Developing Climate Change Economic Case Analysis: A Guide to Using the Climate Change Cost-Benefit Analysis Tool

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Ontario Centre for Climate Impacts and Adaptation Resources

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1.0 Introduction

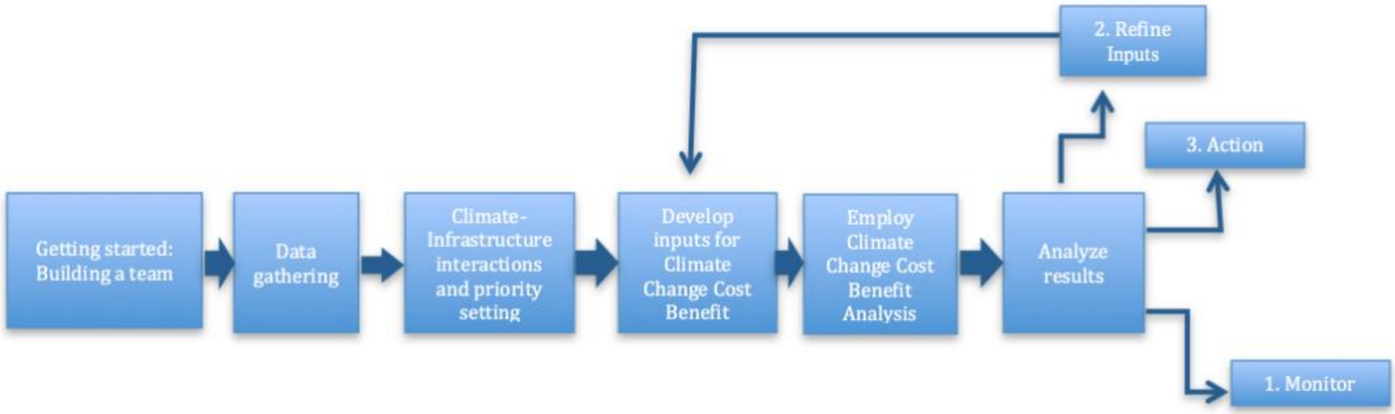
Calculating costs and benefits associated with climate change impacts and adaptation options at a mine site is a difficult task. However, the efforts required to conduct the assessment, including gathering and using climate change data, compiling cost information and calculating benefits, are balanced by the value the results can provide to mine decision-makers: illustrating the potential consequences associated with adaptive action in the face of a particular risk, or identifying optimal adaptive measures to help companies avoid and manage climate risks.

A Cost-Benefit Analysis (CBA) process can be adjusted to assess climate change impacts and adaptation options which define the relationship between climate change impacts and costs for the mine and calculation of the probability of these costs occurring.

Research on the economics of climate change risk management in the Canadian mining sector was conducted to demonstrate how a CBA process could be adjusted to highlight the value of the results for mine decision-makers. A Climate Change Cost Benefit Analysis Tool was developed as a spreadsheet tool, to organize key information including relevant environmental parameters, operational thresholds for the subject mine, and mathematical expressions. The tool was used to calculate the costs of anticipated weather events and the net present value of adaptation options.

This guidebook accompanies the Climate Change Cost Benefit Analysis Tool, providing a detailed description of each step of the cost-benefit analysis (**Fig 1.**). It captures the information and expertise requirements, and explains the approach taken by the researchers. Examples are provided throughout to demonstrate the approach in practice.

Figure 1: Adjusted Cost-Benefit Analysis Approach for Assessment of Climate Change Impacts and Adaptation Options



2.0 Getting Started

The first step in conducting cost-benefit analysis (CBA) for climate change impacts and adaptation options for a mine site is assembling the right team of people based on the required expertise and information. To apply this approach in the economic assessment of climate change on individual mine sites, specific expertise is required, including:

- Expertise in obtaining and managing local climate data;
- Knowledge of specific, local climate risks and vulnerabilities;
- Knowledge of infrastructure thresholds;
- Knowledge of operational management and thresholds;
- Knowledge of specific costs related to operation, coping with climate events and adaptation options; and
- Expertise in modeling and the ability to interpret results.

Engaging management personnel at the very beginning of the process can provide valuable insight into the types of local climate risks and vulnerabilities that were most significant for the site; operational management thresholds; adaptation options under consideration; and key personnel that can be consulted.

Operational staff can provide information on infrastructural thresholds, as well as specific costs relating to the operation, coping measures used to protect the mine from climate-related damage, and avoided costs associated with the implementation of each adaptation option considered in the analysis.

In some cases, staff may possess specialized climate knowledge, however, external expertise (such as Non-governmental organizations, consultants or academic advisors) may be required to provide expertise in obtaining and managing local climate data, or specialized knowledge regarding modeling and interpretation of results.

The make-up of the assessment team may vary depending on site- or location- specific factors, including organizational structure and size of mine site.

3.0 Gathering Data

With the assessment team in place, information can be gathered. There are four types of information that are required for the economic assessment of climate change impacts and adaptation options:

- Local climate data and projections;
- Infrastructural and operational thresholds;
- Cost information including:
    - Direct costs - refers to costs directly triggered by climate (e.g. capital costs related to infrastructural damage caused by a flooding event),
    - Indirect costs - refers to costs that are indirectly related to climate events (e.g. costs related to reputational damage after an overtopping incident),
    - Coping costs – refers to costs related to existing risk management efforts (e.g. costs related to dewatering during rain events), and
    - Adaptation costs – refers to costs related to the implementation and management of adaptation options.
- Benefits related to either climate change impacts (e.g. some mines may experience an increase in locally-available water, reducing the energy required to pump water in to the site) or adaptation options (e.g. avoided damage/costs)

Local Climate Data and Projections of Climate Change

Local, historical climate data provides an understanding of historical climate risks and vulnerabilities. When combined with current cost figures, this data establishes a baseline scenario. Future climate risks and costs can be compared to this baseline scenario to estimate the extent of damage under climate change.

Climate change projections are combined with information on the consequences of climate change impacts to determine climate risk levels occurring under future conditions. When costs are associated with the risks, decision-makers can get a better understanding of the magnitude of future costs related to climate change impacts, and determine whether adaptation measures should be taken.

For site-level cost-benefit analysis higher-resolution climate change projections are preferred over low-resolution ones, as they are better able to account for geographic characteristics that may influence the weather in a region (e.g. mountains or a lake).

Infrastructural and Operational Thresholds

Infrastructural and operational threshold information is used to define climate risks for a mine site. To calculate the future costs associated with the occurrence of these risks, it is necessary to understand the environmental conditions that would result in costs for the mine. Infrastructural thresholds illustrate the magnitude of climate event that individual assets are designed to withstand before experiencing damage or failure. Operational thresholds describe the upper bounds of tolerance for climate impacts.

Using this information, analysts can identify ‘environmental triggers’: the events or environmental conditions that will result in damage/costs for the mine.

Cost Information

Baseline and future costs of climate change impacts and adaptation options can be established by considering four types of costs: direct, indirect, coping and adaptation (**See** above for definitions). Direct and Indirect costs represent the economic effect of climate change impacts on the mine site, while coping and adaptation costs represent the reaction of the mine site to climate conditions.

Considering direct and indirect costs of climate impacts involves the compilation both of costs related to past events, *and* anticipated costs associated with potential future climate impacts. In some cases, anticipated costs may be difficult to estimate (e.g. future wage rates, energy prices etc.). To address this issue, current costs are adjusted using an appropriate inflation rate to estimate future costs.

Calculation of indirect costs, such as damage to transportation infrastructure or reputational decline in the aftermath of negative environmental news, can be difficult to achieve due to the number of assumptions that are required. Examples of such assumptions include extent of damage, level of media attention and speed of infrastructure repair or reclamation activities. In quantifying reputational damage for example, short- and long-term effects of reputational decline should be considered. A recent study of business literature from Deloitte found that stock prices tended to drop significantly within a two-day period following the release of negative environmental news (Flammer, 2011). A drop in support from community, government and society could reduce discount rates relative to the net present value of owned resources from 72% to between 33% and 12% (Henisz et al., 2011). This example demonstrates that indirect costs can be significant and should therefore be considered in CBAs assessing climate change impacts and adaptation options. It also demonstrates that there is a broad range of possible outcomes associated with a climate event. Estimating future costs associated with such an event can be challenging. Additional research may be required to understand the impact on mine operations or the company as a whole.

Table 1: Direct and Indirect Costs to Consider in Economic Analysis of Climate Change Impacts

Direct Costs	**Capital costs**
	Human resources
	Energy
	Additional monitoring/maintenance
	Supplies and Equipment
	Production delay/loss
	Reclamation

Indirect Costs	Supply chain disruption
	Damage to related infrastructure (e.g. transportation routes, energy infrastructure, telecommunication)
	Regulatory (e.g. fines for environmental damage)
	Reputational (e.g. loss in market capitalization)

Considering coping costs is a critical step in establishing an economic baseline. It involves the compilation of costs related to the implementation and maintenance of coping methods currently used to prevent damage caused by climate impacts (e.g. water pumps or berms that are currently being used to reduce the impact of flooding events).

Calculating adaptation costs involves the compilation of anticipated costs related to the implementation and maintenance of selected adaptation options. In most cases, compilation of these costs will involve research to determine the estimated cost requirements (e.g. human resource, energy and maintenance etc.) for each option.

Benefits

The monetary value of adaptation measures is based on the economic theory of willingness to pay[1] as well as a function of costs avoided. Unfortunately, valuation of adaptation measures can be difficult to estimate depending on the nature of associated benefits. For example, it is very difficult to assign value to environmental health and community engagement although they are very real benefits. Similarly, costs avoided can sometimes be contested due to the challenge of anticipating which costs might have occurred in the absence of the adaptation measure.

Using the information gathered, analysts can:

- Define the scope of each case study including the operational theme (e.g. transportation, energy, water management) and environmental parameters (e.g. extreme weather events or long-term temperature increase) (**See** Section 3.1);
- Define the environmental conditions that could trigger costs ("environmental trigger" e.g. greater than a 1 in 100 year rain event) (**See** Section 3.1);
- Compile cost information (**See** Section 5.2);

[1] This economic theory measures the willingness of subjects to pay for the benefits they will likely receive as a result of an action (Boyd et al., 2012).

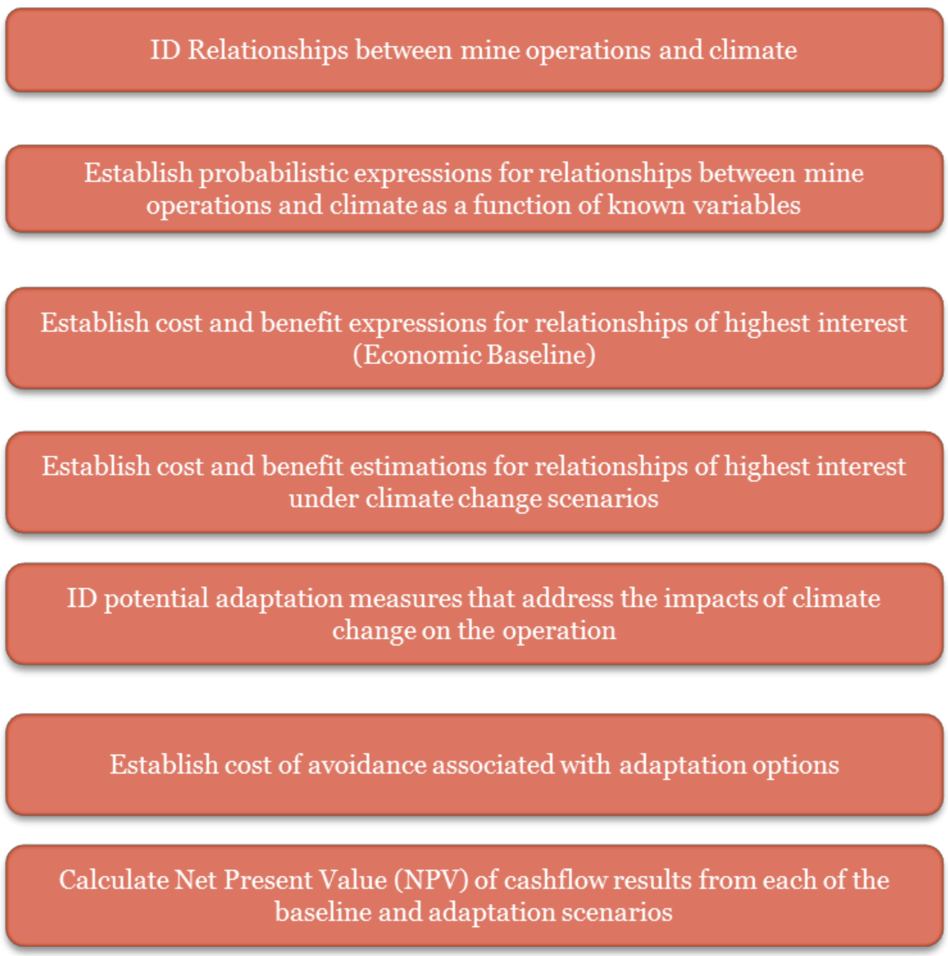
- Identify adaptation options for assessment (**See** Section 6.2);
- Determine inflation and discount rates (**See** Section 3);
- Quantify benefits related to adaptation options (e.g. avoided costs) (**See** Section 6.3); and
- Review CBA results (**See** Section 7).

Given the wide array of highly specific data required for the analysis, it is not uncommon for the data gathering process to be iterative in nature; with new data requests issued during several of the CBA steps

4.0 Climate-Infrastructure Interactions and Setting Priorities

The analysis can be conducted by using the information gathered in the previous steps within the Climate Change Cost Benefit Analysis Tool (**Fig. 2**). The Climate Change Cost Benefit Analysis Tool spreadsheet tool was developed to organize and assess historic and future climate data, as well as the cost and benefit information for use in the cost-benefit analysis.

Figure 2: Steps for employing Climate Change Cost Benefit Analysis Tool



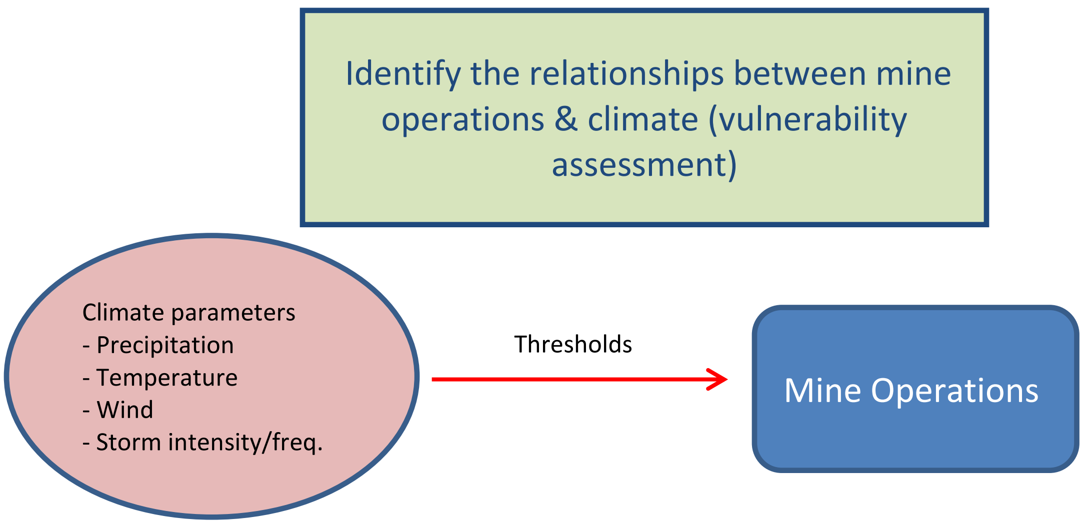
Within the Climate Change Cost Benefit Analysis Tool, the first step is to identify the relationships between mine operations and the climate. This work relies heavily on local climate data, and infrastructure and operational thresholds. In some cases, this work is completed as part of a vulnerability or risk assessment for the mine site. The results of this work will help decision-makers prioritize the mine operations to target in the CBA.

In identifying relationships between mine operations and climate, the first task is to narrowly define the environmental and operations scope of the analysis. This can be achieved by identifying a key theme area within mine operations (e.g. water management, transportation, energy or tailings design and management), and environmental conditions that pose significant risks to operations (e.g. drought, extreme rain, permafrost thaw, extreme wind).

Although operational themes are easy to define, environmental parameters may require further scoping before they can be used in the analysis. Using operations and threshold information, each parameter can be defined in terms of the type or magnitude of event that would trigger costs at the mine site (**Fig. 3**; See Case Studies for specific examples). The narrowly defined conditions are termed ***environmental triggers***. These triggers can be used to calculate costs in the economic baseline and future scenarios under climate change.

Vulnerability assessments and past experience can provide insight into current and future concerns for the operation.

Figure 3: Identifying Climate-Infrastructure Interactions



Environmental Trigger: “If there are 7 consecutive days of more than 10 mm of rain per day, reservoirs will overflow”

5.0 Develop Inputs for Climate Change Cost Benefit Analysis Tool

To perform the analysis, it is necessary to establish probabilistic expressions for the relationships between mine operations and climate using local historic climate data and climate change projections. In addition, cost and benefit expressions are established for the relationships of highest priority.

These inputs will be used to execute the analysis during the next stage.

5.1 Establish probabilistic expressions for relationships between mine operations and climate as a function of known variables

In some cases, significant costs to the operation stem from large-scale extreme events, which are unresolvable at finite spatial and temporal scales. Furthermore, the computational and climate expertise requirements to utilize a regionally downscaled GCM as part of a CBA may not be feasible, requiring significantly more effort and time than can be dedicated to this analysis.

Establishing probabilistic expressions for the relationships between mine operations and climate helps to reduce the uncertainty associated with cost calculations and allows the framework to accommodate varying levels of data resolution, while producing robust results.

To establish probabilistic expressions for the relationships between mine operations and climate, available historical climate data and climate change projections can inform professional judgment in determining the appropriate range of likelihoods (risk "bins") for environmental triggers in each of the examined baseline and future climate scenarios (**Table 1**). Under baseline conditions[2], two factors are considered in the placement of each environmental trigger into risk bins: *historical climate trends* and *analysis of site-specific models* (i.e. a detailed water balance model). Environmental triggers that have been previously observed, or those that have caused significant damage, are assigned to a higher certainty bin. Environmental triggers that have not been previously experienced (e.g. greater than a 1 in 100 -year storm) should still be assumed to have some probability of occurrence.

[2] Where climate conditions are not expected to vary outside of the recorded historical climate

To determine the risk bin categorization under future climate conditions, environmental triggers are compared to future projections. This process enables the revision of risk calculations to reflect the new probabilities associated with each environmental trigger under future climate conditions (**Table 2**).

The risk bin approach featured in the case study analysis mimics the one promoted by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) in their engineering protocol.

Table 2: Risk bin definition

Risk Bin	*General Description*	*Upper Bound Probability*
1	Negligible / Not Applicable	0.001
2	Highly Unlikely / Improbable	0.01
3	Remotely Possible	0.05
4	Possible / Occasional	0.1
5	Somewhat Likely / Normal	0.2
6	Likely / Frequent	0.4
7	Probable / Often	0.7
8	Highly Probable / Approaching Certainty	0.99

Table 3: Risk Bin example comparing risk under baseline and future climate scenarios

Environmental Trigger	*Baseline Climate Scenario*	*Future Climate Scenario*
Significant 24-hr rain event	2	3
Rain on snow event	1	5
Extreme wind event	1	1
Snowstorm	8	8

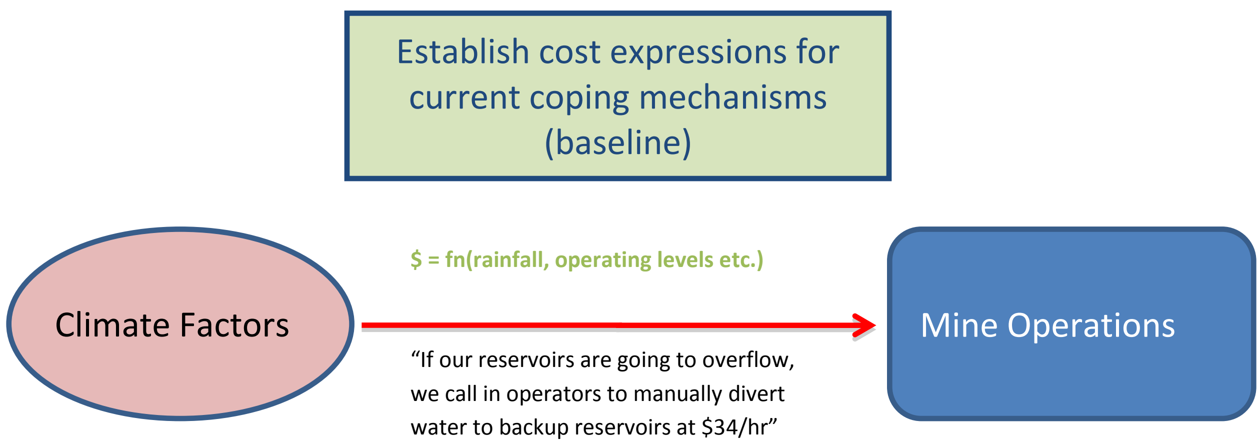
5.2 Establish cost and benefit expressions for relationships of highest interest (Economic Baseline)

Establishing an economic baseline is an important next step in the CBA because it allows for comparison between current and future climate costs and benefits, which informs decision-making on adaptation action. The impact and coping costs and benefits compiled in Step 2, form the economic baseline – the financial impact associated with current climate impacts and the coping measures that have been implemented to reduce climate risk. This dataset is kept separately and used for comparison with future costs.

To complete this stage, mine staff must apply their operational expertise to determine the economic impact they currently experience under current climate conditions. This process included identifying the type of climate events that the site has historically experienced; discussing the extent of damage associated with discrete climate events, and compiling related costs (**Fig. 4**). This process can highlight vulnerable aspects of the mine where future climate events may overwhelm existing coping methods.

Facilitated workshops can be held to build understanding of the requirements associated with the regulatory framework and refine the scenario analysis considered in the CBA. It is important to include members of the operations, maintenance, engineering, environment and management staff to access company knowledge and so that different perspectives can be shared. These workshops can assist the mine site by presenting updates on climate change vulnerability from staff that directly monitor operations and respond to climate events. Workshops may also identify the actions that are currently used to manage climate infrastructure interactions, the costs associated with these actions as well as any avoided costs associated with these coping measures.

Figure 4: Establishing an Economic Baseline



6.0 Employ the Climate Change Cost Benefit Analysis Tool

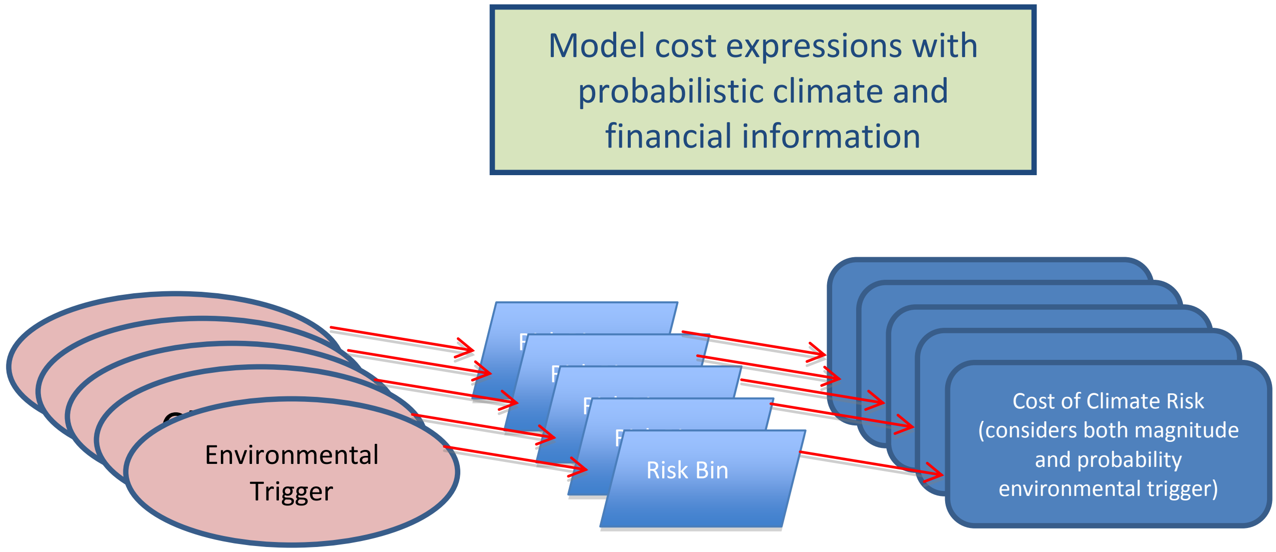
During the last three steps, critical information is gathered, mathematical relationships are established between environmental triggers and infrastructural assets, and costing inputs are developed for use in the Climate Change Cost Benefit Analysis Tool. These materials will be used to inform the analysis as it is conducted.

6.1 Establish cost and benefit estimations for relationships of highest interest under climate change scenarios

The development of risk bins, and the accumulation of cost and benefit information related to the individual environmental triggers have generated the inputs needed to conduct the analysis. Scenario-based simulation (Monte Carlo analysis[3]) can be employed to establish realistic cost and benefit estimations for future environmental triggers under climate change. This process involves testing environmental triggers against future cost impact scenarios to determine the probability of occurrence (**Fig. 5)**. Using scenario-based simulation will result in multiple realizations of a potential future cost scenario based on modeled weather behaviour (GCM and GHG Emissions Scenario variables), and modeled financial behaviour (interest and inflation rate variables). The results of this modeling provide the user with the cost of climate risk, which considers both the risk of the environmental trigger occurring, and future related costs.

[3] Montecarlo analysis builds models of possible results by substituting a range of values – a probability distribution- for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions.

Figure 5: Model cost and benefit estimation for environmental triggers under climate change

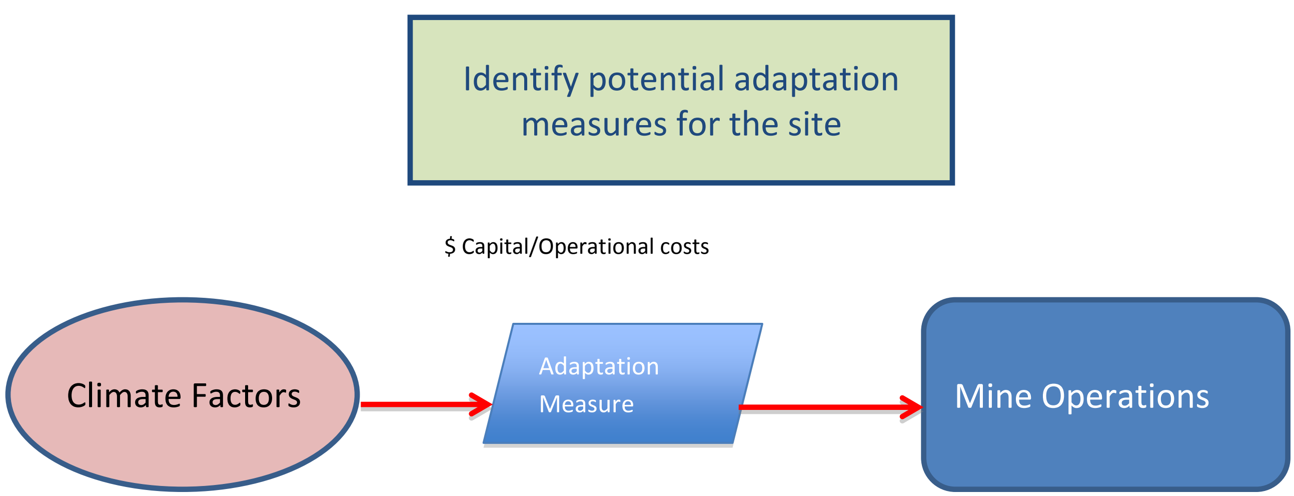


E.g. By 2050, the probability that our reservoirs will overflow due to a 1 in 100-yr storm, imposing $X costs on the mine, is Y, given inflation rate Z.

6.2 Identify potential adaptation measures that address the impacts of climate change on the operation

New risk-reducing measures can now be identified, based on new levels of risk and associated increased costs of impacts. Each adaptation measure should be given a time frame for implementation and a cost, in order to weigh against the costs of impacts/events not adapted to (**Fig. 6**).

Figure 6: Identify adaptation measures to address climate risks for operation



E.g. Upgrading our storm water control measures will allow our reservoirs to withstand a 1 in 100-year event.

6.3 Modify cost and benefit expressions to reflect adaptation measure impacts

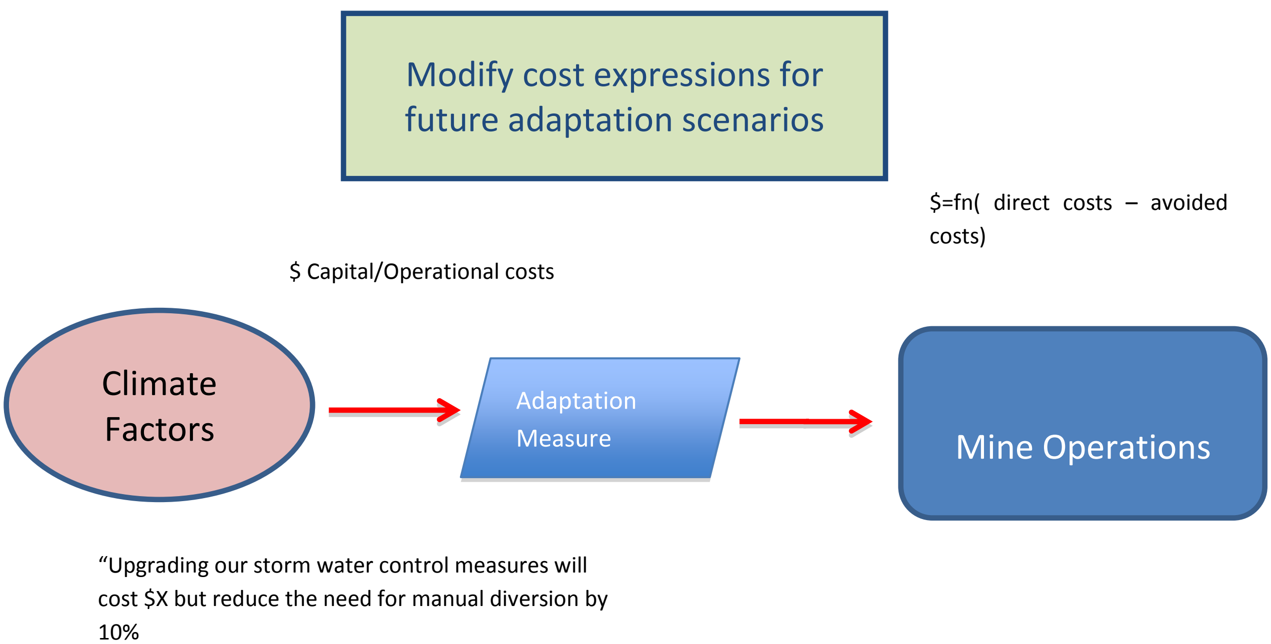
The implementation of any adaptation measure will affect future costs and benefits related to the environmental triggers. For example, if a tailings pond is retrofitted to a higher, more robust design standard, the mine may avoid damage, and associated weather/climate impact costs. To calculate the monetary effect (costs avoided or cost savings) of adaptation measures, it is necessary to understand the level of impact that such measures have on mine operations. Does the implementation of the adaptation measure:

- Prevent the environmental trigger/prevent damage from the environmental trigger?
- Provide greater protection for operations/ reduces level of damage?
- Incorporate redundancy into operations to build resilience?

Based on the level of impact an adaptation measure has on an operation, risk bins can be adjusted to better represent the probability of the environmental trigger occurring. Running the simulated scenarios under these new conditions can help decision-makers to determine the probability of incurring costs with the adaptation measure in place.

The costs of implementing the adaptation measure can then be compared against the benefits (or avoided costs) related to the adaptation measure. Modifying the cost-benefit expressions related to each environmental trigger to reflect the impacts of an adaptation measure allows users to compare the costs and benefits of action to the costs and benefits of inaction (**Fig. 7**).

Figure 7: Modifying cost expressions for future adaptation scenarios



6.4 Calculate Net Present Value (NPV) of cashflow results from each of the baseline and adaptation scenarios

Net Present Value can then be calculated for each adaptation measure. "The NPV of an adaptation action is the algebraic sum of the present values of projected incremental benefits less incremental costs over the action's anticipated life" (Boyd et al., 2012). This process allows for comparison between adaptation options under different implementation dates, benefit time horizons or labour requirements.

Using the costs and benefits data developed for each adaptation action, NPV is calculated using the following equations:

$$NPV = \sum_{t=0}^{n} \frac{NB_t}{(1+r)^t} = \frac{NB_0}{(1+r)^0} + \frac{NB_1}{(1+r)^1} + \cdots + \frac{NB_n}{(1+r)^n}$$

OR

$$NPV = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+r)^t} = \frac{(B_0 - C_0)}{(1+r)^0} + \frac{(B_1 - C_1)}{(1+r)^1} + \cdots + \frac{(B_n - C_n)}{(1+r)^n}$$

Where NB represented incremental net benefit, the difference between incremental benefits (B_t) and costs (C_t) at the beginning of a time period (t).An established discount rate (r) was applied to incremental net benefits.

Calculating NPV for each of the adaptation scenarios highlights the cost differences between a business-as-usual, non-adaptation approach and measures taken to manage climate risk. The calculation also yields information about time-varied benefits of the investment in adaptation.

7.0 Use of Analysis Results

The Climate Change Cost Benefit Analysis Tool approach generates valuable analysis that can answer the critical questions of what, why, when, and how to adapt to expected climate changes at a mine site.

What: The early focus on scoping the project and defining the environmental and operational parameters encourages decision-makers to actively review their climate vulnerability and prioritize areas for analysis and action.

Why: At the simplest level, the use of climate change projections and the definition of environmental triggers can help decision-makers to better understand the scale of climate change impact their operations may face, as well as their organizational adaptive capacity. Quantification of benefits related to proposed adaptation options provides additional incentive for action as decision-makers can calculate the cost saving that can be achieved by taking adaptive action.

When: The Climate Change Cost Benefit Analysis Tool approach models defined environmental triggering events to determine the probability that they will occur in the future. This modeling exercise can help decision-makers determine whether investment in adaptation is required immediately or whether it can be delayed; and can provide probability ranges for the likelihood of environmental triggers occurring during defined time horizons. Decision-makers can use that information to determine the optimal time for investment.

How: Significant value is attached to the fact that Climate Change Cost Benefit Analysis Tool results can assist decision-makers in determining *how* to address climate change impacts on their operations. In particular, there are three key pieces of data that are generated for each environmental trigger assessed: climate risk costs, coping costs and adaptation costs. This information can be used to determine the economic feasibility of proposed adaptation measures.

Climate risk costs

Modeling cost expressions with probabilistic climate and financial information develops the cost of climate risk. This output measures three important factors, namely, the magnitude of an environmental trigger, the probability that it will occur under future climate conditions, and the costs associated with its occurrence. As such it is of primary importance for decision-makers, as it can express the probabilistic range of economic risks that mine sites may face under a changing climate.

As risk management is a central tenet of business, this output is easily understood and used by decision-makers. Climate risk costs are expressed as a range of probable costs (e.g. There is a 40% chance that the Sweeney mine site will experience costs between $4million and $10million by 2030 due to an overtopping event caused by a 1 in 100-yr rainfall event).

Coping Costs
As explained in **Section 2**, coping cost refers to the compilation of costs related to current coping methods and therefore demonstrates the economic impact of environmental triggers on present mine operations. Coping costs are expressed as dollar figures.

Adaptation Costs
As explained in **Section** 2, adaptation cost refers to the compilation of anticipated costs related to the implementation and maintenance of selected adaptation options. Using a benefit-cost ratio, it is possible to compare the assessed options and select the adaptation measure that offers the highest benefit when compared to the associated cost. Adaptation costs are expressed as dollar figures.
These three outputs work together to indicate desirability of adaptation measure and optimal time to invest. When interpreting the results from the Climate Change Cost Benefit Analysis Tool analysis, it may be helpful to consider the following risk matrix (**Fig. 7**). The diagram below captures three possible scenarios and explains how climate risk costs, coping costs and adaptation costs can inform decision-making.

1) Climate Change Cost Benefit Analysis Tool results:

- Low coping costs,
- High adaptation costs, and
- Low climate risk costs

In this scenario, the mine site can choose to take **no action**, given the relatively low level of risk involved. It is recommended in these scenarios that mine sites maintain regular monitoring so as to maximize their preparedness levels.

2) Climate Change Cost Benefit Analysis Tool results:

- Medium coping costs,
- Medium – High adaptation costs, and
- Medium climate risk costs,

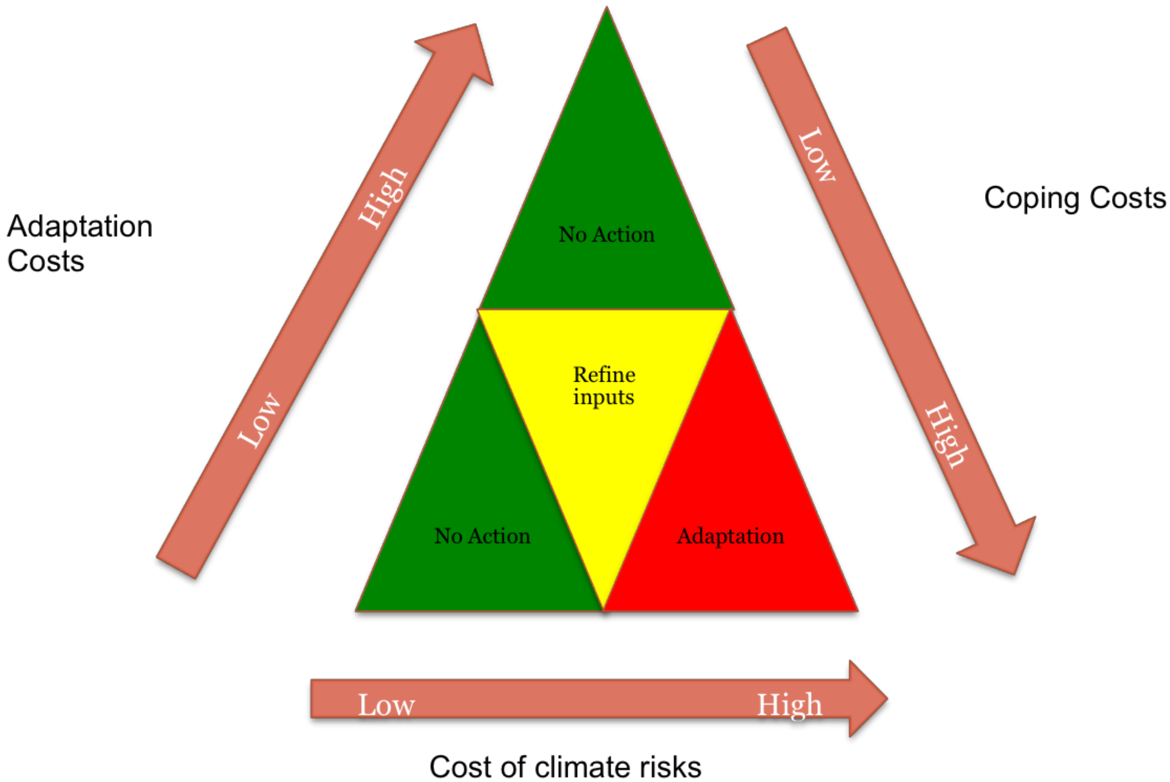
In this scenario, the mine site can choose to **refine** their cost, benefit and climate data inputs to narrow the scope of the analysis to better capture climate risks to the operation. Additional studies may be required to adjust proposed adaptation measures or to better understand operational vulnerability.

3) Climate Change Cost Benefit Analysis Tool results:

- High coping costs,
- Low adaptation costs, and
- High climate risk costs

In this scenario, the mine site can choose to **adapt**, as the costs they face in implementing and maintaining adaptation measures will be offset by the benefit they will realize from avoided climate risk and coping costs. Additional engineering analyses may be undertaken to provide decision-makers with a more detailed understanding of the impact the adaptation measure will have on mine operations.

Figure 8: Interpretation of Climate Change Cost Benefit Analysis Tool results



8.0 Conclusions

The purpose of this guidebook is to assist mine decision-makers in using the Climate Change Cost Benefit Analysis Tool to assess the costs and benefits related to climate change impacts and adaptation options. The guidebook presented six steps that practitioners may follow to complete this type of analysis.

Although economic assessment can be approached in many ways, the key elements of the Climate Change Cost Benefit Analysis Tool include:

- Identify the relationships between mine operations & climate (vulnerability assessment)
- Establish probabilistic expressions for relationships between mine operations and climate as a function of known variables
- Establish cost and benefit expressions for relationships of highest interest (Economic Baseline)
- Establish cost and benefit estimations for relationships of highest interest under climate change scenarios
- Identify potential adaptation measures that address the impacts of climate change on the operation
- Modify cost and benefit expressions to reflect adaptation measure impacts; and
- Calculate Net Present Value (NPV) of cashflow results from each of the baseline and adaptation scenarios

Each mine site is unique in its climate change vulnerability and adaptive capacity. In addition, geographic, environmental, economic and social considerations may vary from case to case. Therefore the specific content and results derived from the Climate Change Cost Benefit Analysis Tool (e.g. cost and benefit expressions, discount rate etc.) will be exclusively meaningful to the practitioner that performed the analysis. However, the approach presented in this guidebook provides a solid base for cost-benefit analysis in the context of climate change impacts and adaptation.

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