Climate Change and Acid Rock Drainage – Risks for the Canadian Mining Sector

MEND Report 1.61.7

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Strategies to Sustainability

DISCLAIMER

The purpose of this report is to assess the impacts of climate change on ARD at Canadian mines using a risk-based approach. The information provided is based on the opinions of the authors and should not be construed as endorsement in whole or in part by the various reviewers or by the partners in MEND (the Government of Canada, Provincial Governments, The Mining Association of Canada, contributing mining companies and participating non-governmental organizations). The reader of this report should assume full responsibility for any action taken as a result of the information contained in this document.

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EXECUTIVE SUMMARY

Stratos Inc. was retained by the Mine Environment Neutral Drainage (MEND) program to assess the impacts of climate change on acid rock drainage (ARD) at Canadian mines. Stratos retained the technical expertise of Brodie Consulting Ltd. for this project.

Climate change poses a number of risks to mining operations. Extreme weather events and changes in precipitation patterns may lead to interruptions in production and damage to mining infrastructure. Permafrost degradation and increases in precipitation may compromise the integrity of waste containment structures such as dams and tailings covers. Drought conditions may lead to a shortage of water required for processing and waste management (e.g. water covers). Climate change may also affect energy and transportation infrastructure on which the mining sector depends to deliver electricity, labour, supplies, and to ship product.

This assessment focuses on risks associated with acid rock drainage and metal leaching (ARD/ML) produced by mining activities. ARD/ML occurs when minerals containing metals and sulphur (sulphides) come in contact with both air and water. At mine sites, the prevention and management of ARD includes the management of water, tailings and waste rock. Therefore, the climate change risks related to ARD arise from the impacts that a changing climate has on water management structures and activities, on waste impoundment structures, and on the hydrologic/ hydrogeologic/ geochemical conditions affecting the flow of water and contaminants at mine sites.

Mining activity occurs across Canada, so mining operations will be exposed to the broad range of regional impacts that are projected by climate models, including more pronounced impacts in the north (due to arctic amplification). Previous studies on climate change impacts in Canada identified a range of potential impacts for the mining sector, including impacts related to ARD. This assessment builds on previous work by looking more closely at the impacts for specific infrastructure elements and determining which of these impacts are most likely and significant for mining operations and for society.

This assessment is a high-level risk analysis and not a detailed technical study. The findings are based on the professional judgment of a multi-disciplinary team (engineering, sustainability, finance). A small set of interviews with technical experts was also conducted. The assessment included a review of recent reports on the impacts of climate change in Canada, and more specifically on climate change and the mining sector. Risks were identified by imposing climate change conditions (2050s projections) onto the mining infrastructure and activities most relevant to the prevention and management of ARD. Indicative estimates of cost impacts were developed for some relevant and more likely scenarios – presented in terms of net present value.

The following conclusions arise from our review and analysis:

Operations – Impact on Activities and Infrastructure

- Many of the effects of climate change, with the notable exception of extreme weather events, will be incremental – small changes over long periods of time. Based on current climate change projections for Canada, mining operations that are active today or that are being planned or constructed today will be able to adapt, through changes in management practices or modest capital investments, to most of these incremental environmental changes over the next 25 to 30 years. This observation is based on our view that during the operation phase of these mines, changes in the environmental parameters (temperature, precipitation, permafrost) that inform the design of key structures relevant to ARD (i.e. covers, dams, treatment systems, and other water management structures) will not change sufficiently to increase ARD or lead to significant changes in the strategies to prevent ARD. As the impacts of climate change will vary between regions, mines will be impacted differently and to varying degrees.

- More frequent heavy precipitation events are projected for Canada (NRCan, 2008; NRTEE, 2010). There is a risk that hydraulic structures at mine sites (dams, ditches, spillways, holding ponds) will have insufficient capacity for such events resulting in more contaminated runoff from the mine site or in other temporary measures being taken, such as flooding pits, which could result in shutdowns. Based on our analysis of the net present value of a hypothetical copper mine in Canada, such shutdowns alone would not make the mine uneconomical but could have a significant impact on the bottom line. While new dams are designed using the most recent climate projections (which include climate change impacts), existing dams may be vulnerable over the long term. The literature reviewed for this assessment suggests that more research is required to determine the impacts of climate change on probable maximum precipitation (PMP) and probable maximum flood (PMF) values that are used in dam design.

Closure – Impact on Activities and Infrastructure

- Of greater concern are the impacts of climate change on post-closure infrastructure required for the long-term or ‘perpetual’ storage and containment of tailings and other contaminants – including tailings covers and dams. These impacts add to the existing policy and technical challenges of ensuring the long-term integrity of mine sites post closure.
- Our assessment indicates that most types of covers (simple soil covers, store and release, water, permafrost, geo-synthetic) are vulnerable to climate change to various degrees. Geo-synthetics are the least susceptible to the direct effects of climate change[1]. Permafrost degradation in permafrost covers could lead to increased percolation into the waste layer. Changes in rainfall patterns, evapotranspiration, and temperature will impact vegetation on covers. More precipitation and wetter conditions may result in increased percolation into the waste layer of store and release covers and compromised permafrost covers leading to increased flushing of contaminants (ARD) and release to the environment. In regions in which more periods of drought are projected, there is an increased risk of exposure of tailings to air and increased ARD, although this can be managed with minor adjustments to the depth of a water cover. In regions where positive water balances are projected with climate change, water covers may be no more vulnerable to climate change than geo-synthetic covers.
- Based on our analysis the scenario with the greatest cost impact for a mining operation involves the use of a geo-synthetic cover instead of a more conventional cover to avoid potential impacts due to climate change. The magnitude of this cost increase would depend on the size of the mine and of the tailings impoundment. Based on our analysis of the net present value of a hypothetical copper mine in Canada, the incremental cost of adaptation could represent on the order of a 20% reduction in NPV[2].
- Cost and risk implications for mine operators and regulators/society will vary depending on how the vulnerabilities of waste covers or other structures are addressed. If the selected

[1] However, these covers may still be vulnerable to certain climate change-related effects such as root or rodent penetration resulting from changing soil conditions.

[2] It is recognized that other factors, such as ore quality, need to be considered when comparing mines of different sizes. For instance, larger mines may be exploiting lower-grade ores, need to disturb larger areas, and thus produce more (ARD-producing) waste – which could make a large mine as sensitive to the cost of this adaptation as a smaller mine.

cover design is poorly adapted to climate change, other and possibly more expensive remedial measures, such as perpetual water treatment, may be required. After planned closure, many mining sites will be left with engineered structures and activities (dams, waste piles, treatment plants) that will require long-term site monitoring and maintenance, possibly in perpetuity. Unless sound long-term financial provisions are in place, it is likely that orphaned or abandoned mines will be created, with financial liability falling to the taxpayer. The increased likelihood of this scenario, or perceptions thereof, may present a risk to a mining proponent's license to operate, especially in jurisdictions where there is already concern about closure plans that involve perpetual water treatment. This represents a near-term risk for mining companies.

- For mines located near the southern boundary of the permafrost zone, or in other areas where significant permafrost degradation is projected, the design of permafrost covers, or the decision to use permafrost cover, should be informed by thermal analysis that takes future climate change scenarios into account. It is important to note that while northern mines may experience more climate change impacts that other mines in Canada, engineering practice in cold climates is already factoring in climate change into designs. However, mines that were closed before these practices were adopted are more likely to be at risk.

Climate change impacts on the ARD Process

- Based on the temperature increases anticipated for the timeframe considered in this study (2.5°C to 3.5°C) (NRTEE, 2010), the impacts of increased temperature on sulphide oxidation rates is not anticipated to have a significant impact on a mine during operation. Where ARD is treated, more treatment reagents may be required but this change alone is not expected to represent a large increase in operating costs or to threaten the business case for the mine.
- Similarly, following closure, an increase in the sulphide oxidation rate may lead to an increase in long-term treatment costs. However, this impact is estimated to be less than other potential impacts of climate change (e.g. tailings cover failure) and non-climate related factors that could lead to a change in approach in managing the site.
- Others have reported that there are still gaps in understanding of how cold temperatures, ice, and permafrost degradation affect acid generation and dynamics of acid generating potential. (Stratos, 2009). MEND Report 1.61.6 (SRK, 2006) reported that limited research has been completed on the effect of low temperature on the performance of mine waste management facilities and recommended that more research in this area be conducted.

It is important to note that mine sites that are already problematic with respect to ARD, due to inadequate design, management, or regulatory oversight, may also be more vulnerable to climate change impacts.

In general, more options and more effective options for minimizing ARD are available earlier in the mine life. Similarly, climate change adaptation measures are more effective and less costly when developed and integrated at the planning and design phase. Anticipatory adaptation would involve adapting infrastructure designs, especially for covers, at the design stage to withstand long-term climate change conditions.

SOMMAIRE

Stratos Inc. a été chargée, dans le cadre du Programme de neutralisation des eaux de drainage dans l'environnement minier (NEDEM), d'évaluer les impacts du changement climatique sur le drainage minier acide (DMA) dans les mines canadiennes. Pour réaliser ce projet, Stratos a fait appel à l’expertise technique de Brodie Consulting Ltd.

Le changement climatique présente plusieurs risques pour l’exploitation minière. À titre d’exemple, des phénomènes météorologiques extrêmes et des variations du régime des précipitations pourraient notamment interrompre la production minière et endommager les infrastructures des mines. La dégradation du pergélisol et l’augmentation des précipitations pourraient menacer l'intégrité des structures de confinement des rejets, p. ex. les couvertures et les digues des parcs à résidus. Les conditions de sécheresse pourraient entraîner une pénurie de l'eau nécessaire au traitement et à la gestion des rejets (dans le cas des couvertures d’aqueuses). Le changement climatique pourrait aussi avoir une incidence sur les infrastructures d’énergie électrique et de transport de la main-d’œuvre, des approvisionnements et des produits, qui sont essentielles au secteur minier.

La présente évaluation porte principalement sur les risques liés au drainage minier acide et à la lixiviation des métaux (DMA/LM) produits par les activités minières. Le DMA et la LM se produisent lorsque les minéraux qui contiennent des métaux et du soufre (appelés minéraux sulfurés) sont exposés à l’air et à l’eau. Dans les sites miniers, la prévention et la gestion du DMA comprennent la gestion de l’eau, des résidus et des stériles. Par conséquent, les risques posés par le changement climatique relativement au DMA découlent des répercussions d’un climat en évolution sur les structures et activités de gestion de l’eau, les structures de retenue des rejets ainsi que sur les conditions hydrologiques, hydrogéologiques et géochimiques influant sur l’écoulement de l’eau et des contaminants dans les sites miniers.

Des activités d’exploitation minière ont lieu partout au Canada, de sorte qu’elles sont exposées au large éventail d’impacts régionaux projetés par les modèles climatiques, y compris les impacts plus marqués dans le nord (à cause de l’amplification arctique). Des études précédentes sur les impacts du changement climatique au Canada ont permis de déterminer divers impacts potentiels dans le secteur minier, notamment ceux qui sont associés au DMA. La présente évaluation s’appuie sur des travaux antérieurs pour analyser de plus près les répercussions possibles sur certains éléments des infrastructures et déterminer quels sont les impacts les plus probables et significatifs sur les activités minières et la société.

La présente évaluation est une analyse de risques de haut niveau, mais il ne s’agit pas d’une étude technique détaillée. Les conclusions sont fondées sur le jugement professionnel d’une équipe multidisciplinaire (ingénierie, développement durable, finances). Un petit nombre d’entrevues ont également été effectuées auprès d’experts techniques. L’évaluation comporte, entre autres, un examen de rapports récents sur les impacts du changement climatique au Canada, et, plus particulièrement, sur l’incidence de ce phénomène sur le secteur minier. Les risques ont été établis en appliquant des conditions de changement climatique (projections pour 2050) à l’infrastructure et aux activités minières les plus pertinentes en tenant compte des pratiques de prévention et de gestion du DMA. Des estimations indicatives des coûts (valeur actualisée nette) associés aux impacts ont été élaborées pour quelques-uns des scénarios pertinents les plus probables.

Les conclusions suivantes ont été tirées à la suite de l'examen et de l'analyse que nous avons effectués :

Exploitation – Impact sur les activités et l'infrastructure

- Un grand nombre des effets du changement climatique, sauf l'exception notable des phénomènes météorologiques extrêmes, seront graduels – de petits changements se produiront sur de longues périodes. Selon les projections actuelles des changements du climat au Canada, il est possible que les travaux d'exploitation minière en cours, qui sont prévus ou entrepris actuellement, puissent s'adapter à la plupart des changements environnementaux qui se produiront progressivement au cours des 25 à 30 prochaines années, en modifiant les pratiques de gestion ou en engageant de modestes dépenses d'investissement. Nous croyons que, pendant la phase d'exploitation de ces mines, les changements de paramètres environnementaux (température, précipitations, pergélisol) qui orientent la conception des structures clés pertinentes au DMA (c.-à-d. les couvertures, digues, systèmes de traitement et autres structures de gestion de l'eau) ne seront pas suffisamment importants pour accroître le DMA ou nécessiter une modification en profondeur des stratégies de prévention du DMA. Étant donné que les impacts du changement climatique varieront d'une région à l'autre, les mines seront touchées différemment et à différents degrés.

- Des épisodes plus fréquents de précipitations abondantes sont prévus au Canada (RNCan, 2008; TRNEE, 2010). Il se pourrait que la capacité des ouvrages hydrauliques dans les sites miniers (digues, fossés, déversoirs de crue, étangs de retenue) ne soit pas suffisante lors de tels événements, ce qui causerait un écoulement contaminé plus important provenant du site minier ou nécessiterait la prise d'autres mesures temporaires, comme l'inondation de la fosse, risquant ainsi de causer l'arrêt des activités. Selon notre analyse de la valeur actualisée nette d'une mine de cuivre fictive au Canada, ces arrêts à eux seuls ne nuiraient pas à la rentabilité de la mine, mais pourraient avoir un impact significatif sur le résultat net. De nouvelles digues sont conçues en tenant compte des projections climatiques les plus récentes (y compris les impacts du changement climatique), mais les digues existantes pourraient, elles, être vulnérables à long terme. Les documents examinés dans le cadre de la présente évaluation semblent indiquer que les travaux de recherche doivent être poursuivis afin de déterminer les impacts du changement climatique sur les valeurs de précipitations maximales probables (PMP) et de crues maximales probables (CMP), qui sont utilisées dans la conception de digues.

Fermeture – Impact sur les activités et l'infrastructure

- Les impacts du changement climatique sur les infrastructures mises en place après la fermeture d'une mine, pour le stockage et le confinement à long terme ou « permanents » des résidus et d'autres contaminants – y compris les couvertures et les digues à résidus – constituent une plus grande inquiétude. Ces impacts compliquent les défis sur le plan de la conception technique et des politiques qu'il faut relever pour assurer l'intégrité à long terme des sites miniers après leur fermeture.

- Notre évaluation indique que la plupart des types de couvertures (simples couvertures de sol, couvertures qui emmagasinent et libèrent l'eau, couvertures d'aqueuse, de pergélisol ou géosynthétiques) sont vulnérables à différents degrés au changement climatique. Les couvertures géosynthétiques sont les moins sensibles aux effets directs du changement climatique[3]. La dégradation du pergélisol dans d'une couverture de pergélisol pourrait entraîner une percolation accrue dans la couche des rejets. Les changements des régimes de précipitations, d'évapotranspiration et de température auront une incidence sur les végétaux qui pousseront sur les couvertures. Des précipitations plus abondantes et des conditions plus humides pourraient augmenter la percolation dans la couche des rejets pour les couvertures qui emmagasinent et libèrent l'eau et aussi pour les couvertures de pergélisol, ce qui augmenterait le lessivage des contaminants (DMA) dans l'environnement. Dans les régions où l'on prévoit un plus grand nombre d'épisodes de sécheresse, il pourrait y avoir une plus grande exposition des résidus à l'air et une augmentation du DMA. Ces risques pourraient toutefois être gérés en modifiant légèrement la profondeur de la couverture aqueuse. Dans les régions où le changement climatique favorisera des bilans hydriques positifs, les couvertures aqueuse ne seraient pas plus vulnérables à l'évolution du climat que les couvertures géosynthétiques.

- Selon notre analyse, le scénario comportant les incidences sur les coûts les plus importantes pour une exploitation minière prévoit l'utilisation d'une couverture géosynthétique plutôt que d'une couverture plus classique afin de réduire au minimum les impacts potentiels du changement climatique. L'ampleur de l'augmentation des coûts dépendrait de la taille de la mine et du parc à résidus. Selon notre analyse de la valeur actualisée nette (VAN) d'une mine de cuivre fictive au Canada, le coût additionnel des mesures d'adaptation pourrait représenter une réduction de l'ordre de 20 % de la valeur actualisée nette (VAN)[4].

- Les conséquences en matière de coûts et de risques pour les exploitants miniers, les organismes de réglementation et la société varieront selon la façon dont on traitera les vulnérabilités des couvertures de rejets ou d'autres structures. Si le modèle de couverture sélectionné est mal adapté aux changements du climat, d'autres mesures correctives probablement plus coûteuses, comme le traitement permanent de l'eau, pourraient s'avérer nécessaires. Après la fermeture planifiée de sites miniers, dans nombre de cas, certaines activités s'y dérouleront encore et il y restera des éléments de structures techniques (digues, amas de rejets, usines de traitement) devant faire l'objet d'une surveillance et d'un entretien à long terme, voire de façon permanente. À moins de prendre des dispositions financières solides à long terme, des mines seront probablement abandonnées ou deviendront orphelines, et la responsabilité financière qui s'y rattache incombera aux contribuables. La probabilité croissante que ce scénario se réalise, ou l'impression qu'il se réalisera, pourraient constituer un risque lorsqu'un promoteur présente une demande de permis d'exploitation minière, particulièrement dans les juridictions où des plans de fermeture prévoyant le traitement permanent de l'eau suscitent déjà des préoccupations. Cela représente un risque à court terme pour les entreprises minières.

- Dans le cas des mines situées près de la limite sud de la zone de pergélisol, ou dans d'autres zones où une dégradation significative du pergélisol est prévue, la conception de couvertures de pergélisol ou la décision d'utiliser une couverture de pergélisol devraient tenir compte d'analyses thermiques qui prennent en considération les scénarios de changements

[3] Cependant, ces couvertures pourraient demeurer vulnérables à certains effets associés au changement climatique, p. ex. la pénétration des racines ou l'introduction de rongeurs résultant de la modification des conditions du sol.

[4] Il est reconnu que d'autres facteurs, comme la qualité du minerai, doivent être pris en considération lorsqu'on compare des mines de tailles différentes. Par exemple, il se pourrait que, dans les grandes mines, on exploite des minerais à plus faible teneur, que les zones perturbées soient plus vastes, et, par conséquent, qu'on produise plus de rejets (générant du DMA) – ce qui pourrait rendre une mine de grande taille aussi sensible, sur le plan du coût des mesures d'adaptation, qu'une mine de plus petite taille.

climatiques futurs. Ces changements auront des répercussions plus grandes sur les mines dans le nord qu'ailleurs au Canada, mais il est important de noter que les méthodes de conception technique tiennent déjà compte de l'évolution des conditions dans les climats froids. Cependant, les mines qui ont été fermées avant que ces méthodes ne soient adoptées sont probablement plus à risque.

Impacts du changement climatique sur le processus de DMA

- On ne prévoit pas que les augmentations de température projetées pendant la période visée par l'étude (2,5 °C à 3,5 °C) (TRNEE, 2010) feront varier de façon significative les taux d'oxydation des sulfures d'une mine au cours de sa période d'exploitation. Lorsque le DMA est traité, un plus grand apport de réactifs de traitement pourrait être nécessaire, mais on ne s'attend pas à ce que ce seul changement entraîne une grande augmentation des coûts d'exploitation ni qu'il ne menace le potentiel de la mine.
- De même, après la fermeture d'une mine, une augmentation du taux d'oxydation des sulfures pourrait entraîner une hausse des coûts de traitement à long terme. Toutefois, on estime que cet impact serait moins important que les autres impacts potentiels du changement climatique (p. ex. la défaillance de la couverture du parc à résidus) et des facteurs non liés au climat, qui pourraient nécessiter une modification de la méthode de gestion du site.
- D'autres ont signalé qu'on ne comprend toujours pas bien l'incidence que les températures basses, la glace et la dégradation du pergélisol ont sur la production d'acides et la dynamique liée au potentiel acidifiant (Stratos, 2009). Selon le rapport 1.61.6 du NEDEM (SRK, 2006), peu de recherches ont été effectuées sur l'effet qu'ont les basses températures sur le rendement des installations de gestion des rejets miniers, et il y est donc recommandé de poursuivre les recherches dans ce domaine.

Il est important de noter que les sites miniers où le DMA pose déjà des problèmes, que ce soit à cause d'une conception, d'une gestion ou d'une surveillance réglementaire inadéquates, pourraient aussi être plus vulnérables aux impacts du changement climatique.

En règle générale, il existe des méthodes et des moyens plus efficaces pour minimiser le DMA plus tôt dans la durée de vie de la mine. De même, les mesures d'adaptation au changement climatique sont plus efficaces et moins coûteuses lorsqu'elles sont élaborées et intégrées aux étapes de la planification et de la conception. L'adaptation préventive comprendrait l'adaptation de la conception des infrastructures, particulièrement des couvertures, à l'étape de la conception afin que les infrastructures résistent aux conditions caractérisant l'évolution du climat à long terme.

1 Introduction

Stratos Inc. was retained by the Mine Environment Neutral Drainage (MEND) program to assess the impacts of climate change on acid rock drainage (ARD) at Canadian mines. Specifically, the objectives of this assessment were to:

- present credible risk-based scenarios that characterize (especially in terms of cost risk) the potential impacts of climate change on ARD at Canadian mines; and in doing so,
- provide an approach to examining the risks due to climate change that can be applied by mining companies and policy makers to inform decisions to promote economic success and sustainability of future mine development.

Climate change poses a number of risks to mining operations. Extreme weather events and changes in precipitation patterns may lead to interruptions in production, damage to mining infrastructure, and emergency discharges. Permafrost degradation and increases in precipitation may compromise the integrity of waste containment structures such as dams and tailings covers. Drought conditions may lead to a shortage of water required for processing and waste management (e.g. water covers). Climate change may also affect energy and transportation infrastructure on which the mining sector depends to deliver electricity, labour, supplies, and to ship product.

This assessment focuses on risks associated with acid rock drainage and metal leaching (ARD/ML). ARD/ML occurs when minerals containing metals and sulphur (sulphides) come in contact with both air and water; the reaction rate is greatly accelerated by bacteria. For simplicity in this report, this drainage is referred to as ARD. At mine sites, the prevention and management of ARD includes the management of water, tailings and waste rock. Therefore, the climate change risks related to ARD arise from the impacts that a changing climate has on water management structures and activities, on waste impoundment structures, and on the hydrologic/ hydrogeologic/ geochemical conditions affecting the flow of water and contaminants at mine sites.

This assessment responds to a need to begin prioritizing risks from climate change effects to help inform business decisions, regulatory efforts, and further technical study. It is also meant to communicate, in a succinct way, the most probable impacts of climate change on ARD to the sector and its stakeholders.

1.1 APPROACH

This assessment is a high-level risk analysis and not a detailed technical study. The findings are based on the professional judgment of a multi-disciplinary team (engineering, sustainability, finance). Stratos retained the technical expertise of Brodie Consulting Ltd. for this project. Additional technical input was obtained through interviews with a small number of experts in the following areas: hydrology, hydraulic structures at mine sites, soil cover design, and soil cover vegetation. However, as a review of this report by the interviewees was beyond the scope of the project, their contributions remain anonymous.

The approach taken to complete this assessment included the following:

- A review of recent reports on the impacts of climate change in Canada, and more specifically on climate change and the mining sector;

- Development of a hypothetical *mine model* for examining the impacts of climate change on infrastructure and activities most relevant to the prevention and management of ARD;
- An initial risk screening to identify the activities and infrastructure most at risk and at what stage of the mine life-cycle;
- Development of indicative estimates of cost impacts for the most relevant and likely scenarios – presented in terms of net present value; and,
- A summary of risks and implications for mining sector stakeholders, highlighting areas of concerns (types of mines, regions, stage of mine cycle).

1.2 SCOPE AND KEY ASSUMPTIONS

This assessment focused on a subset of the potential impacts that climate change may have on Canadian mine sites – those related to ARD. These include impacts on the geochemical processes leading to ARD, and impacts on the activities and infrastructure used to minimize ARD processes or the release of contaminants to the environment.

Other impacts (non-ARD related) may have a greater or lesser impact on a specific mining operation. Prioritizing ARD-related impacts relative to other potential impacts caused by climate change (e.g. impacts on mining transportation networks or energy infrastructure) is beyond the scope of this assessment.

1.2.1 Timeframe

The timeframe considered in this assessment is for mining operations that are being planned or built today or that are currently active. The following assumptions are made:

- The majority of mines that are being planned or that are under construction will be in production within 5 - 10 years; and
- The majority of mines that are currently active, planned, or under construction will have an operating life of 20 years or less (i.e. the majority of today's mines will be closed by 2041 – assuming a 10 year planning period and 20 years of operation – or earlier).

Discussing or attempting to predict the impacts of climate change on operating mines beyond this timeframe is too speculative, as these mines will have been planned and designed under possibly very different circumstances in terms of economic conditions, technological development, our understanding of climate change impacts, and regulatory frameworks.

The IPCC Task Group on Scenarios for Climate and Impact Assessment (TGCIA) has recommended that three fixed time horizons in the future be considered in impacts studies: the 2020s (i.e., 2010-2039), the 2050s (2040-2069), and the 2080s (2070-2099) (IPCC, 1999; NRCan, 2008). Projections for the 2050s time horizon are used in this assessment. The 2050s time horizon provides adequate scope for discussing the impacts of significant climate changes (as compared to 2020s), while being less speculative than the 2080s time horizon. A key implication of the assumptions above is that by the time more significant climate change impacts materialize (i.e. 2050s); the majority of today's mining operations will be in the *post-closure* phase.

1.2.2 Types of Mines

This assessment does not apply to aggregate (gravel) mines and uranium mines. The findings in this study are considered to be most applicable to metal mines, which occur in most parts of Canada and are expected to be exposed to the range of climate change impacts discussed.

1.2.3 Risk Mitigation

In considering the potential cost and environmental risks associated with the impacts of climate change on ARD, it is assumed that mine owners will act in accordance with regulatory permits and accepted engineering practice. The implication of this assumption is that mine owners will take measures to mitigate the impacts of climate change on ARD to avoid environmental impacts that exceed regulatory limits and to avoid catastrophic failures. Therefore, the impacts discussed are largely cost impacts resulting from measures taken by mining companies (during operation or at closure) or by government agencies (post-closure) because the initial design was poorly adapted to climate change. While potential environmental impacts are discussed, they are not characterized in any detail as they are considered to be highly site-specific.

1.2.4 Other Assumptions

The mining sector is a significant user of energy and produces greenhouse gas emissions which contribute to climate change. However, the impacts of the mining sector on climate change (i.e. from the release of greenhouse gases) and its efforts to manage emissions are not within the scope of this assessment.

In addition, this assessment does not consider the impacts of climate change on the vulnerability of receiving environments. It is assumed that environmental regulators will modify environmental criteria to address these ecosystem-specific considerations.

2 Review of Recent Studies on Mining Infrastructure and Climate Change

Selected documents relevant to climate change and the mining sector were reviewed, with a focus on information and findings relevant to ARD. The review focused on secondary sources, including:

- Reports on the impacts of climate which synthesized the findings from primary sources including technical and scientific studies;
- Interviews;
- Industry surveys; and
- Case studies on individual mine sites.

The results of the review are presented in Appendix A. A summary of key issues and common themes is provided here.

2.1 POTENTIAL IMPACTS OF CLIMATE CHANGE ON ARD-RELATED INFRASTRUCTURE AND ACTIVITIES

The following impacts relevant to ARD were reported in most of the sources reviewed:

- For **northern mines**, permafrost degradation could compromise the stability and performance of structures such as dams and waste-covers leading to the release of contaminants.
- **Changes in hydrology** (increases or decreases in mean and maximum annual precipitation, changes in the ratio of water sources from rain, snow, or extreme precipitation events) could lead to flows that exceed the capacity of water management structures and to severe erosion. This could result in the release of contaminants and to the failure of impoundment structures.
- Decreases in mean annual precipitation or seasonal precipitation and increases in evapotranspiration may lead to **drought conditions** and may make it difficult to maintain other closure scenarios, such as sufficient water cover over tailings.

The above impacts were typically presented as part of a broader set of impacts that included the following non-ARD related concerns:

- For **northern mines**, increased reliance on all season roads, marine and air transport due to reduced availability/reliability of winter roads (ice roads);
- **Interruptions to operation** due to storms, forest fires, and/or more days with heavy snowfall; and
- **Reduced availability of water** for processing and increased competition for water resources in regions experiencing drier conditions.

2.2 CURRENT ADAPTATION EFFORTS IN THE MINING SECTOR

As demonstrated by the reports reviewed for this assessment, climate change is increasingly being considered by the mining sector.

Long-term climate change **adaptation planning** has been done by some mining sector practitioners and governmental agencies, especially in northern Canada. The Ekati and Diavik diamond mines in the Northwest Territories are examples of recent mines where the impacts of climate change have been integrated into design. The Indian and Northern Affairs Canada (INAC) contaminated sites program is incorporating climate change impacts into the development of mine closure and remediation plans, especially for higher risk sites requiring long-term care and maintenance and water treatment, such as the Giant Mine (NWT) and the Faro Mine (YT) sites.

A number of **technical strategies** exist and have been applied to combat the impacts of climate change on mining infrastructure (DSF, 2009), such as:

- Thermosyphons and construction on gravel pads to preserve permafrost;
- Removal of permafrost under infrastructure/heap locations to fore-stall impact of future melt; and,
- Use of more resilient tailings cover designs (cover thickness, use of geo-synthetics).

Limitations in the availability of local and regional data and downscaling the results of global circulation models (NRTEE, 2009; CEMI, 2009) present challenges in the development of appropriate technical adaptation measures.

Adaptation must also be achieved through changes in mining policy, regulations, or management approaches. Climate change is being addressed in the design of some new mines and in closure planning, as noted above, and in certain regulatory processes such as environmental assessment. However, the David Suzuki Foundation (2009) suggests that long-term adaptation planning is largely not occurring in the mining sector. A recent survey of mine closure policies in Canada and in foreign jurisdictions (Cowan Minerals Ltd., 2010) identified gaps related to requirements that could help address climate change impacts, including risk assessments for sites under long-term/perpetual care where environmental failure remains a possibility, and specific consideration of catastrophic events.

2.3 IDENTIFICATION AND PRIORITIZATION OF CLIMATE CHANGE RISKS

In the documents reviewed there was limited information on the evaluation or prioritization of risks associated with climate change impacts. In terms of ARD, there was little information on which potential impacts or failure mechanisms might present the greatest risk from a cost or environmental impact perspective. Understandably, the relative risks of different impacts will be very context specific. In taking a vulnerability approach to assessing climate change risk, it is as important to consider the specific mine context as the potential magnitude of climate change effects.

However, some of the documents reviewed did comment on relative ranking of climate change related concerns in terms of the stages of mine life cycle from the perspective of mining practitioners.

- **Climate change risks are significantly higher for mines in the closure and post-closure stages.** Most current mines have a relatively short life span and are not expected to be operating when the most severe effects of climate change manifest themselves in the future. From an operational standpoint, these mines do not necessarily need to be designed to accommodate changing climatic conditions for the near term. However, climate change could present potentially serious risks for mines in the post-operational and closure stages. (DSF, 2009)

- **Addressing climate change involves more of the same, but for slightly more extreme and uncertain conditions.** Building and operating mines, especially in the north, has always involved addressing challenges associated with climatic extremes, uncertainty and variability (CEMI, 2009). Potential impacts associated with extreme precipitation or drought conditions are manageable with adequate application of appropriate adaptation measures already practiced elsewhere in the sector (NRCan, 2008).

- **For mine practitioners, ARD-related risks may rank below other climate change related risks.** In a recent survey of Canadian mining practitioners (DSF, 2009), respondents identified the following priority areas when asked which aspects of company operations are most likely to be affected by climate change:
    - Transportation, with 38% concerned about impacts on transportation networks for export, and 41% concerned about on-site transportation
    - Impacts on processing (43% of respondents)
    - Activity timing (delays) (30% of respondents)
    - Mine drainage (24% of respondents)

  Only one of the above concerns is related directly to ARD (mine drainage) and it was ranked last out of the top five. NRTEE (2010) points out that climate change risk is only one of many factors influencing the viability of new projects including demand from global markets, environmental protection requirements, regulatory barriers, and provisions for equitable distribution of resource revenues.

In summary, the potential impacts of climate change on mining and specifically on ARD have been identified. Key drivers for these impacts include increased precipitation (especially extreme events), permafrost degradation, and drought conditions. There is limited information on the risks associated with these impacts (likelihood and severity) or the relative risk of ARD-related impacts compared to other climate impacts and to other risks facing mining operations. Technical solutions to addressing climate change impacts on ARD exist, but adaptation planning is not well integrated into mine planning, policy and regulations. The risk of climate change impacts may only become significant for current mines after they have closed.

3 Climate Change Conditions Relevant to ARD

Four climate change conditions were identified that were considered to be most relevant to ARD processes and control at Canadian mining operations.

1. **Increase in average temperature** – In addition to being a factor for the impacts listed below, temperature has a direct impact on the sulphide oxidation process that leads to ARD, and on evapotranspiration rates for vegetated waste covers.

2. **Change in mean annual precipitation** (MAP) – Water balance is a key consideration in the design of water management structures, tailings covers, and dams. Furthermore, changes in receiving waters (e.g. increasing or decreasing stream flow) will influence how ARD is assimilated by the environment.

3. **Increase in frequency and intensity of extreme weather events** – Extreme precipitation events govern the design of tailings dams and other aspects of a mine's water management system.

4. **Permafrost degradation** – Certain mine structures depend on permafrost for stability (i.e. dams) or as an infiltration barrier (i.e. tailings cover). Permafrost degradation may reduce the performance of these structures or cause them to fail.

The four conditions are functional categories of physical impacts that cover a wide range of interrelated impacts described in climate change literature. NRCan (2008) and other reports on the impacts of climate change in Canada indicate that the magnitude and nature of impacts vary across the country and that the projected impacts depend on the climate scenario being modelled. The Institute for Catastrophic Loss Reduction (ICLR, 2011) summarizes the observed climate trends to date and some climate related factors for 18 sub-regions of Canada. Projections are then given to 2050 of these key climate and climate-related factors.

3.1 INCREASE IN AVERAGE TEMPERATURE

Figure 1 shows the change in global surface temperature based on the IPCC's B1, A2, and A1B scenarios. The three scenarios are commonly used as the low (B1), moderate (A1B), and high growth (A2) scenarios for GHG emissions based on different combinations of assumptions on economic growth, the level of cooperation among nations to fight climate change, and on the introduction of clean and resource efficient technologies.

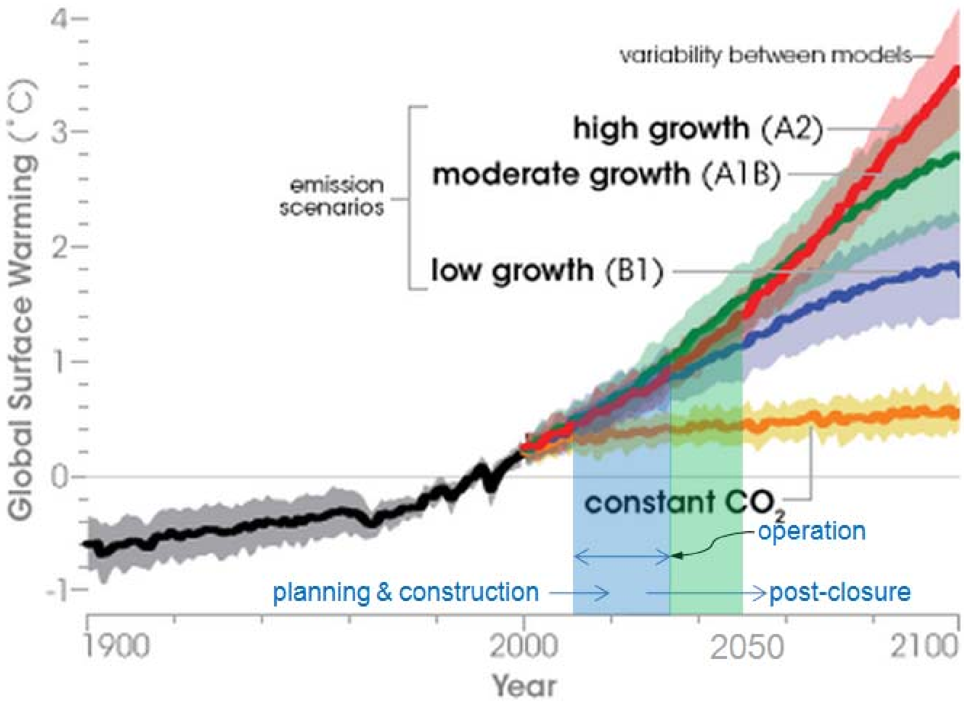

Figure 1: Global surface warming under A2, B1, and A1B scenarios
Source: Adapted from IPCC (2007)

The blue and green shaded columns indicate the approximate periods of operation and post-closure considered in this study and the corresponding increases in global surface temperature over these periods.

During the past century, temperature increases in Canada were approximately double the global average (NRTEE, 2010). This pattern is expected to continue, with Canada as a whole warming at approximately 1.5 times the global average, and the arctic at a rate of up to 3 times the global average. As noted in ICLR (2011), the highest emission scenario (A2) is the closest to observed trends, and recent information on GHG concentrations, emissions and impacts lead to the view that climate change is advancing more rapidly than earlier estimated.

Figure 2 shows the distribution of temperature changes expected across Canada between the current 30 year baseline and approximately 40 years into the future (2050s).

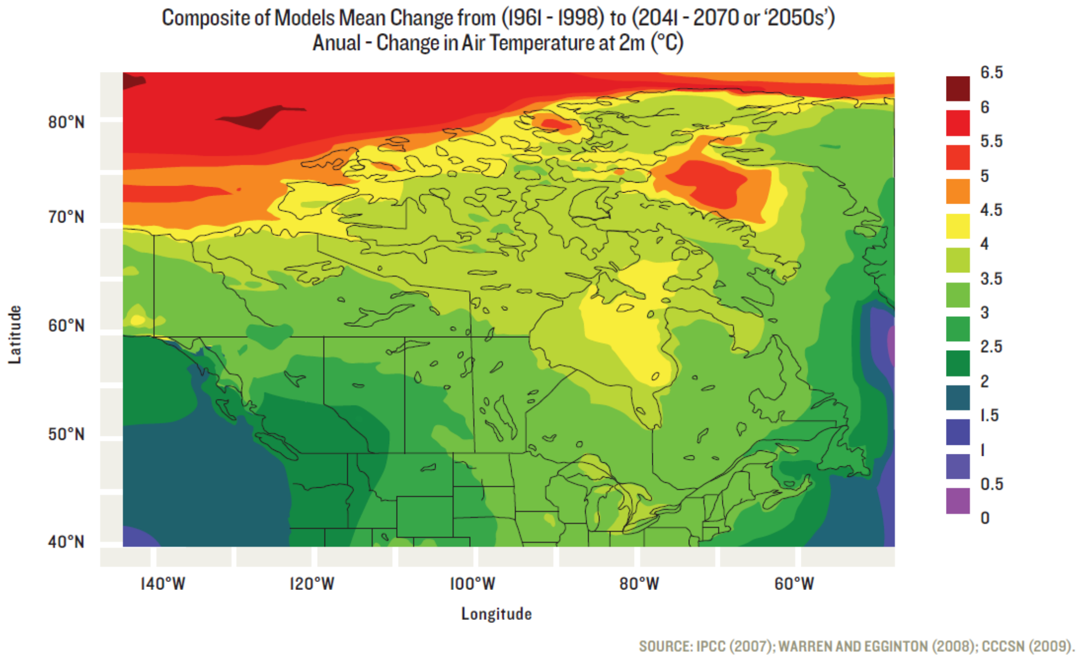

Figure 2: Change in Air temperature to 2050s period
Source: NRTEE (2010)

Figure 3 shows the approximate location of mining operations in Canada in 2009 (some new mines and newly closed mines are not shown). Comparing Figures 2 and 3 shows that metal mines in Canada are located in regions where temperatures are expected to increase by 2.5 to 3.5 °C, with the exception of mines in southern BC and parts of southern Alberta (dark green area). Coal mines are located primarily in regions (southern half of Saskatchewan and Alberta, eastern BC) where temperatures are expected to increase by 2 to 3 °C.

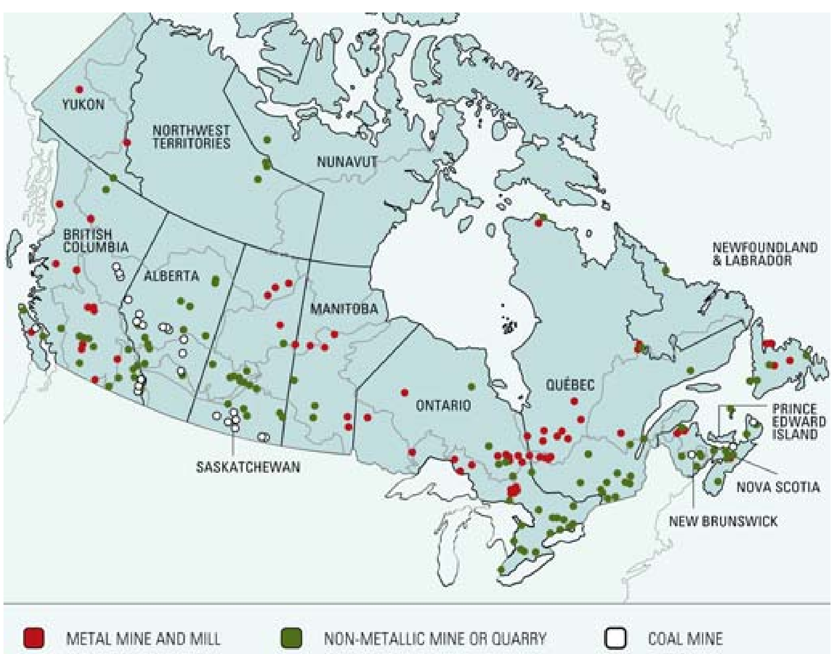

Figure 3: Mines in Canada
Source: NRTEE (2011), originally from NRCan 2009

3.2 CHANGES IN MEAN ANNUAL PRECIPITATION

Changes in precipitation patterns have already occurred – there are, on average, 20 more days with rain in Canada today compared to the 1950s. Figure 4 shows seasonal change in precipitation by the 2050s (relative to 1961-1990), based on the median of seven global climate models and using the emission scenarios of the Special Report on Emissions (IPCC, 2000). Most regions of the maps, with the exception of areas southwestern Canada (BC and Prairies) in the summer and fall, are shaded green - indicating an expected increase in precipitation by 2050, especially during the winter months.

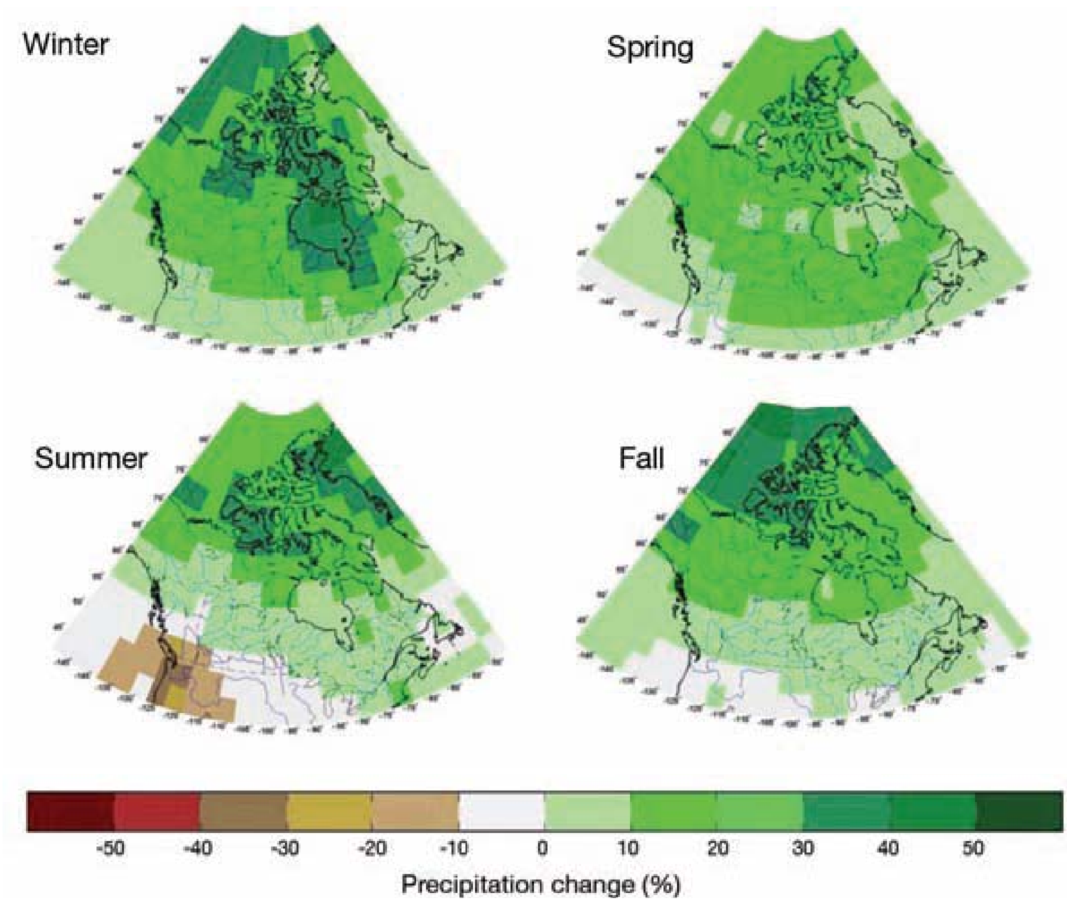

Figure 4: Seasonal change in precipitation by the 2050s (relative to 1961-1990)
Source: NRCan (2008)

Seasonal changes will generally have greater impact on a regional scale than annual totals. Because of enhanced evapotranspiration, driven by higher temperature, many regions will experience moisture deficits despite higher annual precipitation. Regional and site-specific analysis is required to determine how a mining operation should plan for wetter or drier conditions.

Another important change will be an increase in the percentage of precipitation falling as rain instead of snow, as well as an increase in extreme daily precipitation as described in the following section.

3.3 EXTREME WEATHER EVENTS

Although there is considerable uncertainty related to how rainfall may change in a warmer climate, there is an indication from both theoretical and climate models that changes in rainfall resulting from thermodynamic processes will lead to more frequent and perhaps more intense extreme events . In particular this will occur in regions with increase in mean precipitation (Jakob et al., 2009). The climate projections for 2050 for most regions of Canada include increases in mean precipitation and more severe and frequent intense precipitation events (ICLR, 2011).

NRCan (2008) states that changes in daily extreme precipitation are expected to be greater than changes in mean annual precipitation, meaning that these events will be more frequent and more intense. One study cited in the NRCan report (2008) indicated that what was a 100-year precipitation event in 1990 would become a 70-year event by 2055 (between latitudes 20°N and 65°N in North America).

However, based on the research conducted for this assessment, considerable uncertainty remains in quantitative assessments of changes to rainfall used for dam and spillway design. Estimates of probable maximum precipitation (PMP) and probable maximum flood (PMF) are required for design. An important question is how climate change will affect PMF and PMP. The results of a study conducted for the Australian Government's Bureau of Meteorology, which directly addressed this question, "could not confirm that PMP would increase under a changing climate" (Jakob et al., 2009). Hydro-Quebec and BC Hydro, both owners of large hydroelectric dams in Canada, have indicated that they will be exploring this question together in the near future (personal communication with Rene Roy, Hydro-Quebec and Stephanie Smith, BC Hydro).

3.4 PERMAFROST DEGRADATION

Approximately half of the area underlain by permafrost in Canada contains permafrost warmer than -2 °C that could ultimately disappear (thaw) under projected climate warming. Projections of increases in the active-layer depth range from 0% to more than 50% during the next 50 years (NRCan, 2008). Degradation of continuous permafrost and disappearance of discontinuous permafrost are projected to occur at the southern boundaries of these permafrost zones.

Figure 5 shows the thaw sensitivity of permafrost to climate warming – areas with darker shading are more susceptible to permafrost degradation.

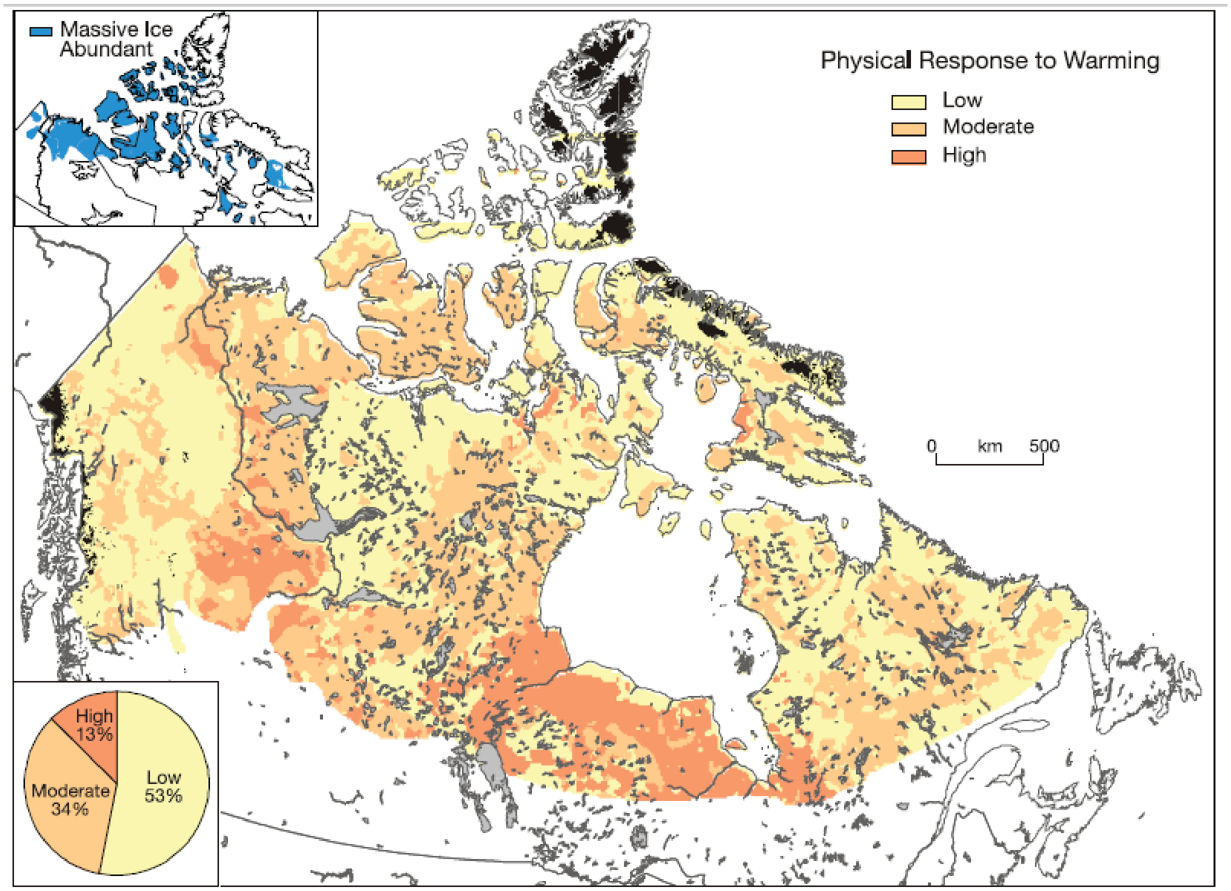

Figure 5: Thaw sensitivity of permafrost to climate warming (Smith and Burgess, 2004)
Source: NRCan (2008)

4 Mining Infrastructure and Activities Relevant to ARD

To explore the impacts of climate change on ARD, the infrastructure and activities relevant to ARD were identified. Figure 6 and 7 show the infrastructure and activity elements for operational and post-closure phases. The figures show the main elements, sub-elements, and the main direct physical impacts that may result from exposure to the climate change conditions presented in the previous section.

In Section 5, these direct impacts are considered in more detail – in terms of the level of mitigation that will most likely be required to minimize ARD impacts on the environment.

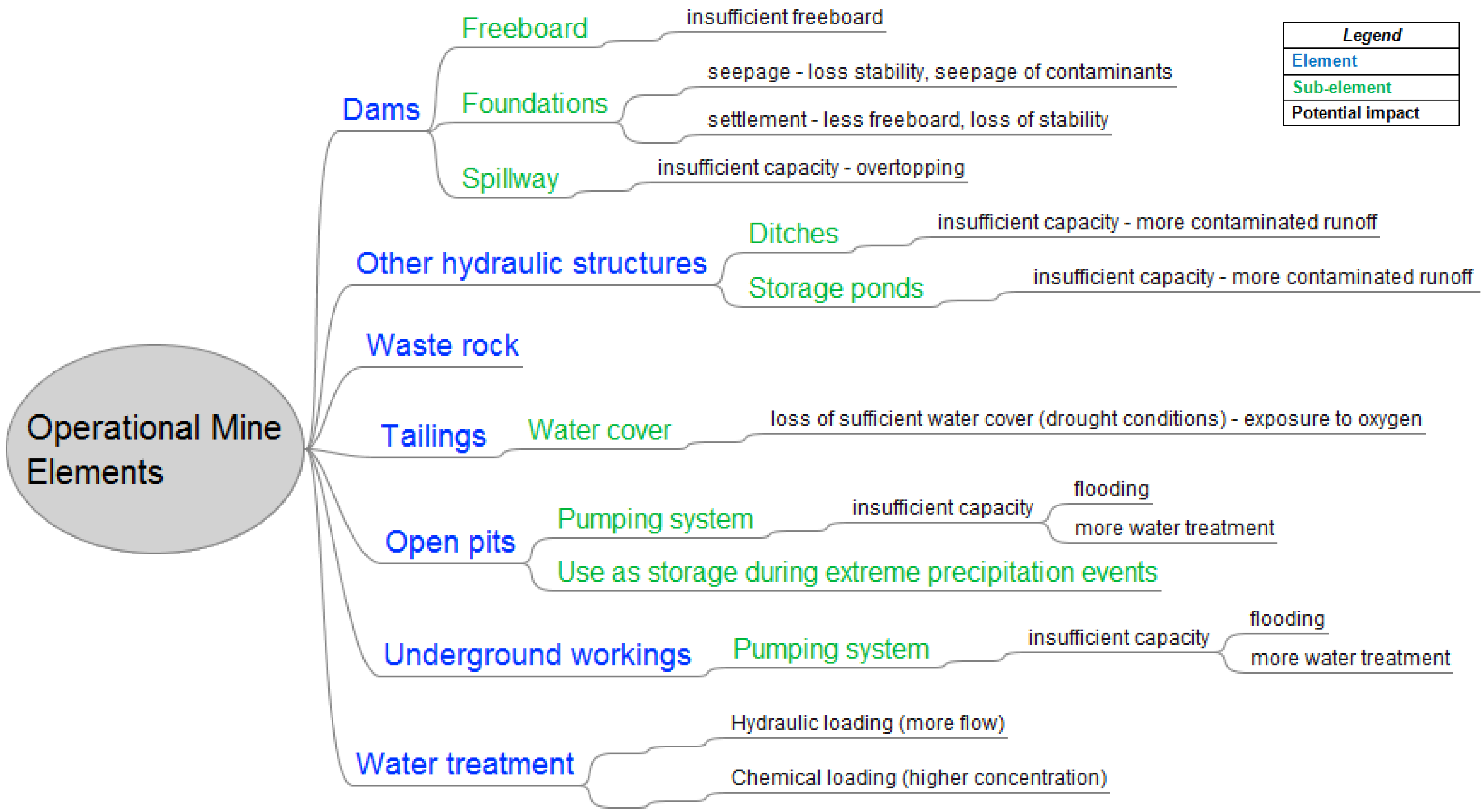

Figure 6: Operational mine elements and potential changes in performance or failures

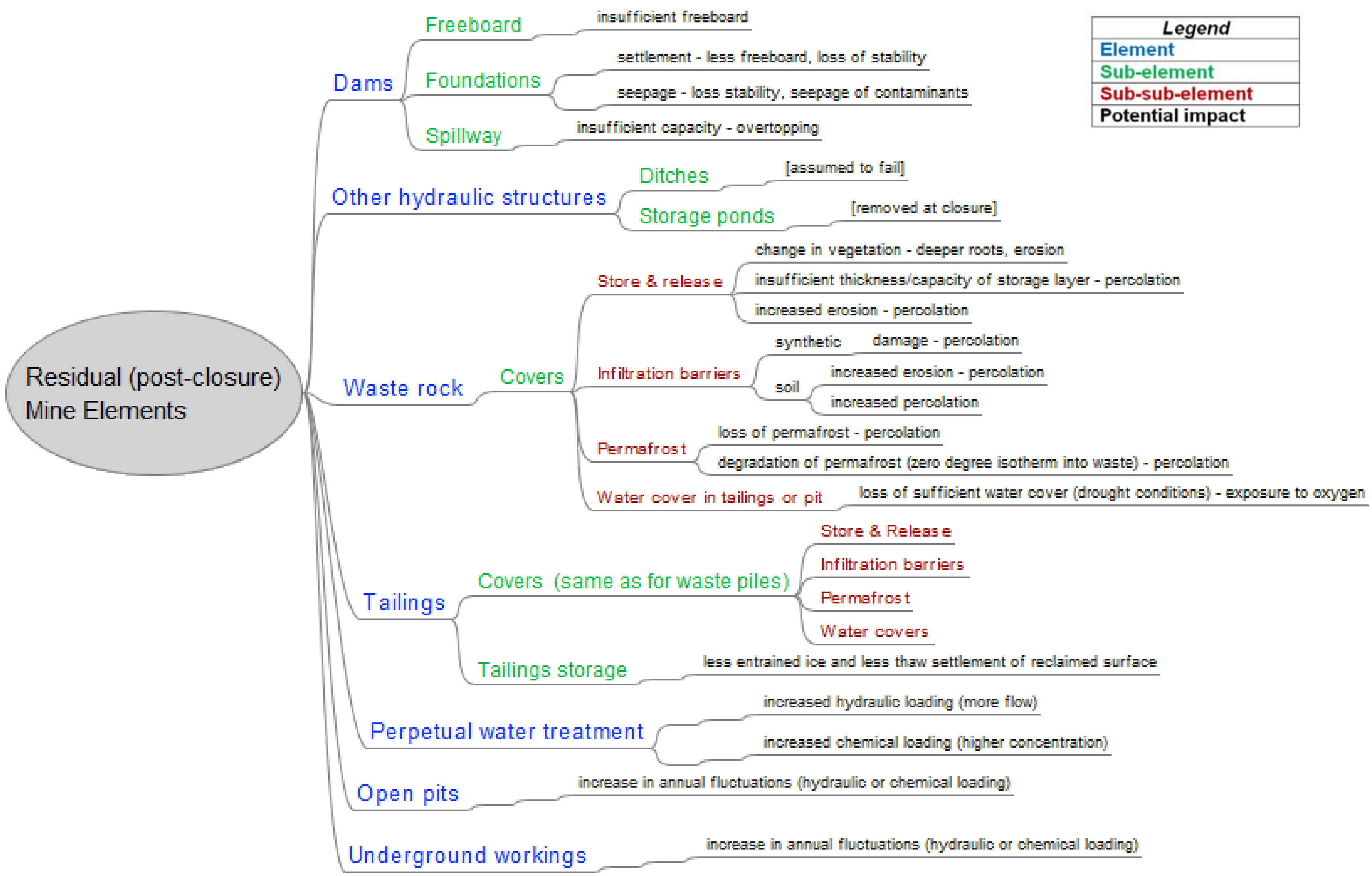

Figure 7: Residual (post-closure) mine elements and potential changes in performance or failures

5 Potential Impacts of Climate Change on ARD at Canadian Mine Sites

5.1 OVERVIEW OF POTENTIAL IMPACTS

To identify the full range of potential climate change impacts from ARD at mining operations, the four climate change conditions were applied to the mine elements (infrastructure and activities) presented above in Figures 6 and 7. These impacts are described in the following table. Each impact is characterized in terms of the climate change conditions that drive the impact, the timeframe during which the impact is considered to be most significant (operation or post-closure), and the level of mitigation that would be required to minimize or avoid additional ARD impacts.

Table 1: Potential Impacts of Climate Change on Mine ARD

Mine Component / Activity	Sub-component / type	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe for ARD Impact		Potential Mitigation
			Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure	
Dams	Foundation	Settlement				✓		✓	Provide additional freeboard
		Increased seepage		✓	✓	✓	✓	✓	Design for stability in frozen and unfrozen state Design for no pond at closure (i.e. dry tailings)
		Slope failure due to rising phreatic surface		✓	✓			✓	Flatter slope or buttress required
	Freeboard / Spillway	Overtopping			✓		✓	✓	Provide additional freeboard, design with option to increase spillway capacity

Mine Component / Activity	Sub-component / type	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe for ARD Impact		Potential Mitigation
			Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure	
Waste piles and tailings	Store and release cover	Storage capacity exceeded, increased percolation		✓	✓			✓	More or different vegetation if possible, increase thickness/capacity of storage layer, increase erosion resistance (flatter slope, earlier vegetation, armoured runoff channels)
		Vegetation poorly adapted (increased percolation, erosion, or metal uptake). Vegetation may also be impacted by an increase in forest fires.	✓	✓	✓ (other extreme events – i.e. forest fires)			✓	
		Cover is eroded, increased percolation		✓	✓			✓	
	Infiltration barrier - soil	Cover is eroded, increased percolation		✓	✓			✓	
	Infiltration barrier - synthetic	Protection layer is eroded, increasing risk of damage to synthetic layer, minimal impact on ARD			✓			✓	Increase erosion resistance of protection layer if required.
	Permafrost cover	Permafrost degrades, increased percolation				✓		✓	Increase thickness of rock cover. Use alternative cover technology (e.g. geo-synthetic)
	Water cover (tailing or pit)	Increased MAP may reduce risk of drought effects but also increase risk of emergency discharge. In some regions where more seasonal drought periods are projected, increased risk of exposure of tailings to air (and increased ARD).	✓ (increased evapotranspiration)	✓			✓	✓	Use alternative cover technology where more negative water balance is projected.
	Tailings storage	Less entrained ice and less settlement of future reclaimed surface (i.e. positive impact)	✓					✓	Slightly smaller dam may be possible.

Mine Component / Activity	Sub-component / type	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe for ARD Impact		Potential Mitigation
			Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure	
Water treatment		Increased hydraulic loading (linked to failure/ underperformance of other components)		✓	✓		✓	✓	Increase mine water treatment system capacity (holding pond, flow)
		Increased chemical loading (linked to failure/ underperformance of other components)	✓				✓	✓	Process modifications, increased use of reagents.
Open pits		Increased flooding of pit and need for pumping and treatment (see water treatment) or emergency releases. Changes in chemical loading to pit water.			✓		✓	✓	Plan for increased use of pit as storage pond for extreme events, increased treatment of pit water, or enhance other diversion structures and storage options.
Underground workings		Increased flooding of underground and need for pumping and treatment (see water treatment).			✓		✓	✓	Plan for increased management of mine water (pumping and treatment), or enhance other and water storage options.
Other hydraulic structures (ditches, diversions, holding ponds)		Diversion ditches and channels are undersized resulting in more infiltration into or contact with acid generating material.			✓		✓		Increase capacity of diversion and storage structures.

Mine Component / Activity	Sub-component / type	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe for ARD Impact		Potential Mitigation
			Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure	
ARD biochemical process (i.e. sulphide oxidation rate)		Increase in rate of sulphide oxidation process due to higher average temperature (other factors considered constant)	✓					✓	Implement water treatment or make process modifications to existing water treatment to address increased chemical loading (e.g. increased use of reagents)

5.2 DISCUSSION

Assuming that most mines have an operational period of 20 years[5] or less, climate change effects are expected to be negligible on the hydraulic capacity (design flow) of mine components (ditches, water management ponds, spillways, water treatment plant, tailings pond supernatant volume) during operation. Although it may be appropriate for engineers to incorporate adjustment for anticipated climate change effects in the design of the operational components of a mine, these are expected to be small refinements and not material in the overall economic viability of a given mine. The reason for this is that during the operation phase, most climate parameters in most regions are projected to change within or close to within a range which is already accounted for by conventional engineering design.

The effects of climate change on the mining industry are expected to be most significant in the design of post-closure mine components, which include all mine features remaining after the mine is reclaimed and closed. This prediction arises because mine closure design must consider the long-term future of a site, a future that extends into the timeframe when the magnitude of climate change effects will become more significant. Therefore, the focus of this discussion is on climate change effects on mine closure design and performance.

The post-closure effects of climate change can be summarized as follows:

- Larger flows through hydraulic structures such as spillways and ditches, and in the extreme case the risk of a dam failure due to insufficient capacity of the spillway;
- Increased percolation through covers (especially store and release, and simple single-layer covers), which in turn causes increased flushing of contaminants from under the cover;
- Increased percolation and/or erosion for soil covers on potentially-acid generating (PAG) mine waste;
- Changes in vegetation types on covers;
- Thawing of frozen cores causing settling of, or increased seepage through, tailings dams; and
- Thawing of permafrost causing increased percolation in permafrost covers.

The above impacts on the post-closure infrastructure, if not mitigated, could result in increased contaminated runoff from the mine site, and in the extreme case, a catastrophic release of tailings if a dam were to fail. However, it is assumed that mine owners or operators will continuously and actively work towards mitigating these potential impacts.

If mitigation is reactive (i.e. **reactive adaptation**), because the impacts described above have occurred, the following activities may be required:

- Increased maintenance, repair, or replacement of covers due to erosion damage or modification of cover;
- Increased maintenance or modification (e.g. buttress, thermosyphons) of frozen core dams to limit or compensate for permafrost degradation;

[5] While some mines have reserves that would extend mine life beyond 20 years, regulatory mine planning is generally still based on a 20-year timeframe.

- Increased burden on water treatment activities (if post-closure treatment is required) in the form of chemical loading (higher concentration) and/or hydraulic loading (higher flow); and
- Clean-up and repair of infrastructure above due to extreme, unexpected events.

The design parameters most relevant to these impacts are the following:

- Cover thickness and type (on tailings or waste rock);
- Spillway capacity for tailings dams; and
- Aggregate volume of water to be managed in perpetual water treatment systems.

Anticipatory adaptation would involve designing infrastructure for post-closure climate change conditions at or before closure. In general, this is the preferred approach as more effective options for minimizing ARD are available earlier in the mine life (INAP, 2010). Similarly, climate change adaptation measures are more effective and less costly when developed and integrated at the planning and design phase.

The following sections provide additional commentary on the nature of impacts and potential mitigations in these areas.

5.2.1 Ditches and Spillways

Given the uncertainty in the extent to which climate change will affect flood flow and that impacts will likely be highly site specific, different mitigation strategies are suggested. One option is to design with future expansion in mind but only build for current conditions. This approach may still leave a contingent liability for future generations. The preferred approach is to build for plausible future conditions (based on predicted climate change effects) and/or incorporate additional conservatism (safety factors) into the design. The challenge lies in determining how to implement this approach – an initial approach may be to increase the level of the design's CDA Dam Classification (Table 2-1, CDA Dam Safety Guidelines, 2007).

5.2.2 Soil Cover Vegetation

Climate change projections suggest that increased MAP is primarily delivered in winter (non-growing) months, and in a proportionally increasing non-frozen form (rain instead of snow). Given these assumptions, coupled with projected higher temperatures and CO_2 levels, it is expected that plant growth rate and evapotranspiration may increase. However, this increase will need to be supported by an increased use of soil water. As a corresponding increase in water will not be delivered during the growing season, it is expected that vegetation would develop deeper root systems, where possible, to acquire water during moisture-limiting periods in the growing season. These changes may be accompanied by vegetation shifts, as plants more suited to warmer growing seasons with more drought are favoured over plants found in current conditions.

It is predicted that growth rate would marginally increase, and that plant types would potentially shift towards plants more tolerant of drier growing seasons (e.g., grasses instead of trees), and that root penetration would marginally increase. Deeper root penetration may not be desirable for geotechnical or other reasons. This would also have an effect on the designed thickness of the cover material. Root penetration should be limited to the cover layer and not go into the waste material below, which would result in a pathway for possible contamination release.

5.2.3 Soil Cover Erosion Effects

Climate change projections suggest an increase in extreme daily precipitation, and these extremes are disproportionately responsible for surface erosion, as overland flow and detachment of soil particles occurs when precipitation rates exceed soil infiltration rates (i.e. in extreme events). As discussed above, increased precipitation is expected to be delivered primarily in winter months (and more as rain), when plants are not transpiring and there is little evaporative demand at the soil surface, due to reduced insolation (solar radiation energy). Therefore, an increase in delivered water may not be proportionately removed by evapotranspirational mechanisms, and may result in both increased net percolation and increased surface erosion.

Surface erosion of covers is probably the most serious process leading to long-term loss of cover performance. Quantitative predictions of effects and design are beyond the scope of this report. However, the gradual deepening of gullies and erosion of a cover is something which can readily be monitored, and if necessary, repairs undertaken. These types of problems, if they occur, will likely be localized effects and not affect the entire cover area. Consequently, in terms of the overall cost of the cover, the future maintenance issue is likely to be primarily limited to local repairs on an infrequent basis (i.e. once per decade). A modest provision of a $1/m^2/decade multiplied by the area of the cover should provide sufficient means for future generations to manage any issues should they arise (consistent with responsible maintenance funding for long-term maintenance involving infrequent repairs).

One might expect increases in cover maintenance costs to be roughly proportional to the relative increases expected in extreme daily precipitation. This increase could potentially be mitigated by use of more aggressive surface-erosion control techniques, such as increased landform grading or bio-engineering.

Increased percolation through the cover could lead to flushing of the underlying contaminants. In cases of severe ARD risk, this could ultimately lead to the covered area yielding a greater volume of seepage and possibly at a higher metal concentration as stored oxidation products are flushed out. Additional measures to mitigate impacts to the receiving environment (e.g. water treatment) could be needed.

5.2.4 Implications for Cover Design

At Canadian mines, there are four broad categories of reclamation covers: simple or single-layer covers, infiltration barriers, store and release covers, and permafrost covers. Except for simple covers, all of the cover types are site-specific engineered structures which depend primarily upon two independent parameters: climate/water balance factors and availability of local materials for construction. Table 2 summarizes the most likely potential effects on each type of cover and the mitigation required.

Table 2: Potential Impacts of Climate Change on Reclamation Covers

Cover Type	Purpose	Potential Impacts of Climate Change and Increased MAP
Simple	Aid in re-establishing vegetation	Little or none, possibly a shift in type of vegetation, or temporary loss of vegetation due to increased forest fire activity.
Infiltration Barrier (using geo-synthetic material)	Minimize flushing of metals	Negligible compared to other cover types. Potential need for thicker or more robust protective cover due to increased erosion.
Store & Release (soil cover which stores freshet/rain water for later release by evaporation/evapo-transpiration)	Reduce flushing of metals	Increased MAP may lead to: • Cover will need to be modified (possibly greater storage capacity or more robust), increase may not be proportional to increased MAP due to increased evaporation/evapo-transpiration) in longer/warmer summer • Cover thickness exceeding what can be released – in such a case a switch to barrier cover may be needed Also, potential temporary loss of vegetation due to increased forest fire activity.
Permafrost cover (rocky cover to induce and preserve permafrost)	Minimize flushing of metals	Warmer climate may lead to: • Cover will need to be thicker (deeper active layer), • Permafrost cover may be impractical – in such a case store & release or barrier cover may be required.

5.2.5 Most Significant Risks

Based on the discussion above, two types of scenarios have been identified as likely to pose the most significant risks related to ARD from climate change at Canadian mines. These risks are presented as scenarios in Table 3 below.

Table 3: Most Significant Risk Scenarios Related to Climate Change Impacts on ARD

Scenario	Impacts	Timeline	Affected Groups	Other Considerations and Risks
To adapt to a changing climate, a mine operation must implement a reclamation cover design that is significantly more expensive than the original option (e.g. geo-synthetic cover instead of store and release cover)	a. Additional reclamation costs for mine owners. b. Cost of long-term/perpetual treatment required if cover deficiency not addressed. c. Increased ARD and environmental impacts if not mitigated.	Cost impacts occur during operation or closure. Cost impacts occur post-closure. Environmental impacts occur post-closure	Mine owner Mine owner, government agency / society Society, ecosystem	The potential impacts of climate change on closure infrastructure may cause concern among mine stakeholders – less certainty in the long-term integrity of covers and increased likelihood of long-term treatment requirements.
More frequent and intense extreme weather events force temporary shut-downs and modification to water management structures (holding ponds, ditches, dam, spillway, treatment system) to address problems and prevent re-occurrences.	a. Cost impacts due to loss of production during shutdown and requirement for modifications b. Periodic releases of contaminated effluent (above permit limit) and associated environmental impacts if not mitigated	Cost impacts occur during operation. Environmental impacts occur during operation.	Mine owner Society, ecosystem	Linking individual extreme weather events to climate change is challenging. However, this link will be made by stakeholder if water management structures and strategies consistently underperform during rainstorm events.

The financial costs of these scenarios are explored in more detail in the following section.

6 Financial Modelling of Climate Change Adaptation Measures

Some basic financial modelling was conducted to obtain a sense of scale of the potential financial impacts of climate change adaptation measures on mines – focusing on a scenario where a significantly more costly cover design (i.e. use of a geo-synthetic) is required to adapt to climate change conditions during post-closure. A basic financial model was developed of a hypothetical Canadian copper mine with characteristics similar to those that would be impacted by the need to adapt to climate change impacts. The difference in the mine's Net Present Value (NPV) was estimated based on the need to take adaptation measures by increasing the amount of funds set aside for reclamation purposes prior to production. The same analysis was then conducted for two other mine size scenarios – small (half the size of the base model) and large (twice the size of the base model).

6.1 MODEL ASSUMPTIONS

The model assumes a base case copper mine with the following characteristics:

- An open-pit copper mine with a total of 702,000 tonnes of copper reserves and a life of 10 years, at an average annual production rate of 70,200 t of copper;
- Capital costs and operating costs are derived from "rules of thumb"[6]
    - Capital costs are calculated on the basis of $1300 per t of Cu produced;
    - Operating costs are calculated on the basis of $\$80*(1)^{0.6}$ per tonne for a mine of 1mtpa and adjusted downwards for larger mines and upwards for smaller mines
- The model assumes a 2-year construction period with capital costs split evenly between the 2 years;
- Reclamation costs are $45 million dollars and paid at the end of year 2, prior to production (in the form of a bond or other security). Forty per cent of the reclamation costs represent a store and release cover at a cost of $8 per square metre for 2.25 million square metres.
- The climate change scenario assumes that the store and release cover would need to be replaced by a polysynthetic cover at a cost of $35 per square metre, also paid at the end of year 2.
- The model assumes a tax rate of 25%, an average copper price of $4,500 per tonne and a discount rate of 10%.

[6] See *The Mining Valuation Handbook* by Dr. Victor Rudenno, John Wiley and Sons.

6.2 OVERVIEW OF RESULTS

A summary of the results is provided in Table 4 below:

Table 4: Impacts of Climate Change Adaptation Costs on NPV for Hypothetical Copper Mine

	Base (Medium) Sized Copper Mine	Small Copper Mine Case	Large Copper Mine Case
Base Scenario (no climate change) NPV	$388.6 Million	$185.4 Million	$797 Million
Climate Change Adaptation Scenario NPV	$333.3 Million	$157.7 Million	$686.3 Million
Difference	$55.3 Million	$27.7 Million	$110.7 Million
% NPV Erosion from Climate Change Adaption	14.2%	14.9%	13.9%

The analysis indicates the following:

- The need to account for climate change impacts alone (by setting aside a higher level of funds for a more costly cover design at reclamation) would not make any of the mine size scenarios uneconomical. In all cases, NPV remains positive.
- Nevertheless, differences between the base and the climate change adaptation scenarios in all cases are significant – with NPV erosion ranging from 13.9% to 14.9%. **These would represent significant financial impacts to any mine developer**.
- The percentage difference in NPV erosion is slightly greater for smaller mines and slightly smaller for larger mines. This would be expected given the greater economies of scale that tend to exist for larger mines.
- The model assumes that climate change costs are absorbed within closure costs that are set aside prior to production, as is the norm in the Canadian context. The model would yield different results should these costs not be set aside prior to production and if any failure to properly plan for closure leads to tailings spills or other environmental impacts. Such impacts could lead to additional costs – clean up, liabilities, etc. – that would likely be borne by the mine owner or in some cases (e.g. where the mine owner no longer exists), by the Crown.

6.3 BASE CASE (MEDIUM COPPER MINE)

The base case shows a difference in the mine project's NPV of $55.3 million ($386.6 million versus $333.3 million), or 14.2% of the original NPV. The need to account for climate change adaptation also lengthens the mine's payback period. A summary of the difference in cash flows is provided in Figure 8 below.

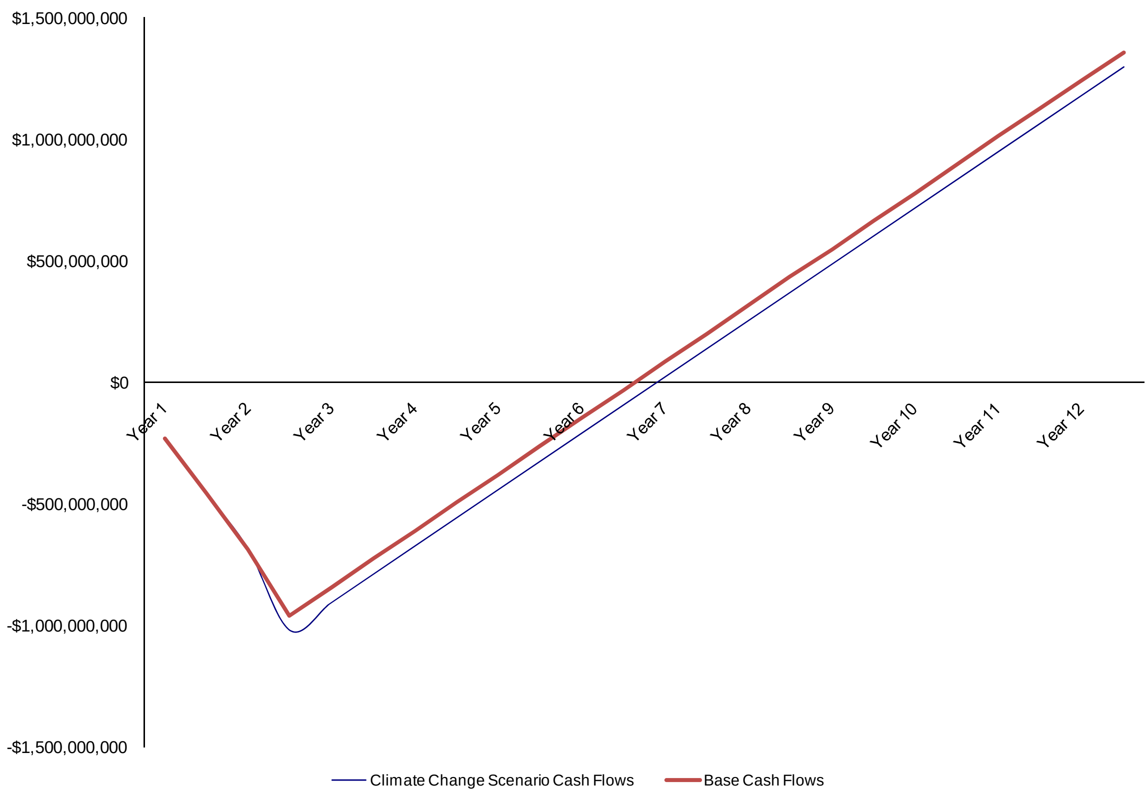

Figure 8: Medium Sized Copper Mine Cash Flows – Impact of Adaptation Costs

6.4 SMALL COPPER MINE CASE

The size of the base case mine was reduced by half in total reserves (to 351,000 t), annual production (to 35,100 tpa) and reclamation costs (to $22.5 million). Capital costs and operating costs were adjusted according the prescribed rules of thumb. The mine still maintains a positive NPV ($157.7 million versus $185.4 million) although the value erosion is 14.9% in this case.

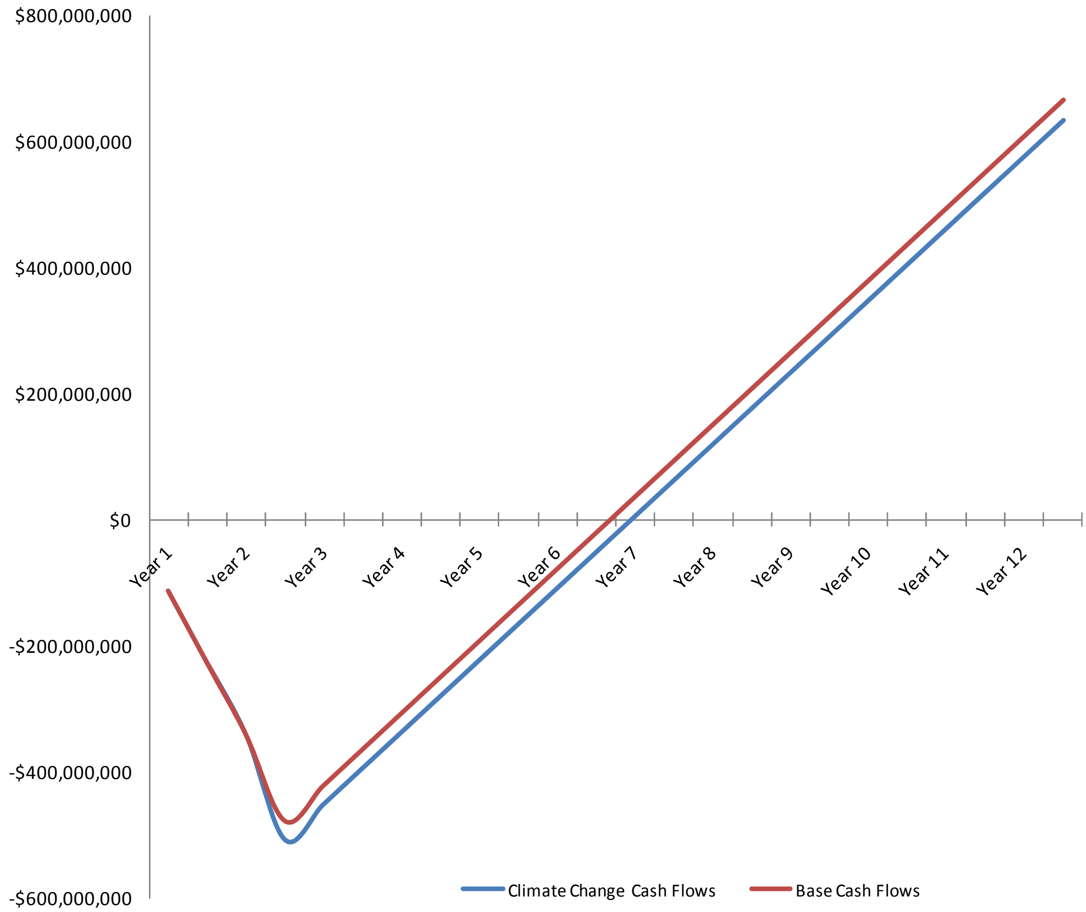

Figure 9: Small Copper Mine Cash Flows – Impact of Adaptation Costs

6.5 LARGE COPPER MINE CASE

The large mine doubles the base case in terms of size of reserves (1,404,000 mt), production (140,400 tpa) and reclamation costs (to $90 million) and adjusts capital. In this case, NPV erosion is $110.7 million ($683.3 million versus $797 million) or 13.9% of the original NPV.

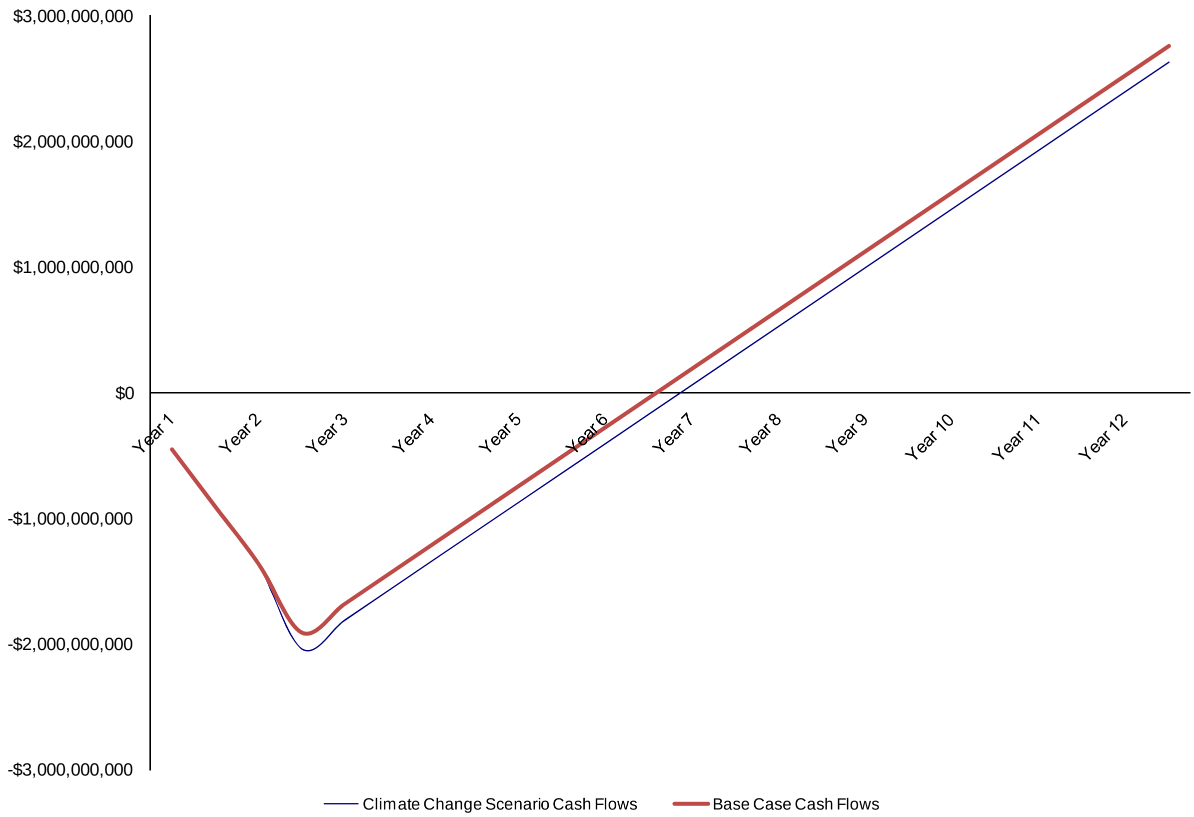

Figure 10: Large Copper Mine Cash Flows – Impact of Adaptation Costs

6.6 POTENTIAL FINANCIAL IMPACTS OF CLIMATE CHANGE-RELATED SHUTDOWNS

Another potential climate change impact is shutdowns stemming from extreme weather events and/or underestimated levels of precipitation leading to water overflows at mine sites (i.e. an extreme weather event forces a temporary shut-down and modification to the mine development to address the problem and avoid a re-occurrence). In order to consider the potential financial impacts of such events, a number of scenarios were considered, taking into account the effect of one to three six-month shutdown (where no production occurs) on NPV in combination with increased reclamation costs associated with an adapted cover design (as described above). The medium-sized mine was modelled with one, two and three 6-month shutdowns occurring at various points during the project lifecycle. The results of this analysis are shown in Table 5. It is recognized that these scenarios represent an extreme combination of conditions (i.e. need to adopt more costly cover design in combination with lengthy shutdowns due to extreme weather) and may only apply to a small number of mines. As projected increases of mean annual precipitation and intense precipitation events are greater for northern Canada (ICLR, 2011), mines in these regions may be more vulnerable to these types of shutdowns.

Table 5: Impacts of Climate Change-Related Shutdowns on NPV for Hypothetical Copper Mine

Scenario	NPV Erosion*	NPV Erosion as % of Base NPV
One 6-month shutdown (at end of year 5 of production)	$79.1 Million	20.3%
Two 6-month shutdown (at end of year 2 and year 5 of production)	$122.6 Million	31.5%
Three 6-month shutdown (at end of year 2, year 5 and year 8 of production	$132 Million	34%

* NPV erosion reflects impacts of both shutdown and increased costs of implementing and climate change adapted reclamation cover design.

Although significant, at no point would these delays render the project uneconomical, even with increases in reclamation costs due to a more costly cover design. NPV remains positive in all cases as shown in Figure 11.

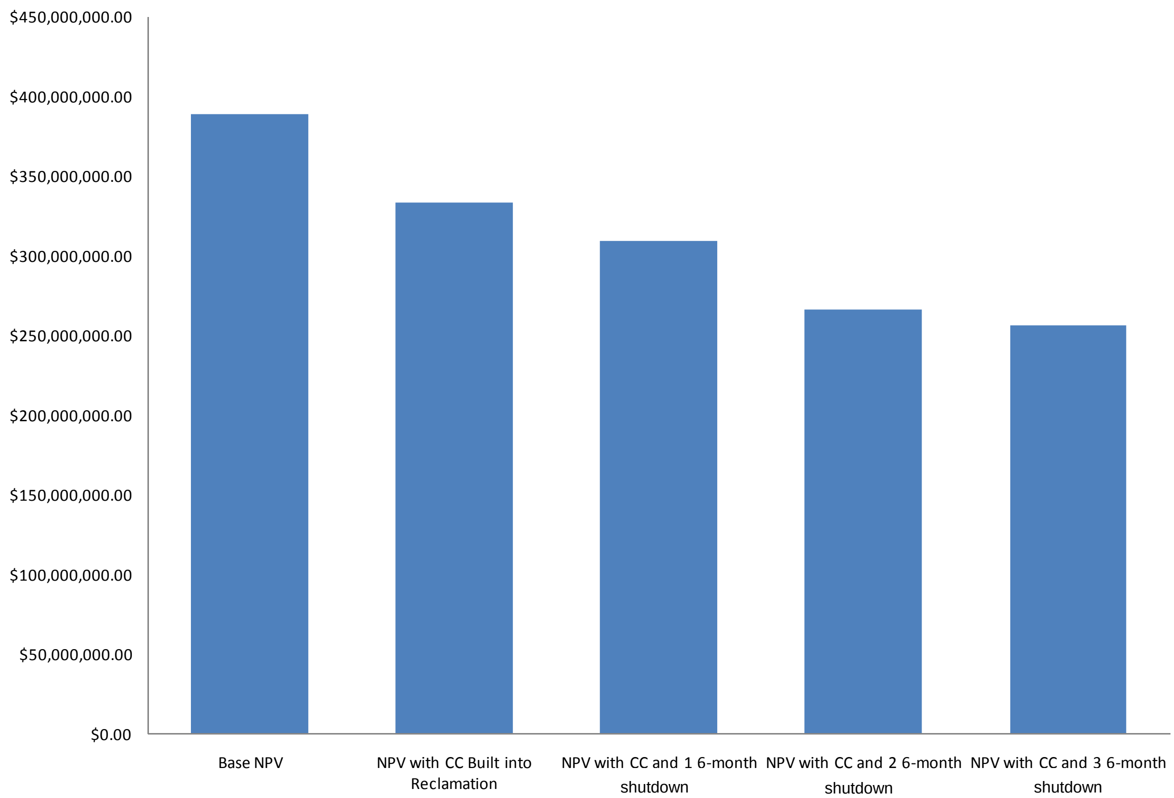

Figure 11: Effect of Climate Change-Related Shutdown on NPV

7 Summary and Conclusions

Climate change will impact all of Canada's natural resource sectors - including mining. Mining activities occur across Canada, so mining operations will be exposed to the broad range of regional impacts that are projected by climate models, including more pronounced impacts in the north (due to arctic amplification). Previous studies on climate change impacts in Canada identify a range of potential impacts for the mining sector, including impacts that could affect ARD from mine sites. Very little work has been done on evaluating and prioritizing the risks associated with these impacts to help communicate these risks and to inform adaptation strategies in the sector.

This assessment aims to improve the understanding of the climate change impacts on ARD from Canadian mine sites and to identify which aspects are most at risk from a cost and environmental perspective. The assessment provides an approach to examining climate change impacts on ARD by:

- identifying a set of climate change conditions most relevant to ARD at mines that are currently active or that are being planned today;
- identifying a list of mine elements and activities related to ARD;
- describing a range of potential impacts and required mitigation as a basis for identifying priority risks; and
- illustrating the potential impacts of climate change (with respect to ARD) on the net present value (NPV) for a hypothetical copper mine.

The following conclusions are made based on this review and analysis:

Operations – Impact on Activities and Infrastructure

- Many of the effects of climate change, with the notable exception of extreme weather events, will be incremental – small changes over long periods of time. Based on current climate change projections for Canada, mining operations that are active or that are being planned or constructed today will be able to adapt, through changes in management practices or modest capital investments, to the impacts of these incremental environmental changes on ARD-related activities and infrastructure over the next 25 to 30 years. This observation is based on our view that during the operation phase of these mines, changes in the environmental parameters (temperature, precipitation, permafrost) that inform the design of key structures relevant to ARD (i.e. covers, dams, treatment systems, and other water management structures) will not change sufficiently to increase ARD to such levels that make prevention uneconomical.

Closure – Impact on Activities and Infrastructure

- Of greater concern are the impacts of climate change on post-closure infrastructure required for the long-term or 'perpetual' storage and containment of tailings and other contaminants. These impacts add to the existing policy and technical challenges of ensuring the long-term integrity of post-closure infrastructure, including tailings covers and dams.
- Most types of covers (water, store and release, permafrost, geo-synthetic), are vulnerable to climate change to various extents due to the direct effects of warmer temperature (permafrost degradation, increased evapotranspiration) and/or increased precipitation (increased erosion, higher infiltration). Geo-synthetics are the least susceptible to the direct effects of climate change. Based on our analysis, climate change could result in more water infiltration for both store and release and permafrost covers resulting in the flushing of contaminants (ARD) into

the receiving environment.

- Based on this analysis, the scenario with the greatest cost impact for mining operations involves the decision to use a geo-synthetic cover instead of a more conventional soil cover to avoid potential impacts due to climate change. The magnitude of this cost increase would depend on the size of the mine and the relative size of the impoundment. Based on an analysis of the net present value of a hypothetical copper mine in Canada, the incremental cost of adaptation could represent on the order of a 20% reduction in NPV. This analysis does not indicate that this change in technology alone would necessarily undermine the financial case for developing the mine, but smaller mines may be more sensitive to such changes.
- Cost and risk implications will vary depending on how this vulnerability of covers is addressed. If the selected cover design is poorly adapted to climate change, other and more expensive remedial measures, such as perpetual water treatment, may need to be implemented. Depending on the mine closure framework and other circumstances (e.g. how long after closure the vulnerability or impacts is discovered), these costs may ultimately be borne by society. The increased likelihood of this scenario, or perceptions thereof, may present a risk to a mining proponent’s license to operate, especially in jurisdictions where there is already concern about, or a policy against, closure plans that involve perpetual water treatment.
- For mines located near the southern boundary of the permafrost zone, or in other areas where significant permafrost degradation is projected, the design of permafrost covers, or the decision to use permafrost cover, should be informed by thermal analysis that takes future climate change scenarios into account. It is important to note that while northern mines may experience more climate change impacts that other mines in Canada, engineering practice in cold climates is already factoring in climate change into designs. However, mines that were closed before these practices were adopted are more likely to be at risk.

Climate change impacts on the ARD Process

- Temperature has a direct effect on the rate of abiotic and bacterially mediated sulphide oxidation. As a general rule, reaction rates approximately double for every 10°C increase in temperature (INAP, 2011). However, the actual reaction rate will depend on a range of factors.
- Based on the temperature increases anticipated for the timeframe considered in this study (2.5°C to 3.5°C), the impacts of increased temperature on sulphide oxidation rates is not anticipated to have a significant impact on a mine during operation. Where ARD is treated, more treatment reagents may be required but this change is not expected to represent a large increase in operating costs or to undermine the business case for the mine. It is recognized that significant changes in treatment requirements could also result in the need for additional infrastructure, such as a larger sludge storage facility.
- Similarly, following closure, an increase in the sulphide oxidation rate may lead to an increase in long-term treatment costs. However, this impact is estimated to be less than other potential impacts of climate change (e.g. tailings cover failure) and non-climate related factors that could lead to a change in approach in managing the site.
- Others have reported that there are still gaps in understanding of how cold temperatures, ice, and permafrost degradation affect acid generation and dynamics of acid generating potential (Stratos, 2009). MEND Report 1.61.6 (SRK, 2006) reported that limited research has been completed on the effect of low temperature on the performance of mine waste management facilities and recommended that more research in this area be conducted.

Mining companies and regulators are encouraged to incorporate the potential impacts of climate change on their designs and requirements related to ARD. Based on this assessment, reclamation cover design is a priority risk area with potentially significant impacts on closure costs. Water management during extreme precipitation events (in both operation and closure phases) is also an area of risk, based on the potential for shutdowns (loss of production) and/or emergency releases.

To better understand and quantify the potential impacts for a specific mining operation, these risks should be explored using appropriate risk management and financial analysis tools with mine-specific technical and financial information and regional-scale climate change projections. ARD-related infrastructure can then be adapted pro-actively where it matters most in terms of the financial performance of the mine, protecting the environment, and minimizing future liabilities.

Many organizations may postpone action to adapt their businesses and management activities to the changing climate because of uncertainties about future climatic conditions. However, planning horizons for mine closure align with (or go beyond) the 2050s time horizon for which modelled results are not very divergent – that is, different scenarios and models project similar results for this time horizon (ICLR, 2011). It is hoped that the risk areas highlighted in this assessment, when examined in a mine specific context with regional climate change projections, will assist in demystifying climate change to permit initiation of pro-active adaptation measures.

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Appendix A – Review of Key Reports on Climate Change Impacts and Impacts on the Mining Sector

DAVID SUZUKI FOUNDATION, "CLIMATE CHANGE AND CANADIAN MINING: OPPORTUNITIES FOR ADAPTATION", 2009.

The David Suzuki Foundation (DSF) report *Climate Change and Canadian Mining: Opportunities for Adaptation* describes the vulnerability of the Canadian mining industry to climate change and highlights opportunities for adaptation. The report features an extensive literature review, two surveys of mining practitioners (one by the Prospectors and Developers Association of Canada (PDAC) and another cross-Canada survey) and six in-depth mine site case studies. The research was guided by a vulnerability assessment framework and involved mining operations dealing with metallic and non-metallic minerals, including coal and diamonds, but excluding oil and gas.

The following summary of findings and conclusions focuses on those most relevant to climate change impacts on ARD.

Key conclusions and recommendations from the report are outlined below.

1. The mining sector is sensitive to climatic hazards and more particularly to extreme weather events, permafrost thaw and changing water levels. Stresses related to changes in temperature, precipitation, extreme weather and storms have affected mining infrastructure and operations in the past, and continue to do so today. Both the PDAC and the cross-Canada surveys have highlighted that the mining sector is sensitive to climatic hazards, and more particularly to snowfall, ice conditions, extreme cold and forest fires. Permafrost thaw, rising average temperatures, stronger winds, changing water levels and greater intensity and frequency of precipitation will also affect the mining sector. However, climate change impacts and sensitivities vary by regions.

The mine site case studies stress that the majority of mine sites have been designed to operate effectively within particular climatic parameters and to manage events of a certain recurrence interval (e.g. 1 in 50 year storm events). However, climatic events that exceed mine design sometimes occur and have had dramatic consequences. These events are expected to become more intense and frequent with climate change.

2. Climate change poses a number of risks to mining operations such as tailings management, mine site drainage and site hydrology. In northern regions, frozen waste rock piles and tailings retention structures could lose their integrity over time if warming temperatures are not managed properly. In all regions of Canada, mine site drainage and hydrologic regimes could also be affected by climate change. Depending on the region, more frequent 'extreme' weather events could unleash large amounts of precipitation in relatively short periods of time, evaporation trends may be altered and drought could ensue, and the timing of expected seasonal events could change. This could have implications for tailings management, dust suppression, flooding, and water use needs on site. In addition, water scarcity can impact mine drainage composition and the covering of tailing ponds, amongst other issues.

Table A1, below, summarizes key exposure sensitivities in relation to specific mining aspects.

TableA1: Exposure-Sensitivities within the Mining Sector

Aspect	Exposure/Risk
Containment Facilities (Tailings)	• Warmer average temperatures leading to acid mine drainage • Altered freeze-thaw cycles exposing previously frozen tailings • Water scarcity limiting tailing pond covering options • High intensity precipitation causing saturation of tailings impoundment, overtopping, and erosion leading to risk of failure. • Wind and wave action of extreme weather events causing re-suspension of tailings and formation of ice dams
Mine Site Geography	• Erosion induced by greater frequency and intensity of precipitation and/or permafrost thaw of slopes, berms, and mine pit walls. • Rising average temperatures and extreme weather events (wind storms) damage Northern snow fences protecting tailing ponds from oxidation and re-suspension

Source: Adapted from David Suzuki Foundation, "Climate Change and Canadian Mining: Opportunities for Adaptation", August 2009, p.21-25.

3. Significant vulnerabilities may exist in the mine post-operational phase: Most current mines have a relatively short life span and are not expected to be operating when the most severe effects of climate change manifest themselves in the future. From an operational standpoint, these mines do not necessarily need to be designed to accommodate changing climatic conditions for the near term. However, climate change could present potentially serious risks for mines in the post-operational and closure stages.

4. Barriers to adaptation include cost and uncertainty. Respondents to the PDAC survey identified cost and uncertainty as the most common barriers to adaptation. Cost is particularly an issue for smaller operations. Other barriers identified in the literature review include lack of technical information, high capital costs, configuration of current operations, competitive pressures, perception of risk among senior management and existing industry regulations. The David Suzuki Foundation report points out that a thorough evaluation of the organizational barriers faced by mining companies in regards to climate change adaptation, such as employee attitudes, poor communications, past practice and inadequate top management leadership, has yet to be undertaken. In fact, most adaptations are currently reactive and ad hoc in nature.

5. Poor understanding of anticipated trends exacerbates vulnerability: The report highlights that there is considerable dissonance between the message about future climate change and its implications delivered by scientists, and awareness of predicted trends by many in the mining industry. Mining sector representatives generally acknowledge that the climate is changing, but the nature of possible changes and their probable impact on the sector are not well understood by them. The cross-Canada survey outlined that knowledge of climate change (nature, magnitude and speed of changes) is generally low amongst mining sector practitioners. Practitioners further identified a need for more information on projections of climate change, adaptation options and climate change impacts.

6. Long-term adaptation planning is largely not occurring in the mining sector. The report stresses that long-term adaptation planning, that is planning that considers present and projected future climate change impacts, is not currently occurring throughout the mining sector, which is probably a consequence of climate change being considered a minor risk to mining operations. Regulatory processes such as environmental impact assessment have increasingly required the potential impacts of climate change to be considered in mine planning, and some mine designers have included climate change parameters into their plans. Pro-active adaptation planning, however, is currently limited to only a select few mining operations and there are as yet no clear, generally agreed upon guidelines for how to undertake critical tasks, such as interpreting a range of climate change scenarios and model outputs and factoring them into infrastructure and closure design.

Mine Site Case Studies

The David Suzuki Foundation report features in-depth case studies to document climate change risks, opportunities and adaptation strategies for the mining industry in Canada. The case studies containing information relevant to risks related to ARD include:

1. Base metal and gold mining in Northeastern Ontario
2. Diamond mining in the Northwest Territories
3. Voisey's Bay nickel-copper mine in Nunatsiavut, Labrador
4. Mining in the Yukon Territory

The table below presents a summary of the key findings of these six case studies with regards to climatic impacts related to water management, tailings, acid drainage and extreme weather.

Table A2: Summary of Key Exposure-Sensitivities, Adaptations and Vulnerabilities across Select Case Studies

Case study	Exposure-Sensitivities	Current Adaptations	Key Remaining Vulnerabilities
1. Northeastern Ontario	• Changing climatic norms (e.g. precipitation, temperature) • Extreme weather events	• Reactive responses to damage caused by extreme weather have prevailed • Numerous mining research initiatives exist in Northeastern Ontario, focusing on a variety of relevant topics (e.g. mine engineering, environmental sustainability) • Climate change is increasingly becoming a topic of discussion for the sector (e.g. at conferences, amongst mining practitioners)	• Extreme precipitation and snow melting events could lead to flooding, release of contaminants and failure of impoundment structures and transport infrastructure • Abandoned mine infrastructure may need to be retrofitted for climate change • Lack of long-term planning for the impacts of climate change by the mining sector • New technologies to combat the impacts of climate change needed • Limited climate modeling data • Continued reliance on permafrost in the design of retention facilities
2. NWT	• Changing climatic norms (e.g. precipitation, temperature) • Melting permafrost • Extreme weather events	• A number of technologies/strategies exist to combat the effects of climate change (e.g. thermosyphons, modifying tailings cover) • Long term climate change adaptation planning has been done by some mining sector practitioners	• Limited long-term planning for the impacts of climate change by the mining sector • Frozen core water and tailings retention structures could lose their structural integrity due to warming • Extreme weather increases susceptibility of infrastructure to damage • Drainage and hydrologic regimes could be affected. Flooding and erosion could result. • Accurate climate modeling data does not yet exist • New mines and mine closure and reclamation planning will need to consider climate change. Structures could become increasingly vulnerable if changing climate parameters are not accounted for
3. Voisey's Bay	• Severe snow storms lead to mine closures • High intensity rainfall could stress surface water management system	• Water containment system designed for the 1 in a 100 year storm or the 1 in a 25 year storm • Culverts and roads at the mine site have been designed to manage current rainfall patterns • Mine infrastructure has been designed to withstand extreme cold temperatures	• Projected increases in the frequency and magnitude of extreme weather events could affect mine operations by further restricting air transportation to the mine. • Water containment systems may be compromised if 1 in 25 year and 1 in a 100 year storm events become more frequent
4. Yukon	• Increased snowfall • Earlier/increased run-off • Increased variability and unpredictable conditions	• Construction on gravel pads; use of thermosyphons • Removal of permafrost under infrastructure/heap locations to fore-stall impact of future melt	• Extreme precipitation leads to potential overflow of holding ponds • Access road erosion • Highway system vulnerable to permafrost degradation; slope instability; wash-outs

Case study	Exposure-Sensitivities	Current Adaptations	Key Remaining Vulnerabilities
	• Increased annual temperatures; change in “shoulder seasons” when rivers freeze and thaw • Permafrost degradation	• Flood protection measures (e.g. dike around Dawson City) • More vigilant climate monitoring • “Adaptive management”—anticipating events and responding when they occur • Increased pre-project bonding for de-commissioning costs • New mines considering future climate in planning	• Relict closed mines and associated waste and spoilheaps potentially affected by increased precipitation and permafrost degradation • Still relatively little known about climate future in region

Source: Adapted from David Suzuki Foundation, “Climate Change and Canadian Mining: Opportunities for Adaptation”, August 2009, p.62-65.

Survey of Mining Practitioners – Climate Change Impacts of Greatest Concern

The report presented the results of a cross-Canada survey administered in summer 2008 to 62 randomly selected mining practitioners working 'on the ground' at mine sites across the country.

When asked which aspects of company operations are most likely to be affected by climate change, respondent identified the following priority areas (60% (n=37) of respondents answered this question):

- The most commonly identified problem concerned transportation, with 38% concerned about impacts on transportation networks for export, and 41% concerned about on-site transportation.
- 43% of respondents were concerned about impacts on processing
- 30% of respondents were concerned about activity timing; and
- 24% were concerned about mine drainage.

NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY, "DEGREES OF CHANGE: CLIMATE WARMING AND THE STAKES FOR CANADA", 2010.

This report explains the implications of a changing climate for Canada and Canadians. It is the second report in the *Climate Prosperity* series by the National Round Table on the Environment and the Economy (NRTEE) on the economic risks and opportunities to Canada of climate change.

The impacts described in the report focused more on broad economic implications of natural resource sectors rather than on site-level environmental or operational risks. None of the implications for the mining sector were explicitly related to ARD. Key points from the report for the mining industry are as follows:

- Reduced seasonal water supplies and increased demands over the next several decades could enhance competition among water users and lead to conflict in some basins.
- A changing climate alters accessibility to the oil, gas, and mineral resource potential of Canada's North and to enhanced navigation options through increasingly open Arctic waters. However, the report points out that other elements such as operational costs in a changing climate — such as the need to shut down operations due to more frequent and intense storms — demand from global markets, environmental protection requirements, regulatory barriers, provisions for equitable distribution of resource revenues, among others, also influence the viability of new projects.

NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY, "TRUE NORTH: ADAPTING INFRASTRUCTURE TO CLIMATE CHANGE IN NORTHERN CANADA", 2009.

The purpose of this report was to raise the profile and hence, the urgency of dealing with climate change adaptation in Canada's North, and to provide immediate and longer-term advice to governments at all levels on adapting northern infrastructure — through the application of known risk-based mechanisms — to become more resilient and less vulnerable to climate change.

In terms of climate change impacts in the north, the report states the following general projections for the 2050 time horizon:

- Mean annual temperature increases of 2 to 9°C

- Mean annual precipitation increases of 0 to 20%
- More intense precipitation events, and fewer moderate and low-intensity events.
- Warming and thawing of permafrost (area and depth) and disappearance of permafrost at southern margins.
- About half of Canada’s permafrost zones are moderately or highly sensitive to thawing in warmer climate conditions, terrain with high water content being particularly susceptible to collapse if disturbed.

In terms of risks to the mining sectors, the following areas were identified:

- Supply chain disruptions related to reduced winter road availability
- Risk of release of contamination from waste rock and tailings due to containment structures being compromised by permafrost melting and ground instability
- Operational risks from changing patterns of severe weather
- New deep port (Bathurst Inlet) and related gravel road network could present growth opportunities (as could other changes in marine and river shipping routes).

The report emphasized that the risks to containment structures due to permafrost degradation are greatest for mines that have already closed, where there is less flexibility in managing them. The report cites a 2008 report by Engineers Canada on ten thermosyphon systems in NWT, which found that these systems are likely to be resilient in the near-term contingent on proper maintenance and monitoring, as well as rates of climate change. It was also noted that Canada (at the time of the report’s publication, 2009) lacks formal guidance on the application or maintenance of thermosyphons.

The report cites two studies on the costs of adaptation for Canadian infrastructure. One study estimates that climate change would add 10 to 20% to the infrastructure operating budgets through 2080, but that integrating climate change into infrastructure planning today could reduce costs up to 13% between now and 2030, and by as much as 45 per cent between now and 2080. The other study, which focused on the potential impacts of permafrost degradation on building foundations between now and 2069, found that proactive adaptation could result in savings of up to 70% compared to non-adaptation scenarios. Both studies focused on residential and public infrastructure and neither looked potential costs and saving for the mining sector.

The report also highlights the gap in the availability and accessibility of data and information to inform the establishment and application of new ‘climate design values’ to enable the integration of climate change information into the design, construction, and management of infrastructure, including mining infrastructure.

NATURAL RESOURCES CANADA (NRCAN), “FROM IMPACTS TO ADAPTATION: CANADA IN A CHANGING CLIMATE”, 2008

In 2008, NRCan published this detailed assessment of the impacts of climate change on Canada. Through a primarily regional approach, this assessment discusses current and future risks and opportunities that climate change presents to Canada, with a focus on human and managed systems. It is based on a critical analysis of existing knowledge, drawn from the published scientific and technical literature and from expert knowledge. The report informs the descriptions of climate change impacts described in section 3 of this report.

Notable findings and observations specific to the mining sector include the following:

- Reduced access to northern mining sites using winter roads, necessitating the development of all-season roads and/or water-based transportation systems.
- The stability of waste-rock piles, tailing piles, and tailings-containment impoundments that depend on frozen conditions.
- For recent projects, climate change has been considered in the design phase and such consideration is a requirement of the Canadian environmental assessment process. An example is the design of the frozen-core tailings dams at the Ekati diamond mine in NWT.
- For the Quebec region, increased drought and extreme precipitation were identified as risks for mining infrastructure – specifically the risk of tailings capped with water being exposed, and of contaminated water being released due to overflow of containment facilities. However, it was also noted that these potential impacts are manageable with application of appropriate adaptation measures already practices elsewhere in the sector.

The NRCan assessment describes potential impacts on various natural resource sectors including mining. Key points include:

- Both drought and extreme precipitation impact mining infrastructure
- Tailings ponds with water covers are at risk of overflowing and releasing contaminants when heavy rainfall occurs.
- Increased evaporation from tailings ponds could potentially expose raw tailing to sub-aerial weathering
- Wind erosion of any exposed tailings could contribute to acidification of the watershed
- However, all of the above impacts can be managed by applying appropriate adaptation measures already practiced elsewhere in the mining sector.
- Of greater concern was the potential scarcity of water for mining processes in regions experience drought conditions.

For northern mines, key vulnerabilities included:

- Permafrost degradation could undermine the stability of waste rock piles, tailing piles, and tailings containment impoundments and lead to the release of additional ARD.
- Reduction in the availability of ice roads could necessitate the construction of additional all-season roads or the use of water-based transportation.

NATIONAL ORPHANED/ABANDONED MINES INITIATIVE, “THE POLICY FRAMEWORK IN CANADA FOR MINE CLOSURE AND MANAGEMENT OF LONG-TERM LIABILITIES: A GUIDANCE DOCUMENT”, 2010

The National Orphaned/Abandoned Mines Initiative commissioned a report to provide guidance for mine closure and management of long-term liabilities. The document provides an overview of key policy elements and associated recommendations based on a survey of 17 agencies in Canada and 20 foreign agencies. While the document only briefly mentions climate change, it speaks to a number of policy elements required to effectively avoid or manage the long-term liabilities which are relevant to climate change adaptation.

- The report identifies climate change effects as a potential factor contributing to the environmental risk, which should be considered in the design of closure plans. Changes in precipitation and the frequency and intensity of storm events could have a major impact on

water storage/management facilities.
- Several agencies report that they will not accept properties with ongoing water treatment/ contamination concerns. Only one jurisdiction in Canada, Saskatchewan, has established a process and related regulations and policies to provide an approach for long-term care and monitoring following closure.
- Several of the jurisdictions surveyed do not consider catastrophic events in mine closure planning on a regular basis. Among those that do, none explicitly address climate change. The report recommends, for sites under long-term/perpetual care where there remains the potential for physical environmental failure, that a risk assessment process should be employed to identify potential risks and that contingency/emergency plans should be developed.

CENTRE FOR EXCELLENCE IN MINING INNOVATION (CEMI), "CLIMATE CHANGE IMPACTS ON MINING OPERATIONS AND INFRASTRUCTURE", 2009

In 2009, Stratos conducted a scoping study for the Centre of Excellence in Mining Innovation (CEMI) to provide an overview of current knowledge about climate change and its impacts on mining activities and infrastructure, and to propose a set of research priorities and a potential pool of researchers to foster development of a niche research stream. The study focused primarily on mining in northern Canada, north of the 60^{th} parallel.

Key issues identified in this study include:

- Mines in the North are most at risk because:
    - climate change effects are more pronounced in the North – a phenomenon known as arctic amplification;
    - mining infrastructure often relies on permafrost to ensure structural stability, slope stability, and the containment of contaminants; and
    - power and transportation infrastructure is more limited and therefore more vulnerable to warmer temperatures and extreme weather events.
- There is a need for techniques/approaches for adapting existing structures/systems required for post-mine closure (tailings retention structures, water diversions, erosion control structures)
- Operational impacts may include the need for increased maintenance or modification of structures relying on permafrost.
- Standard approaches are required for assessing acid-generating potential in cold climates as the current gaps in knowledge also impair our ability to assess the effects of warmer temperatures and loss of permafrost on acid generation from tailings and waste rock.
- Standard approaches are needed for integrating Global Circulation Models (GCMs) with local historical data and real-time data input to develop meaningful regional climate projections and to inform engineering analysis
- There is a need for improved/innovative tailings management approaches to address short and long-term climate change impacts, for southern and northern mines.