10 TERRESTRIAL RESOURCES

10.1 SCOPE OF ASSESSMENT

10.1.1 Terms of Reference

The Terrestrial Resources section provides information required in the Terms of Reference

The Terrestrial Resources section of the environmental assessment (EA) for the De Beers Canada Mining Inc. (De Beers) Snap Lake Diamond Project provides information required by the Mackenzie Valley Environmental Impact Review Board (MVEIRB) in the Terms of Reference. The Terrestrial Resources section specifically addresses the Terms of Reference shown in Table 10.1-1. Topics listed in Sections 2.5.2, 2.6.2, 2.6.3, and 2.6.6 that are addressed in other sections are not included in Table 10.1-1. The entire Terms of Reference may be found in Appendix I.2.

Table 10.1-1 Terms of Reference for Terrestrial Resources

TOR Section	Environmental Assessment or Topic
2.5.2	**Description of the Existing Environment** De Beers shall provide a brief and clear textual and graphic depiction of the existing environment and its use, as it pertains to the potential impacts of the proposed development. The existing environment includes the resources being extracted over the predicted life of the mine . . . All existing reports and documents shall be appropriately referenced. De Beers will be expected to clearly and succinctly describe the following environmental components, as they relate to the proposed development: IV. wildlife and wildlife habitat, including migratory birds; V. vegetation and plant communities; VI. terrain, surficial geology, bedrock geology, seismicity, geological hazards, permafrost, soils…; VII. structural geology
2.6.1	**Air Quality and Climate** The analysis should also include: III. acid deposition and impact of the acidic precipitation resulting from release of gasses such as NO_X and So_X; and IV. impact on biological receptors such as vegetation and wildlife;
2.6.2	**Terrain** The environmental assessment shall provide a detailed description of the ground and permafrost conditions at the site including a description of surface materials and geology, ground ice content, a description of permafrost configuration including the frozen/unfrozen interfaces in the underground portion of the mine. Report the impacts on the environment when surficial geology, bedrock or soils are disturbed or used for construction purposes. The analysis shall include: I. the proposed development’s impact on the thermal milieu, including: a. impact on permafrost physical conditions (including physical strength characteristics) and thermal regime; b. impact of modified permafrost temperatures and ground ice conditions underground in the mine and above ground on roadway, waste rock piles, etc.;

Table 10.1-1 Terms of Reference for Terrestrial Resources (continued)

TOR Section	Environmental Assessment or Topic
2.6.2 (cont)	c. impact of thermal erosion in relation to altered drainage; d. impact of ice wedge occurrences and beneath containment structures; e. impact of frost heave; f. impact of the water content contained in the processed kimberlite deposited in the north pile and the potential for pore-water expulsion during freeze back of the pile; and, g. the impact of climate change on the above. II. impacts of aggregate use including limitations on volumes of resource material and minimization of terrain disturbance associated with ground ice thaw; IV. seismicity and potential for rock heave; VIII. impact of quarry development at esker including gravel, sediment, overburden and aggregate use; Report the impacts on the environment of the esker quarry south of the minesite. Include information on the timing and amounts of material required over the life of the diamond mine, the size of the esker, extractable quantities, and a quarry management plan suitable for environmental assessment purposes.
2.6.3	**Vegetation and Plant Communities** The EAR should analyze impacts of the proposed development on: I. local plant communities (classified as vegetation cover types); II. rare or highly valued species; III. long-term, direct and indirect, habitat loss or alteration; and IV. vegetation productivity.
2.6.4	**Water Quality and Quantity** III.b. De Beers shall provide a description of the predicted impacts of releases of any effluents, surface runoff and seepages that may be directed to land (include consideration of surface ponding), with particular attention to impact linkages on vegetation, soil and wildlife. Ensure that criteria used to predict impacts are explicit and precautionary. IV. impact of treated sewage flows to associated wetlands and downstream waters;
2.6.6	**Wildlife and Wildlife Habitat** The environmental assessment report should provide an analysis of the proposed development's impacts, (both direct and indirect), on wildlife and wildlife habitats, including migratory birds, giving consideration to and demonstrating linkages between predicted physical and biological changes resulting from the proposed development De Beers shall also give special consideration to species identified in COSEWIC's listing as "Endangered," "Threatened" and of "Special Concern." The analysis of development should include: I. impact of loss of terrestrial habitat, and the quality of lost habitat for relevant species; II. disturbance of feeding, nesting, denning or breeding habitats; III. wet-land habitat alteration, loss; IV. physical barriers to wildlife; V. disruption, blockage, impediment and sensory disturbance, of daily or seasonal wildlife movements (e.g., migration, home ranges, etc.); VI. rare, vulnerable, threatened or endangered species as outlined in the Canadian Organization of the Status of Endangered Wildlife in Canada (COSEWIC), as well as, species of international significance; VII. direct wildlife mortality; VIII. indirect wildlife mortality; IX. reduction in wildlife productivity; and X. implications of the proposed development acting as an attractant for particular species.

Table 10.1-1 Terms of Reference for Terrestrial Resources (continued)

TOR Section	Environmental Assessment or Topic
2.8	**The Effect(s) of the Environment on the Proposed Development** De Beers should assess the effect(s) of the environment on the proposed development, and activities forming part of the proposed development. De Beers should consider the full range of climate conditions including extreme weather events, wet, dry and normal precipitation and extreme temperature spells) and climate change (e.g. global warming scenarios). The discussion must specifically describe and assess how the potential for climate change, and extremes in current climate could affect permafrost and soils with high ice content in relation to the integrity of the proposed development infrastructure, particularly the tailings (processed kimberlite) containment impoundment, water retention dikes, the winter road and waste rock piles.

Source: Terms of Reference and Work Plan for the Environmental Assessment of the De Beers Canada Mining Inc. Snap Lake Diamond Project, September 20, 2001. Issued by: Mackenzie Valley Environmental Impact Review Board (MVEIRB).

10.1.2 Component Description and Organization

Terrestrial Resources includes three subsections

To address the EA Terms of Reference, the terrestrial resources section has been subdivided into the following three subsections:

- geology and terrain;
- ecological land classification (ELC) and biodiversity; and,
- wildlife.

Each subsection is divided into the baseline and impact assessment

Each subsection of Terrestrial Resources is organized under two main headings:

- baseline (*i.e.*, pre-development); and,
- impact assessment.

Ecological land classification approach is used in all three subsections

The ELC approach recommended by the Department of Resources, Wildlife and Economic Development (RWED) has been used as the basis for parts of terrain, biodiversity, ELC, and wildlife habitat. The ELC approach integrates terrain and vegetation attributes into discrete ecological units. It is a quantitative method that provides a standardized systematic approach that is being used elsewhere in the Northwest Territories (NWT). By using the RWED system, data presented in the baseline and impact assessments of the three subsections are comparable to data gathered elsewhere.

Cumulative effects in Section 12

The cumulative impact of the Snap Lake Diamond Project on terrestrial resources is presented separately in Section 12 as part of a cumulative effects assessment of all impacts.

10.1.3 Assessment Approach

10.1.3.1 Key Issues and Key Questions

Issues derived from a variety of sources initiate the assessment

The assessment process begins with the identification of issues associated with the Snap Lake Diamond Project that are important to the communities that may be affected. Issues were identified by a variety of means including the following:

- EA Terms of Reference;
- traditional knowledge;
- community consultation;
- discussions with territorial and federal regulators;
- scientific literature; and,
- experience of De Beers staff and their consultants.

Related issues are combined to form a question

In most cases, similar issues were identified from a number of sources. Related issues were combined in the form of a question. Key questions were developed for each component of the terrestrial environment (Table 10.1-2). The purpose of the assessment is to answer the key questions.

Table 10.1-2 Key Questions Addressed in the Terrestrial Resources Section

Question Number	Key Question
GT-1	What direct impacts will the Snap Lake Diamond Project have on terrain units in the local study area?
GT-2	What impacts will the Snap Lake Diamond Project quarrying have on the esker?
GT-3	What impacts to the Snap Lake Diamond Project will occur due to the seismic characteristics of the region?
GT-4	What impacts will the Snap Lake Diamond Project have on the ground thermal regime?
GT-5	What impacts will the presence of ground ice have on the stability of containment structures?
GT-6	What impacts will freeze-back of the north pile have on surface water quality?
GT-7	What impacts will climate change have on the development?
ELC-1	What direct impacts will the Snap Lake Diamond Project have on ecological land classification units?
ELC-2	What direct impacts will the Snap Lake Diamond Project have on biodiversity?
ELC-3	What indirect impacts will air emissions from the Snap Lake Diamond Project have on vegetation (ELC unit) health?
ELC-4	What indirect impacts will water releases from the Snap Lake Diamond Project have on vegetation (ELC unit) health?
W-1	What impacts will the Snap Lake Diamond Project have on wildlife habitat?
W-2	What impacts will the Snap Lake Diamond Project have on wildlife movement and behaviour?
W-3	What impacts will the Snap Lake Diamond Project have on wildlife abundance?

10.1.3.2 Impact Assessment

Linkages between project activities and environmental effects are analyzed to determine if they are valid

Once the key questions have been established, the impact analysis examined the ways that the Snap Lake Diamond Project could result in changes to the environment. For a change to occur there has to be a pathway, or linkage, between a project activity and a component of the environment. Section 3, Project Description, and the baseline information in this section were used to determine linkages between specific activities and changes in the environment (*e.g.*, changes in terrain units or wildlife habitat). These changes could, in turn, impact ecosystem components such as caribou. Each section contains a diagram showing these linkages and then analyzes each linkage to determine if it is valid or invalid. It is possible that an issue may have been raised from experience at other projects (*e.g.*, an open pit mine) that will not occur at Snap Lake because there is no linkage. If the linkage is valid, the assessment proceeds.

Impacts that may persist after mitigation are residual impacts

Mitigation measures to minimize potential impacts to the environment are then identified. For some activities, mitigation may eliminate the potential impact. Potential impacts that are likely to persist after mitigation are identified as residual impacts.

Impact analysis is as quantitative as possible

The detailed analysis of impacts is done on the residual impacts. The detailed analysis is as quantitative as possible using databases, statistical analysis, geographic information system (GIS) methods, and modelling, as appropriate. To answer some questions, a more qualitative approach has to be used; then, a review of published literature, field observations, traditional knowledge, and professional judgement are used. Traditional knowledge is incorporated wherever it is available. The predicted residual impacts are presented as tables of estimated quantities (*e.g.*, ha of each habitat type predicted to be lost due to disturbance) if possible. Impacts are analyzed at two scales: local and regional.

The residual impact is classified as magnitude, duration, geographic extent, etc.

In the next section, the residual impact classification, the residual impact is described using criteria such as the magnitude, duration, and geographic extent of the impact. The definitions associated with the criteria (*e.g.*, high, moderate, low or negligible magnitude) are provided in Section 10.1.5. To answer the initial question as succinctly as possible, the overall environmental consequence of the impact is estimated. Environmental consequence is determined by considering criteria representing the key characteristics (*e.g.*, magnitude, geographic extent, duration, and reversibility) together. The probability of occurrence of the impact and the level of confidence in the prediction are provided. The EA does not determine the significance of the impact.

10.1.3.3 Temporal Considerations

Construction Phases

Construction will last three years beginning in 2003 and the project will continue until closure in 2028

The terrestrial resources section assesses the impacts for the construction, operation, closure, and post-closure phases of the project. Assuming that permits for construction and operation have been received during the first quarter of 2003, a limited pre-construction work program will begin in 2003. Full construction will begin in early 2004 and be completed by the end of 2005. The production phase will be approximately 21 years from 2006 to 2026, although pre-production mining from underground development will occur from 2003 to 2005. The site closure activities will be carried out primarily in 2027, with limited final clean-up and the continuation of effectiveness monitoring in 2028. Reclamation and monitoring of the effectiveness of reclamation techniques will occur during the operation phase. The total elapsed duration of the project is 26 years. The proposed schedule for the Snap Lake Diamond Project is provided in more detail in Section 3.2.

10.1.4 Study Area

There is both a local and a regional study area

The impacts of the Snap Lake Diamond Project on terrestrial resources are assessed at two scales. All terrestrial components will use the same two study areas: the regional study area (RSA) and the local study area (LSA).

The regional study area is contained within a 31 km radius

The RSA is defined as the area within a 31 km radius of the centre of the active mine site (Figure 10.1-1). The potential impacts of the winter access road, which will be constructed annually from the Tibbitt-Contwoyto winter road to the mine site, will be assessed within the RSA. The esker access road is also located within the RSA. The Tibbitt-Contwoyto winter road is addressed in Section 12.

The regional study area is based on project-related effects and wildlife species attributes

One RSA will be used for Terrestrial Resources since these resources are closely linked. Many of the terrestrial resources are assessed using ELC units (*e.g.*, terrain, ELC, biodiversity and wildlife habitat); therefore, the ELC unit data (*e.g.*, % open spruce forest) had to be common to all users. The characteristics of the terrain (*e.g.*, extent of rock outcrops) and vegetation (*e.g.*, extent of open spruce forest or eskers) strongly influence wildlife since they represent the habitat, travel corridors and other factors that have direct effects on wildlife abundance and movement. However, the spatial boundaries for wildlife depend on both the extent of project-related effects and the attributes of a given wildlife species, some of which have

Figure 10.1-1 Regional Study Area for Terrestrial Resources

large home ranges. The wildlife requirements were given priority in selecting the RSA boundary. The specific requirements of vegetation and wildlife for the selection of the LSA and RSA are described in more detail in Sections 10.3.1 and 10.4.1.

The local study area is the project footprint plus a 500 m buffer

The LSA is the area that may be directly disturbed by the development of the mine site. The LSA consists of the project footprint surrounded by a 500 m buffer (Figure 10.1-2). The buffer ensures that the direct effects of activities near the edge of the footprint (*e.g.*, dust from roads) will be included in the LSA, although dust from the on-site quarry extends slightly beyond the edge of the buffer (see also Section 7.3.3 and 7.3.4).

10.1.5 Assessment Methods

The classification system, including definitions and methods are explained

The classification of residual impacts is based on the direction, magnitude, geographic extent, duration, reversibility and frequency of the impact as described in Section 10.1.5.1. Definitions of the residual effect classification terms that are specific to the terrestrial components are provided in Section 10.1.5.2. Determination of the overall environmental consequence is described in Section 10.1.5.3.

10.1.5.1 Residual Impact Criteria

The residual impacts are assessed by using specific criteria

The following criteria are listed in Section 2.5.4 of the final Terms of Reference (MVEIRB 2001):

- magnitude;
- geographic extent;
- timing;
- duration;
- frequency;
- irreversibility of impacts;
- ecological resilience; and,
- probability of occurrence and confidence level.

Classification terms are defined

The classification used in this report generally follows the above list; however, there are some changes and additions that are described below. This section defines all of the impact classification terms as they are used in Terrestrial Resources as follows.

Figure 10.1-2 Local Study Area for Terrestrial Resources

Direction describes an impact or effect as being neutral, positive, or negative

Direction describes an impact or effect as being neutral, positive or negative. The direction usually reflects the change from baseline as illustrated for the ELC section. Direction for ELC units is determined based on the net change in the area of each ELC or terrain unit in the far future (100 years). For example, a positive direction would be assigned to an ELC unit if the area (*i.e.*, aerial extent) of that ELC unit is predicted to be greater in the far future than at baseline (*i.e.*, pre-development). Conversely, a negative direction would be assigned if the area of an ELC unit is predicted to be less than at baseline. For biodiversity, a direction of negative will be assigned if a change, either increase or decrease, is determined. If there is no measurable effect between far future and baseline, the direction is considered neutral for both ELC and biodiversity residual effects. For wildlife, a change that reduces habitat, restricts wildlife movement, changes behaviour, or lowers abundance is classified as negative.

Magnitude is a measure of the intensity or severity of the impact

Magnitude is a measure of the intensity or severity of an impact. It is a measure of the degree of change in a measurement or analysis endpoint. For example, the complete removal of a unit of habitat is a greater magnitude of impact on that unit than a change in the percent cover within the unit. Magnitude is classified into four levels as negligible, low, moderate, and high; the definitions of these terms are specific to each component (*e.g.*, terrain, wildlife). They are based on scientific and traditional knowledge and the characteristics of the component. Because there is an element of professional judgement needed to assign the levels, the definitions of each level are provided in the following section. This makes the classification process transparent since reviewers can see exactly what is meant by words such as low or high.

Geographic extent refers to the geographic location where the impact is predicted to occur

Geographic extent refers to the geographic location where the impact is predicted to occur. A local geographic extent is assigned if the effect is restricted to the LSA. A regional geographical extent is assigned if the effect extends beyond the LSA into the RSA. For example, the winter access and esker access roads extend beyond the LSA into the RSA; therefore, all effects on ELC units and biodiversity that occur in this location would be considered regional.

The choice of the geographic extent requires a balance

It is recognized that a method of defining impacts within the RSA, in terms of the percentage of a certain vegetative or habitat unit, is influenced by the size of the RSA. Therefore, an overly large RSA would dilute the impacts making them appear as very small quantities or percentages. However, the boundary must also reflect the maximum zone of influence of the proposed development for the species selected for assessment. The RSA has been selected to show the entire impact by not making the area too small while not diluting the impact by including it in an area that is too large. The intent is to obtain a balance.

Frequency refers to how often an effect will occur and is expressed as low, medium, or high

Frequency refers to how often an effect will occur and is expressed as low, medium, or high. Direct losses or alteration of ELC units and biodiversity, for example, are considered to have a low frequency since site disturbance and clearing will only occur once. The effects of dust on plant health are predicted to be medium since the effects will occur intermittently throughout the growing season.

Duration is defined as the length of time that an impact will occur

Duration is defined as the length of time that an impact will occur. Duration and timing have been combined within the definition of duration used in this EA. Duration is defined by the timing of the phases of the project. The years in which these durations are expected to occur (*i.e.*, the timing of the project) is provided in Section 10.1.3.3. A short-term duration is assigned if effects are limited to the pre-construction and construction phases, which are expected to occur within the first three years. Medium-term is related to the overall duration of the active project, which is dominated by the operation phase, but also includes a blending of construction, operation, and closure since these activities overlap in time. Medium-term duration is expected to occur within 26 years. Long-term duration is assigned if the effects are predicted to extend beyond the operation and closure phases of the project (>26 years).

Reversibility is classified as reversible (short term), reversible (long term), or irreversible

Reversibility is an indicator of the potential for recovery from the impact. The reversibility category is classified as reversible in the short term, reversible in the long-term, or irreversible. Since confusion can arise between the terms long-term duration and reversible in the long-term, these two terms are differentiated by the endpoint of the impact. The endpoint of duration is the cessation of the activity causing the disturbance. From this point forward the environment may be recovering from the impact; this aspect is classified as reversible in the short term, reversible in the long term, or irreversible.

Impacts are reversible when the ecological land classification unit returns to an equivalent capability

Reversible in the long-term is assigned if the effect can be reversed in 100 years following closure of the project. For example, it is predicted that some ELC units will re-establish within 100 years, defined as the far future, and other ELC units are not currently predicted to re-establish due to limited information on technology and reclamation research. If the effects are not predicted to re-establish to a baseline equivalent capability then these effects are considered irreversible. The concept that ecosystems are completely reversible (*i.e.*, can be completely restored to the original condition) is debatable. Therefore, this EA uses equivalent capability to determine reversibility. The definition of 100 years is very conservative for some wildlife species since it will include a number of generations; however, it is relevant to wildlife habitat, particularly lichen.

Ecosystems are not truly reversible because they continually respond to change

"All systems change, all the time, and our actions are an inevitable part of that change" (Matthews *et al.* 1996). The post-development state of an ecosystem will be different; it may be equally functional with the desired structure, but it will not be the same as before development (Landis and McLaughlin 2000).

Ecological resilience is the rate of ecosystem recovery

Ecological resilience is usually defined as the rate of ecosystem recovery following a disturbance (DeAngelis 1980; Cottingham and Carpenter 1994). Resilience is assessed as the rate at which the ecosystem returns to a stable state. Each of these concepts is also embodied in the classification of reversible in the short- or long-term described above. The concept of recovery is central to the understanding of the resilience of an ecosystem; therefore, there is overlap with the concept of reversibility. A broader definition of ecological resilience is the capacity of a system to absorb disturbances (Raufflet 2000).

Sub-arctic and Arctic ecosystems are resilient to extreme conditions

Sub-arctic and Arctic systems generally have low taxonomic diversity, low functional redundancy, and low productivity with highly cyclic populations of plants and animals that interact with disturbances in poorly understood ways (Pastor *et al.* 1998). The literature emphasizing resiliency of ecosystem structure stresses the importance of conserving biodiversity (Folke *et al.* 1996; Schindler 1998). For this reason, biodiversity is included as a key question in the EA, because biodiversity assesses one of the foundations of ecological resilience.

Since ecological resilience is currently being debated by scientists, it will be discussed, but not rated

Because of the lack of consensus in the literature on ecological resilience and the lack of scientific knowledge on the resilience of Arctic and sub-arctic ecosystems, resilience could not be used as a criterion for the assessment of impacts in the same manner as magnitude, geographic extent, duration or frequency. To do so would imply that there is sufficient scientific consensus on this topic to make it possible to classify ecological resilience. Therefore, impact assessments in this terrestrial section will consider ecological resilience as discussed in the paragraph above, but not assign a particular rating. Biodiversity is assessed since these methods are available.

The probability of occurrence will usually be low because most predictions overestimate the impact

Probability of Occurrence is the likelihood that the environmental consequence indicated in the impact prediction will occur if the project goes ahead. Because of the uncertainty inherent in most predictions of future conditions, conservative assumptions were used in these predictions. Therefore, it is likely that the project impact will have a lower environmental consequence than predicted.

Level of confidence is directly linked to the degree of certainty in the prediction

Level of Confidence is directly related to the degree of certainty in the impact prediction. There are a number of sources of uncertainty. These include lack of data about the environment, natural variability in the data, errors in obtaining and handling data, capability of the model (which is always based on a simplification of the environment) and a lack of understanding of Arctic ecosystem processes (including recovery following reclamation).

10.1.5.2 Definitions of Criteria

Criteria are defined in Table 10.1-3

The criteria described above are ranked for each section of Terrestrial Resources. Definitions for the ranking of some criteria such as geographic extent, duration, reversibility, and frequency have been standardized so that they are common to all terrestrial resources. However, the ranking of magnitude is often specific to the component (*e.g.*, wildlife). The definitions are provided in Table 10.1-3.

10.1.5.3 Environmental Consequence

The primary choices made in developing this method were to keep the process simple and transparent

Environmental consequence provides an overall assessment of the residual effects based on a ranking system that incorporates the key criteria. Combining the criteria shown in the residual impact classification into a single answer to the key question involves choices. The choices that have been made in this EA include the following:

- the method is transparent;
- the results will be shown as a bar graph (Figure 10.1-3) and as words in the residual impact classification table;
- the criteria will be added to form the bars of the graph;
- the criteria will be given equal weight except for the following:
    - only one criterion related to time will be used to prevent time from being over-weighted;
    - reversibility and magnitude will be slightly over-weighted due to the greater severity of the consequence of an irreversible impact of high magnitude.

Table 10.1-3 Definitions of Impact Criteria for Terrestrial Resources

Resource	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Geology and Terrain						
Ground Thermal Regime	**Neutral**: no change in ground thermal regime; **Negative**: an increase in the depth of the active layer.	**Negligible**: no measurable effect on the ground thermal regime; **Low**: an increase in the depth of the active layer by 50% or less; **Moderate**: an increase in the depth of the active layer by more than 50%, but less than 100%; **High**: complete thawing of the permafrost.	**Local**: effect is restricted to the LSA (*e.g.*, mine footprint plus 500 m); **Regional**: effect extends beyond the LSA into the RSA; **Beyond Regional**: effect extends beyond the RSA.	**Short-term**: 3 years; includes pre-construction and construction phases; **Medium-term**: 26 years; includes operation phase; **Long-term**: +26 years; following closure.	**Reversible Short-term**: effect can be reversed during closure of the project; **Reversible Long-term**: effects can be reversed in 100 years; **Irreversible**: effects cannot be reversed.	**Low**: occurs once; **Medium**: occurs intermittently; **High**: occurs continuously.
ELC[a] and Biodiversity						
Ecological Land Classification	**Neutral**: no change in the area and/or quality of ELC units, VECs, and/or plant health in the far future; **Positive**: an increase in the area and/or quality of ELC units, VECs, and/or plant health; **Negative**: a decrease in the area and/or quality of ELC units, VECs, and/or quality of ELC units, VECs, and/or plant health.	**Negligible**: no measurable effect (<1% change from baseline) in the area or quality of ELC units, VECs, or plant health; **Low**: <10% change or loss in the area and/or quality of ELC units, VECs, and/or plant health; **Moderate**: 10 to 20% change and/or loss in the area and/or quality of ELC units, VECs, and/or plant health; **High**: >20% change and/or loss in the area and/or quality of ELC units, VECs, and/or plant health.	**Local**: effect is restricted to the LSA (*e.g.*, mine footprint plus 500 m); **Regional**: effect extends beyond the LSA into the RSA; **Beyond Regional**: effect extends beyond the RSA.	**Short-term**: 3 years; includes pre-construction and construction phases; **Medium-term**: 26 years; includes operation phase; **Long-term**: +26 years; following closure.	**Reversible Short-term**: effect on ELC units can be reversed within 26 years during pre-construction, construction, operational and/or closure phases of the project; **Reversible Long-term**: effects on ELC units can be reversed in 100 years into the far future[b]; **Irreversible**: effects cannot be reversed.	**Low**: occurs once; **Medium**: occurs intermittently; **High**: occurs continuously.

Table 10.1-3 Definitions of Impact Criteria for Terrestrial Resources (continued)

Resource	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Biodiversity **Landscape**	**Neutral**: no change in landscape level indices (*e.g.*, patch number, mean patch size, mean nearest neighbour); **Negative**: change reflected as either an increase or decrease in landscape level indices.	**Negligible**: no measurable effect (<1% change from baseline) in landscape level indices (*e.g.*, patch number, mean patch size, mean nearest neighbour); **Low**: <10% change in landscape level indices; **Moderate**: 10 to 20% change, either an increase or decrease, in landscape level indices; **High**: >20% change in landscape level indices.	**Local**: effect is restricted to the LSA (*e.g.*, mine footprint plus 500 m); **Regional**: effect extends beyond the LSA into the RSA; **Beyond Regional**: effect extends beyond the RSA.	**Short-term**: 3 years; includes pre-construction and construction phases; **Medium-term**: 26 years; includes operation phase; **Long-term**: +26 years; following closure.	**Reversible Short-term**: effect can be reversed within 26 years during pre-construction, construction, operational and/or closure phases of the project; **Reversible Long-term**: effects can be reversed in 100 years; **Irreversible**: effects cannot be reversed.	**Low**: occurs once; **Medium**: occurs intermittently; **High**: occurs continuously.
Biodiversity **Ecosystem**	**Neutral**: no measurable change in the areas of high, moderate and/or low biodiversity potential; **Negative**: a decrease in high or moderate biodiversity potential and an increase in low biodiversity potential.	**Negligible**: no measurable effect (<1% change from baseline) in the areas of high, moderate and/or low biodiversity potential; **Low**: <10% change in the area of high, moderate and/or low biodiversity potential; **Moderate**: 10 to 20% change in the area of high, moderate and/or low biodiversity potential; **High**: >20% change in the area of high, moderate and/or low biodiversity potential.	**Local**: effect is restricted to the LSA (*e.g.*, mine footprint plus 500 m); **Regional**: effect extends beyond the LSA into the RSA; **Beyond Regional**: effect extends beyond the RSA.	**Short-term**: 3 years; includes pre-construction and construction phases, or closure; **Medium-term**: 26 years; includes operation phase; **Long-term**: greater than 26 years (extends beyond closure).	**Reversible Short-term**: effect can be reversed within 26 years during pre-construction, construction, operational and/or closure phases of the project; **Reversible Long-term**: effects can be reversed 100 years in the far future; **Irreversible**: effects cannot be reversed.	**Low**: occurs once; **Medium**: occurs intermittently or periodically; **High**: occurs continuously.

Table 10.1-3 Definitions of Impact Criteria for Terrestrial Resources (continued)

Resource	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Wildlife						
Wildlife habitat, movement and behaviour, and abundance	**Neutral**: no measurable change in wildlife habitat, movement, or abundance; **Negative**: a reduction in habitat, restriction in movement, change in behaviour, or reduction in abundance.	**Negligible**: no detectable change from baseline conditions; **Low**: exceeds the average value for baseline conditions, but within the range of natural variation and well below a guideline or threshold value; **Moderate**: exceeds the average value for baseline conditions, approaches the limits of natural variation, but below or equal to a guideline or threshold value; **High**: predicted to exceed baseline conditions or a guideline or threshold value so that there will be a detectable change beyond the range of natural variation (*i.e.*, change of state from baseline conditions).	**Local**: effect is restricted to the LSA (*e.g.*, mine footprint plus 500 m); **Regional**: effect extends beyond the LSA into the RSA; **Beyond Regional**: effect extends beyond the RSA.	**Short-term**: 3 years; includes pre-construction and construction phases, or closure; **Medium-term**: 26 years; includes operation phase; **Long-term**: greater than 26 years (extends beyond closure).	**Reversible Short-term**: effect can be reversed within 26 years during pre-construction, construction, operational and/or closure phases of the project; **Reversible Long-term**: effect can be reversed in 100 years in the far future; **Irreversible**: effects cannot be reversed.	**Low**: occurs once; **Medium**: occurs intermittently or periodically; **High**: occurs continuously.

[a] ELC definitions are also used for Terrain.

[b] Far Future is defined as 100 years following closure.

Figure 10.1-3 Generic Environmental Consequence

Numbers have been used only to determine relative positions in the bar graph

The words (*e.g.*, negligible, low, moderate, high) used to rank the criteria (*e.g.*, magnitude) have been assigned numbers to create the bar graph, but the numbers have no meaning other than to ensure that ranks are shown in the correct relative position to each other. The numbers used are shown in Table 10.1-4. Environmental consequence is only determined for residual impacts that are negative in direction.

Table 10.1-4 Generic Residual Impact Classification

Magnitude	Geographic Extent	Duration	Reversibility
Negligible (0)	local (0)	short-term (0)	reversible (short-term) (0)
Low (5)	regional (5)	medium-term (5)	reversible (long-term) (5)
Moderate (10)	beyond regional (10)	long-term (10)	irreversible (15)
High (15)			

Environmental consequence is ranked as negligible, low, moderate, or high

The environmental consequence has been determined by adding the numbers and comparing the sum to the scale determined on the following basis:

- negligible = ≤ 5;
- low = > 5 to ≤ 20;
- moderate = > 20 to ≤ 30; and,
- high = > 30.

The ranking of environmental consequence was based on professional judgement

The relative positions of negligible, low, moderate, and high are shown on the graph. Since the true environmental consequence would occur over a continuum rather than four categories, the position of the lines determining the consequence scale is based on professional judgement. For example, an impact that was of moderate magnitude, regional extent, medium-term duration, and irreversible was deemed to be a high environmental consequence. If the same impact was reversible in the long-term, it was deemed to be a moderate environmental consequence. If it was reversible in the short-term, it was deemed to be a low environmental consequence. Professional judgement was used *a priori* to determine the ranking. The determination of environmental consequence for each residual impact followed this method and was not modified within individual sections.

The environmental consequence method is simple and transparent

Because other professionals may have other opinions on the method or scale, the method used here to bring all the information together has been kept as simple and transparent as possible, while still providing a standardized comparison of the consequence of the project across all parts of the EA. This method of determining environmental consequence will be used to summarize all residual impacts in the EA.

10.1.5.4 Valued Ecosystem Components

Rare plant and traditional plant potential were selected as VECs

The valued ecosystem components (VECs) selected for the ELC, rare plant, traditional plant, and biodiversity components are representative of traditional, public and scientific values. The VECs selected include rare plant potential and traditional plant potential, which rank ELC units as having a high, moderate, or low potential to support rare or traditional plants. A potential was assigned to each ELC unit since it was not possible to search and locate rare and traditional plants throughout the entire LSA and RSA.

Wildlife VECs were selected for many reasons

Because it is not economically or logistically possible to study the potential impacts of mining activities on all wildlife species, a group of VECs are typically selected. Criteria for choosing which wildlife VECs to study were based on a combination of the ecological, social, cultural and economic aspects of the ecosystem. The eight wildlife VECs were also chosen for consistency with the wildlife effects monitoring program for the BHP EKATI™ mine and the EA of the Diavik Diamonds Project.

Ten vegetation and wildlife valued ecosystem components were selected

In total, ten VECs were selected for the assessment of the impact of the Snap Lake Diamond Project on vegetation and wildlife:

- rare plant potential;
- traditional plant potential;
- Bathurst caribou herd;
- barren-ground grizzly bears;
- wolves:
- foxes;
- wolverines;
- upland breeding birds (passerines, shorebirds, ptarmigan);
- raptors (peregrine falcon, gyrfalcon); and,
- waterfowl.

10.2 GEOLOGY AND TERRAIN

10.2.1 Baseline

10.2.1.1 Introduction

The baseline follows the Terms of Reference

The geology and terrain baseline has been prepared to meet the Terms of Reference established by the Mackenzie Valley Environmental Impact Review Board (MVEIRB) for the environmental assessment (EA) of the Snap Lake Diamond Project. The baseline describes existing conditions prior to development of the Snap Lake Diamond Project.

This section includes terrain, geology, seismicity, soils, and permafrost

The baseline section describes the terrain, surficial geology, bedrock geology, structural geology, geological hazards, seismicity, permafrost, and soils, as they relate to the proposed development. Lake sediments are described in Section 9.4.1.6. Permafrost conditions (*i.e.*, frozen subsurface conditions) at the site including ground ice content and permafrost configuration (including the frozen/unfrozen interfaces in the underground portion of the mine) are briefly described in this section.

There are local and regional study areas

The impacts of the Snap Lake Diamond Project on geology and terrain are assessed at two scales: the regional study area (RSA) and the local study area (LSA).

The regional study area is contained within a 31 km radius

The RSA is defined as the area within a 31 km radius of the centre of the active mine site (Figure 10.2-1). The potential impacts of the esker quarry and esker access road will be assessed within the RSA.

The local study area consists of the project footprint with a 500 m buffer

The Snap Lake Diamond Project terrestrial LSA is defined as the mine footprint with a 500-m buffer (Figure 10.2-2). A 500-m buffer around the mine footprint provides suitable area to assess all direct and indirect impacts from mine related activities on terrestrial resources. For example, all direct impacts from mine clearing and landform alteration, with the exception of the esker, on terrain units will be confined to the mine footprint, which is situated within the LSA. Further details on LSA selection is provided in the Scope of Assessment (Section 10.1), and ELC and Biodiversity (Section 10.3).

Figure 10.2-1 Regional Study Area for Terrain

Figure 10.2-2 Local Study Area for Terrain

10.2.1.2 Terrain

10.2.1.2.1 Setting

The local study area is gently sloping with occasional bedrock knolls

The majority of the proposed site development will be on the northwest peninsula of Snap Lake as shown in Figure 10.2-2. The topography of the northwest peninsula can be described as gently sloping with occasional bedrock knolls. Some areas of peat and organic soils occur on the northern portion of the peninsula. Large scattered boulders and frost shattered rocks dominate the ground. The surface elevations vary from just less than 445 m at the Snap Lake lakeshore to approximately 482 m on a knoll located immediately southwest of the water management pond (WMP) (see Figure 3.3-1).

The dominant soil type is dystric brunisols

Dystric brunisols are the dominant soil type. The soils at permafrost sites consist of turbic cryosols and organic cryosols. These permafrost features occur in poorly drained, peat-filled depressions that are present in small pockets throughout the LSA. These features are discontinuous with low ice content and sparse ice wedges present in soil profiles.

10.2.1.2.2 Methods

Field data used to classify ecological land classification units, including terrain units, from satellite imagery

Field investigations were conducted from July 8 to July 15, 1999 to classify, describe, and inventory terrain, soil, and vegetation within each ecological land classification (ELC) unit. ELC units, which are described in more detail in Section 10.3.1, were later re-classified into terrain units. A total of 120 field plots were surveyed collectively within both the LSA and RSA. A helicopter was used to access survey locations and to undertake aerial mapping. These survey locations were used as ground truthing for the final satellite mapping (*i.e.*, to determine that the ELC identified from the satellite correctly identified the ELC observed at that location). The field surveys were focused on sampling large homogeneous ELC units as well as complexes of ELC units to ensure that the satellite imagery could be accurately classified into distinct ELC units. A stratified sampling approach was undertaken, whereby there was a larger number of field plots in ELC units that were more dominant in the RSA and LSA. Some ELC units such as deep water were only identified from an aerial survey.

Field data collected included terrain data

At each survey location, UTM coordinates and site conditions such as terrain, moisture regime, slope, aspect, microtopography (*i.e.*, minor variations in surface relief), soil, and plant percent covers were recorded. All information collected was entered into an ELC database. A data analysis was undertaken to describe ELC units, which included terrain units.

Enhanced satellite imagery was used to classify the ecological land classification units, including terrain

Satellite imagery was used for mapping ELC units in the RSA and LSA. Landsat Thematic Mapper imagery was acquired from August 1994 and enhanced with false colour infrared wavelengths to increase the contrast associated with various ELC units patterns. ELC units, including terrain, were classified and mapped based on an automated classification process. Manual edits of some terrain features such as eskers were required since these features could not be differentiated through the automated classification process. Once the ELC mapping was finalized, ELC units were reclassified into prominent terrain features to derive terrain units. Further details on mapping are provided in the ELC section (Section 10.3.1.4.2).

10.2.1.2.3 Terrain Units

In the local study area, terrain units have been classified into boulder, moraine, organic (shallow), organic (deep), and deep water

In the LSA, terrain units have been classified into boulder, moraine, organic (shallow), organic (deep), and deep water (Table 10.2-1). The boulder unit consists of a moraine veneer (*i.e.*, a thin layer of earth and stones deposited by a glacier) that is variable in thickness but does not tend to exceed 50 cm. The boulder unit occupies most (54.7%) of the LSA. The moraine unit overlays boulders or bedrock and often exceeds 50 cm in depth. This unit, which comprises 5.3% of the LSA, has enough soils accumulation to support wooded growth such as spruce and heath shrubs. Shallow organic deposits occur in depressions and comprise 7.6% of the LSA. Deep organic deposits also occur in depressions or low-lying areas and comprise 1.5% of the LSA (Table 10.2-1). Deep water comprises the remaining 30.9% of the LSA.

Table 10.2-1 Terrain Units in the Local Study Area

Terrain Units	ha	%
Boulder	784.5	54.7
Moraine	75.5	5.3
Organic (shallow)	110.3	7.6
Organic (deep)	21.2	1.5
Deep water	443.5	30.9
Total	***1,435.3***	***100.0***

Eskers are long sinuous ridges that comprise 552 ha or 0.2% of the regional study area

Esker complexes are not found in the LSA, but do occur in the regional study area (RSA). Eskers account for 552.0 ha or 0.2% of the RSA. Materials will be extracted from eskers to construct roads and other mine related infrastructure for the Snap Lake Diamond Project. As such, potential losses to eskers will be included in this impact assessment.

10.2.1.3 Geology

Regional and local bedrock geology is known

The Snap Lake Diamond Project site is located approximately 70 km north of the east arm of Great Slave Lake in the Slave Geological Province of the Canadian Shield. Regional bedrock geology of the area was provided by Henderson (1944). Detailed geologic mapping of the northwest peninsula was recently done by Stubley Geoscience (1998).

Surficial geology generally consists of a thin veneer of till containing cobbles and boulders

The area was described as a rolling boulder plain by geologists of the Geological Survey of Canada (Henderson 1944). However, there was little published information on the local surficial (*i.e.*, surface) geology. Based on aerial photograph review, site reconnaissance observations, and test pit and borehole (*i.e.*, exploratory groundwater well) information, the surficial geology of the area consists of a veneer of Quaternary morainal deposits (till) that contain cobbles and boulders mixed with a finer-grained matrix of sand and silt with some gravel. The till is generally thin (generally less than 2 m thick) but can be thicker (one observation of a 6 m thickness was made) in topographic depressions. Fields of boulders, felsenmeer (*i.e.*, a veneer of large angular blocks of rock), and shattered rock debris are also found in topographic depressions. Bedrock outcrops are common. Occasionally there are other types of unconsolidated deposits, including possibly lacustrine deposits along the lakeshore and various organic deposits. In fine grained, saturated or organic deposits, the effects of frost action can be observed and the materials appeared cryoturbated (*i.e.*, disturbed by frost action) on aerial photographs.

Bedrock geology consists of granitic and metavolcanic rock cut by two east-west trending faults

The regional bedrock geology consists of Archean-aged granitic rocks overlain locally by relatively small bodies of metavolcanic rocks. These are cut by diabase (*i.e.*, dark fine-grained rock) dykes (*i.e.*, vertical walls) and sills (*i.e.*, horizontal flat sheets) of Proterozoic Age. The major structures in the area are two east-west trending, roughly vertically-oriented faults: the Snap Fault and the Crackle Fault. The surface expression of these faults is characterized by quartz-hematite (iron oxide) veining. Drill core through these faults is intermittently broken. Intersecting the Snap Fault is an unnamed north-south trending fault that divides a granodiorite (*i.e.*, granite/quartz) granite assemblage to the west and metavolcanic rocks to the east. Interpretations of magnetically-defined lineaments in the area indicate that bedrock fracture sets occur in three or four different orientations. It has been possible to correlate a few of the north-south oriented lineaments with fracture zones intersected in drill core and in the underground development.

The orebody is a kimberlite dyke that is present under the till on the northwest peninsula and then dips beneath Snap Lake

The kimberlite dyke subcrops in metavolcanic host rocks on the northwest peninsula, directly beneath overburden till, and dips beneath Snap Lake. The orebody can be further described as a diamond-bearing hypabyssal (*i.e.*, fine-grained igneous rock) macrocrystic (*i.e.*, with visible texture) serpentinized (*i.e.*, with a greasy or silvery lustre) kimberlite dyke. This dyke averages 2 m to 3 m in true thickness, and dips to the northeast in a shallow antiformal (*i.e.*, convex upward) fashion at about 11° to 15° (Figure 10.2-3). The kimberlite dyke, as currently outlined, measures approximately 2,000 m wide and extends approximately 2,800 m long (down dip in a southwest to northeast direction).

The kimberlite dyke is located in metavolcanic rocks near the northwest peninsula and granitic rocks farther away

The kimberlite dyke within 300 m of the northwest peninsula is hosted by a metavolcanic-leucogabbro package equivalent to the Yellowknife Supergroup. The metavolcanics consist mainly of well-foliated high-grade amphibolites (*i.e.*, complex silicates). Farther away from the northwest peninsula (Figure 10.2-3), the kimberlite dyke is hosted by an Archean variably-foliated granitoid suite. Overlying the metavolcanics and granitoids are glacial sediments, mainly till and glacio-lacustrine deposits.

Diamond is the only mineral in the dyke; it occurs at 0.4 parts per million

The only ore mineral present in the kimberlite dyke is diamond. The diamond content has been shown by surface bulk sampling to average about 2 carats per metric tonne. This is equivalent to 0.4 parts per million by weight or 0.00004% diamond.

10.2.1.4 Geological Hazards and Seismicity

No geological hazards were identified

Identification of existing geological hazards is included in the Terms of Reference. The importance of geological hazards is their potential effect on the project. Geological hazards include landslides, mudflows, debris flows, rock slides and earthquakes. Slides and flows can occur in the Slave Geological Province depending on topography, particularly if the permafrost has been disturbed. They are not generally associated with the gently sloping topography of the LSA. Possible disturbances to permafrost will be discussed further in Section 10.2.2.5 Earthquakes are discussed further under seismicity.

Potentially damaging earthquakes have not occurred near the Snap Lake Diamond Project

The importance of seismic activity and its effects on the Snap Lake Diamond Project pertains to structural integrity and subsequent performance of the structures after a large seismic event. Figure 10.2-4 shows the epicenters of potentially damaging (*i.e.*, greater than a magnitude of 5) earthquakes for the past century in Western Canada provided by the Pacific Geoscience Centre. No earthquakes have occurred near the Snap Lake

Figure 10.2-3 Location of Simplified Cross-section of the Kimberlite Dyke

Figure 10.2-4 Epicenters of Potentially Damaging Earthquakes for the Past 100 Years

Diamond Project. The largest and closest earthquake to the mine site was a magnitude (M) 6 to 8 earthquake, located approximately 1,000 km west of the site. Figure 10.2-5 shows the regional earthquake activity for the last five years provided by the Pacific Geoscience Centre. There are no seismic events recorded within 500 km of the site. The geographic distribution of the epicenters in Figures 10.2-4 and 10.2-5 appears to be controlled by the eastern edge of the Cordillera which is located to the west and south of the site.

The largest earthquake recorded in this region was located in the Mackenzie Mountains, approximately 1,000 km to the west

The northern Rocky Mountain region of the Cordillera is the most seismically active area nearest to Snap Lake. This region is over 1,000 km west of Snap Lake. The largest earthquake recorded in this region, to date, is the magnitude 6.9 earthquake of December 23, 1985 in the Mackenzie Mountains (Northwest Territories). A number of earthquakes exceeding magnitude 6 have occurred, including the May 1940 (M=6.2), the June 1940 (M=6.5), and the March 1955 (M=6.6) earthquakes in the Richardson Mountains (YK), as well as the October 5, 1985 (M=6.6) earthquake in the Mackenzie Mountains.

Peak horizontal ground acceleration is 0.013 g and peak horizontal ground velocity is 0.039 m/s

Based on up-to-date information obtained from the Pacific Geoscience Centre, Sidney, B.C., the peak horizontal ground acceleration for the Snap Lake Diamond Project area for an event having a risk of exceedance of 10 percent in 50 years (equivalent to a 475-year return period) is 0.013 g (Table 10.2-2). In other words, in the event of a 475-year return period earthquake occurring in the project area, the maximum acceleration at which the ground surface would shake along the horizontal direction is equivalent to slightly over one percent of gravity or 0.0 g. The Pacific Geoscience Centre gives the peak horizontal ground velocity for this event as 0.039 m/s.

Table 10.2-2 Seismic Risk Data for the Snap Lake Diamond Project Location

Probability of Exceedance per Annum	Probability of Exceedance in 50 Years (%)	Peak Horizontal Ground Acceleration (g)[a]	Peak Horizontal Ground Velocity (m/s)
0.01	40	0.009	0.027
0.005	22	0.011	0.032
0.002	10	0.013	0.039
0.001	5	0.016	0.047

Reference: Seismic risk calculation provided by Natural Resources Canada, Geological Survey of Canada – Pacific Geoscience Centre, Sidney, B.C. on July 18, 2001.

[a] g = gravity.

Figure 10.2-5 Epicenters of Earthquakes in Western Canada for the Past Five Years

Little or no ground deformations and rock displacements are anticipated

Since the effect of an earthquake is also related to rock types, the geotechnical investigation program identified the native rock types at the site as meta-volcanic and granitic. Rock cores indicated a rock quality designation of 100% with core recovery of 100%. Given these rock characteristics, little or no deformation would be anticipated in the event of a 0.01g earthquake; therefore, the potential for rock heave due to a seismic event is negligible. Semi-empirical formulae may be used for estimating the length of rupture as a function of the earthquake magnitude. However, the length of the rupture along faults was not estimated, given the extremely low probability of an earthquake at Snap Lake.

Conclusions supported by National Building Code

Based on the 1995 National Building Code of Canada, the area is located in the acceleration zone Za=0 and in the velocity zone Zv=0 with a zonal velocity ratio (Za/Zv) of zero.

10.2.1.5 Permafrost

The Snap Lake Diamond Project is located in continuous permafrost, but unfrozen areas occur under Snap Lake and in the upper "active" zone

Information published by the International Permafrost Association (1997) indicates that the Snap Lake Diamond Project is situated just north of the border between the zones of discontinuous and continuous permafrost. Accordingly, the depth of permafrost is expected to be approximately 140 m to 180 m at locations away from the influences of lakes. Taliks (unfrozen zones within continuous permafrost) may be extensive adjacent to and underneath large bodies of water. A talik exists beneath Snap Lake with permafrost becoming thicker with distance from the lake. The "thaw" or "active" zone beneath the project site has been observed to be up to 8 m thick. The active zone is the layer of permafrost closest to the surface that melts during the summer.

The presence of ice lenses in both the overburden and the frost-shattered bedrock was investigated

Sub-surface investigations carried out at the Snap Lake Diamond Project site were directed at identifying the depth of frost shattered bedrock as well as the presence of substantial ice lenses in either the overburden (mineral) soils or in the upper zone of frost shattered bedrock. To this end, a number of boreholes drilled as part of the subsurface investigation program were completed using a chilled brine solution as the drilling fluid in an attempt to obtain undisturbed, frozen samples of overburden and bedrock for examination.

Eight thermistors were installed to monitor temperature below ground level

In addition, thermistor cables were installed in some boreholes to monitor the thermal regime in the area. Eight thermistors were installed to varying depths during the two site investigation programs. The thermistors used were YSI 44007 thermistor beads, which have a 0.2°C accuracy rating. All of the thermistor cables were fabricated by M^2 Instrumentation of Cochrane, Alberta. All cables were ice-bath calibrated before installation.

Three thermistors were installed in April 1999

During the April 1999 program, three thermistors were installed at BH-1, BH-2, and BH-3 (Figure 10.2-6). The thermistor in BH-1, angled underneath the shoreline of Snap Lake, showed sub-zero conditions to approximately 28 m vertically below ground surface, warming up below that depth. The thermistor in BH-2, installed in the felsenmeer at the outfall of the small lake IL1 (now the location of the water management pond), did not exhibit any sub-zero temperatures within 18 m of the ground surface. The flowing outfall water from IL1 appears to have limited the formation of permafrost at that location. The thermistor in BH-3, showed sub-zero conditions from 3 m to 4 m below ground surface to a depth of 21 m. The ground temperature was -2°C at the 21 m depth.

Observations are made from thermistors installed in August 1999

During the August 1999 program, five thermistors were installed, in boreholes BH-18, BH-12, BH-8, BH-24, and BH-30. The following observations can be made based on the readings taken from these thermistors:

- No permafrost conditions were encountered within 8 m below the ground surface at the location of BH-8 (airstrip), during the period of record. Hence, the data indicate that the active layer depth at that location, which is at a higher elevation than the rest of the site, is likely greater than the 8 m depth investigated.
- The ground at the location of BH-12 was frozen from depth 7 m to 16.2 m, where the ground temperature was –3.5°C.
- The ground at the location of BH-18 (Dam 2) was frozen from depth 7 m to 17.3 m, at which the ground temperature was –2.4°C.
- No permafrost (*i.e.*, sub-zero temperatures) was observed at the location of BH-24 (at northwest peninsula near the Snap Lake shoreline) within the 14-m vertical depth investigated with this cable. This result, coupled with the subsurface thermal data collected from BH-1, indicates that the talik exists some 20 m to 40 m back from the shoreline of Snap Lake.
- The ground at the location of BH-30 was frozen sub-zero in the thermistor interval measured from depth 15 m to 85 m, at which depth the ground temperature was –1.7°C. Extrapolation of the temperature-depth curve indicates that the bottom of permafrost at this location would be approximately 140 to 150 m below the ground surface.

At locations more than 50 m from Snap Lake, the active layer ranges from 5 m to 7 m deep

The thermistors located in boreholes more than 50 m from the Snap Lake shoreline, indicate that the active layer ranges from 5 m to 7 m deep at most locations (except the airstrip), depending on aspect and soil/rock conditions. The depth of zero annual amplitude is projected to be between 15 and 20 m below ground surface, and the ground temperature at this depth is in the range of -1.3°C to about -2°C.

Figure 10.2-6 Location of Thermistors During Advanced Exploration Program

Overburden is less than 2 m thick

The soils within the project area are typically less than 2 m thick and the active layer extends into the underlying bedrock. Except in the low lying areas with peat deposits, the soils will only contain seasonal ice.

The site is located in continuous permafrost

Based on these results, the site is situated within an area of continuous permafrost; however, proximity to Snap Lake has a substantial effect on its distribution. Although a portion of Dam 1 (at the south end of the water management pond) will be located within the talik zone, most of the proposed site development facilities will be located on continuous permafrost.

There will be two frozen/unfrozen interfaces in the mine: the first near the mine portal and the second at the shore of Snap Lake

There will be two frozen/unfrozen interfaces in the mine. The portal will be in the active layer which will freeze and thaw annually to a depth of approximately 7 m. The ramp will then continue downwards through permafrost until the second interface is reached near the shoreline of Snap Lake. From the shore onwards the mine will be under the lake and in the talik zone, which will be unfrozen.

Subsurface investigations showed that no substantial ice lenses were present

The results of the subsurface investigations (Golder Associates Ltd. 2001) indicate that minor ice lensing exists at the site. Frost shattered bedrock was evident near surface in most boreholes drilled on site; however, no substantial ice lenses were evident. Some ground ice was encountered within and beneath peat deposits in small, poorly drained low areas. No zones of massive ground ice were encountered during the investigation program.

10.2.2 Impact Assessment

10.2.2.1 Introduction

Issues are used to develop key questions

A number of issues have been identified in the Terms of Reference with respect to the potential impacts of the Snap Lake Diamond Project on quarry development at the esker, seismicity, and permafrost. The issues related to permafrost can be summarized as follows:

- changes in the ground thermal regime;
- presence of ground ice; and,
- climate change.

Key questions are listed

The issues and activities for the Snap Lake Diamond Project formed the basis of the following key questions:

Key Question GT-1: What direct impacts will the Snap Lake Diamond Project have on terrain units in the local study area?

Key Question GT-2: What impacts will the Snap Lake Diamond Project quarrying have on the esker?

Key Question GT-3: What impacts to the Snap Lake Diamond Project will occur due to the seismic characteristics of the region?

Key Question GT-4: What impacts will the Snap Lake Diamond Project have on the ground thermal regime?

Key Question GT-5: What impacts will the presence of ground ice have on the stability of containment structures?

Key Question GT-6: What impacts will freeze-back of the north pile have on surface water quality?

Key Question GT-7: What impacts will climate change have on the development?

The steps in the impact assessment are listed

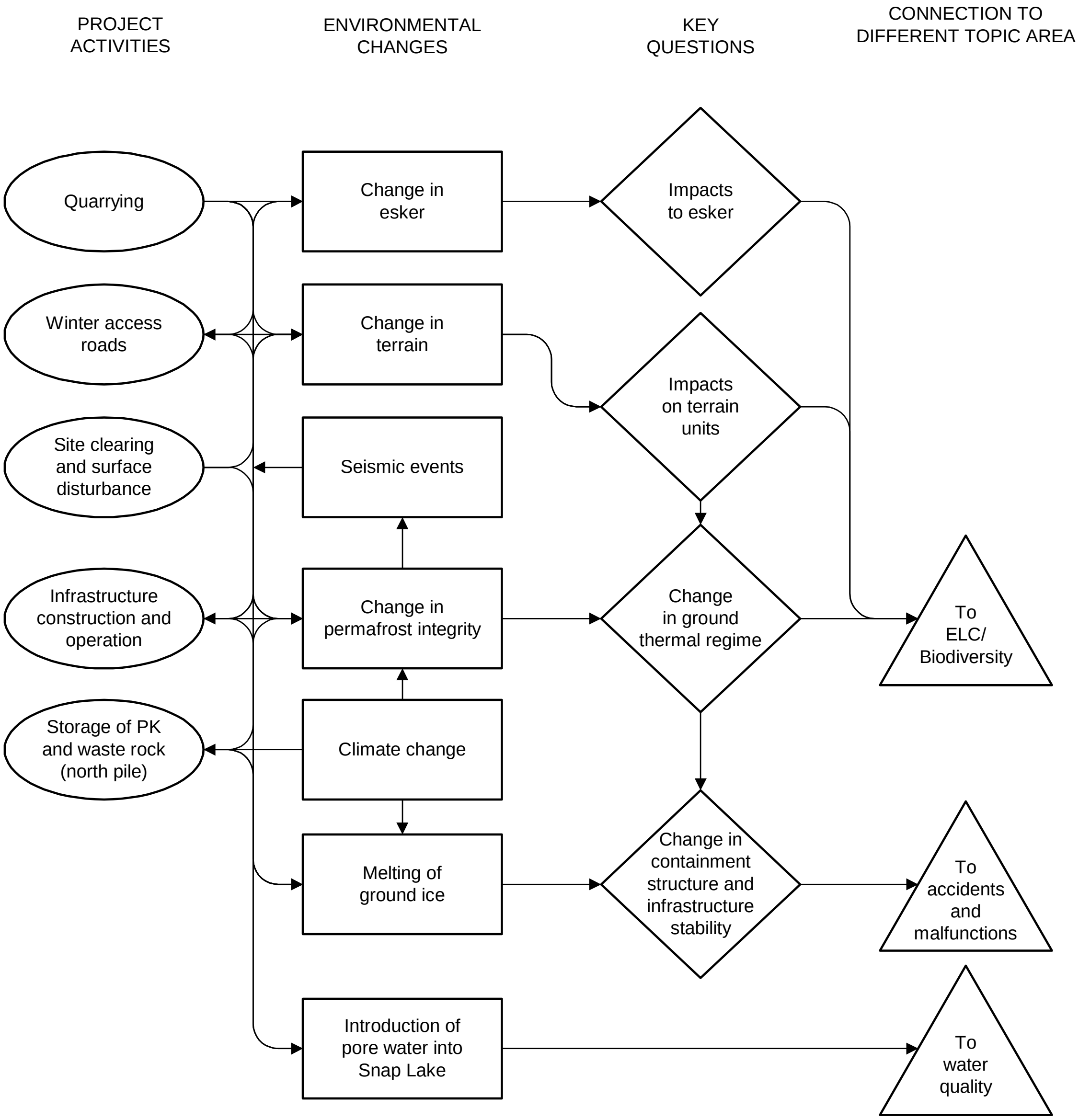
The key questions were addressed by quantifying the impacts using the following methodology:

- identifying the linkage of various project activities with the issues and determining whether the linkage is valid;
- describing the mitigation measures that will be implemented to minimize impact on the environment;
- conducting analyses to quantify the impact on the environment considering four phases (construction, operation, closure, and post-closure);
- classifying the residual impacts using the criteria and definitions in Section 10.1; and,
- describing monitoring programs that will be implemented to monitor the identified impacts.

Linkages between project activities and environmental effects are shown

The linkages between project activities and effects on the terrain are shown in the linkage diagram (Figure 10.2-7). This linkage diagram is unusual in that it includes a number of reverse linkages illustrating that changes in the environment (*e.g.*, climate change, seismic events) may affect the project infrastructure.

Figure 10.2-7 Linkage Diagram for Geology and Terrain



10.2.2.2 Key Question GT-1: What Direct Impacts Will the Snap Lake Diamond Project Have on Terrain Units in the Local Study Area?

Impacts from project related activities will result in the direct loss or alteration of terrain units

Direct impacts associated with construction and operation of the Snap Lake Diamond Project will result in direct losses or alteration to terrain units in the LSA. Specifically, this key question will quantify the direct losses and/or alteration of terrain units during construction and operation as well as provide predictions on terrain units that will be reclaimed following closure.

The impact assessment will quantify and describe the change in terrain units between baseline and the completion of reclamation at closure.

10.2.2.2.1 Linkage Analysis

Site clearing and surface disturbances will impact terrain units

The only linkage (Figure 10.2-7) that will result in direct impacts (*i.e.*, loss or alteration) to terrain units is site clearing and surface disturbances. The majority (*i.e.*, 559.5 ha) of direct impacts on terrain units will result from site disturbances that are necessary for the construction and operation of the Snap Lake Diamond Project. Accordingly, site disturbance is a direct impact on terrain units and the linkage is valid. These mine related disturbances will occur within a defined project footprint, which is situated within the LSA (Figure 10.2-2). The location of infrastructure within the project footprint is shown in Figures 3.1-4 and 3.3-1 in the Project Description (Section 3).

Project footprint area is assumed for determining losses to terrain units, even though disturbance will occur in only part of the footprint

Collectively, all mine related development areas occur with a project footprint (Figure 10.2-2). Losses to terrain units were assumed to occur within the entire project footprint; however, the actual development area (identified as the mine site) is less than the project footprint area. This assumption provides a conservative estimate since the project impacts are based on a maximum area. Detailed information on the specific areas calculated for individual mine-related developments is provided in the Decommissioning and Reclamation Plan (Appendix III.11).

10.2.2.2.2 Mitigation

Mitigation will reduce impacts to terrain units

A detailed discussion of closure planning is provided in the Decommissioning and Reclamation Plan (Appendix III.11). The following specific mitigation will reduce and/or eliminate disturbances to terrain resources from the Snap Lake Diamond Project area:

- limiting the size of the project footprint;
- avoiding, or reducing, impacts to terrain units during project planning by re-using previously disturbed areas (*e.g.*, the processed kimberlite containment area will be used as the water management pond), where possible;
- re-contouring closure landforms (*i.e.*, terrain units) and placement of reclamation materials to ensure that the final topography and site conditions are similar to other terrain units in the region; and,

- ensuring that adaptive management approaches will be undertaken to include the results of monitoring and advances in reclamation research in final closure planning efforts.

Mitigation will return terrain resources to pre-development capability

The objective of reclamation is to return the developed area to a condition of "equivalent capability". Equivalent capability is defined as the capacity of an area to support similar ELC units as elsewhere in the region, but not necessarily in the same proportion or numbers as baseline. Unlike ELC units, which include vegetation requiring long periods to recover, terrain units are reclaimed by physical processes (*e.g.*, re-contouring) that can be done during closure. Applying appropriate mitigation methods and allowing for adaptive reclamation management will help to ensure terrain resources will be returned to pre-development capability.

10.2.2.2.3 Impact Analysis

Impacts from direct removal or alteration of terrain units during construction and operation are assessed

The analysis of potential linkages indicates that losses or alteration of terrain units are primarily due to site disturbance during the construction and operation phases of the Snap Lake Diamond Project. The majority of mine related disturbances are restricted to the LSA; however, there will be 0.5 ha of esker, which is located outside the LSA, that will be affected (as described in Key Question GT-2). The following provides an impact analysis of direct effects on terrain units in the LSA.

Direct Losses/Alterations from Site Disturbance

Approximately 560 ha of land disturbance will result in the loss or alteration of terrain units in the LSA

Table 10.2-3 shows the areas of each terrain unit that will be lost or altered in the LSA during the construction and operation phases of the project. A total area of 559.5 ha or 39.0% of the LSA will be lost or altered as a result of the Snap Lake Diamond Project. Specifically, there will be permanent or temporary alterations to 414.6 ha boulder, 49.6 ha of moraine, 53.9 ha of shallow organic, 8.9 ha of deep organic, and 32.5 ha of deep water units.

Following closure, the waste rock pile will be re-contoured and constructed to the boulder unit

Following closure, the waste rock pile will be re-contoured and constructed to the boulder unit. As a result, there will be an overall increase of 13.7% of boulder unit following closure. There will be a decrease of 58.9% of the moraine unit. In addition, there will be decreases of 48.9% and 42% to the organic (shallow) and organic (deep) units. There will be a loss of 1 ha of the deep water unit, which will result in a decrease of 0.2% following closure. Detailed information on closure landforms or terrain units is provided in the Decommissioning and Reclamation Plan (Appendix III.11).

Table 10.2-3 Direct Losses and Alterations of Terrain Units in the Local Study Area

Terrain Unit	Baseline (ha)	Baseline %[a]	Loss/Alteration Due to Snap Lake Diamond Project (ha)	Loss/Alteration Due to Snap Lake Diamond Project %[b]	Area at Closure (Following Reclamation) (ha)	Change from Baseline ELC Units (%)[c]
Boulder (moraine veneer)	784.8	54.7	414.6	52.8	892.1	13.7
Moraine	75.5	5.3	49.6	65.7	31.0	58.9
Organic (shallow)	110.3	7.6	53.9	48.9	56.4	48.9
Organic (deep)	21.2	1.5	8.9	42.1	12.3	42
Deep water	443.5	30.9	32.5	7.3	442.5	0.2
	1,435.3	**100.0**	**559.5**	**39.0**	**1,435.3**	**0**

[a] % of total LSA baseline area.
[b] % of baseline area of ELC unit within the LSA.
[c] % change from baseline area of ELC unit within the LSA.

10.2.2.2.4 Residual Impact Classification

Although the magnitude is high for moraine and organic units, the extent is 99.7 ha

Table 10.2-4 provides a summary of the residual impact classification associated with each terrain unit in the LSA. Although the magnitude of impacts to moraine and organic (shallow and deep) units is high, this key question pertains only to the LSA. Since the LSA was initially defined as the area of direct impacts, a substantial change from baseline is expected. However, the total area of moraine and organic units that is lost or altered is 99.7 ha. This area represents 6.9% of the LSA and 0.03% of the RSA.

Table 10.2-4 Classification of Residual Impacts to Terrain Units in the Local Study Area

Component Criteria	Impact Assessment Criteria: Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Boulder (moraine veneer)	positive	moderate	local	medium-term	reversible (short-term)	low	no negative consequence
Moraine	negative	high	local	medium-term	irreversible	low	high
Organic (shallow)	negative	high	local	medium-term	irreversible	low	high
Organic (deep)	negative	high	local	medium-term	irreversible	low	high
Deep water	negative	negligible	local	medium-term	irreversible	low	low

Reversible: it is possible to construct this unit.

Environmental consequence is low to high

Overall, losses to terrain units in the LSA are ranked as having a low to high environmental consequence. The boulder unit will exceed pre-development areas whereas the moraine, organic and deep water units will result in some permanent loss. The Snap Lake Diamond Project will not result in complete removal of any terrain unit within the LSA. The impact assessment is based on the conservative assumption that the entire project footprint will be altered, which is unlikely since the active mine site is a smaller area within the project footprint.

The probability of occurrence and level of confidence are provided

There is a high probability that the impacts on terrain will be less than those predicted due to the conservative assumptions (*e.g.*, assuming loss or alteration of the entire footprint). Although this section predicts changes after reclamation, the level of confidence is high. Terrain units are reclaimed primarily by physical processes such as the placement of materials and recontouring, which are based on known technology.

10.2.2.2.5 Monitoring

Monitoring will be used to enhance reclamation through adaptive management

The Snap Lake Diamond Project will initiate a decommissioning and reclamation monitoring program throughout the construction, operation, and decommissioning phases of the project. New reclamation measures will be incorporated that may provide more closure landform (terrain) re-establishment options. Moreover, De Beers will develop an adaptive management approach to reclamation that will incorporate the results of the monitoring program as well as reclamation approaches that have been developed as part of other mine operations and new research in the region.

10.2.2.3 Key Question GT-2: What Impacts Will the Snap Lake Diamond Project Quarrying Have on the Esker?

10.2.2.3.1 Linkage Analysis

Project requires borrow material from one esker

The Snap Lake Diamond Project requires a source of borrow material for site construction, roadways, maintenance, and closure. One source of this material has been identified within a portion of an esker, located 9 km south of the project area (Figure 10.2-1). Eskers have been identified as providing an important travel route for many mammal species (*e.g.*, caribou, musk-ox, furbearers, and humans) and denning habitat. In addition, eskers provide a source of topographic diversity within the northern landscape for cultural land uses (hunting, foraging), while providing a ready source of gravel and sand materials for construction uses.

A total of 75,000 m^3 of esker sand will be needed

Approximately 25,000 m^3 of primarily sand material will be required from the esker during construction and approximately 50,000 m^3 of additional esker material will be needed periodically during the 22 year mine production period. These materials will be excavated from this esker during winter.

Removal of esker sand will involve heavy equipment working at one location only

Materials will be extracted from one point source on the esker. Esker material will be extracted using dozers, front-end loaders, trucks, and possibly a portable screening plant. Sandy materials will be scraped from the surface using a dozer to a depth of approximately 2 to 3 m. This will result in removal and disturbance of vegetation and soils to the esker surface, as well as a localized reduction in size and volume of the esker itself.

The linkage is valid

It is concluded that the quarrying operations of the Snap Lake Diamond Project will lead to changes to the esker complex within the regional study area (RSA); therefore, the linkage is considered valid and the impact will be assessed.

10.2.2.3.2 Mitigation

0.5 ha of disturbance to the esker complex

The majority of quarried materials required for the Snap Lake Diamond Project will be derived from quarry sites located within the project footprint. Only a limited amount of sand material will be extracted from the esker. Using the on-site quarry will greatly reduce the extent of impact to esker landforms within the regional study area.

Periodic use of the esker for borrow material over 22 year operating period is anticipated

In addition to the limited spatial extent of esker disturbance, temporal use of the esker will be restricted to specific project life-cycle periods. Following project start–up needs for sand material in 2002, it is expected that access to the esker will be needed in 2004 and 2005 and thereafter on three or four occasions during the 22 year operating period. The esker quarrying activity during these periods of active use is expected to be restricted to about six to eight weeks during the winter months.

Esker access road will be constructed to winter road standards

Access to the esker will be via an existing winter road alignment. The construction and operation of the winter road to the esker quarry will conform to the same standards that are in place at MacKay Lake for the operation of the winter access road from the Tibbitt-Contwoyto road to the site.

Quarry Management Plan to govern access, use, and reclamation

Esker impacts will be minimized during quarry activities by adherence to a Quarry Management Plan (Appendix III.5). This will clearly delineate the boundaries of the disturbance zone, access routes to be followed for material haulage, and equipment to be used for excavation. In order to maintain positive drainage at the esker quarry site, the bottom of the working area will be maintained above the surrounding ground level. A ridge of esker material will also be maintained around the perimeter of the work area to minimize erosion from the work site during summer months.

Pit slopes re-contoured after use

Following completion of each esker quarry activity, all pit slopes will be re-contoured to ensure minimal potential for erosion or danger to wildlife use. The overall shape of the esker slope will be kept in place to maintain the integrity of the landform and its subsequent use by wildlife and human use following reclamation efforts.

10.2.2.3.3 Impact Analysis

Less than 1% of the eskers complex affected within the RSA

An analysis of impacts to these landforms requires an assessment of the amount of esker landform disturbed as part of the Snap Lake Diamond Project. Table 10.2-5 shows that a total of 0.5 ha of esker will be disturbed over the course of the project operations. This represents 0.09% of the total esker landforms which occur within the RSA. Expressed as a percentage of the one discrete esker that will be used for quarry materials, the 0.5 ha of disturbance represents 5.6% of its total surface area within the RSA. The total esker quarry area extending beyond the esker is estimated at 1.5 ha.

Table 10.2-5 Area of Esker Landforms Affected within the Regional Study Area

	Disturbance Area (ha)	Esker Area (ha)	% of Esker Area That Is Disturbed (%)
One esker to be quarried	0.5	8.9	5.6
Total esker area in RSA	0.5	547.9	0.09

10.2.2.3.4 Residual Impact Classification

Esker disturbance has a moderate environmental consequence

The disturbance of 0.5 ha (0.09% of the total) of esker landform within the RSA can be expressed as having a moderate environmental consequence, as derived from Table 10.2-6. Although the magnitude of the impact is negligible, the loss of borrow material is irreversible, which increases the environmental consequence.

Table 10.2-6 Classification of Residual Impacts of Loss and Disturbances to the Esker

Component Criteria	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Loss/disturbance of esker landforms	negative	negligible	regional	medium term	irreversible	medium	moderate

Overall volumes of esker materials required is low

The probability of occurrence of disturbance to esker landforms is high, given the need for quarry materials found in eskers and the necessity of using such materials as part of the project construction and operation. While the volume of esker materials required is based on the maximum amounts anticipated, it is possible that actual volumes will be less, given efficiencies in roadway design and layout, innovation in construction techniques over time, and possible re-use of materials.

Level of confidence is high

The level of confidence in the assessment of residual impacts is high, based on the understanding of project needs, volume estimates required, and geographic location of the material source.

10.2.2.3.5 Monitoring

Monitoring will be done

Monitoring will be part of the quarry management plan where volumes of material extracted will be recorded during each period of use. Slope re-contouring and reclamation efforts will be documented using diagrams and table information summaries. Following site de-commissioning, reclamation and re-vegetation monitoring will be completed at the esker site.

10.2.2.4 Key Question GT-3: What Impacts to the Snap Lake Diamond Project Will Occur Due to the Seismic Characteristics of the Region?

10.2.2.4.1 Linkage Analyses

The potential for the environment to impact the project is analyzed

The linkage that exists between the Snap Lake Diamond Project and the seismic characteristics of the area is actually a reverse linkage. It is the environment (*i.e.*, the naturally occurring seismicity) that has a potential impact on the proposed development. The importance of seismic activity and its effects on the mine site installations pertains to structural integrity and subsequent performance of the structures after a large seismic event.

Peak horizontal ground velocity is 0.039 m/s

If an event did occur, the ground velocity would not be potentially damaging. Based on up-to-date information obtained from the Pacific Geoscience Centre, Sidney, B.C., the peak horizontal ground velocity for the Snap Lake Diamond Project area for an event having a risk of exceedance of 10 percent in 50 years (equivalent to a 475-year return period) is 0.039 m/s (Table 10.2-2).

No seismic events have been recorded within 500 km of the site

A seismic event is unlikely to occur at the Snap Lake Diamond Project based on past events. There were no seismic events recorded within 500 km of the site and there were no events exceeding a magnitude 5 (*i.e.*, potentially damaging) within a distance of approximately 1,000 km.

The linkage is invalid

Based on the 1995 National Building Code of Canada, the area is located in the acceleration zone Za=0 and in the velocity zone Zv=0 with a zonal velocity ratio (Za/Zv) of zero. Consequently, the linkage between the seismic characteristics of the region and the Snap Lake Diamond Project is invalid. Because there is no linkage between the seismic characteristics and the project, no further assessment was done.

10.2.2.5 Key Question GT-4: What Impacts Will the Snap Lake Diamond Project Have on the Ground Thermal Regime?

10.2.2.5.1 Linkage Analysis

Buildings will locally change the thermal regime

The construction of heated structures will result in a general warming of the ground below and immediately around the structures. In addition, the removal of natural overburden and rock materials from the area of the structures will result in a change in the thermal conductivity of the area. On closure of the project, the heated structures will be removed. However, the removal of natural materials, and replacement with imported fills (*i.e.*, sand or crushed granite from the esker or on-site quarries) will result in a long-term change in the thermal regime within the active layer.

Thawing of massive ground ice would cause rutting or sinkholes

Major impacts on the operation of these facilities could occur as a result of thawing of massive ground ice which would result in rutting or development of sinkholes in the fills. This impact can be minimized through the removal of any ice-rich materials or materials which are soft when thawed prior to construction.

Roads and pads will locally change thermal regime

Construction of site roads and the airstrip, as well as the mill and related facilities will require the placement of imported fill materials over the natural ground. This fill construction will result in a substantial change in the thermal conductivity of the near surface materials. Upon closure, the intent is to simply remove culverts, and regrade the roads and airstrip to re-establish natural drainage channels and to blend with the natural terrain. However, the original heat exchange capacity of the road alignments will not be re-established.

The underground mine will locally change the thermal regime

During development and operation of the underground mine, warm air will be vented from the underground. This air will warm the ground in the immediate area of the portal and ventilation raises. Upon closure, the mine will be sealed and the thermal regime around these openings is expected to return to pre-development conditions.

Development of the north pile will locally change the thermal regime

Similar to the construction of site roads, development of the north pile will result in the placement of a large volume of fill materials. Fill for the perimeter berms will be derived from a combination of compacted rockfill or the coarse fractions of the processed kimberlite. The processed kimberlite contained in the facility will also act as a fill material which has been heated during the processing. Upon closure, the processed kimberlite in the north pile will freeze and an active layer will be developed on an annual basis. A permafrost regime will be established, although it will be different than the original thermal regime for the site.

The linkage is valid

As a result of the above, the linkage between the development of the Snap Lake Diamond Project and the ground thermal regime is valid for all phases (construction, operation, closure and post closure). There is also a reverse linkage, since the changes in ground thermal regime caused by the project described above have the potential to affect the performance of the project infrastructure.

10.2.2.5.2 Mitigation

An insulating layer between structures and the permafrost will be constructed

Mitigation strategies will consist of minimizing changes in the ground thermal regime by providing an insulating layer between the permafrost and any structures/facilities to be constructed. The insulating layer could consist of a synthetic insulation under or around buildings or provision of a layer of non-frost susceptible fill materials over permafrost. For heated structures, insulation will slow the rate heat transmission, but will not eliminate it.

Thawing of massive ground ice would cause rutting or sinkholes

Impacts on the operation of structures/facilities at the mine site resulting from thawing of massive ground ice will be minimized through the removal of any ice-rich materials, if present.

10.2.2.5.3 Impact Analysis

Thermal modelling was carried out for north pile only

The potential impacts of the Snap Lake Diamond Project on the ground thermal regime are discussed in terms of the potential for an increase in the ground temperature as a result of the development activities. For the north pile, these potential temperature increases were evaluated with a numerical thermal model. For site infrastructure such as roadways, airstrip, mill, ancillary facilities, and the mine, the potential impacts are evaluated on the basis of past experience for other mining projects in permafrost areas, a limited review of relevant literature, an understanding of the bedrock and surficial geology of the site, and an understanding of the infrastructure to be constructed as part of the development.

North Pile

A thermal model was developed to predict the effect on the ground thermal regime

A thermal model of the north pile was developed to investigate the effect of development of the north pile on the ground thermal regime in the area. In particular, the following thermal analyses were conducted:

- to predict the thermal performance of the north pile during deposition for a rapid deposition scenario and a slow deposition scenario;
- to predict the thermal performance of the north pile after deposition was complete; and,
- to estimate the active layer depth within the processed kimberlite within the north pile.

Material Properties

Thermal properties for fill materials were based on past experience

Table 10.2-7 summarizes the material properties used in the thermal analyses. In general, thermal properties of the materials were estimated from previous experience with similar materials. The thermal conductivity of the processed kimberlite composition Full Mix was determined in the laboratory.

Methodology

1-D and 2-D finite element models developed

The computer program TEMP/W, developed by Geoslope Inc., was used to conduct the thermal analyses. Both one- and two-dimensional finite element thermal models were developed. The typical cross-section of the north pile (Appendix III.1) was used to develop the two-dimensional finite element mesh for the thermal analyses.

Boundary conditions developed

The assumed boundary conditions used in the thermal analyses are as follows:

- zero heat flux along the vertical boundaries;
- unit heat flux along the lower boundary (-80 m) of 0.004 watts per square metre (W/m^2); and,
- surface temperature distributions (based on the monthly average air temperatures shown in Table 10.2-8).

Table 10.2-7 Material Properties Used in the Thermal Analyses of the North Pile

Material	Dry Density (Mg/m^3)[a]	Moisture Content (%)	Porosity, n (%)	Degree of Saturation (%)	Volumetric Water Content Θ [b]	Thermal Conductivity (W/m °C)[c]			Volumetric Heat Capacity (MJ/m^3 °C)[d]
						Frozen	Thawed	Frozen	Thawed
Granite bedrock	2.5	5	5	100	0.05	2.9	2.5	2.6	2.8
Frost shattered and weathered granite bedrock	2.1	10	20	100	0.20	4.8	4.4	2.4	2.9
Mineral soil	1.9	15	30	95	0.28	4.8	4.4	2.0	2.5
Full mix [e] (75% solids) saturated	1.6	33	48	100	0.48	2.8	2.1	2.1	2.8
Full mix unsaturated	1.6	25	42	90	0.40	1.4	1.15	1.9	2.3
Coarse PK unsaturated	1.6	4	42	15	0.06	0.6	0.5	1.3	1.4
Coarse PK saturated	1.6	11	42	1.0	0.42	2.7	1.6	2.0	2.9

PK = processed kimberlite.

[a] megagrams per cubic metre.

[b] a proportion of volume of water to volume of soil or rock.

[c] watts per metre per degree Celsius.

[d] megajoules per cubic metre per degree Celsius.

[e] Full mix is a processed kimberlite paste consisting of coarse PK, grits, and fines. The paste that will be placed within the north pile is typically full mix. Occasionally, the paste will be composed mainly of fines, when the coarse PK and grits are used for building embankments.

Table 10.2-8 Surface Temperature Distribution Used in the Thermal Analyses of the North Pile

Month	Average Temperature (°C)[a]	N Factor[b]	Calculated Surface Temperature (°C)
January	-29.4	0.5	-14.7
February	-27.6	0.5	-13.8
March	-22.4	0.5	-11.2
April	-11.9	0.5	-6.0
May	-0.5	0.5	-0.3
June	9.0	1.8	16.2
July	13.2	1.8	23.8
August	11.4	1.8	20.5
September	4.3	1.8	7.7
October	-4.8	0.5	-2.4
November	-17.7	0.5	-8.9
December	-25.6	0.5	-12.8

[a] Average temperatures referenced from Yellowknife and Lupin climate data. Period of record 1998 to 2000.

[b] N Factor is a standard factor applied to air temperatures to estimate the temperature at the ground surface (ground surface temperature = N factor × air temperature).

Model was calibrated to ground temperatures from thermistor data

The first step of the model was to calibrate the predevelopment conditions against the existing thermistor data. Once a satisfactory fit was achieved, the development of the pile was modelled by adding horizontal layers to the top of the pile and running a transient analysis for the time period representing that layer. Subsequent layers were added and the model continued. Processed kimberlite placement rates of 9 m/yr and 3 m/yr were used. For both cases, the model was run for a period of three years after the end of processed kimberlite discharge to determine when the pile would completely freeze. Time steps used in the modelling varied between five and 30 days.

Model was developed for varying deposition rates

Initial temperatures of the deposited processed kimberlite for a placement rate of 9 m/yr were assumed to vary with the surface temperature for that time of year. Initial temperatures of the deposited processed kimberlite materials for a placement rate of 3 m/yr were kept constant at 5°C for winter deposition and 10°C for summer deposition.

Short-term average temperatures were consistent with the long-term record

The average monthly temperatures for the period 1998 to 2000 were used in the thermal analysis of the north pile (Table 10.2-8). The average temperatures used are consistent with the long-term record (Table 9.3-4). Between 1998 to 2000, the average temperatures in the coldest months, December, January, and February were -25.6ºC, -29.4ºC, and -27.6ºC, respectively (Table 10.2-8). The mean temperatures between 1942 to 2001 for these months were very similar at -25.4ºC, -29.2ºC, and -27.0ºC, respectively. Average temperatures for the warmest months in the short-term period of record were 13.2ºC in July and 11.4ºC in August (Table 10.2-8). Summer mean temperatures between 1942 to 2001 were very similar at 13.4ºC in July and 11.5ºC in August (Table 9.3-4). The modelling is representative of past and present conditions. Temperature concerns related to future global warming are addressed in Key Question GT-7 (Section 10.2.2.8).

Results

Temperature profiles were calculated

The initial foundation temperature profiles (Appendix III.1) were established using the calculated surface temperature data and compared to the existing thermistor data from site.

For rapid placement, the pile was completely frozen after Year 3

The results for a processed kimberlite placement rate of 9 m/yr indicate that the lifts deposited during the summer months initially remain unfrozen, and lifts placed in winter freeze and remain frozen. After the end of Year 3, the entire pile is frozen and remains in that state.

For slow placement, the pile was frozen two years after deposition ends

The results for a processed kimberlite placement rate of 3 m/yr indicate that the lifts placed in summer remain unfrozen and this unfrozen condition persists into the following winter. However, these lifts freeze during the second winter after deposition. The entire pile is frozen two years after deposition ends.

The active layer in the north pile will be two metres deep

A refined model with thinner near-surface elements was used to estimate the active layer depth in the final deposited processed kimberlite material. The results of this model indicate that an active layer would develop to 2 m depth below the pile surface.

Site Roads and Airstrip

Construction using non-frost susceptible materials

The primary focus during design and construction of site roads and the airstrip is to provide a competent running surface for the vehicles, mine equipment, and aircraft that will use these facilities. All of these facilities will be constructed using fill which is not susceptible to frost action and is also thaw stable.

Placement of fill will change thermal properties

As noted in Johnston *et al.* (1981), construction of a fill will result in substantial changes in the capacity for heat exchange at the ground surface. This change may include the potential for the surface of the fills to absorb more radiation in the summer months. This may result in a substantial change in the ground temperature, thereby increasing the depth of the active layer. The impact on natural permafrost below the constructed embankments can be minimized either through construction of a relatively deep fill, or through the placement of a synthetic insulating material. Both measures would limit the depth of the active layer which will then develop in the natural materials below the embankment.

No massive ground ice anticipated

An increase in the depth of the active layer would ultimately result in thawing of ground ice which may be present in the natural overburden or rock materials. As noted in Section 10.2.1 above, investigations carried out on the site indicate that the overburden and near surface bedrock do not contain any substantial zones of massive ground ice. Therefore, no problems in the performance of these facilities are anticipated as a result of any change in the ground thermal regime.

A new thermal regime will establish on closure

On closure of the project, any culverts which were installed will be removed and the embankment fills will be regraded and contoured to match the natural topography. Natural drainage patterns will also be re-established to the extent possible. As a result, a natural thermal regime will develop in the fill materials and will include an active layer that will develop on an annual basis. This active layer may extend to a greater or lesser depth than the predevelopment active layer in the same area, but there will be minimal impact in the long term.

Mill and Ancillary Facilities

Buildings will not be impacted by thawing of ground ice

No modelling of the impact of construction of the mill and ancillary facilities was completed during the design of the structures. All structures required for the mill and ancillary facilities on the site will be constructed either on piles socketed into bedrock or on footings or slabs constructed on a non-frost susceptible fill or on bedrock. Both heated and unheated structures will be built on the site.

Little ground ice was encountered where the mill and related facilities will be built

Sub-surface investigations carried out in support of the design studies indicate that little ground ice exists at the proposed location of the mill and ancillary facilities. The investigations indicate that the depth of overburden is generally less than 2 m thick. Intact bedrock was generally encountered within 3.1 m of the ground surface (Golder Associates Ltd. 2001).

No settlement is expected

During operations, some warming of the bedrock under the structures is expected as a result of heat transfer from these facilities. As no massive ground ice was encountered during the investigations, it is expected that this warming will not result in noticeable settlement of any of the structures, since they are constructed on intact bedrock.

Buildings will be removed and the ground will freeze, but the depth of the active layer may change

On closure of the Snap Lake Diamond Project, all structures will be removed, foundations will be removed to 1 m below the natural grade and the site regraded. As noted above in the discussion on roads and airstrip, the presence of fill materials will result in a change in the thermal properties of the site. Based on past experience at other mines in permafrost areas, and modelling completed for the north pile, the ground under structures is expected to freeze once the structures are removed. An active layer will develop through the fill materials to be placed over the sites and likely into the bedrock. As a result of the presence of the fill materials, the absorption of radiation may be higher than under pre-development conditions and hence, the depth of the active layer which will develop may be greater than the pre-development active layer. The depth of the active layer will depend on the depth and thermal conductivity of fill materials placed at these locations.

Underground Mine

The analysis is based on literature and experience

No thermal modelling was completed to determine the impact of the underground mine on the ground thermal regime. The impact analysis is discussed in terms of past experience, a brief review of literature on the topic, and the results of the thermal modelling completed for the north pile.

No massive ground ice was identified

During the development of the underground mine for the advanced exploration program, a ramp was excavated from surface. The upper portion of the underground workings is excavated through permafrost. As noted previously, during investigations for the mill and ancillary facilities, no massive ground ice was noted. Similarly, no massive ground ice was noted during development of the ramp.

The thawed ground around mine openings will freeze on closure

Some warming of the ground surrounding the ramp and the ventilation raises in the permafrost zone is expected as a result of the movement of warm air from the mine to the surface. Upon closure of the mine, it is anticipated that the ground surrounding these openings will freeze once the workings are sealed and the movement of warm air stops. In areas of disturbance around the mine openings, the ground thermal regime will be changed from the pre-development conditions. However, the ground is expected to freeze and an active layer will develop on an annual basis. The depth of the active layer may vary from the pre-development conditions.

10.2.2.5.4 Residual Impact Classification

Impacts will occur during the project (26 years)

The results of the impact analysis indicate that the mine, mill, and ancillary structures will have some impact on the ground thermal regime in the medium-term (26 years). Upon closure of the facilities, heat will no longer be added and the ground thermal regime is expected to return to a frozen condition. However, because the depth of the active layer will be altered where the subsurface materials have been altered (*e.g.*, fill has been added), the impact is considered irreversible. The north pile will be completely frozen within about two years after cessation of deposition activities and an active layer will develop in the deposited processed kimberlite. The environmental consequence is low to moderate, but the impacts are limited to locations within the LSA.

Probability of occurrence is high

The probability of occurrence of disturbance to the ground thermal regime as a result of development of the Snap Lake Diamond Project is high given the fact that any changes to the surficial materials as a result of removal of natural overburden or placement of fill material may substantially change the thermal conductivity of the near surface profile within the area of disturbance. Although this disturbance is predicted to continue far into the future, the level of confidence in the prediction is high. The fill materials will not be removed except by erosion or weathering processes and are, therefore, considered irreversible.

Table 10.2-9 Classification of Residual Impacts to the Ground Thermal Regime

Ground Thermal Regime	Direction	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Environmental Consequence
Roads and airstrip	negative	low	local	short-term	low	irreversible	low
Mill and ancillary facilities	negative	low	local	medium-term	high	irreversible	moderate
Underground mine	negative	low	local	medium-term	high	irreversible	moderate
North pile	negative	low	local	medium-term	high	irreversible	moderate

10.2.2.6 Key Question GT-5: What Impacts Will the Presence of Ground Ice Have on the Stability of Containment Structures?

10.2.2.6.1 Linkage Analysis

Quantities of ground ice that could be a concern were not found in north pile area

Sub-surface investigations have been carried out in the area of the proposed north pile (Golder Associates Ltd. 2001). The purpose of these investigations was to obtain an indication of the sub-surface conditions in the area of the proposed north pile and to identify any areas of substantial ground ice. During the investigations, the maximum depth of overburden encountered was 5.9 m with an average depth of less than 2 m over bedrock. No zones containing sufficient ground ice to affect the infrastructure upon thawing were encountered during the investigation.

Foundation preparation will be carried out

Based on the results of the investigations, design parameters were developed for the containment structures. In general, prior to construction of any fills for the containment structures, the foundation area will be prepared. This preparation will include removal of all organic and mineral soils down to the bedrock surface. Highly fractured bedrock which contains substantial quantities of ground ice will also be removed. The initial embankment construction will then be completed on this prepared foundation.

Linkage is invalid

Because of these reasons, the link between the presence of ground ice and the stability of containment structures is considered invalid and no further impact assessment is necessary.

10.2.2.7 Key Question GT-6: What Impacts Will Freeze-back of the North Pile Have on Surface Water Quality?

10.2.2.7.1 Linkage Analysis

The north pile will contain 4.5 million m^3 of pore water

The development of the north pile will result in approximately 9 million m^3 of processed kimberlite being deposited. The processed kimberlite deposited will contain approximately 4.5 million m^3 of pore water. Some of this processed kimberlite will remain unfrozen for a period of time after deposition. As this portion freezes, some of the contained pore water may be expelled from the pore spaces.

Pore water will be collected and treated

During operation and closure, all pore water expelled from the processed kimberlite will be collected either in a system of perimeter ditches or in temporary sedimentation ponds within the north pile footprint. This water will all be directed to the water treatment plant for treatment.

The north pile will freeze within two years of closure

Thermal modelling of the north pile indicates that the entire pile will be frozen within two years after cessation of deposition of processed kimberlite. After this time, an active layer will develop near the surface of the pile on an annual basis. Provided the perimeter collection system is maintained for this period, no further pore water expulsion should occur as a result of freeze-back of the north pile.

Linkage is invalid

Because of these reasons, the link between the freeze-back of the north pile and water quality is considered invalid.

10.2.2.8 Key Question GT-7: What Impacts Will Climate Change Have on the Development?

10.2.2.8.1 Linkage Analysis

The north pile would be stable if it thawed

Climate change could result in thawing of permafrost should temperatures rise sufficiently. Stability analysis carried out on the north pile containment structures using strengths appropriate to thawed material indicate that the pile would be stable under both static and pseudo-static (dynamic/ earthquake) loading conditions.

Porewater from the north pile would reach surface waters if the pile thawed in post-closure

Thawing of the permafrost could lead to further consolidation of the processed kimberlite which would ultimately lead to additional expulsion of pore water. During the operating period, and implementation of closure measures, pore water would be collected either internal to the north pile or in the perimeter collection ditches. Post closure, thawing of the permafrost would result in pore water being discharged directly to surface water courses.

Thawing of permafrost would have minimal effect on infrastructure

The site roads and airstrip will be constructed of non-frost susceptible fill materials. The fill materials will be placed either directly on bedrock or on mineral soils with little or no ground ice. Thawing of the permafrost will have minimal impact on this infrastructure.

Thawing would not affect the piles

The mill and ancillary facilities will be founded either on piles socketed in bedrock or on spread footings on bedrock or engineered fills. These structures will be removed on closure of the mine. Dams 1 and 2 (associated with the water management pond) are founded on bedrock. Therefore, climate change will have no impact on these facilities.

The linkage between global warming and effects on the project is invalid

The linkage between impacts of changes due to global warming on the project is not valid because the north pile has been designed to be stable if the pile material is unfrozen; site roads and the airstrip are constructed of non-frost susceptible fill; and the mill and ancillary facilities are not supported by permafrost surfaces. The water management pond retention dikes are founded on bedrock. If the ground thaws, increased seepage from the water management pond is expected. The long-term effect of global warming, however, is not likely to cause this impact during the operation period when the water management pond is in use. If the north pile thaws during post-closure, pore water would seep to surface waters. This linkage is valid, but it is addressed appropriately in water quality (Section 9.4).