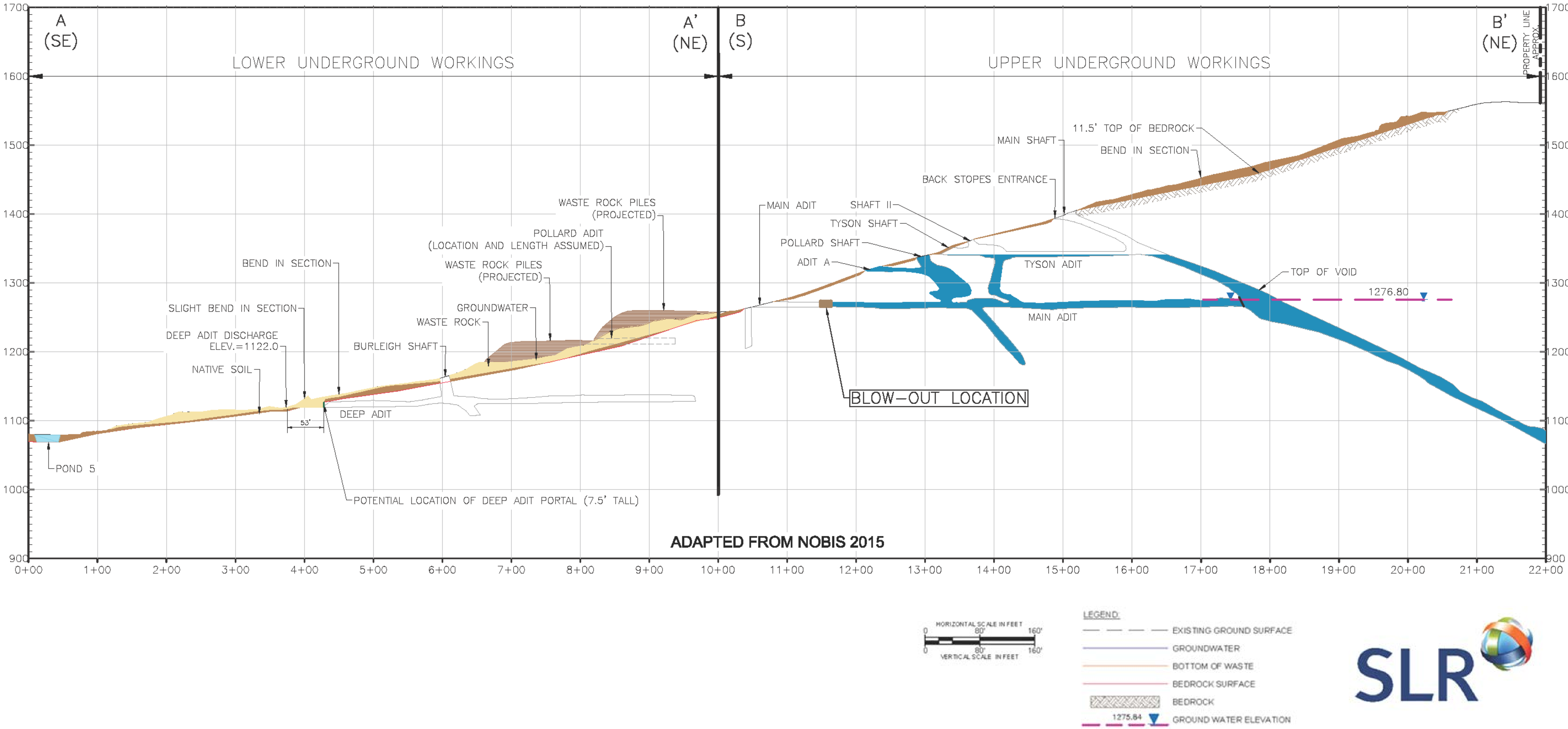


Figure 6-3: Failure Mode 2 Diagram

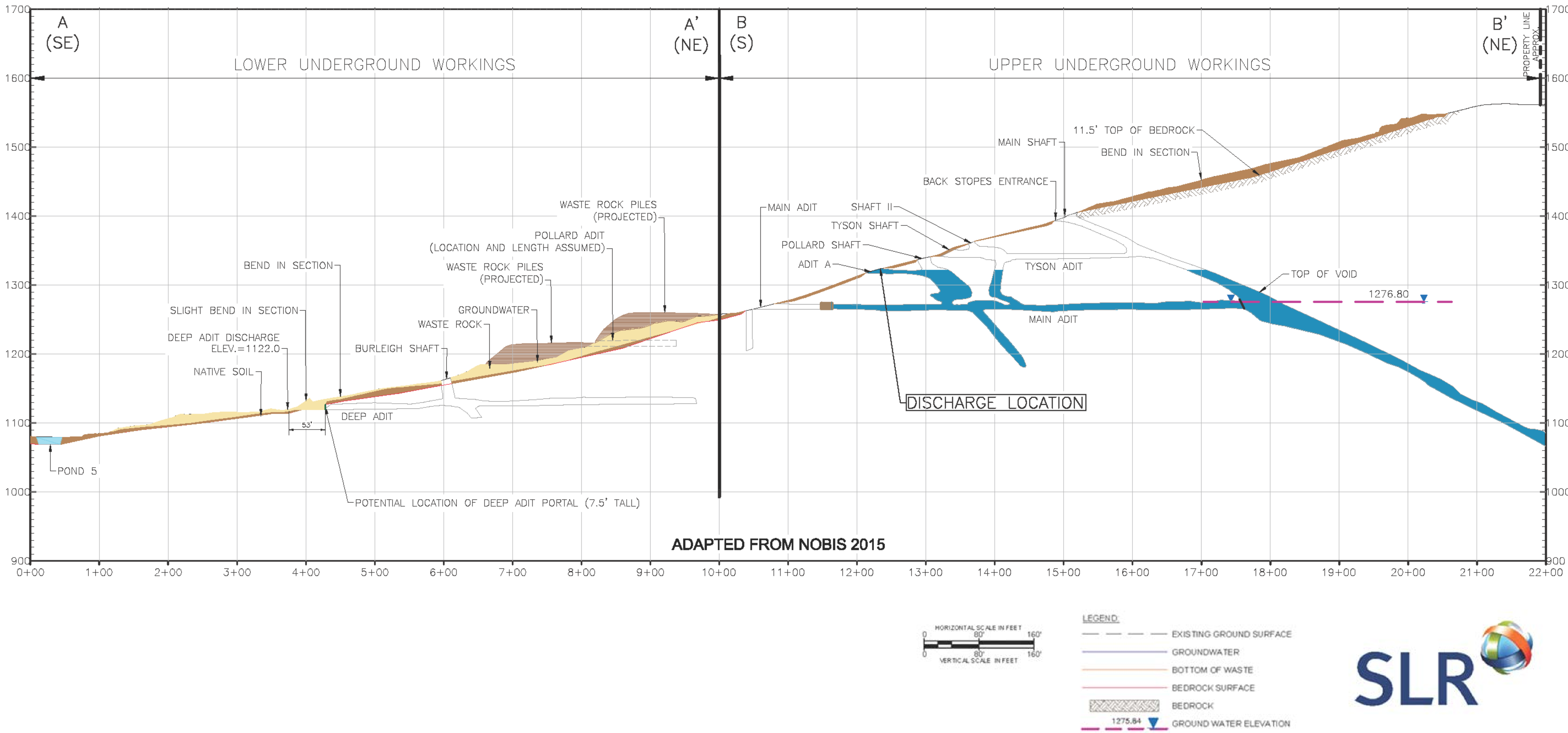


Figure 6-4: Failure Mode 4 Diagram

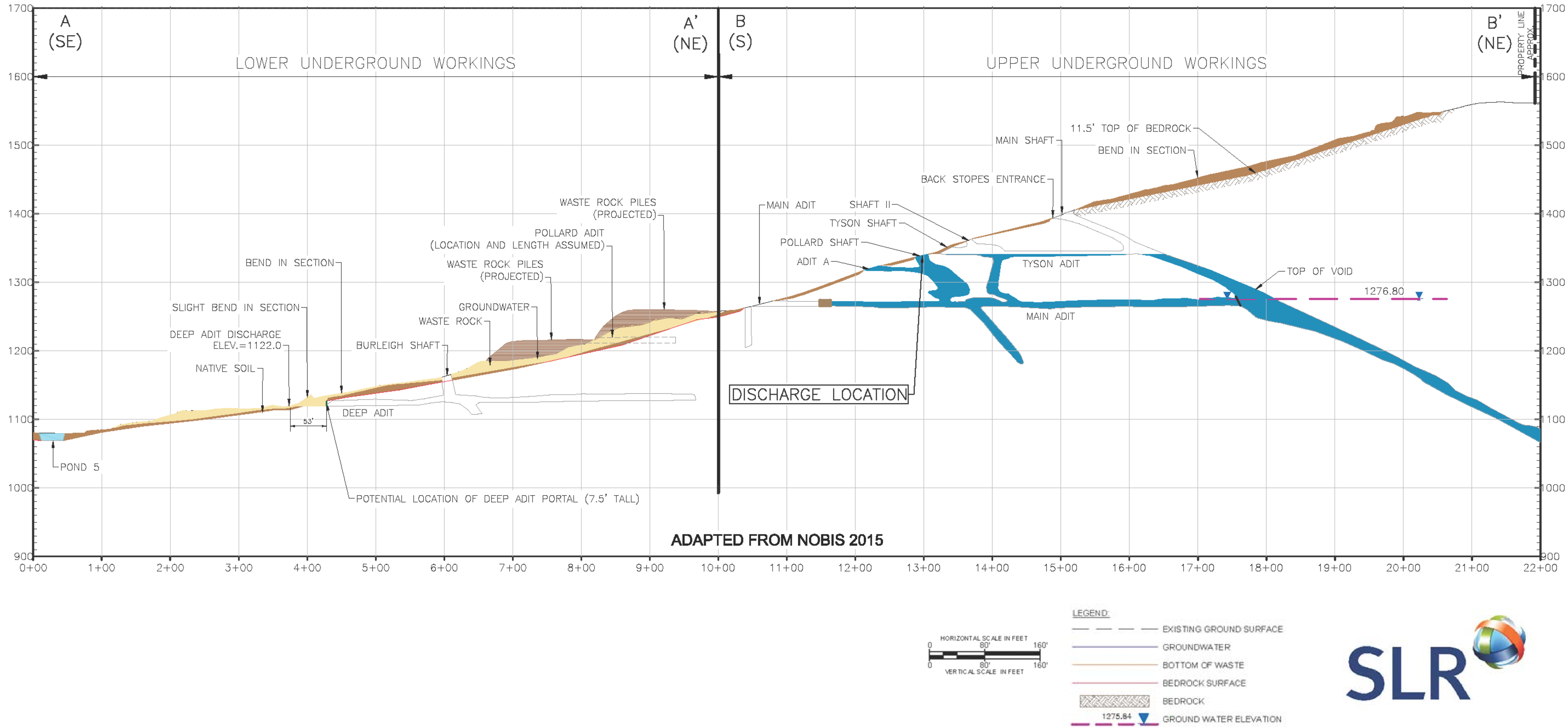


Figure 6-5: Failure Mode 3 Diagram

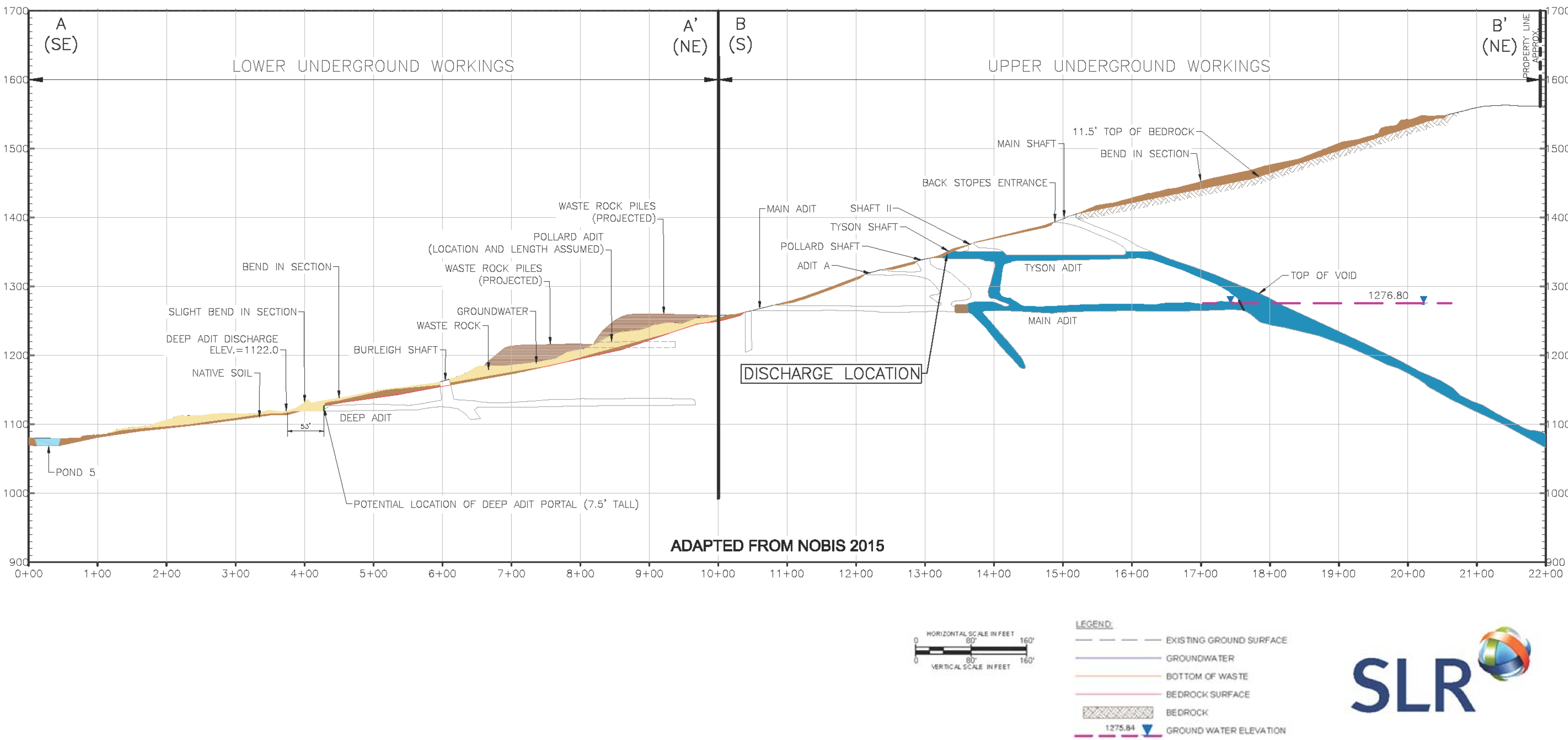


Figure 6-6: Failure Mode 3a Diagram

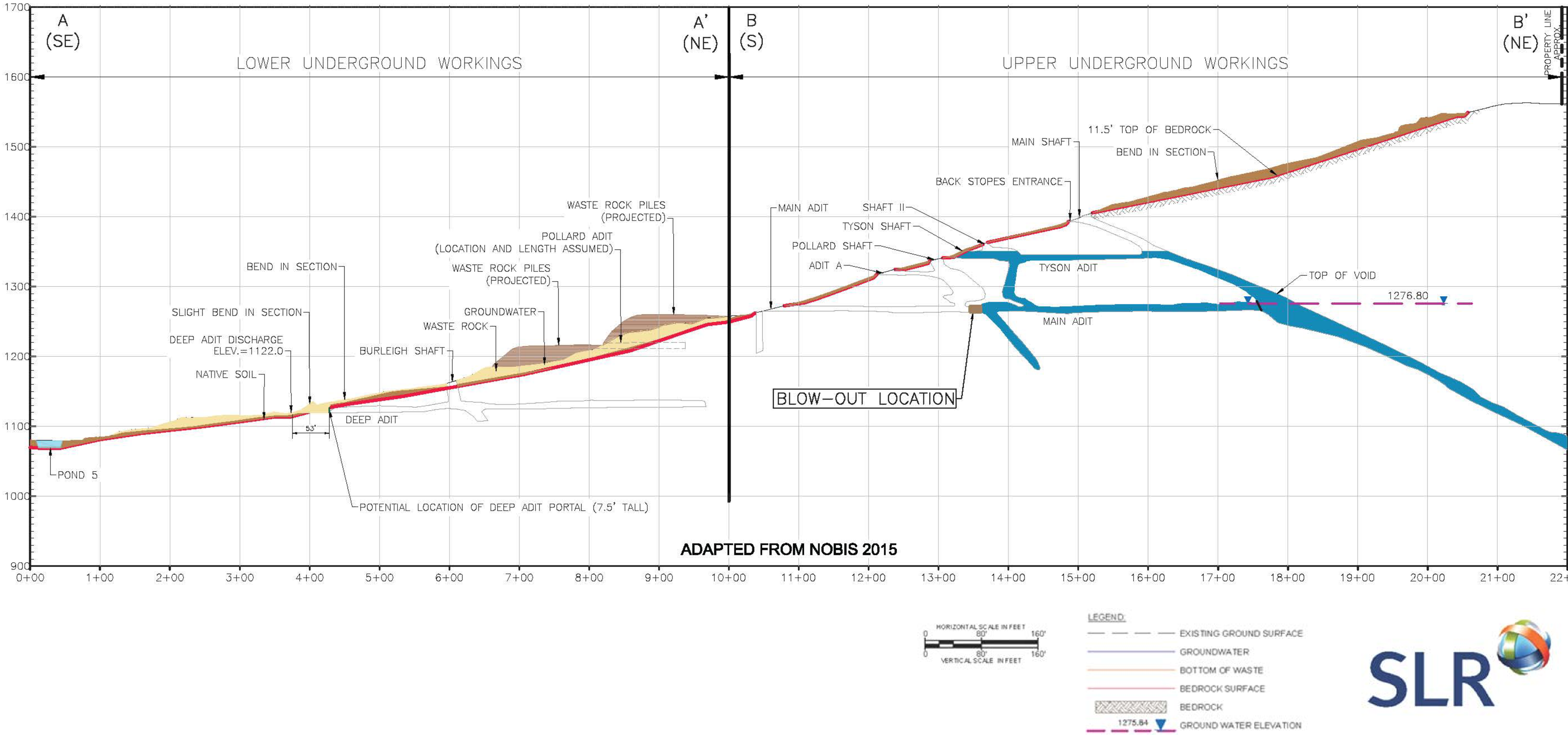


Figure 6-7: Failure Mode 5 Diagram

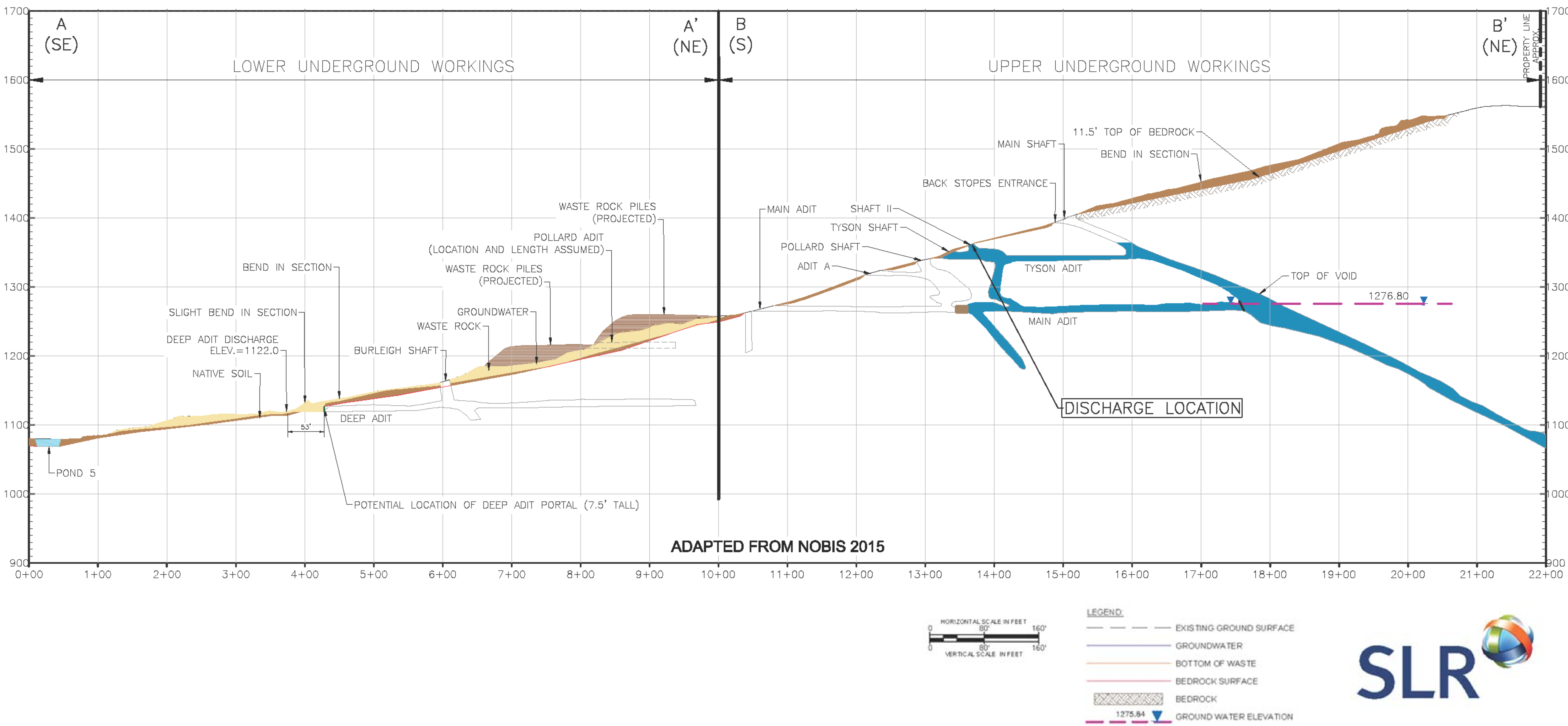


Figure 6-8: Failure Mode 6 Diagram

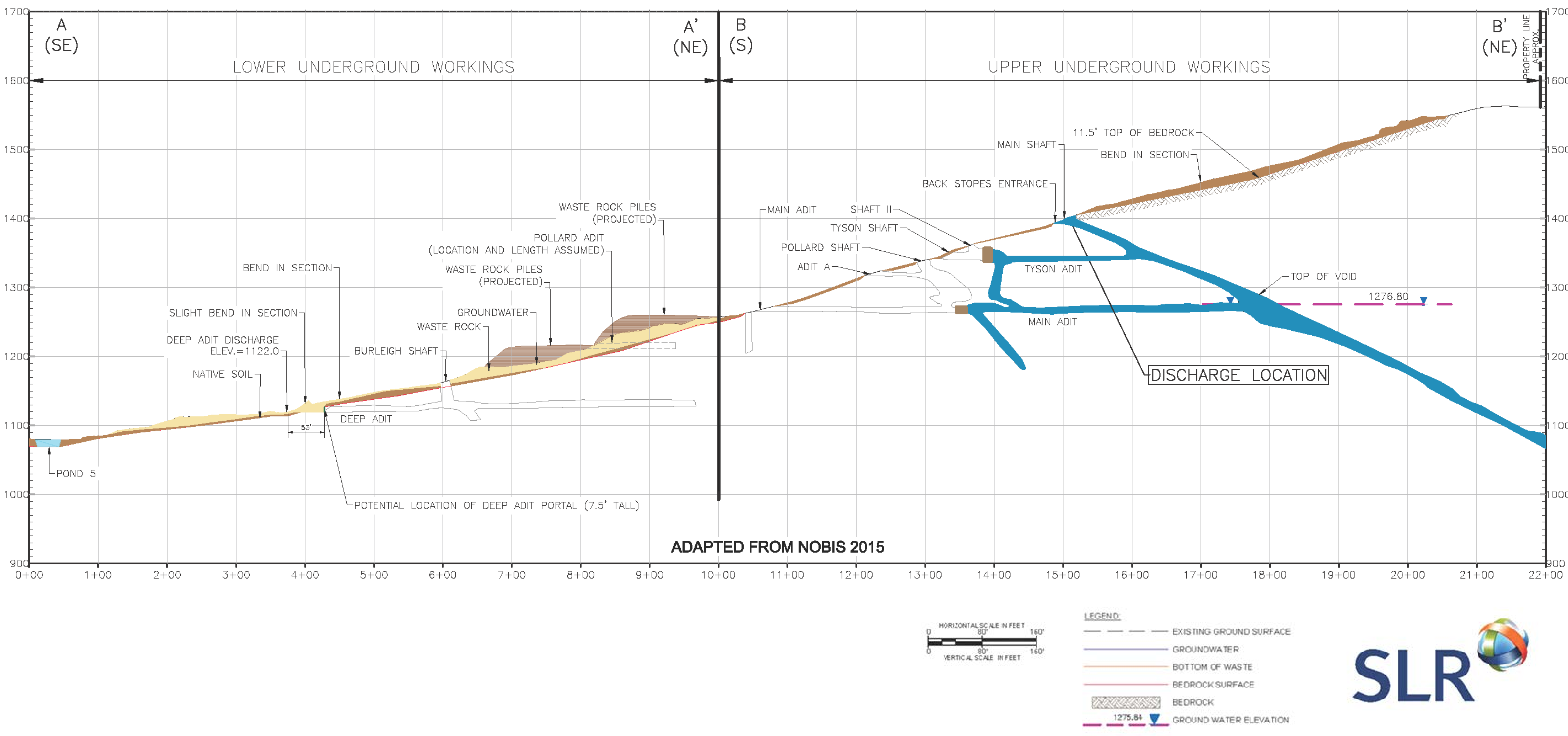


Figure 6-9: Failure Mode 7 Diagram

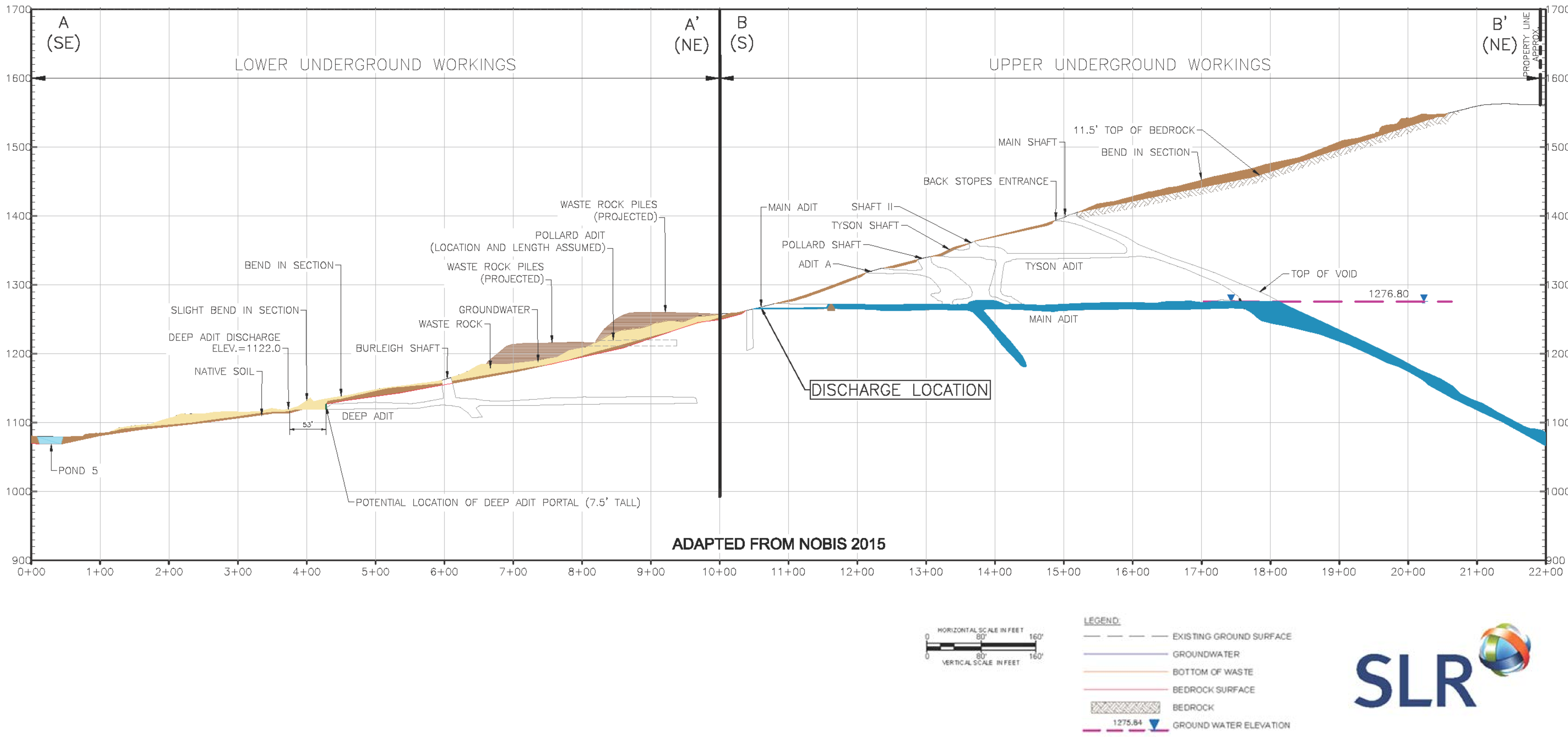


Figure 6-10: FMEA for Failure Mode 1a – Phase III

N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
						Measures	Cost (US$)	Failure Mode Impacts		
		CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit and water rise in Pollard Shaft	**300**	**3**	**900**	Blow-out of the Main Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Main Adit will release approximately 571,000 gallons of water, eroding EBT-3 on its way to Ely Brook, damaging the culver under South Vershire Road and the road itself, before entering Schoolhouse Brook and the EBOR.	**Passive Treatment:** Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.	100k-1M	**300**	**3**	**900**

Figure 6-11: Failure Mode 12 Diagram

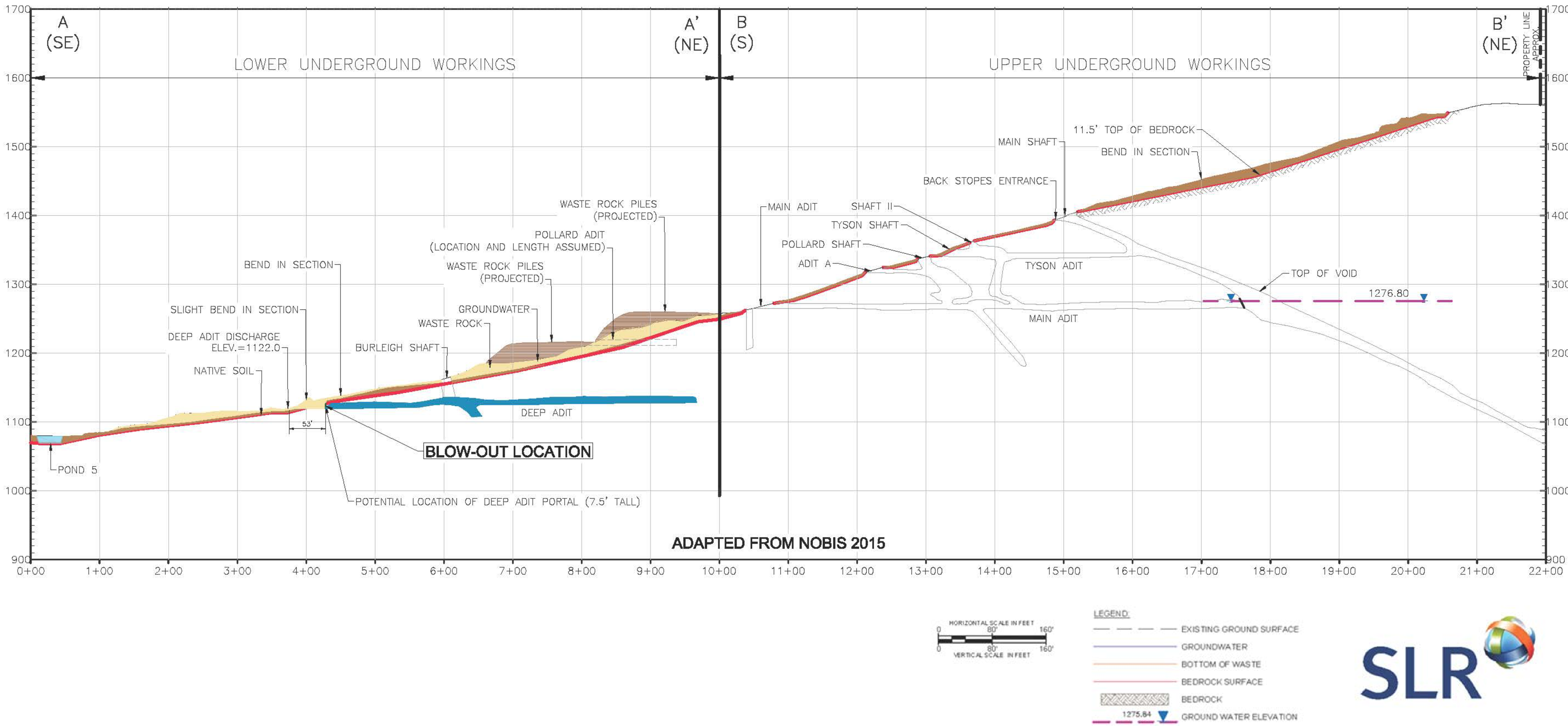


Figure 6-12: Failure Mode 12a Diagram

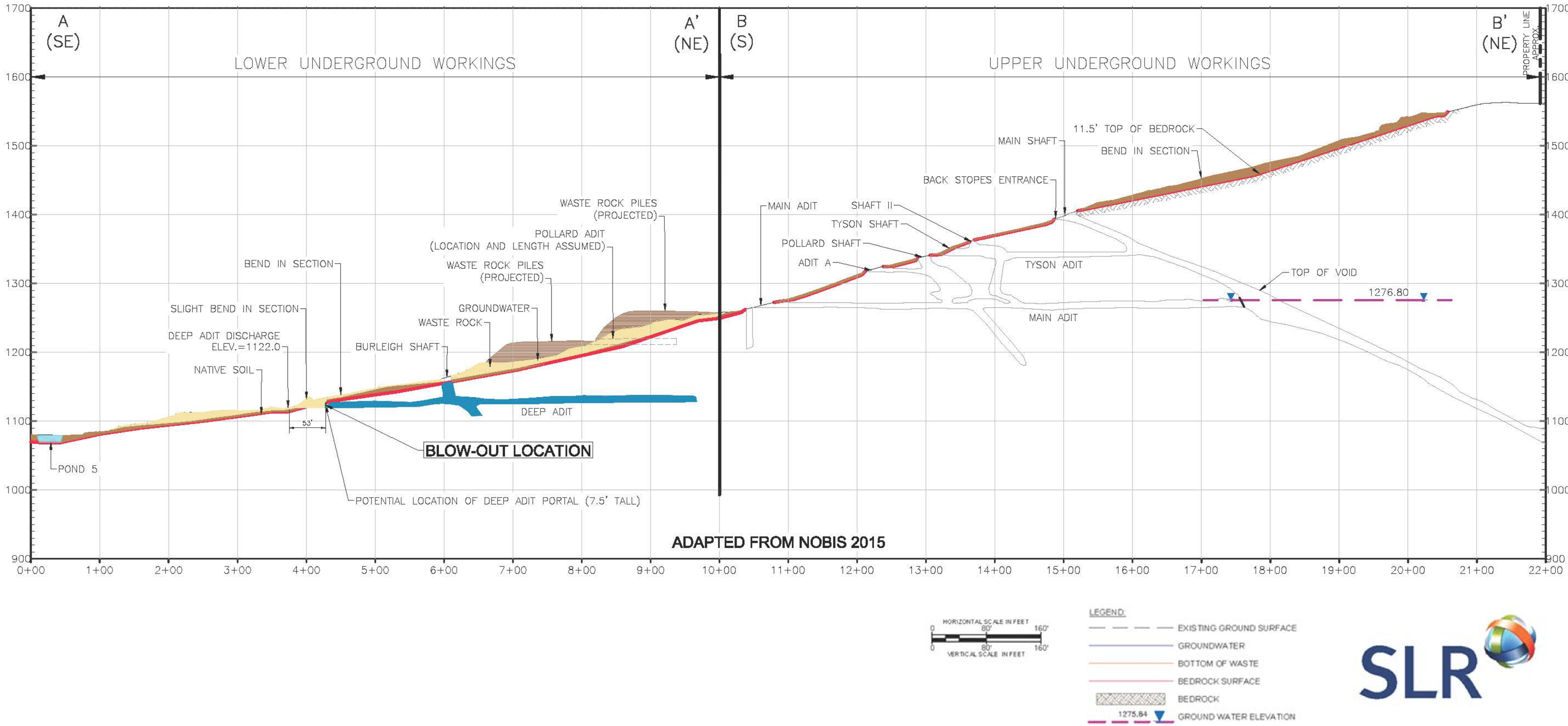


Figure 6-13: Failure Mode 16 Diagram

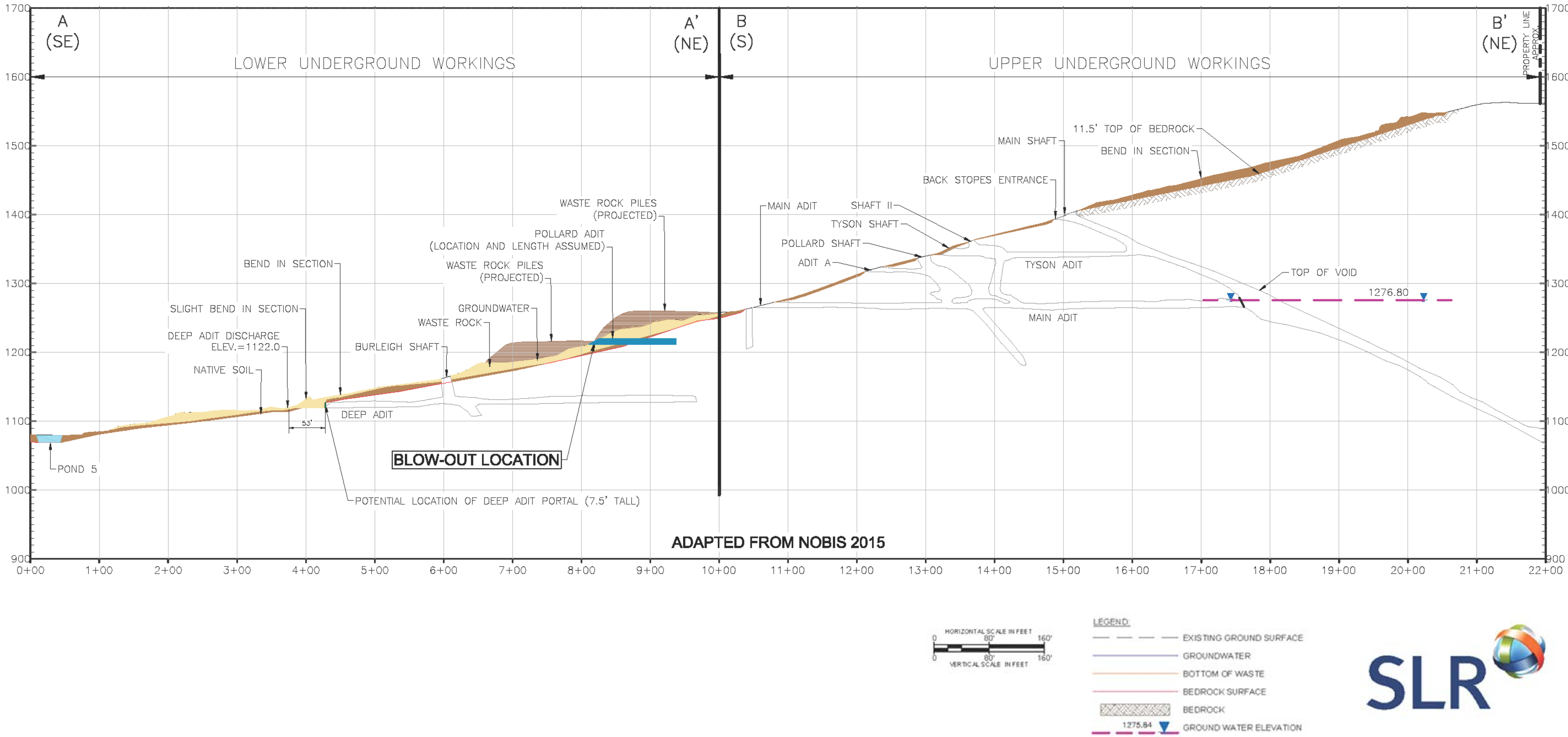


Figure 6-14: Failure Mode 17 Diagram

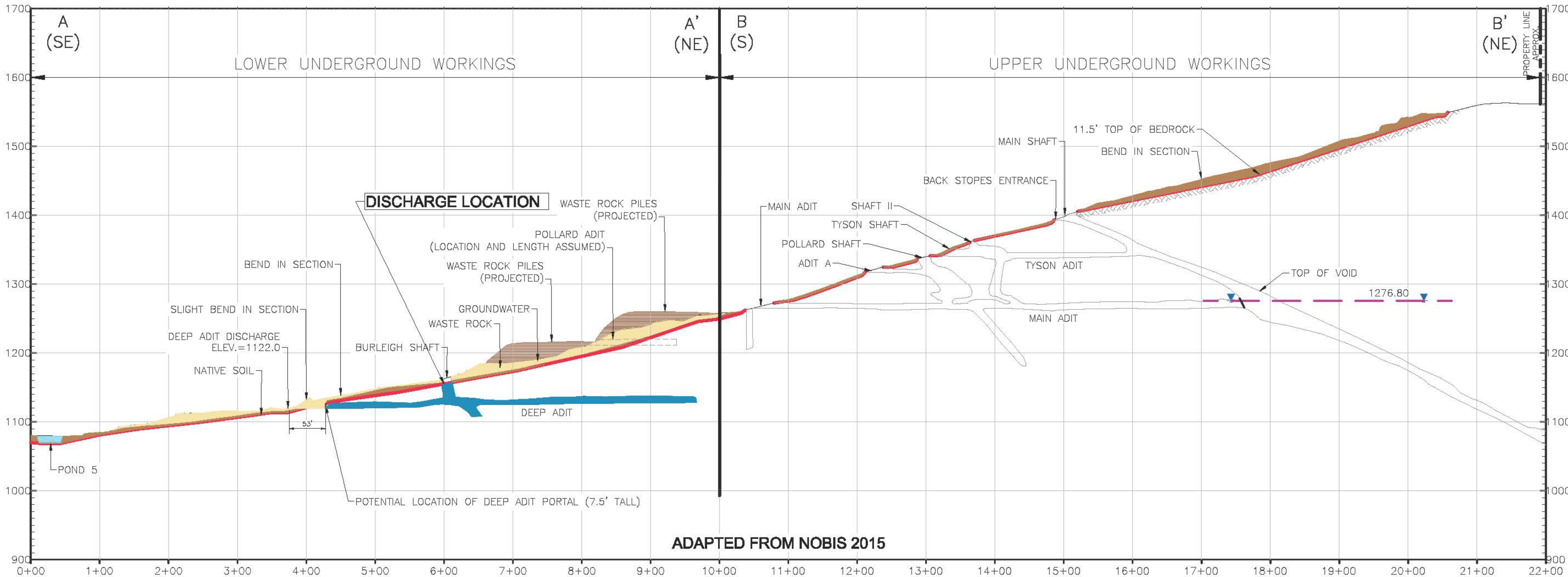


Figure 6-15: Failure Mode 18 Diagram

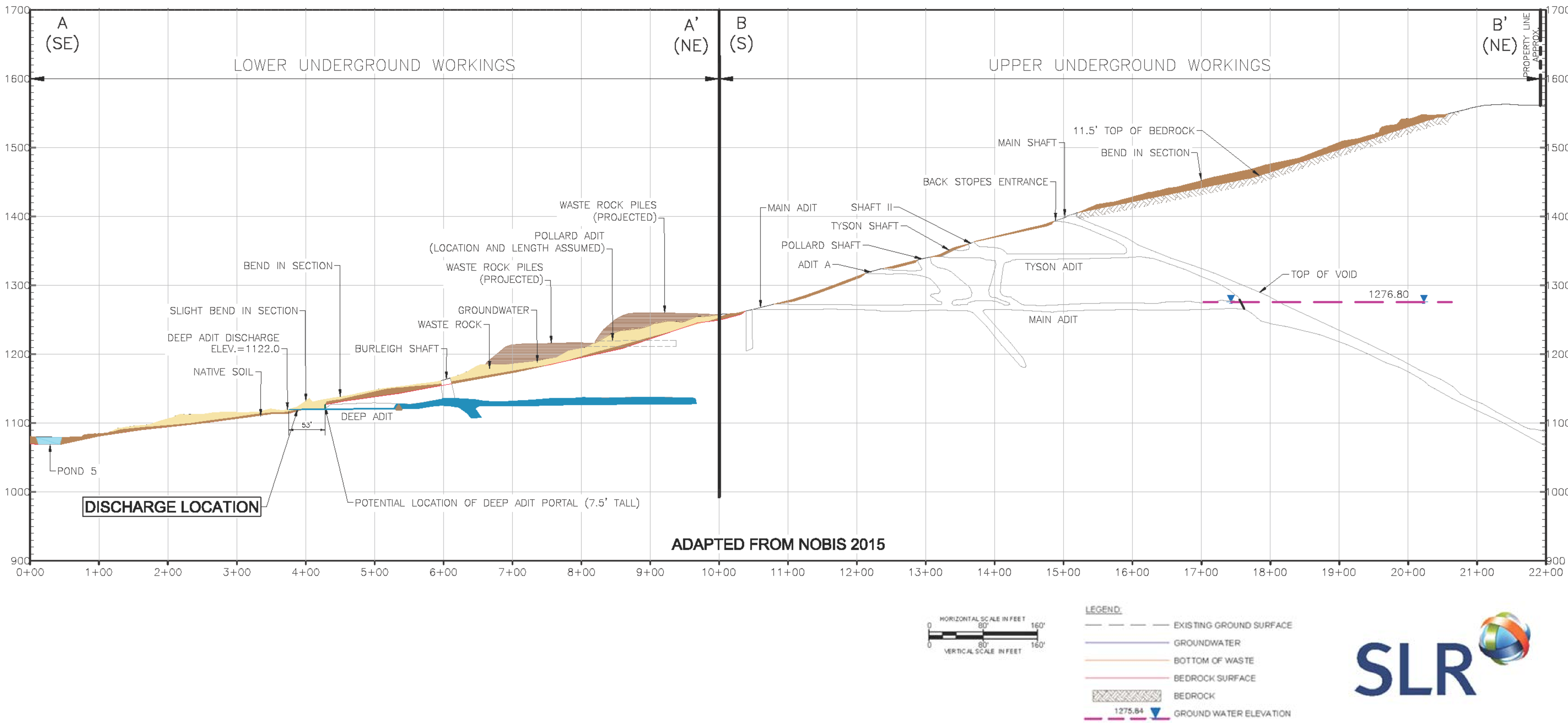


Figure 6-16: FMEA for Ely Underground Workings – Phase I

FMEA Consequence		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
	Level 3 300		1a, 12, 12a,	15a	
	Level 2 100		6, 7, 8, 21		
	Level 1 30		9, 17, 18		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-17:FMEA for Ely Underground Workings – Phase I with Mitigation Measures

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	6, 7	1a, 8, 12, 12a, 15a		
	Level 1 30	17, 18	9, 21		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-18: FMEA for Ely Underground Workings – Phase II

FMEA Consequence		FMEA Likelihood: Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
	Level 3 300		1a, 12, 12a	15a	
	Level 2 100		6, 7, 8, 12, 12a, 17, 18, 21	9, 16	
	Level 1 30		19, 20	22, 23	
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1	(pink)	High likelihood Level 3 consequences
2	(orange)	Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3	(yellow)	Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4	(green)	Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5	(blue)	Low likelihood Level 1 consequences

Figure 6-19: FMEA for Ely Underground Workings – Phase II (Construction) with Mitigation Measures

FMEA Consequence		FMEA Likelihood: Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
	Level 3 300				
	Level 2 100	6, 7, 17, 18	1a, 12, 12a, 15a,		
	Level 1 30	8	9, 16, 19, 20, 21, 22, 23		
	No Significant Consequence 0				

Risk Levels

FMEA Method: Priority	Color	Description
1	Red	High likelihood Level 3 consequences
2	Orange	Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3	Yellow	Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4	Green	Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5	Blue	Low likelihood Level 1 consequences

Figure 6-20: FMEA for Ely Underground Workings – Phase III

FMEA Consequence		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
	Level 3 300				1a
	Level 2 100			6, 7, 8, 9, 10, 11, 17, 18, 21, 24, 25	12, 12a, 13
	Level 1 30				
	No Significant Consequence 0				

Risk Levels

FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Figure 6-21: FMEA for Ely Underground Workings – Phase III with Mitigation Measures

FMEA Consequence		FMEA Likelihood: Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
Level 3	300				1a (Passive)
Level 2	100	21		6 (Passive), 7 (Passive), 8 (Passive)	
Level 1	30	10, 11, 12, 12a, 13, 24, 25	1a* (Plugs), 6* (Plugs), 7* (Plugs), 8* (Plugs), 9, 17, 18		
No Significant Consequence	0	1a* (Slurry), 6* (Slurry), 7* (Slurry), 8* (Slurry)			

Risk Levels

FMEA Method: Priority	Color	Description
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Notes:

* Implementation of Mitigation Measure potentially prohibited due to concerns about endangered bat species habitat

APPENDIX A

Technical Memorandum from Carl Fietze about Geology

Memorandum

To: Tarik Hadj-Hamou, Ph.D., P.E.

From: Carl Fietze

Date: February 11, 2016

Subject: Ely Mine FMEA

1. INTRODUCTION

The Ely Mine is an abandoned copper mine in Vermont, USA. The mine was an underground mine and operated from the early 1800's to the early 1900's and again sporadically during World War I and World War II. The mine is located within what is known as the Vermont Copper Belt, a 20 mile long ore deposit within the County of Orange in Vermont.

The likelihood of the following occurring at the abandoned Ely Mine need to be understood:

- Could the adits collapse creating dams?
- Could the rocks slowly decompose and debris accumulates and blocks the adit/shaft?
- Is there a reason to think that the underground working connecting the UUGW and LUGW existed and collapsed?
- Could fractures open in the rock when the stockpiles are removed and a larger volume of water penetrates the underground workings?

The following sources of information were used to review the geological and geotechnical environment of the Ely Mine in order to provide an answer of likelihood of the questions occurring.

- Geochemical prospecting Investigation in the Copper Belt of Vermont, F.C. Canney. Geological Survey Bulletin 1198 – B, 1965.
- Preliminary Report, geology of the Orange County Copper District, Vermont, W.S. White and J.H. Eric, United States Department of the Interior Geological Survey, August 1944.
- Ely Copper Mine Superfund Site Vershire, Vermont, Remedial Investigation/Feasibility Study, July 2011.
- Historical Context and Preliminary Resource Evaluation of the Elizabeth Mine, South Strafford, Orange County, Vermont, Arthur D. Little, October 2000.

2. BACKGROUND

2.1. Geology

The Ely Mine is located on what is known as the Orange County Copper district or the Copper Belt of Vermont. This copper belt comprises three districts the Corinth, Copper-Field and South Strafford districts and lies along a north-south line, which corresponds to the direction of schistosity of the country rock.

The Vermont Copper Belt is highly metamorphosed and intensely deformed of early Palaeozoic age (Canny, 1965), and forms part of a thick series of metasedimentary and meta-volcanic rocks. The western part of the belt consists of calcareous schists, known as the Waits River Formation, and the eastern part consists of quartz-mica schist (Gile Mountain Formation?) The foliatioin is intensely folded, with well-developed cleavage, which lies parallel to the axial planes of major and minor folds (White, 1944). The ore bodies of the Copper Belt are lenticular or tabular and generally are developed parallel to the cleavage of the wall rock.

The Ely deposit is characterized by several small deposits which overlap and are elongated shoots which run parallel to the plunge of minor folds. The deposit is hosted in quartz mica schist. The deposit is straiform and stratabound and follows the same orientation as the layering in the host rock. The foliation trends north and dips more east than the cleavage. Two vertical faults were encountered in an adit (no mention is made of which adit). These faults were characterized by up to a foot of breccia and abundant coarse calcite. It has been surmised that these faults are the same as structural features known as “dike walls” on the old mine plan.

2.2. Underground Workings

Twelve adits, shafts or vents have been developed over the Ely’s life-of-mine. These openings were developed down dip following the bedding at 25 degrees to the northwest, away from the slope of the hillside. These openings are divided into upper and lower workings. The upper workings comprise the Main and Pollard adit and shaft, while the lower workings comprise the Deep Adit and the Burleigh shaft.

The stopes were developed by excavating the ore from one of both sides of the inclined shaft in blocks. Large stopes are associated with the upper workings and the majority of these stopes have collapsed ground. Cross-sections drawn by White 1944, surmise that these stopes are blocked and that all the workings were flooded and at least 90 % of the main shaft was flooded. White also noted collapsed ground in the north eastern areas of the upper workings, highlighted in Figure 1, with cross-sections shown in Figure 2 and 3.

Groundwater seepage is prominent from the Deep Adit and Main Adit. With these being the two main sources of flowing water year around.

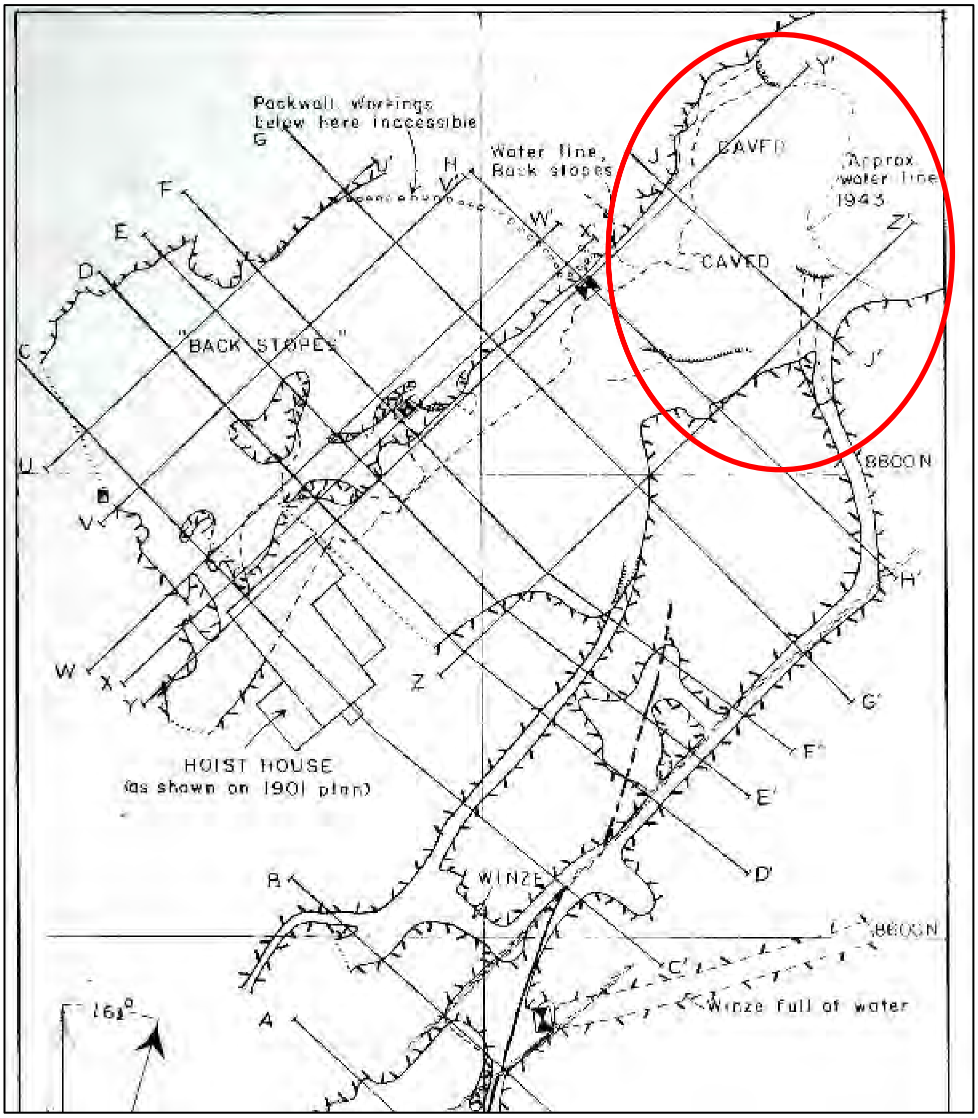
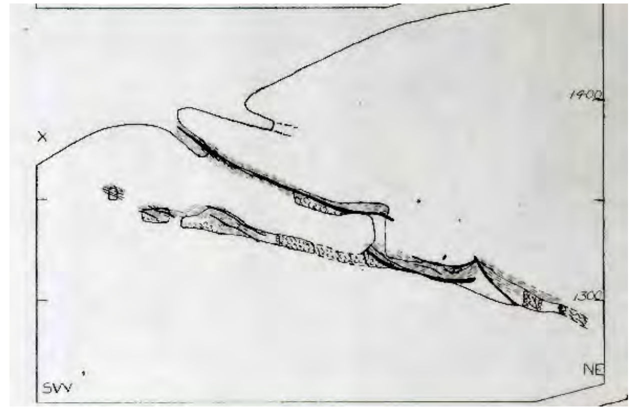
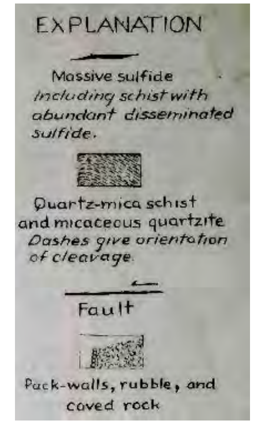


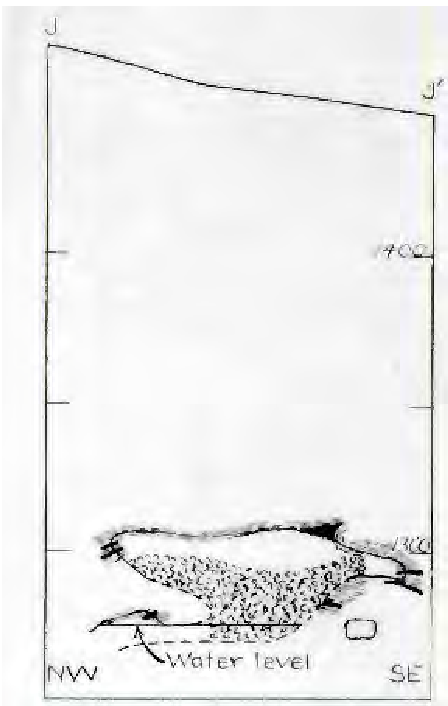
Figure 1: Plan Showing the Upper Workings and location of cross-sections, White 1944.

Section Y-Y

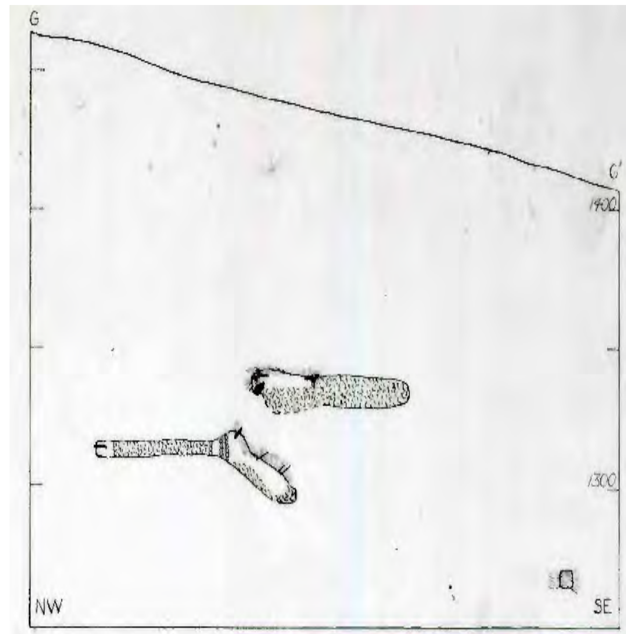


Section X-X





Section J-J



Section G-G

Figure 2: Selection of Cross-sections prepared by White, 1944 showing extend of collapsed ground in the north eastern part of the upper workings.

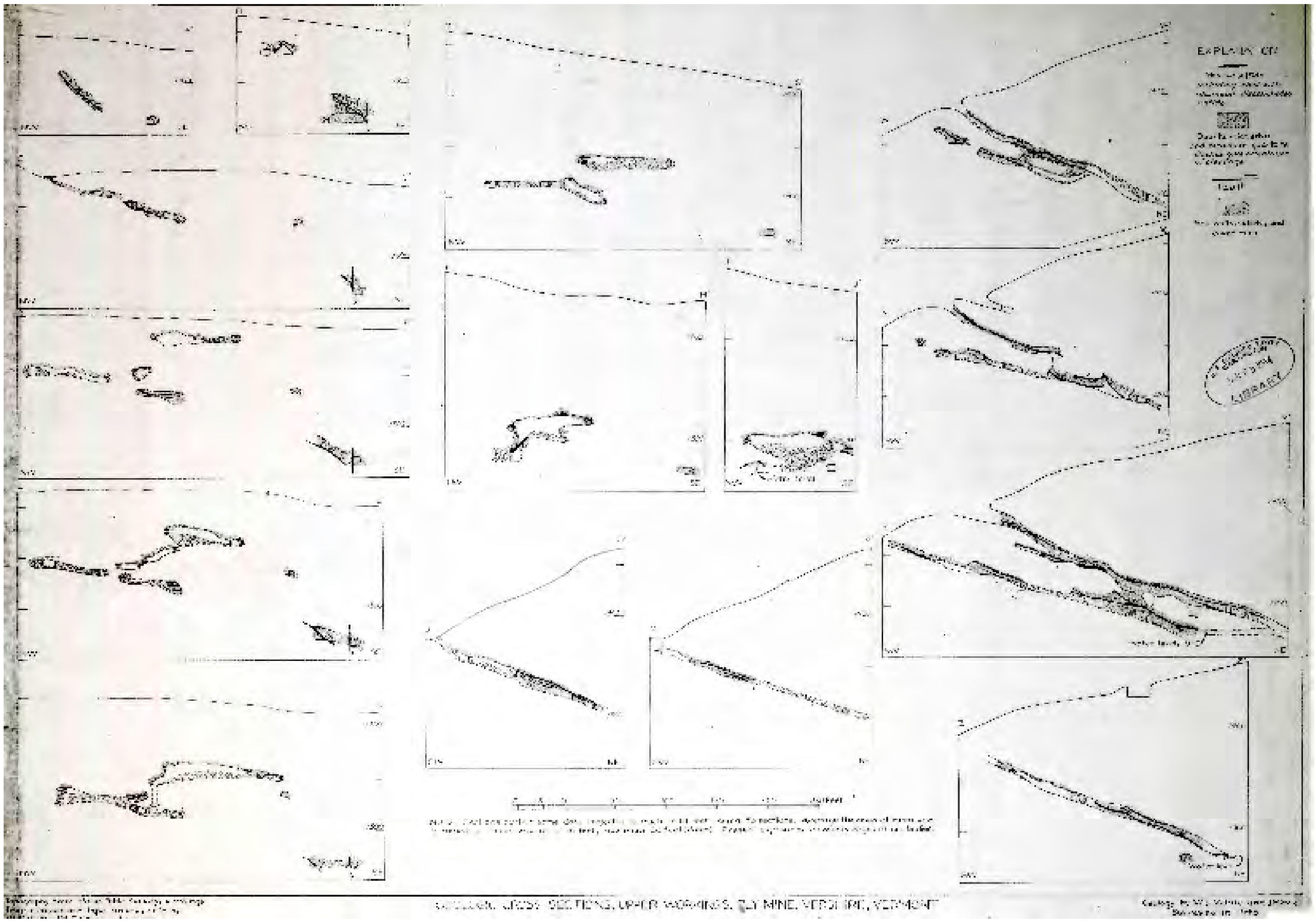


Figure 3: Cross-sections prepared by White, 1944

3. ENGINEERING GEOLOGICAL ASSESSMENT

A high level engineering geological assessment has been carried by an SLR Rock Engineer, based on experience of working in stratified underground ore deposits There is limited geotechnical information on the conditions of the underground workings, however mention is made of work carried out by URS in 2008, where Rock Quality Designation ("RQD") values where determined. A trend of low RQD values was observed to a depth of 30 ft. It was also stated that more fractures were observed in this 30 ft zone when compared to the deeper rock mass.

Typically schists (Ely Mine country rock) display a strong anisotropic strength due to their pronounced foliation, with intact strength determined by the direction of loading on the foliation. These rock types are generally not durable and tend to deteriorate at exposed surfaces due to slaking along foliation, decomposition of sulphide minerals etc. The Ely country rock is quartz schist and will be more resistant to weathering when compared to other schists, weathering at surface exposures would however occur, specifically over the length of time that the Ely Mine has been open.

Structurally the schists can contain minor faults which are either parallel to the foliation and/or the folds in the schists, such as at Ely Mine. These foliation shears form due to inter-lay slip. An internet search of the history of the Ely Mine was carried out and photos of the underground workings were found. These photos show that structural features are typical of a stratified rock mass with prominent foliation, as discussed above. These photos also show that there is an accumulation of fallen rock which is controlled by the structural orientation. The shape of the fallen rock can be termed as "platy" with failure planes along foliation. The blocks of rock are 3 to 6 ft in length and this would suggest that there is a wide sub-vertical orthogonal joint set which separates the blocks into these sizes. An example of these photos is shown in Figure 4 and 5. With deterioration of the rock mass due to weathering and alteration, the shear strength along these discontinuities (foliation and sub-vertical joints) will decrease and the frequency and size of these falls of ground are expected to increase over time. Where faults such as the "dike walls" are encountered larger falls of ground are expected with possibility of blockage in these areas.

It is also anticipated that the fall of ground will increase closer to surface due to a combination of factors such as a low stress environment, increased fracture frequency and decrease in the shear strength of the discontinuities with weathering.

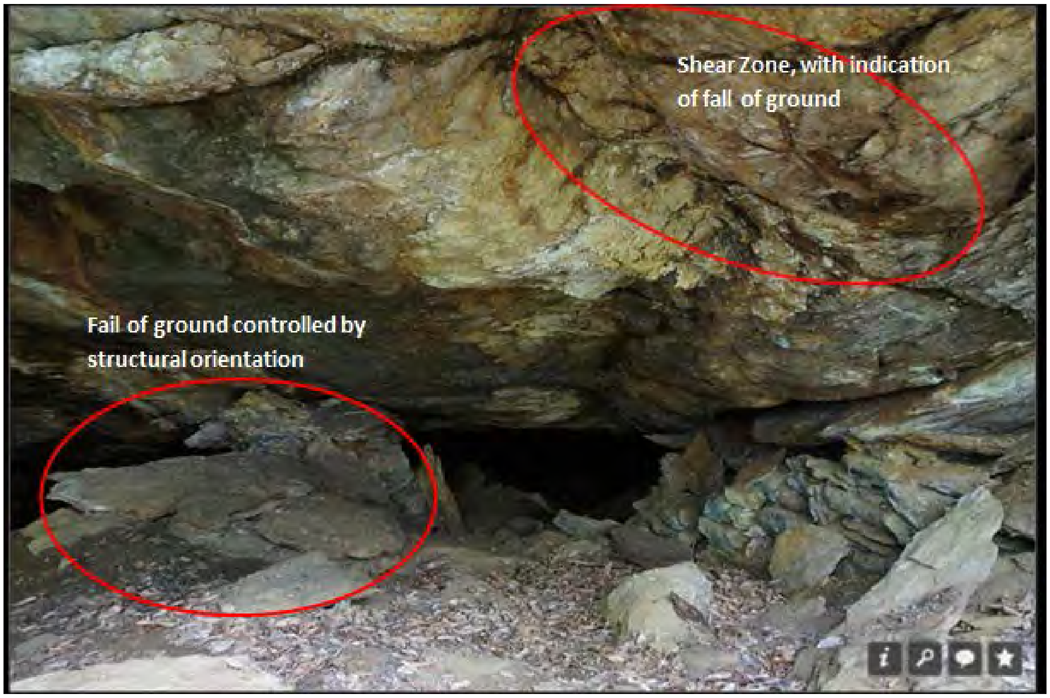


Figure 4: Ely Copper Mine, Underground of Unknown location.

Figure 5: Ely Copper Mine, Underground of Unknown location.

4. CONCLUSIONS

Following the review of the geology and underground workings the following is concluded

- Could the adits collapse creating dams.

  The likelihood of the adits collapsing is high, and has most likely already collapsed. This is due to adverse structural orientations and deterioration of the rockmass, due to weathering and alteration. The volume of material collapsing will depend also on the shape and size of the workings, larger spans will mean large volumes of collapse which have the potential to create a plug for damming of water. This is most likely the case in the upper workings within the stops due to excavating the ore from one of both sides of the inclined shaft in blocks.

  Also the questions arising from here are (1) how much water would/would have accumulated if the collapse occurred, and (2) whether or not this will be over-pressurized.

- Could the rocks slowly decompose and debris accumulates and blocks the adit/shaft.

  The likelihood of this occurring is high. As weathering of the rock mass occurs the rock mass strength will deteriorate leading to significant back break. This debris will accumulate over time and block the adits.

- Is there a reason to think that the underground working connecting the UUGW and LUGW existed and collapsed?

  There is nothing in literature which would suggest that the UUGW and the LUGW were connected.

- Could fractures open in the rock when the stockpiles are removed and a larger volume of water penetrates the underground workings.

  There is a possibility of this occurring in the upper 30 ft of the profile. Further work would be required to quantify the risk of this occurring.

Please contact myself if require any additional feedback.

APPENDIX B

FMEA Calculations

TABLE B-1 - IDENTIFIED FAILURE MODES FOR SELECTED PHASES

LOCATION	RISK TYPE	N°	FAILURE MODE	PHASES AT RISK	FURTHER RISK SCREENING NECESSARY?	FIGURE
Upper Workings	**Adit Collapse/Blow-out**	1	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-1
		1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit and water rise in Pollard Shaft	All Phases	YES	6-2
		2	Blow-out of Adit A due to rising pressure/water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-3
		3	Blow-out of the Tyson Adit due to rising pressure/water levels behind collapse induced blockage in Main Adit (behind Pollard Shaft)	All Phases	NO - represented by 1a	6-5
		3a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit behind Pollard Shaft and water rises in Shaft II	All Phases	NO - represented by 1a	6-6
		4	Slow discharge from the Pollard Shaft due to rising water levels behind collapse induced blockage in the Main Adit	All Phases	NO - represented by 1a	6-4
		5	Slow discharge from Shaft II due to rising water levels behind collapse induced blockage in the Main Adit (behind Adit A)	All Phases	NO - represented by 1a	6-7
		6	Slow discharge from the Main Shaft due to rising water levels behind collapse induced blockages in the Main Adit (behind connector/Shaft II in Main Adit) and in Tyson Adit	All Phases	YES	6-8
		7	Sporadic outflow surges from main adit due to partial Main Adit blockage	All Phases	YES	6-9
	Stope Collapse	8	Stope collapse into mine pool causing surge of water from the mine shaft pool to discharge out of the Main Adit	All Phases	YES	
	Surface Slope Failure	9	Any surface slope failure resulting in blockage of lower adits	All Phases	YES	
	Geochemical Conditions	10	Formation and washing out of precipitates	Phase III (Post Remedy)	YES	
		11	Continual water quality degradation due to evolving geochemistry	Phase III (Post Remedy)	YES	
Lower Workings	**Adit Collapse/Blow-out**	12	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit	All Phases	YES	6-11
		12a	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft	All Phases	YES	6-12
		13	Blow-out of the Deep Adit due to rising pressure/water levels from an unidentified fracture network supplying water to material	All Phases	NO; Saturation from unidentified fracture networks will not induce mine working collapses. (See Report for further rationale)	
		14	Blow-out of the Deep Adit due to rising pressure/water levels from opening of fractures during construction activities which supply water to material	Phase II (Construction)	NO; Saturation from unidentified fracture networks will not induce mine working collapses. (See Memo for further rationale)	
		15	Blow-out of the Deep Adit due to an unidentified high pressure/water level buildup behind existing blockage	Phase I (Current Conditions) Phase II (Construction)	NO - represented by 15a	
		15a	Blow-out of existing plug during investigation or construction	Phase I (Current Conditions) Phase II (Construction)	YES	
		16	Blow-out of the Pollard Adit due to stability disturbances caused by vibrations/release of pressure from construction activities	Phase II (Construction)	YES	6-13
		17	Slow discharge from the Burleigh Shaft due to rising water levels behind collapse induced blockage in the Deep Adit	All Phases	YES	6-14
		18	Sporadic outflow surges from the Deep Adit due to partial blockage within the Deep Adit	All Phases	YES	6-15
		19	Any adit collapse induced blockage during construction from equipment vibration/pressure resulting in lost time/injury	Phase II (Construction)	YES	
		20	Any adit collapse induced blockage during construction from rebound/pressure release caused by removing stock piles	Phase II (Construction)	YES	
	Surface Slope Failure	21	Any surface slope failure resulting in blockage of lower adits	All Phases	YES	
		22	Any surface slope failure during construction from equipment vibration/pressure resulting in lost time/injury	Phase II (Construction)	YES	
		23	Any surface slope failure during construction from rebound/pressure release caused by removing stock piles	Phase II (Construction)	YES	
	Geochemical Conditions	24	Formation and washing out of precipitates	Phase III (Post-Construction)	YES	
		25	Continual water quality degradation due to evolving geochemistry	Phase III (Post-Construction)	YES	

TABLE B-2 - PHASE I (CURRENT CONDITIONS AND INVESTIATION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
Upper Workings	Adit Collapse/Blockage	1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit	300	0.3	90	Blow-out of the Main Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Main Adit will release approximately 571,000 gallons of water, eroding EBT-3 on its way to Ely Brook, damaging the culver under South Vershire Road and the road itself, before entering Schoolhouse Brook and the EBOR.	**Site Characterization:** Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the main adit portal. AND/OR; **Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0.3	30
		6	Slow discharge from the Main Shaft due to rising water levels behind collapse induced blockages in the Main Adit (behind connector/Shaft II in Main Adit) and in Tyson Adit	100	0.3	30	Collapse of the Main Adit behind the connector/Shaft II with collapse in the Tyson Adit leads to blockage due to entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Main Shaft, potentially entering Ely Brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0	
		7	Sporadic outflow surges from main adit due to partial Main Adit blockage	100	0.3	30	Partial collapse of the Main Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0	
	Stope Collapse	8	Stope collapse into mine pool causing surge of water from the mine shaft pool to discharge out of the Main Adit	100	0.3	30	Stope collapse into the mine pool could cause a surge of water to be discharged out of the Main Adit. The discharge could potentially enter the brook.	**None**		100	0.3	30
	Slope Failure	9	Any surface slope failure resulting in blockage of lower adits	30	0.3	9	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass	100k-1M	30	0.3	9

TABLE B-2 - PHASE I (CURRENT CONDITIONS AND INVESTIATION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
Lower Workings	Adit Collapse/Blockage	12	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit	300	0.3	90	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Site Characterization:** Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the deep adit portal. AND/OR; **Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0.3	30
Lower Workings	Adit Collapse/Blockage	12a	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft	300	0.3	90	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Site Characterization:** Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the deep adit portal. AND/OR; **Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0.3	30
Lower Workings	Adit Collapse/Blockage	15a	Blow-out of existing plug during investigation or construction	300	1	300	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Site Characterization:** Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigation activites should be sequenced from the highest to lowest elevations with respect to the deep adit portal. AND/OR; **Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0.3	30
Lower Workings	Adit Collapse/Blockage	17	Slow discharge from the Burleigh Shaft due to rising water levels behind collapse induced blockage in the Deep Adit	30	0.3	9	Collapse of the Deep Adit eventually leads to blockage due to the entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Burleigh Shaft, potentially entering the brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs.	100k-1M	30	0	
Lower Workings	Adit Collapse/Blockage	18	Sporadic outflow surges from the Deep Adit due to partial blockage within the Deep Adit	30	0.3	9	Partial collapse of the Deep Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released, potentially entering the brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	30	0	

TABLE B-2 - PHASE I (CURRENT CONDITIONS AND INVESTIATION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
	Surface Slope Failure	21	Any surface slope failure resulting in blockage of lower adits	**100**	**0.3**	**30**	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass	100k-1M	**30**	**0.3**	**9**
					AVERAGE	**63**			AVERAGE			**14**
					MAXIMUM	**300**			MAXIMUM			**30**

NOTE: For each mitigation identify appropriate measures to control, store, and treat any uncontrolled release that could occur as a result of the activity and evaluate the extent to which site infrastructure can be modified to address a potential large uncontrolled release from the UUGW or LUGW

If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

TABLE B-3 - PHASE II (CONSTRUCTION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
				CONSQ	PROB	FMEA		Measures	Cost (US$)	Failure Mode Impacts CONSQ	PROB	FMEA
Upper Workings	**Adit Collapse/Blockage**	1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit and water rise in Pollard Shaft	**300**	**0.3**	**90**	Blow-out of the Main Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Main Adit will release approximately 571,000 gallons of water, eroding EBT-3 on its way to Ely Brook, damaging the culver under South Vershire Road and the road itself, before entering Schoolhouse Brook and the EBOR.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	**100**	**0.3**	**30**
		6	Slow discharge from the Main Shaft due to rising water levels behind collapse induced blockages in the Main Adit (behind connector/Shaft II in Main Adit) and in Tyson Adit	**100**	**0.3**	**30**	Collapse of the Main Adit behind the connector/Shaft II with collapse in the Tyson Adit leads to blockage due to entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Main Shaft, potentially entering Ely Brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	**100**	**0**	
		7	Sporadic outflow surges from main adit due to partial Main Adit blockage	**100**	**0.3**	**30**	Partial collapse of the Main Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	**100**	**0**	
	Stope Collapse	8	Stope collapse into mine pool causing surge of water from the mine shaft pool to discharge out of the Main Adit	**100**	**0.3**	**30**	Stope collapse into the mine pool could cause a surge of water to be discharged out of the Main Adit. The discharge could potentially enter the brook.	**BMPs:** Install BMP's to control uncontrolled flow	0-100k	**30**	**0**	
	Slope Failure	9	Any surface slope failure resulting in blockage of lower adits	**100**	**1**	**100**	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect area before beginning of construction an remove potentially instable soil masses	0-100k	**30**	**0.3**	**9**
Lower Workings	**Adit Collapse/Blockage**	12	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit	**300**	**0.3**	**90**	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	**100**	**0.3**	**30**
		12a	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft	**300**	**0.3**	**90**	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	**100**	**0.3**	**30**

TABLE B-3 - PHASE II (CONSTRUCTION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
Lower Workings	Adit Collapse/Blockage	15a	Blow-out of existing plug during investigation or construction	300	1	300	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0.3	30
		16	Blow-out of the Pollard Adit due to stability disturbances caused by vibrations/release of pressure from construction activities	100	1	100	Blow-out of the Pollard Adit could violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Pollard Adit would release a minimum of 6,000 gallons of water, potentially entering the brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	30	0.3	9
		17	Slow discharge from the Burleigh Shaft due to rising water levels behind collapse induced blockage in the Deep Adit	100	0.3	30	Collapse of the Deep Adit eventually leads to blockage due to the entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Burleigh Shaft, potentially entering the brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0	
		18	Sporadic outflow surges from the Deep Adit due to partial blockage within the Deep Adit	100	0.3	30	Partial collapse of the Deep Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released, potentially entering the brook.	**Monitoring and Dewatering Plan:** Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.	100k-1M	100	0	
		19	Any adit collapse induced blockage during construction from equipment vibration/pressure resulting in lost time/injury	30	0.3	9	Equipment induced adit collapses could form blockages which could lead to blow-outs or discharges. Additionally, adit collapses during construction could result in construction equipment/personnel being seriously harmed.	**Monitoring Plan:** Monitor flow to determine when blockage occurs.	100k-1M	30	0.3	9
		20	Any adit collapse induced blockage during construction from rebound/pressure release caused by removing stock piles	30	0.3	9	Stock pile removal induced adit collapses could form blockages which could lead to blow-outs or discharges. Additionally, adit collapses during construction could result in construction equipment/personnel being seriously harmed.	**Monitoring Plan:** Monitor flow to determine when blockage occurs.	100k-1M	30	0.3	9
	Slope Failure	21	Any surface slope failure resulting in blockage of lower adits	100	0.3	30	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass	0-100k	30	0.3	9
		22	Any surface slope failure during construction from equipment vibration/pressure resulting in lost time/injury	30	1	30	Equipment induced surface slope failures could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass	0-100k	30	0.3	9
		23	Any surface slope failure during construction from rebound/pressure release caused by removing stock piles	30	1	30	Stock pile removal induced surface slope failures could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass	0-100k	30	0.3	9
			AVERAGE			63			AVERAGE			10
			MAXIMUM			300			MAXIMUM			30

NOTE: For each mitigation identify appropriate measures to control, store, and treat any uncontrolled release that could occur as a result of the activity and evaluate the extent to which site infrastructure can be modified to address a potential large uncontrolled release from the UUGW or LUGW

TABLE B-3 - PHASE II (CONSTRUCTION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA

If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

TABLE B-4 - PHASE III (POST-CONSTRUCTION) FMEA

LOCATION	RISK TYPE	N°	FAILURE MODE	FAILURE MODE IMPACTS			DESCRIPTION	MITIGATION				
								Measures	Cost (US$)	Failure Mode Impacts		
				CONSQ	PROB	FMEA				CONSQ	PROB	FMEA
Upper Workings	Adit Collapse/Blockage	1a	Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the Main Adit and water rise in Pollard Shaft	300	3	900	Blow-out of the Main Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Main Adit will release approximately 571,000 gallons of water, eroding EBT-3 on its way to Ely Brook, damaging the culver under South Vershire Road and the road itself, before entering Schoolhouse Brook and the EBOR.	**Passive Treatment:** Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.	100k-1M	300	3	900
								***Water Tight Plug and Dewatering:** Plug designed to withstand anticipated head. Also includes dewatering system to remove water behind plug.	100k-1M	30	0.3	9
								***Drainage Plug:** Drainage plugs designed to include redundancy (2 drains) and withstand anticipated adit specific head.	100k-1M	30	0.3	9
								***Slurry Filling:** Filling of the lower underground workings. Requires an estimated 4,100 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	1-10M	0	0	
		6	Slow discharge from the Main Shaft due to rising water levels behind collapse induced blockages in the Main Adit (behind connector/Shaft II in Main Adit) and in Tyson Adit	100	1	100	Collapse of the Main Adit behind the connector/Shaft II with collapse in the Tyson Adit leads to blockage due to entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Main Shaft, potentially entering Ely Brook.	**Passive Treatment:** Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.	100k-1M	100	1	100
								***Water Tight Plug and Dewatering:** Plug designed to withstand anticipated head. Also includes dewatering system to remove water behind plug.	100k-1M	30	0.3	9
								***Drainage Plug:** Drainage plugs designed to include redundancy (2 drains) and withstand anticipated adit specific head.	100k-1M	30	0.3	9
								***Slurry Filling:** Filling of the lower underground workings. Requires an estimated 4,100 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	1-10M	0	0	
		7	Sporadic outflow surges from main adit due to partial Main Adit blockage	100	1	100	Partial collapse of the Main Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released.	**Passive Treatment:** Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.	100k-1M	100	1	100
								***Water Tight Plug and Dewatering:** Plug designed to withstand anticipated head. Also includes dewatering system to remove water behind plug.	100k-1M	30	0.3	9
								***Drainage Plug:** Drainage plugs designed to include redundancy (2 drains) and withstand anticipated adit specific head.	100k-1M	30	0.3	9
								***Slurry Filling:** Filling of the lower underground workings. Requires an estimated 4,100 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	1-10M	0	0	

Upper Workings	Stope Collapse	8	Stope collapse into mine pool causing surge of water from the mine shaft pool to discharge out of the Main Adit	100	1	100	Stope collapse into the mine pool could cause a surge of water to be discharged out of the Main Adit. The discharge could potentially enter the brook.	**Passive Treatment:** Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.	100k-1M	100	1	100
								***Water Tight Plug and Dewatering:** Plug designed to withstand anticipated head. Also includes dewatering system to remove water behind plug.	100k-1M	30	0.3	9
								***Drainage Plug:** Drainage plugs designed to include redundancy (2 drains) and withstand anticipated adit specific head.	100k-1M	30	0.3	9
								***Slurry Filling:** Filling of the lower underground workings. Requires an estimated 4,100 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	1-10M	0	0	
	Slope Failure	9	Any surface slope failure resulting in blockage of lower adits	100	1	100	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide mass that could block the adits	100k-1M	30	0.3	9
	Geochemical Conditions	10	Formation and washing out of precipitates	100	1	100	Precipitate induced discharge will incur moderate environmental violations.	**Modify the Water Treatment Plant**	0-100k	30	0	
		11	Continual water quality degradation due to evolving geochemistry	100	1	100	Evolving geochemistry induced degradation of the water quality will result in non-compliance discharges, incurring moderate environmental violations.	**Modify the Water Treatment Plant**	0-100k	30	0	
Lower Workings	Adit Collapse/Blockage	12	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit	100	3	300	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	30	0	
		12a	Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft	100	3	300	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, which could elnter the ponds, damage EBT-2 and reach Ely Brook. The water slug could overtop the culver at South Vershire Road and damage the road itself before reaching Schoolhouse Brook and the EBOR.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	30	0	

Lower Workings	**Adit Collapse/Blockage**	13	Blow-out of the Deep Adit due to rising pressure/water levels from an unidentified fracture network supplying water to material	**100**	**3**	**300**	Blow-out of the Deep Adit will violently release built up pressure and water, endangering anyone near the adit. Blow-out of the Deep Adit will release approximately 280,000 gallons of water, potentially entering the brook.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	**30**	**0**	
		17	Slow discharge from the Burleigh Shaft due to rising water levels behind collapse induced blockage in the Deep Adit	**100**	**1**	**100**	Collapse of the Deep Adit eventually leads to blockage due to the entrapment of sediment fines and chemical precipitates. The blockage results in rising water/pressure levels until water discharges from the Burleigh Shaft, potentially entering the brook.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	**30**	**0.3**	**9**
		18	Sporadic outflow surges from the Deep Adit due to partial blockage within the Deep Adit	**100**	**1**	**100**	Partial collapse of the Deep Adit allows water to sporadically be built up and discharged. During sporadic discharge episodes, high volumes of built up water will be released, potentially entering the brook.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	**30**	**0.3**	**9**
	Slope Failure	21	Any surface slope failure resulting in blockage of lower adits	**100**	**1**	**100**	Surface slope failure could result in the blockage of lower adits, which in turn could lead to blow-outs or discharges from higher adits/shafts. Additionally, slope failure could reach mine facilities or the brook.	**Inspection and Excavation:** Inspect and remedy - Excavate potential slide masses	0-100k	**100**	**0**	
	Geochemical Conditions	24	Formation and washing out of precipitates	**100**	**1**	**100**	Precipitate induced discharge will incur moderate environmental violations.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	**30**	**0**	
		25	Continual water quality degradation due to evolving geochemistry	**100**	**1**	**100**	Evolving geochemistry induced degradation of the water quality will result in non-compliance discharges, incurring moderate environmental violations.	**Slurry Filling:** Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.	0-100k	**30**	**0**	
			AVERAGE			**143**			AVERAGE			**48**
			MAXIMUM			**300**			MAXIMUM			**900**

Notes:

NOTE: For each mitigation identify appropriate measures to control, store, and treat any uncontrolled release that could occur as a result of the activity and evaluate the extent to which site infrastructure can be modified to address a potential large uncontrolled release from the UUGW or LUGW

If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

RISK SCALES

Likelihood Classes and Scale		
Likelihood Class	**FMEA Score**	**Probability of Occurrence during Phase**
High (Likely)	3	>50%
Moderate (Neutral)	1	10-50%
Low (Unlikely)	0.3	0-10%
Ruled Out	0	0%

Consequence Categories and Scale		
Consequence Category	**FMEA Score**	**Consequence Description**
Level 3	300	Economic consequences and impacts to the downstream population (loss of road use due to culvert damage or washout at South Vershire Road); water quality within site (ponds, Ely Brook, tributaries) and downstream of site in Schoolhouse Brook and Ompompanoosuc River is adversely impacted to an extent greater than current impacts for an extended period of time. Extensive visual/aesthetic impacts for an extended period of time. Major erosion on-site requiring substantial repair, possible extended loss of use of site access roads.
Level 2	100	No significant economic consequences or impacts to the downstream population (loss of road use or damage to property); water quality within site (ponds, Ely Brook, tributaries) and downstream of site in Schoolhouse Brook and Ompompanoosuc River is adversely impacted to an extent greater than current impacts for a short period of time. Extensive visual/aesthetic impacts for a short period of time. Moderate erosion on-site requiring substantial repair, possible short-term loss of use of site access roads.
Level 1	30	No significant economic consequences or impacts to the downstream population (loss of road use or damage to property); water quality within site (ponds, Ely Brook, tributaries) may experience degraded water quality for a limited period of time but no significant impacts to Schoolhouse Brook or Ompompanoosuc River. Minor erosion may occur and access road repair or other minor repairs may be necessary.
No Significant Consequences	0	No significant economic consequences or impacts to the downstream population. Any release will be of a volume and chemistry within range of what is currently taking place under current site conditions.

RISK CHARACTERIZATION MATRIX

	FMEA Likelihood			
FMEA Consequence	**Ruled Out** 0	**Low (Unlikely)** 0.3	**Moderate (Neutral)** 1	**High (Likely)** 3
Level 3 300				
Level 2 100				
Level 1 30				
No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

RISK ASSESSMENT CALCULATIONS

Mine Workings Characterization									
Location		Dimensions (ft)[1]				Total Volume (ft^3)	Total Volume (gal)	Equilibrium Recharge Rate[2] (gpm)	Time to Fill[3] (days)
		Length	Width	Height	Diameter				
Lower Workings	Deep Adit	600	7	6	-	25,200	188,496	7.9	16.6
	Burleigh Shaft	17	7	10	-	1,190	8,901	7.9	0.8
	West Adit	285	7	6	-	11,970	89,536	7.9	7.9
	Pollard Adit	19	7	6	-	798	5,969	2	2.1
Upper Workings	Main Adit	715	7	6	-	30,030	224,624	11.1	14.1
	Adit A	48	7	6	-	2,016	15,080	11.1	0.9
	Pollard Shaft	-	-	50	9	3,179	23,781	11.1	1.5
	Shaft II	-	-	10	13	1,327	9,923	11.1	0.6
	Shaft II Connector	-	-	45	10	3,533	26,423	11.1	1.7
	Tyson Adit	250	7	6	-	10,500	78,540	11.1	4.9
	Main Shaft	200	30	10	-	60,000	448,800	11.1	28.1

Notes:

[1] Based on available information (Nobis 2015a, Nobis 2015b) and approximated from mine drawings.

[2] Maximum adit outflows recorded by Nobis in 2014-2015. The measured outflow from the Deep Adit of 7.9 gpm was used as a replacement value for missing outflows in the Lower Workings. The measured outflow from the Main Adit of 11.1 gpm was used as a replacement value for missing outflows in the Upper Workings.

[3] Total Volume/Discharge Rate

Blow-out Failure Mode Characterization			
Failure Mode Number	Volume of Water Blown-out (gal)	Head (ft)	Time to Fill[3] (days)
1	224,624	10	14.1
1a	571,036	70	35.7
2	15,080	10	35.7
3	78,540	15	33.5
3a	509,018	70	33.5
12	278,032	10	24.4
12a	284,001	35	26.5
16	5,969	10	2.1

FMEA - PHASE I - CURRENT CONDITIONS

FMEA Consequence		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300		1a, 12, 12a,	15a	
	Level 2 100		6, 7, 8, 21		
	Level 1 30		9, 17, 18		
	No Significant Consequence 0				

Risk Levels

FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

FMEA - PHASE I - CURRENT CONDITIONS - WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	**Low (Unlikely)** 0.3	**Moderate (Neutral)** 1	**High (Likely)** 3
FMEA Consequence	**Level 3** 300				
	Level 2 100	6, 7	1a, 8, 12, 12a, 15a		
	Level 1 30	17, 18	9, 21		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		**Description**
Priority	**Color**	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

FMEA - PHASE II - CONSTRUCTION

		FMEA Likelihood			
		Ruled Out 0	**Low (Unlikely)** 0.3	**Moderate (Neutral)** 1	**High (Likely)** 3
FMEA Consequence	**Level 3** 300		1a, 12, 12a	15a	
	Level 2 100		6, 7, 8, 12, 12a, 17, 18, 21	9, 16	
	Level 1 30		19, 20	22, 23	
	No Significant Consequence 0				

Risk Levels		
FMEA Method		**Description**
Priority	**Color**	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

FMEA - PHASE II - CONSTRUCTION - WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				
	Level 2 100	6, 7, 17, 18	1a, 12, 12a, 15a,		
	Level 1 30	8	9, 16, 19, 20, 21, 22, 23		
	No Significant Consequence 0				

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

FMEA - PHASE III - POST-CONSTRUCTION

FMEA Consequence		FMEA Likelihood			
		Ruled Out 0	**Low (Unlikely)** 0.3	**Moderate (Neutral)** 1	**High (Likely)** 3
	Level 3 300				1a
	Level 2 100			6, 7, 8, 9, 10, 11, 17, 18, 21, 24, 25	12, 12a, 13
	Level 1 30				
	No Significant Consequence 0				

Risk Levels

FMEA Method		Description
Priority	**Color**	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

FMEA - PHASE III - POST-CONSTRUCTION - WITH MITIGATION MEASURES

		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
FMEA Consequence	Level 3 300				1a (Passive)
	Level 2 100	21		6 (Passive), 7 (Passive), 8 (Passive)	
	Level 1 30	10, 11, 12, 12a, 13, 24, 25	1a* (Plugs), 6* (Plugs), 7* (Plugs), 8* (Plugs), 9, 17, 18		
	No Significant Consequence 0	1a* (Slurry), 6* (Slurry), 7* (Slurry), 8* (Slurry)			

Risk Levels		
FMEA Method		Description
Priority	Color	
1		High likelihood Level 3 consequences
2		Moderate likelihood Level 3 consequences and high likelihood Level 2 consequences
3		Low likelihood Level 3 consequences, moderate likelihood Level 2 consequences, and high likelihood Level 1 consequences
4		Low likelihood Level 2 consequences and moderate likelihood Level 1 consequences
5		Low likelihood Level 1 consequences

Notes:
* Implementation of Mitigation Measure potentially prohibited due to concerns about endangered bat species habitat

APPENDIX C

Selected Failure Mode Summary Sheets

Phase I: Failure Mode 1a

Description:
Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the main adit and water rise in the Pollard Shaft. Blow-out of the Main Adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 571,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:

- Erosion of EBT-3 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:

- Blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind blockage.
- Investigation disturbances (ie. drilling).

Factors Decreasing Likelihood of Failure Mode:

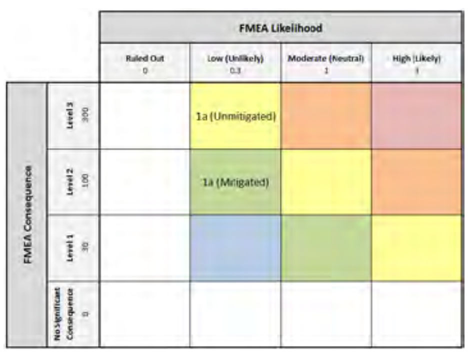
- Geology of underground workings is relatively stable and not likely to collapse during Phase I.
- Flowing water from adit suggests complete blockage has not occurred.

Mitigation Measures:

<u>Monitoring and Dewatering Plan</u>**:**

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

<u>Site Characterization:</u>

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Additional Information/Actions Potentially Affecting Consequence Severity:

<u>Site Characterization:</u>

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Notes:

Phase II: Failure Mode 1a

Description:
Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the main adit and water rise in the Pollard Shaft. Blow-out of the Main Adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 571,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:

- Erosion of EBT-3 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:

- Blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind blockage.
- Construction disturbances (vibrations, pressure, material removal) could result in adit blockage

Factors Decreasing Likelihood of Failure Mode:

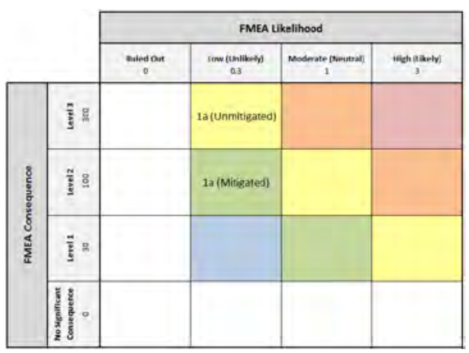
- Geology of underground workings is relatively stable and not likely to collapse during Phase II.
- Phase I Mitigation Measures (ie. Investigation and Characterization, Monitoring and Dewatering)

Mitigation Measures:

<u>Monitoring and Dewatering Plan:</u>

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



FMEA Consequence		FMEA Likelihood			
		Ruled Out 0	Low (Unlikely) 0.3	Moderate (Neutral) 1	High (Likely) 3
	Level 3 300		1a (Unmitigated)		
	Level 2 100		1a (Mitigated)		
	Level 1 30				
	No Significant Consequence 0				

Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Additional Information/Actions Potentially Affecting Consequence Severity:

Notes:

Phase III: Failure Mode 1a

Description:
Blow-out of the Main Adit due to rising pressure/water levels behind collapse induced blockage in the main adit and water rise in the Pollard Shaft. Blow-out of the Main Adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 571,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:

- Erosion of EBT-3 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:

- Blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind blockage.
- Precipitate formation and sediment build-up

Factors Decreasing Likelihood of Failure Mode:

- None

Mitigation Measures:

Passive Treatment:

Concern about endangered bat species habitat prevents implementation of mitigation measures at this time.

*Water Tight Plug and Dewatering:

Plug designed to withstand anticipated head. Also includes dewatering system to remove water behind plug.

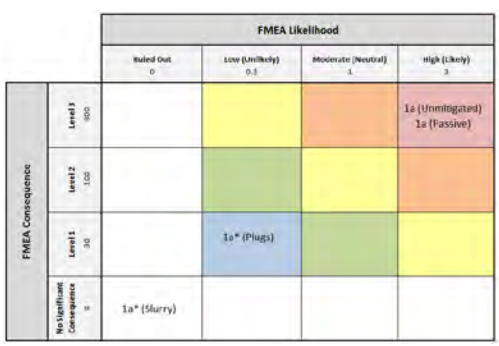
*Drainage Plug:

Drainage plugs designed to include redundancy (2 drains) and withstand anticipated adit specific head.

*Slurry Filling:

Filling of the lower underground workings. Requires an estimated 4,100 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Additional Information/Actions Potentially Affecting Consequence Severity:

Notes: *Implementation of Mitigation Measure potentially prohibited due to concerns about endangered bat species habitat

Phase I: Failure Mode 12a

Description:
Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft. Blow-out of the Deep adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 284,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:

- Erosion of EBT-2 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:

- Additional blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind existing portal blockage.
- Investigation disturbances (ie. drilling).

Factors Decreasing Likelihood of Failure Mode:

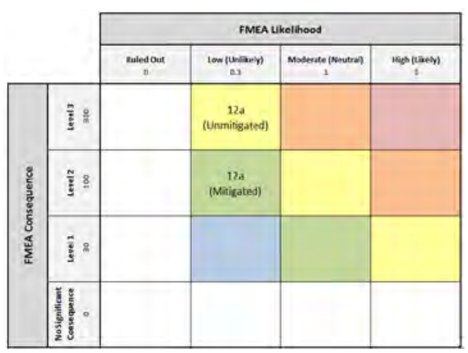
- Geology of underground workings is relatively stable and not likely to further collapse during Phase I.
- Flowing water from adit suggests complete blockage has not occurred.

Mitigation Measures:

<u>Monitoring and Dewatering Plan</u>**:**

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

<u>Site Characterization:</u>

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Additional Information/Actions Potentially Affecting Consequence Severity:

<u>Site Characterization:</u>

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Notes:

Phase II: Failure Mode 12a

Description:
Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft. Blow-out of the Deep adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 284,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:
- Erosion of EBT-2 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:
- Additional blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind existing portal blockage.
- Construction disturbances (vibrations, pressure, material removal) could result in additional adit blockage

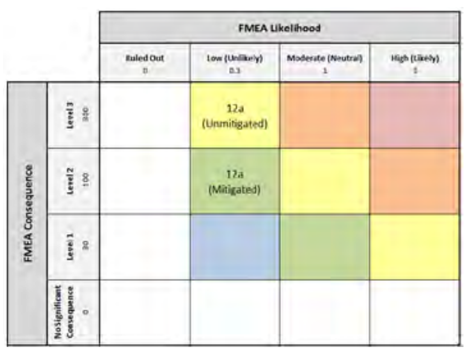
Factors Decreasing Likelihood of Failure Mode:
- Geology of underground workings is relatively stable and not likely to collapse during Phase II.
- Phase I Mitigation Measures (ie. Investigation and Characterization, Monitoring and Dewatering)

Mitigation Measures:

Monitoring and Dewatering Plan:

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Additional Information/Actions Potentially Affecting Consequence Severity:

Notes:

Phase III: Failure Mode 12a

Description:
Blow-out of the Deep Adit due to rising pressure/water levels behind collapse induced blockage in the Deep Adit and water rise in the Burleigh Shaft. Blow-out of the Deep adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 284,000 gallons of water will be blown-out, potentially affecting the surrounding environment and community.

Consequences:
- Erosion of EBT-2 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:
- None

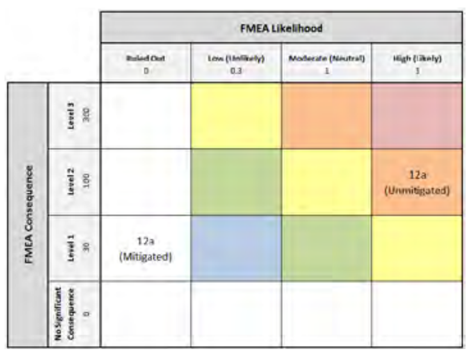
Factors Decreasing Likelihood of Failure Mode:
- Phase II Mitigation Measures (ie. Monitoring and Dewatering)

Mitigation Measures:

Slurry Filling:

Filling of the lower underground workings. Requires an estimated 1,500 cubic yards of slurry to fill the Lower Workings. Residual risk of discharge still remains but is unlikely.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Additional Information/Actions Potentially Affecting Consequence Severity:

Notes:

Phase I: Failure Mode 15a

Description:
Blow-out of the existing Deep Adit plug due to investigation or construction disturbances. Blow-out of the Deep adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 284,000 gallons of water will be blown-out if the adit is full, potentially affecting the surrounding environment and community.

Consequences:
- Erosion of EBT-2 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:
- Additional blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind existing portal blockage.
- Investigation disturbances (ie. drilling).

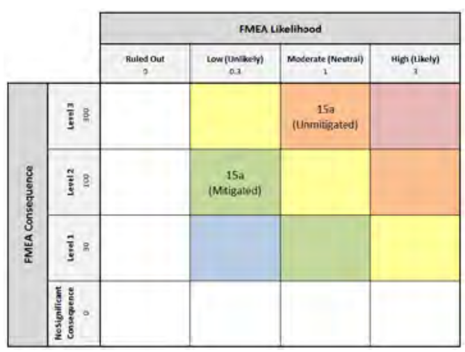
Factors Decreasing Likelihood of Failure Mode:
- Geology of underground workings is relatively stable and not likely to further collapse during Phase I.
- Flowing water from adit suggests complete blockage has not occurred.

Mitigation Measures:

Monitoring and Dewatering Plan**:**

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Site Characterization:

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Additional Information/Actions Potentially Affecting Consequence Severity:

Site Characterization:

Conduct site characterization activities (ex. boreholes) to determine whether underground workings are flooded. Boreholes or other investigative activities should be sequenced from the highest to lowest elevations with respect to the adit portal.

Notes:

Phase II: Failure Mode 15a

Description:
Blow-out of the existing Deep Adit plug due to investigation or construction disturbances. Blow-out of the Deep adit will violently release built-up pressure and water, endangering anyone near the adit. Approximately 284,000 gallons of water will be blown-out if the adit is full, potentially affecting the surrounding environment and community.

Consequences:

- Erosion of EBT-2 and Ely Brook
- Damage to South Vershire Road and culver
- Discharge to Schoolhouse Brook and EBOR

Factors Increasing Likelihood of Failure Mode:

- Additional blockage of adit due to surface slope failure, or roof/wall collapse.
- Build-up of pressure/water levels behind existing portal blockage.
- Construction disturbances (vibrations, pressure, material removal) could result in additional adit blockage

Factors Decreasing Likelihood of Failure Mode:

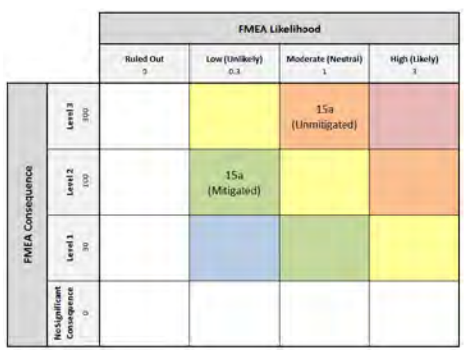
- Geology of underground workings is relatively stable and not likely to further collapse during Phase II.
- Phase I Mitigation Measures (ie. Investigation and Characterization, Monitoring and Dewatering)

Mitigation Measures:

Monitoring and Dewatering Plan:

Monitor flow to determine when blockage occurs. If blockage is indicated, install and operate a dewatering system connected to a treatment system, as necessary.

Risk Levels:



Additional Information/Actions Potentially Affecting Likelihood of Occurrence:

Additional Information/Actions Potentially Affecting Consequence Severity:

Notes: