# SECTION 6.2

# PHYSICAL ENVIRONMENT

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## 6.2 PHYSICAL ENVIRONMENT

The subsections in this Section detail the effects assessments for aspects of the physical environment that may be affected by Project construction, operation and closure, and which was screened in as VCs by the scoping process (see Section 6.1). These VCs include terrain, soils and geology; climate and air quality; noise; hydrology; navigable waters (as defined by the *Navigable Waters Protection Act*); groundwater resources, surface water quality (including sediments), and environmental health. The respective Section references are the following:

| | | | |
|---|---|---|---|
| Terrain, Soils & Geology | 6.2.1 | Navigable Waters | 6.2.5 |
| Climate & Air Quality | 6.2.2 | Groundwater Resources | 6.2.6 |
| Noise | 6.2.3 | Surface Water Quality | 6.2.7 |
| Hydrology | 6.2.4 | Environmental Health | 6.2.8 |

### 6.2.1 Terrain, Soils and Geology

This Section presents the effects assessment for the terrain, soil and surficial geology components of the Shore Gold Star-Orion South Diamond Project (the Project).

#### 6.2.1.1 Introduction

The purpose of this Section is to:

- describe the valued components (VCs) for terrain, soils and geology;
- evaluate the potential interactions among Project components;
- identify potential effects arising from those interactions;
- identify avoidance and mitigation measures;
- rate residual effects based on effective application of mitigation measures; and
- identify and assess potential cumulative environmental effects (CEE) from other current or future land use activities.

#### 6.2.1.2 Scoping and Effects Identification

The approach to issues scoping is presented in Section 6.1.4.2 (in Section 6.1, Overview and Methods). Effects on soils and landscapes can result from the Project due to site clearing, soil stripping and stockpiling, construction activities, reclamation activities, spills and leaks, and emission/deposition of dust and various chemicals. Issues relating to soil, terrain and surficial geology resources were initially identified for detailed examination in this impact assessment, as follows:

- loss of soil cover;
- changes to the quality of the soil resource, particularly changes in physical and chemical soil attributes;
- change in soil moisture regime;
- changes to the quantity of the soil resource, particularly in terms of topsoil loss;
- changes to terrain (surface geologic material and surface expression) through alteration of material composition, topography, slopes and drainage patterns;
- changes to land capability for forestry;
- changes to land capability for agriculture; and
- loss of unique soil and landscape features.

Potential issues were identified by comparing the Project phases and components or activities within phases (from Table 6.1-1 of Section 6.1.1, Assessment Methods Introduction) that could result in potential to soil, terrain and surficial geology resources, as presented in Table 6.2.1-1. Each issue was then assessed and validated in terms of whether or not it would result in a residual effect, based on evidence from other similar assessments, regulatory requirements or guidelines (e.g., Guidelines for Northern Mine Decommissioning and Reclamation, Saskatchewan Ministry of Environment (SMOE) 2008), and professional judgment of soil and landscape sensitivity.

*Table 6.2.1-1: List of Project Components and Activities*

| Potential Effect | Project Phase | Component/Activity [1] | Valued Component | Effect Confirmation/ Validation |
|---|---|---|---|---|
| Removal of soil profiles ( A, B, LFH and O horizons[2]) from the landscape by excavation or burial | Construction | Surface infrastructure installations<br>Water source and waste water management<br>Processing plant and facilities<br>Solid waste management<br>Water management reservoir | Soil cover<br>Agricultural capability<br>Forestry capability<br>Unique soil or terrain | Valid |
| | Construction, Operations | Land clearing, excavating and grading | | Valid |
| Admixing (by overstripping, mixing during soil transport and placement) | Construction | Soil and till salvage, handling and storage | Soil quality | Valid |
| | Closure and Decommissioning | Facility closure and reclamation<br>Internal access roads decommissioning and reclamation | | Valid |
| Burial of topsoil (by incomplete salvage, spillage and trampling) | Construction | Soil and till salvage, handling and storage | Soil quality<br>Soil quantity | Valid |
| | Closure and Decommissioning | Facility closure and reclamation<br>Internal access roads decommissioning and reclamation | | Valid |
| Soil compaction (by machinery, equipment) | Construction | Access development and transportation/traffic | Soil quality | Valid |
| | Construction, Operations | Mining equipment | | Valid |
| | Construction, Operations | Erosion control and soils/till stockpiles management | | Valid |
| | Construction, Operations, Closure and Decommissioning | Machinery and Construction equipment | | Valid |
| | | Transportation and access | | Valid |
| | Closure and Decommissioning | Monitoring and maintenance of water discharge flow and quality<br>Monitoring and maintenance of soil/terrain stability and vegetation<br>Monitoring and maintenance of fine and coarse processed Kimberlite<br>Monitoring and maintenance of overburden and rock storage piles | | Valid |
| | | Processed Kimberlite Containment Facility and Coarse PK pile decommissioning | | Valid |
| | | Site rehabilitation/re-vegetation | | Valid |

| Potential Effect | Project Phase | Component/Activity [1] | Valued Component | Effect Confirmation/ Validation |
|---|---|---|---|---|
| Chemistry changes during storage (pH, organic matter, nutrients) | Construction, Operations | Soil and till salvage, handling and storage | Soil quality | Minor |
| Soil acidification due to seepage of potentially acidic substances from PKCF to adjacent soils | Construction, Operations, Closure and Decommissioning | Overburden and rock storage pile, Coarse PK pile and PKCF | Soil quality | Minor |
| Soil contamination by spills and leaks | Construction, Operations, Closure and Decommissioning | Fuels and hazardous materials storage and management | Soil quality | Minor |
|  | Closure and Decommissioning | Hazardous substances removal |  | Minor |
| Dust generation and trace element deposition on adjacent soils | Construction, operations | Pit excavation and development | Soil quality | Valid |
|  | Closure and Decommissioning | PKCF decommissioning |  |  |
| Acid deposition on soils in surrounding area | Operations | Processing Plant | Soil quality | Minor |
|  | Construction, Operations, Closure and Decommissioning | Emissions and dust generation (traffic, equipment operation and movement) |  | Minor |
| Erosion of exposed soil, stockpiles, sloping areas | Construction | Soil and till salvage, handling and storage | Soil quality<br>Soil quantity | Valid |
|  | Closure and Decommissioning | Facility closure and reclamation<br>Internal access roads decommissioning and reclamation<br>Processed Kimberlite containment decommissioning |  | Valid |
| Changes in soil drainage regime in areas adjacent to disturbed area | Construction, Operations, Closure and Decommissioning | Surface and groundwater management | Soil moisture regime | Valid |
|  | Operations | Waste water management and drainage control<br>Water supply and distribution |  | Valid |
|  | Closure and Decommissioning | Stream drainage restoration |  | Valid |

| Potential Effect | Project Phase | Component/Activity [1] | Valued Component | Effect Confirmation/ Validation |
|---|---|---|---|---|
| Geological material redistribution and alteration of topography by excavation, cut, fill, and development of waste piles | Construction | Surface infrastructure installations<br>Water source and waste water management<br>Processing plant and facilities<br>Solid waste management<br>Water management reservoir | Surficial material distribution and topography<br>Unique soil/terrain | Valid for terrain and surficial material distribution<br>Not valid for unique soils and terrain |
| | Construction, operations | Pit excavation and development<br>Land clearing, excavating and grading<br>PKCF<br>Coarse PK pile | | |
| | Construction, Operations, Closure and Decommissioning | Overburden and rock storage pile, Coarse PK pile and PKCF<br>Overburden management | | |
| Effect on Project issue: seismic activity could lead to change in geology/ terrain, Project damage | Construction, Operations, Closure and Decommissioning | Seismic activity | Surficial material distribution and topography | Minor |
| Effect on Project issue: landscape instability (landslides, slumps) could lead to change in geology/ terrain, Project damage | Construction, Operations, Closure and Decommissioning | Seismic activity | Surficial material distribution and topography | Valid |

**Note:** [1] from Project Description. [2] A horizon: topsoil horizon; B horizon: the upper subsoil horizon (below the A horizon); LFH: leaf litter layer; O: organic soil layer; see Glossary for detailed soil horizon definition.

#### 6.2.1.3 Effects Confirmation

The purpose of Table 6.2.1-1 is to assist assessment of each of the potential issues relevant to soils, terrain, and surficial geology and to determine the validity of the issue after applying mitigation measures. The issues listed above considered to be valid require further analysis to determine the possibility of a residual effect after mitigation. This approach to pathway validity is based on scientific knowledge and the assessment of similar developments, or if there was a relatively high level of uncertainty due to unique circumstances or dissimilarity from other projects.

***Minor or Not Valid Effects***

The following discusses the reasons for categorizing some potential issues or effects as minor or not valid. Minor and not valid effects are initial issues identified as potentially having an effect on soils, terrain or surficial geology, but which upon further analysis have no actual effect, or potentially have an effect small enough to be considered within natural variation, or have an effect that is readily mitigated. Further assessments are not carried out on the minor or not valid issues.

*Loss of Unique Soils or Terrain*

Certain landscapes might be considered to be unique within a local, regional or provincial context. Examples are eskers, permafrost soils, springs, and patterned fens. Some landscape features may be of cultural importance; however, these are considered in the Archaeology and Heritage Resources assessment (Section 6.4.6). These unique cultural features are generally recognized at the baseline description phase but none were identified in the soil and terrain baseline assessment, and are therefore not examined further.

*Soil Changes During Storage*

Many changes can occur in soils upon salvaging and stockpiling. These can include changes in acidity, oxidation-reduction conditions, microbial activity, and soil physical properties such as aggregate structure. Based on Thurber Consultants Ltd. et al. (1990) soil storage does not appear to have any severe and long-term effects on topsoil quality. Chemical changes can be rectified with amendments, such as fertilizers and manure, applied at time of reclamation. Physical changes are more severe during the salvaging and handling of topsoils. Microbial populations have been shown to revert to pre-disturbance levels with time. To maintain quality, broad, shallow stockpiles are preferable to deep stockpiles. Based on the literature review, it is concluded that any stockpiling of topsoils during the Project will likewise result in limited changes, and further assessment is not warranted for this Project.

*Acid Deposition Effects on Soils*

It is indicated in the Climate and Air Quality Assessment (Section 6.2.2) that potential acidic deposition was not assessed because Project sources would produce minor levels of nitrogen and sulphur oxides. Consequently, the levels of potential acid input to soils are predicted to be minor with minimal or no effects. 'Minimal effect' of acid deposition refers to any changes in soil acid chemistry parameters remaining within levels of natural variation over the life of the Project.

*Soil Acidification Due to Seepage of Acidic Substances from Processed Kimberlite Containment to Adjacent Soils*

Seepage from processed kimberlite containment could result in acidic substances leaking to adjacent soils, resulting in soil acidification with related effects such as aluminum and other toxic element solubilization. Most soils in the local study area (LSA) are sandy Brunisols with low acid buffering capacity and as such are rated as being highly sensitive to acidic inputs (Wiens et al. 1987). However, studies of acid-base accounting on samples of kimberlite rock from the Project have shown that the rock is not acid generating and will have no potential to result in acid mine drainage (Section 5.2.3, Metal Leaching and Alkaline/Acid Rock Drainage Geochemistry). Consequently, potential soil acidification by acid mine drainage is not considered to be a valid effect.

*Contamination of Soils by Spills and Leaks*

Spills and leaks, should they occur, are expected to be low in frequency and to be contained within small areas, resulting in limited area of affected soil (either on-site or off-site). Furthermore, these occurrences are preventable by following protocols for storage, transport, and use of chemicals, including fuels and other hydrocarbons. Systems will be in place to prevent and handle spills (see Section 7.2, Environmental Risk Management). These events are expected to be infrequent and localized, and are therefore considered as a minor effect with no further assessment warranted.

*Seismic Effects on Terrain and on the Project*

Seismic activity can result in displacement and upheaval of surficial sediments and underlying bedrock, in initiating slides and slumps in sensitive terrain, in destructive effects on Project excavations and facilities, and in potentially unsafe situations. The 2005 National Building Code of Canada (Natural Resources Canada 2010) seismic hazard maps show that the peak ground disturbance with 2% probability of exceedance in 50 years (0.000404 per annum) for firm ground conditions is 0.059 g (1 g = 9.8 m/sec$^2$). This can otherwise be stated as probability being 10% for exceedance of peak ground acceleration of <0.2 m/s$^2$, on a 475 year return period. These seismic parameters characterize the region of lowest seismic hazard in Canada.

Earthquakes of magnitude up to about 5.5 have been recorded in Saskatchewan, although all of these were located in the southern and south-western parts of the province (Gendzwill 2006).

Based on the above Geological Survey of Canada (GSC) probability assessments and the historical information (Gendzwill 2006), it is considered improbable that seismicity will have an effect on the Project; therefore, no further assessment was undertaken. With respect to local seismicity due to blasting operations, unstable terrain and mine walls could be affected. However, these issues will be mitigated through geotechnical design, mine operation and safety protocols, as defined within the Project description.

### *Confirmed or Valid Issues*

The following potential effects were determined to be valid based on the discussion below. These potential effects were considered in relation to Valued Components (VCs) in the assessment.

*Effects on Soil Distribution/Loss of Soil Cover*

Site clearing and construction of facilities will result in loss of soil cover. Project decommissioning will return soil cover, albeit with different physical and chemical characteristics (e.g., horizon sequence) than those existing prior to development. The goal is to return the functionality of soil cover to achieve the objective of “restoring the mining site to a condition that is similar to the conditions that existed prior to disturbance by mining operations” (SMOE 2008). Based on the Project description, there is potential for loss of soil area to other landscape features, and further examination is carried out to assess the effect.

*Effects on Soil Quantity*

Soil quantity can be affected in two ways:

- soil loss due to soil materials being mixed or buried during soil salvage and stockpiling, as well as during reclamation; and
- soil loss by wind and water erosion during soil salvage, stockpiling, storage, and reclamation.

These effects are predictable but not readily quantifiable, and further assessment is therefore carried out.

*Effects on Soil Quality*

Various Project activities can result in changes to soil chemical and physical properties. Soil salvage, stockpiling, machinery operation, and traffic can result in soil admixing, compaction and chemical changes. Wind transport of dust arising from excavating, blasting, and traffic can settle on soils in adjacent lands, resulting in changes in soil chemistry. These effects are likely to occur, but cannot be predicted quantitatively. They are consequently discussed and assessed further in this analysis.

*Effects on Soil Moisture Regime*

A change to drier moisture regimes in soils in the LSA and possibly the RSA could result from lowering of groundwater levels due to pit dewatering. This potential effect may be caused by a linkage between the groundwater and soil, and may continue to the vegetation components of the landscape. Organic soils (developed in bogs and fens), marshes and shallow open water bodies, which have direct linkage to groundwater, could be affected, as could upland soils as a result of effects on the unsaturated zone in soils. Localized effects such as interruption of drainage by roadways and other infrastructure may also occur.

*Effects on Surficial Material Distribution/ Effects on Topography*

Site construction will involve clearing, removal and contouring of Quaternary and Recent sediments, such that these materials will be redistributed over the landscape. Commonly occurring surficial materials (Quaternary and Recent sediment) will be contoured, removed and used for fill. The overburden and rock storage pile, Coarse PK pile and the PKCF will be developed in portions of upland areas. These features will have landform and drainage characteristics differing from the pre-disturbance terrain. The Project effects thus not only involve removal of terrain materials but addition of new terrain features. These Project changes are assessed further in terms of how they affect the landscape.

*Land Capability for Forestry/ Soil Capability for Agriculture*

Ratings for forestry and agricultural capability are based on the Canada Land Inventory (CLI) rating systems. These are based on soil quality as well as on landscape features, particularly slope of the land. While other issues such as terrain distribution and soil quality are assessed individually, elements of these are combined in the CLI system. As such, both forestry and agriculture are assessed in addition to the individual soil and terrain issues.

*Natural Hazards/Terrain Stability*

Natural hazards are addressed in the sense of effects of the environment on the Project. Major natural hazards include the movement of unstable ground. Natural seismicity was identified previously as being highly improbable and is not discussed further. Terrain stability is identified as an issue for further discussion because of the large areas of steep slopes associated with valleys of tributaries of the Saskatchewan River.

### 6.2.1.4 Valued Components

The valid issues identified above constitute the soil and terrain VCs. A number of sub-issues can be considered as VC indicators. For example, soil admixing, contamination, and compaction are assessed separately, but together they define the soil quality VC. In the effects analysis, the highest residual effect in any one indicator confers that same level of effect to the entire VC. Based on the preliminary VCs listed previously, and on the above confirmation analysis, the valid VCs in this assessment are:

- surficial material distribution and topography;
- soil cover and distribution;
- soil quality;
- soil moisture regime
- soil quantity;
- terrain stability
- land capability for forestry; and
- soil capability for agriculture.

Several properties of the individual soil and terrain types in the LSA were considered in the evaluation of key impact issues. These include:

- properties that contribute to susceptibility to chemical or physical degradation (e.g., soil texture, drainage, organic matter content);
- properties considered important in spill remediation (e.g., cation exchange capacity, organic matter content; texture; drainage); and
- properties that may be considered problematic for mitigation or reclamation (e.g., thin topsoil horizons, very coarse or very fine textures, impeded drainage, high water tables, frozen layers).

#### 6.2.1.5 Effects Assessment

The effects assessment for each VC is described below.

##### *Effects on Terrain and Surficial Material Distribution*

Two components were identified in the issue identification process (Table 6.2.1-1), namely: 1) site clearing, excavation, cut and fill and other disturbances of Quaternary and Recent sediments and bedrock, which will result in redistribution of materials; and, 2) excavation, overburden management, and production of processed kimberlite, which will result in changed topography through excavation and waste pile construction. A related effect concerns terrain stability, which has two aspects: 1) having potential to change terrain due to Project-induced land sliding; and, 2), inherent sensitivity which could result in land sliding and affect Project operations and safety.

Disturbance of geological materials will extend into pre-Quaternary formations and kimberlitic materials. The overall effects on geology, including the deeper formations as well as effects of removal of aquitards are discussed in Section 6.2.6 (Regional Geology and Hydrogeology).

The effects of the Project on material distribution are partly presented quantitatively, based on geographic information system spatial analysis of different surficial geological types disturbed by the Project. The terrain map (Figure 5.2.2-1 in Section 5.2.2, Soils and Terrain) was overlain by the Project footprint to calculate the areas of different terrain types affected by the Project. Some components are discussed qualitatively because some effects analyses can only be assessed in terms of relative risk or sensitivity of specific soil and material properties (e.g., wind erosion risk is based on soil properties, and also on frequency of wind events) .

#### *Redistribution of Materials*

Redistribution of materials in the LSA and the redistribution of materials in the access corridor in the RSA are described below.

#### Redistribution in the LSA

Removal and disturbance of the surficial sediments will occur during the site preparation and infrastructure development phase of the Project, as well as during the operations phase. The development of this Project will cause direct effects to most of the terrain units within the LSA. The areal extent of terrain unit disturbance is summarized in Table 6.2.1-2. The total disturbance area is expected to be 3,882.2 ha, which represents 34.1% of the LSA. The largest areas of terrain units that will be disturbed, expressed as percent of the LSA, are as follows: eolian (E) (12.8%), Fluvial-Lacustrine/Eolian complex (12.0%), Colluvium-Organic complex (2.1%) and Fluvial-Lacustrine (2.0%). All other terrain units as well as previously disturbed lands will have 0 to 1% disturbance due to the Project.

Project components such as the site facilities, camp, sewage lagoon and roads (ROW) will not result in major, lasting disturbances to the landscape. As part of reclamation, this disturbed landscape will be contoured such that slopes and runoff will be compatible with that of the surrounding terrain. Some other Project components will result in permanent changes to topography within the LSA Landscape, as discussed in the following section. In terms of overall material properties and distribution, redistribution and contouring during reclamation is expected to result in a landscape with form and functionality compatible with the surrounding terrain. The overall direction of impact is therefore considered to be neutral.

#### Loss of Upland Terrain

Pit excavation and development will result in terrain disturbance without return to original conditions. Replacement of terrain by water bodies will occur through development of the Star and Orion South end pit lakes. When the Star Pit development ceases, it is proposed that it be filled in with materials from the Orion South pit and with fine PK. Approximately half of the excavation will remain at closure as a lake (Star Pit Lake). The Orion South pit for the most part will not be filled in, and will remain as Orion Pit Lake upon closure. Smaller features such as the Water management reservoir and the Polishing Pond will be returned to a small water body and drainage similar to the pre-existing condition. The water bodies represent a loss of terrestrial area in the LSA. Table 6.2.1-3 shows that the map units that will be replaced with water bodies consist mainly of Fluvial-Eolian, Eolian and Colluvium-Organic complex. The terrain area affected is about 5.9% of the LSA (3.5% due to Orion South Pit Lake, plus an estimated half of the 4.8% of the LSA occupied by the partially filled-in Star pit.

The soil area replaced by end pit lakes represents a moderate magnitude of change within the LSA. The magnitude in relation to the RSA is low (0.5% of the RSA affected). The effect is adverse, local, continuous during the life of the Project, and beyond long-term (or permanent).

***Table 6.2.1-2: Change in Surficial Material in the Local Study Area***

| Dominant Surface Material | Terrain Unit | Baseline Terrain Unit (ha) | Baseline Terrain Unit (% of LSA) | Project Disturbance (ha) | Project Disturbance (% of LSA) |
|---|---|---|---|---|---|
| Alluvium (Av) | Av | 258.8 | 2.1 | - | 0.0 |
| | Av – O | 39.0 | 0.3 | - | 0.0 |
| Colluvium (C) | C | 476.4 | 3.9 | 11.9 | 0.1 |
| | C – O | 1,694.3 | 13.9 | 258.0 | 2.1 |
| Eolian (E) | E | 3,305.9 | 27.1 | 1561.1 | 12.8 |
| Fluvial – Lacustrine (FL) | FL | 728.7 | 6.0 | 238.3 | 2.0 |
| | FL – E | 3187.9 | 26.1 | 1467.0 | 12.0 |
| | FL – GLs | 465.3 | 3.8 | 53.6 | 0.4 |
| Sandy Glaciolacustrine (GLs) | GLs | 208.0 | 1.7 | 24.8 | 0.2 |
| | GLs – FL | 314.6 | 2.6 | 6.3 | 0.1 |
| Silty Glaciolacustrine (GLsi) | GLs – Glsi | 95.9 | 0.8 | 0 | 0.0 |
| | GLsi – GLs | 162.6 | 1.3 | 0 | 0.0 |
| Organic (O) | O | 227.1 | 1.9 | 34.0 | 0.3 |
| | O – FL | 165.4 | 1.4 | 3.9 | 0.0 |
| Organic Veneer (Ov) | Ov | 164.3 | 1.3 | 62.8 | 0.5 |
| | Ov – FL | 64.7 | 0.5 | 0.5 | 0.0 |
| Water | Water | 407.4 | 3.3 | 1.2 | 0.0 |
| Baseline Disturbances | Access | 129.2 | 1.1 | 61.5 | 0.5 |
| | Open Site | 12.9 | 0.1 | 10.1 | 0.1 |
| | Other Disturbance | 87.5 | 0.7 | 76.5 | 0.6 |
| | Reclaimed Site | 18.2 | 0.1 | 9 | 0.1 |
| | Gravel Pit | 0.4 | 0.0 | 0 | 0.0 |
| | Industrial | 1.1 | 0.0 | 1.1 | 0.0 |
| | Tower Site | 2.0 | 0.0 | 0.5 | 0.0 |
| | Well Site | 0.1 | 0.0 | 0.1 | 0.0 |
| ***Baseline Subtotal*** | | ***12,217.7*** | ***100.0*** | ***3882.2*** | ***31.8*** |

| Dominant Surface Material | Terrain Unit | Baseline Terrain Unit (ha) | Baseline Terrain Unit (% of LSA) | Project Disturbance (ha) | Project Disturbance (% of LSA) |
|---|---|---|---|---|---|
| Project Disturbances | Camp | - | - | -0.1 | 0.0 |
| | Orion South Pit | - | - | -427.5 | -3.5 |
| | Star Pit | - | - | -588.8 | -4.8 |
| | Coarse PK | - | - | -179.9 | -1.5 |
| | PKCF | - | - | -513.6 | -4.2 |
| | Waste Rock | - | - | -2008.3 | -16.4 |
| | Conveyor | - | - | -32.8 | -0.3 |
| | Diffuser | - | - | -1.2 | -0.0 |
| | Explosives | - | - | -0.04 | 0.0 |
| | Pipeline | - | - | -3.0 | 0.0 |
| | Polishing Pond | - | - | -1.2 | -0.0 |
| | ROW-LSA | - | - | -79.6 | -0.7 |
| | Runoff Pond | - | - | -6.2 | -0.1 |
| | Sewage Lagoon | - | - | -2.9 | 0.0 |
| | Site Facilities | - | - | -37.0 | -0.3 |
| | Well | - | - | -0.1 | 0.0 |
| ***Project Disturbance Subtotal*** | | ***-*** | ***-*** | ***3,882.2*** | ***(34.1)*** |
| **Overall Total** | | **12,217.7** | **100.0** | **0.0** | **0.0** |

*Table 6.2.1-3: Terrain Units Affected by the Overburden and Rock Storage Pile, Coarse PK Pile, PKCF and the Orion South and Star Pits*

| Terrain Unit | Overburden and Rock Storage Pile Terrain Unit Area (ha) | Coarse PK Pile Terrain Unit Area (ha) | PKCF Terrain Unit Area (ha) | Orion South Pit Terrain Unit Area (ha) | Star Pit Terrain Unit Area (ha) [1] |
|---|---|---|---|---|---|
| C [2] | 0.5 | - | | | 10.3 |
| C - O | 93.9 | - | 1.3 | 7.6 | 143.3 |
| E | 713.9 | 166.4 | 359.7 | 94.0 | 167.5 |
| FL | 145.8 | - | 4.7 | 52.4 | 37.1 |
| FL - E(FL-FE) | 970.1 | 13.5 | 117.6 | 272.7 | 168.6 |
| FL GLs | 42.3 | - | 2.2 | - | 6.2 |
| GLs | 0 | - | 0 | - | 22.6 |
| GLs - FL | 0 | - | 0 | - | 3.9 |
| O | 33.6 | - | 0 | - | 0 |
| O - FL | 0 | - | 0 | 0.8 | 0 |

| Terrain Unit | Overburden and Rock Storage Pile Terrain Unit Area (ha) | Coarse PK Pile Terrain Unit Area (ha) | PKCF Terrain Unit Area (ha) | Orion South Pit Terrain Unit Area (ha) | Star Pit Terrain Unit Area (ha) [1] |
|---|---|---|---|---|---|
| Ov | 8.2 | - | 28.1 | - | 29.3 |
| **Total Area** | **2008.3** | **179.9** | **513.6** | **427.5** | **588.8** |
| **Total (% of LSA)** [3] | **16.4** | **1.5** | **4.2** | **3.5** | **4.8** |

**Notes:** [1] About half of the area of Star Pit will remain as Star Pit Lake at closure.
[2] See Table 6.2.1-2 for full names of terrain unit abbreviations.
[3] LSA area = 12,217.7 ha

### Access Corridor in the RSA

An access corridor right-of-way (ROW) encompassing a roadway, communication lines and a natural gas pipeline passing through the FalC forest (i.e., the RSA) is proposed for construction in association with the Project development. It would extend from Highway 55 near Smeaton south to the current bridge at the Whitefox River. The road will replace an existing road to the site, which will be straightened and improved to a paved surface. The portions of the existing road that are abandoned will be reclaimed.

The access corridor will pass through a number of terrain types, as indicated in Table 6.2.1-4. The table compares the ROW areas in the LSA and RSA; while the portion in the RSA represents only the ROW for the main access road, the portion within the LSA comprises a portion of the main access road along with local access roads within the Project area. The ROW area (i.e., access road area) totals 149.4 ha, with 79.7 ha within the LSA, and the remaining 69.7 ha in the RSA.

***Table 6.2.1-4: Right-of-Way Disturbance in the Regional Study Area***

| Dominant Surface Material | Terrain Unit | Terrain Unit Area in RSA (ha) | LSA and RSA ROW Area (ha) | LSA ROW Area (ha) | RSA ROW Area (ha) | RSA ROW Area (% of RSA) [1] | RSA ROW Area (% of Map Unit) |
|---|---|---|---|---|---|---|---|
| Colluvium (C) | C | 1,295.4 | 0.6 | 0.6 | - | - | - |
|  | C - O | 2,431.3 | 13.6 | 13.6 | - | - | - |
| Eolian (E) | E | 38,377.2 | 43.7 | 38.0 | 5.7 | <0.01 | <0.1 |
|  | E - GLs | 2,579.7 | 9.7 | - | 9.8 | 0.01 | 0.4 |
| Fluvial – Lacustrine (FL) | FL | 15,477.0 | 44.1 | 1.2 | 43.0 | 0.04 | 0.3 |
|  | FL - FE | 18,583.3 | 23.0 | 23.0 | - | - | - |
|  | FL - GLs | 6,375.0 | 0.9 | 0.9 | - | - | - |
| Sandy Glaciolacustrine (GLs) | GLs | 1,299.2 | 9.2 | 0.9 | 8.1 | 0.01 | 0.6 |

| Dominant Surface Material | Terrain Unit | Terrain Unit Area in RSA (ha) | LSA and RSA ROW Area (ha) | LSA ROW Area (ha) | RSA ROW Area (ha) | RSA ROW Area (% of RSA) [1] | RSA ROW Area (% of Map Unit) |
|---|---|---|---|---|---|---|---|
| | GLs - FL | 6,624.0 | 0.8 | 0.8 | - | - | - |
| Organic (O) | O - FL | 1,274.8 | 0.2 | 0.2 | - | - | - |
| | O - GLs | 1,143.1 | 3.1 | - | 3.1 | <0.01 | 0.3 |
| Organic Veneer (Ov) | Ov - FL | 64.7 | 0.5 | 0.5 | - | - | - |
| **Total** | | 95,524.7 [1] | 149.4 | 79.7 | 69.7 | 0.05 | - |

**Notes:** [1] RSA area = 132,768.7 ha (the sum of the terrain unit areas in this table does not equal the total RSA area because some units are not crossed by the ROW).

### *Effect on Topography Due to New Terrain Features*

Portions of the current undulating terrain of the LSA will be used to develop large, hill-like piles of overburden and PK materials. Overburden will be composed of Quaternary materials and some shale from the top of the Cretaceous layer. The overburden ranges in thickness from 90 to 130 m and overlies the Star Kimberlite (see Section 5.2.1, Deposit and Local Area Geology). The overburden of glacial sediments consists of surficial sands, some of which have been reworked by eolian activity, underlain by at least two strata of clay sediments, which in turn are underlain by glacial till. The till consists of both clay till and a sandy till. The overburden and rock storage pile will therefore consist of a mixture of these sediments. It will also include some shales and sandstones of the Lower Colorado group; these will be buried under at least 2 m of sandy or glacial till material because they are saline-sodic and would be unsuitable as soil material. Based on the proportions of sand, clay and till expected at the Star pit, approximately 15% of the surface area is expected to have a sandy topsoil texture, approximately 10% of the surface area will have a clay topsoil texture, and due to the predominance of glacial till material, the remainder the surface area will have clay to clay loam topsoil texture (see Section 7.5, Closure and Reclamation Plan).

The overburden and rock storage pile is expected to be 2,008.3 ha in area and up to 45 m high. The resulting topography will thus consist of elevated terrain, which will be contoured to undulating topography, with drainage designed to direct water both to the north and to the south (see Section 7.5, Closure and Reclamation Plan). The overburden and rock storage pile would have slopes no steeper than 4H:1V (see Section 2.6.4, Overburden and Rock Storage).

Other built up features will consist of the Coarse processed kimberlite (Coarse PK) pile and the processed kimberlite containment facility (PKCF). The Coarse PK pile layout design entails a 179.9 ha footprint, final side slopes of 4H:1V, and a maximum pile height of 54 m. The PKCF is planned to be 513.6 ha in area, and to have an ultimate height of 60 m. Maximum slopes will also be 4H:1V.

The anticipated total area of the overburden and rock storage pile, the Coarse PK pile and the PKCF facilities is about 2,701.8 ha. The areas of terrain types that will be replaced by these features are indicated in Table 6.2.1-3. Most of the overburden and rock storage pile area will be returned to a landscape similar that of the surrounding terrain, with the exception that slopes of up to 4H:1V will surround the feature. The sloping sides will at most account for about 20% of the total area of the overburden and rock storage pile, or about 3.3% of the LSA. The PKCF and Coarse PK pile will occupy 4.2% and 1.5% of the LSA, respectively (Table 6.2.1-3). The sum of these percent changes in areas of new topographic features is about 9.0% of the LSA.

The elevated terrain features and the lakes represent very different terrain characteristics as compared to baseline conditions. In particular, the slopes (up to 4H:1V, or 25%) would have relatively higher risk of instability and water erosion as compared to the pre-existing landscape. This risk can be managed through timely revegetation of slopes, and by application of engineered slope stability and erosion control measures, as necessary.

The magnitude of the change (9.0% of the LSA) is moderate. The direction of the change is considered neutral, based on mitigation as indicated above.

### *Natural Hazards/Terrain Stability*

Terrain instability can affect the Project through activity disruption and compromised safety. However, landslide activity can be initiated through Project activities and would thus affect topography and material distribution. Terrain stability mapping completed for the LSA is reported in the Soils and Terrain baseline (Section 5.2.2). Five terrain stability classes were identified based on the parent material type, drainage conditions, slope gradient, and presence of geomorphic processes within a terrain polygon (British Columbia Ministry of Forests 1999). In general, terrain instability and the associated likelihood of landslide initiation increases with slope gradient, moisture content, and the presence of existing instability features. Terrain instability increases as the class increases, with Class 5 having high potential for landslide initiation.

Within the Project footprint, polygons with Classes 4 and 5, which indicate the greatest potential for instability, occupy approximately 99 ha, and less than 1 ha, respectively (Table 6.2.1-5). These ratings reflect the steep gullied slopes leading to the Saskatchewan River. As noted in the Soils and Terrain baseline (Section 5.2.2), terrain stability mapping within the LSA was based on mapping at a 1:30,000 scale. This assessment presents the potential risks of landslide initiation, but site specific, geotechnical evaluation is required for further risk assessment and risk mitigation planning.

The effect is considered adverse, low in magnitude (in terms of area affected), short-term in duration, local, rare and irreversible.

*Table 6.2.1-5:* **Terrain Stability Classes within Disturbance Areas in the LSA**

| Terrain Stability Class [1] | Likelihood of Landslide Initiation | LSA Baseline Area (ha) | LSA Baseline Area (% of LSA) | LSA Disturbance Area (ha) |
|---|---|---|---|---|
| 1 | Negligible | 3,948 | 32.3 | 948.8 |
| 2 | Very Low | 6,066 | 49.6 | 2619.0 |
| 3 | Low | 758 | 6.2 | 55.3 |
| 4 | Moderate | 796 | 6.5 | 98.9 |
| 5 | High | 240 | 2.0 | 0.2 |
| Water | - | 407 | 3.4 | 1.1 |
| Disturbed Land | - | 251 | 2.1 | 158.9 |
| Total | - | 12,218 | 100.0 | 3,882.2 |

**Note:** [1] Adapted from Forest Practices Code of British Columbia (British Columbia Ministry of Forests 1999).

### *Effects on Soil Distribution/Cover*

Site clearing and construction of the Project will result in changed soil distribution. Soil distribution refers to two aspects of soils, namely the types of soil cover that will be affected, and the area or extent of the effect. Soil removal will occur mainly during the construction stage of the Project, but may occur to a small extent during the operations phase as well. The areas of disturbed soil map units in the LSA are presented in Table 6.2.1-6. The analysis is based on the total disturbance area; however, the mine footprint will gradually increase to this total during the operations phase.

The largest area of soil map units that will be disturbed of the total 3,882.2 ha disturbance area (31.8% of the LSA) belongs to the Pine soils, at 27.2% of the LSA (Table 6.2.1-6). Hillwash disturbance represents 2.2% of the LSA, and previously disturbed lands within the Project footprint account for 1.3% of the LSA. Disturbance of each of the other soil map units will be <0.5% of the LSA.

*Table 6.2.1-6: Change in Soil Map Unit Areas in the Local Study area*

| Dominant Soil Association/Complex | Soil Map Unit | Baseline Map Unit Area (ha) | Project Disturbance Area (ha) | Project Disturbance Area (% of LSA) |
|---|---|---|---|---|
| Alluvium | Av | 258.8 | - | - |
| | Av-Wx | 39.0 | - | - |
| ***Total Alluvium Map Units*** | | ***297.8*** | ***0.0*** | ***0.0*** |
| Arbow | Aw | 118.4 | 60.1 | 0.5 |
| | Aw-Mw | 14.2 | 2.7 | <0.1 |
| ***Total Arbow Map Units (mainly Gleysols on various materials)*** | | ***132.6*** | ***62.8*** | ***0.5*** |
| Bowl Bog | Bb | 29.4 | 29.4 | 0.2 |
| | Bb-Fb | 186.5 | 4.6 | <0.1 |
| ***Total Bowl Bog Map Units*** | | ***215.9*** | ***34.0*** | ***0.3*** |
| Bowl Fen | Fb | 11.3 | - | - |
| ***Total Bowl Fen Map Units*** | ***Fb*** | ***11.3*** | ***0.0*** | ***0.0*** |
| Hillwash | Hw | 0.02 | - | - |
| | Hw1 | 7.4 | 0.5 | <0.1 |
| | Hw1-Wx | 233.3 | 46.9 | 0.4 |
| | Hw2 | 45.9 | 10.8 | 0.1 |
| | Hw2-Wx | 395.4 | 95.1 | 0.8 |
| | Hw3 | 115.4 | 0.4 | <0.1 |
| | Hw3-Wx | 783.8 | 115.4 | 0.9 |
| | Hw4 | 307.7 | 0.2 | <0.1 |
| | Hw4-Wx | 281.8 | 0.7 | <0.1 |
| ***Total Hillwash Map Units (Regosols, Brunisols and Luvisols on valley slopes)*** | | ***2170.7*** | ***270.0*** | ***2.2*** |
| La Corne | Lc1 | 87.3 | 24.8 | 0.2 |
| | Lc1-Pn1 | 314.6 | 6.3 | 0.1 |
| | Lc3 | 120.7 | - | - |
| | Lc3-Pp7 | 95.9 | - | - |
| ***Total La Corne Map Units (Gray Luvisols on sandy glaciolacustrine materials with)*** | | ***618.5*** | ***31.1*** | ***0.3*** |
| Meadow | Mw | 17.0 | - | - |
| | Mw-Aw | 14.6 | - | - |
| | Mw-Pn6 | 64.7 | 0.5 | <0.1 |
| ***Total Meadow Map Units (undifferentiated Gleysolic soils)*** | | ***96.3*** | ***0.5*** | ***<0.1*** |
| Pine | Pn1 | 3,187.9 | 1,467.0 | 12.0 |
| | Pn1-Lc1 | 252.7 | 9.9 | 0.1 |

| Dominant Soil Association/Complex | Soil Map Unit | Baseline Map Unit Area (ha) | Project Disturbance Area (ha) | Project Disturbance Area (% of LSA) |
|---|---|---|---|---|
| | Pn1-Lc3 | 212.5 | 43.7 | 0.4 |
| | Pn2 | 3,305.9 | 1,561.1 | 12.8 |
| | Pn6 | 440.5 | 168.2 | 1.4 |
| | Pn7 | 288.2 | 70.1 | 0.6 |
| ***Total Pine Map Units (Brunisol and Regosols on sandy glaciofluvial, glaciolacustrine and eolian materials)*** | | ***7,687.7*** | ***3,320.0*** | ***27.2*** |
| Porcupine Plain | Pp5 | <0.1 | - | - |
| | Pp5-Lc1 | 162.6 | - | - |
| ***Total Porcupine Plain Map Units (Gray Luvisols on medium to moderately fine textured glaciolacustrine deposits)*** | | ***162.6*** | ***0.0*** | ***0.0*** |
| Wetland | Wx-Pn6 | 165.4 | 3.9 | <0.1 |
| ***Total Wetland (Gleysols (peaty phase) and Organics of variable thickness along ravines)*** | | ***165.4*** | ***3.9*** | ***<0.1*** |
| Water | Water | 407.5 | 1.1 | <0.1 |
| ***Total Water*** | | ***407.5*** | ***1.1*** | ***<0.1*** |
| Baseline Disturbance | Access | 129.2 | 61.5 | 0.5 |
| | Open Site | 12.9 | 10.1 | 0.1 |
| | Other Disturbance | 87.5 | 76.5 | 0.6 |
| | Reclaimed Site | 18.2 | 9.0 | 0.1 |
| | Industrial | 1.1 | 1.1 | <0.1 |
| | Tower Site | 2.0 | 0.5 | <0.1 |
| | Well Site | 0.1 | 0.1 | 0.0 |
| ***Total Baseline Disturbance*** | | ***251.4*** | ***158.8*** | ***1.3*** |
| ***Total Soil and Baseline Disturbance*** | | - | ***3,882.2*** | ***31.8*** |
| Project Disturbance | Camp | - | -0.1 | (<0.1) |
| | Orion South Pit | - | -427.5 | (3.5) |
| | Star pit | - | -588.8 | (4.8) |
| | Coarse PK | - | -179.9 | (1.5) |
| | PKCF | - | -513.6 | (4.2) |
| | Overburden and rock storage | - | -2008.3 | (16.4) |
| | Conveyor | - | -32.8 | (0.3) |

| Dominant Soil Association/Complex | Soil Map Unit | Baseline Map Unit Area (ha) | Project Disturbance Area (ha) | Project Disturbance Area (% of LSA) |
|---|---|---|---|---|
| | Diffuser | - | -1.2 | (<0.1) |
| | Explosives | - | -0.04 | (<0.1) |
| | Pipeline | - | -3.0 | (<0.1) |
| | Polishing Pond | - | -1.2 | (<0.1) |
| | Reservoir | - | -0 | (<0.1) |
| | ROW | - | -79.6 | (0.7) |
| | Runoff Pond | - | -6.2 | (0.1) |
| | Sewage Lagoon | - | -2.9 | (<0.1) |
| | Site Facilities | - | -37.0 | (0.3) |
| | Well | - | -0.1 | (0.0) |
| ***Total Project Disturbance Area*** | | **-** | ***(3,882.2)*** | (31.8) |
| **Total Area** | | **12,217.7** | **0.0** | **0.0** |

As indicated in the previous section regarding terrain disturbance (Access/Utility Corridor in the RSA), new topographic features will be constructed and the Orion South pit and part of the Star pit will remain as water bodies upon decommissioning. Upland features will be reclaimed with the landscape expected to be restored to forest ecosystems. It is proposed that the Star pit be developed into an end pit lake with about half of it filled in with materials from the Orion South pit. Smaller features such as the water management reservoir and the polishing pond will be returned to a small water body and drainage similar to the pre-existing condition. The combination of these two end pit lakes represents a loss of soil area in the LSA. Table 6.2.1-7 presents those map units that will be replaced with a water body at closure, affecting approximately 5.9% of the LSA (assuming about half of Star pit will constitute Star Pit Lake). The soil map units mainly affected by this change include the Pn (Pine) and Hillwash (Hw) soils.

The soil area replaced by end pit lakes represents a moderate magnitude of change. The change is adverse, local, occurs once, and is beyond long-term (or permanent).

*Table 6.2.1-7: Soil Map Units Replaced by Orion South Pit and Star Pit*

| Soil Map Unit | Orion South Pit Soil Map Unit Area (ha) | Orion South Pit Soil Map Unit Area (% of LSA)[1] | Star Pit Soil Map Unit Area (ha)[2] | Star Pit Soil Map Unit Area (% of LSA)[2] |
|---|---|---|---|---|
| Aw | - | - | 29.3 | 0.2 |
| Hw1-Wx | 7.6 | 0.06 | 19.4 | 0.2 |
| Hw2 | - | - | 10.3 | 0.1 |
| Hw3-Wx | - | - | 123.8 | 1.0 |
| Lc1 | - | - | 22.6 | 0.2 |
| Lc1-Pn1 | - | - | 3.9 | <0.1 |
| Pn1 | 272.7 | 2.2 | 168.7 | 1.4 |
| Pn1-Lc1 | - | - | 6.2 | <0.1 |
| Pn2 | 94.0 | 0.8 | 167.5 | 1.4 |
| Pn6 | 52.4 | 0.4 | - | - |
| Pn7 | - | - | 37.1 | 0.3 |
| Wx-Pn6 | 0.8 | 0.007 | - | - |
| ***Total Area*** | ***427.5*** | ***3.5*** | ***588.8*** | ***4.8*** |

**Notes:** [1] LSA area = 12,217.7 ha
[2] About half of the area of Star Pit will remain as Star Pit Lake at closure.

### Soil Units Affected by the Access Corridor to Highway 55

As indicated in a previous section, a proposed access and utility corridor will pass through the RSA and the LSA. The corridor will pass through a number of soil types, as indicated in Table 6.2.1-8. The table compares the ROW areas in the LSA and RSA; while the portion in the RSA represents only the ROW for the main access road, the portion within the LSA includes a portion of this road as well as local access roads within the Project area. The 79.7 ha component in the LSA consists mainly of Pine soils, with a component of Hillwash-Wetland complex. The 69.7 ha component in the RSA also consists mainly of Pine soils, with LaCorne soils constituting a subdominant component.

*Table 6.2.1-8: Right-of-Way Disturbance of Soil Map Units in the Regional Study Area*

| Soil Map Unit | Soil Map Unit Area in RSA (ha) [1] | LSA plus RSA ROW Area (ha) | LSA ROW Area (ha) | RSA ROW Area (ha) | RSA ROW Area (% of RSA) | RSA ROW Area (% of Map Unit) |
|---|---|---|---|---|---|---|
| Bf-Lc3 | 837.3 | 3.1 | - | 3.1 | <0.01 | 0.4 |
| Hw1-Wx | 233.3 | 12.2 | 12.1 | - | - | - |
| Hw2 | 45.1 | 0.5 | 0.5 | - | - | - |
| Hw3-Wx | 783.9 | 1.4 | 1.4 | - | - | - |
| Hw4 | 307.7 | 0.1 | 0.1 | - | - | - |
| Lc1 | 11,141.0 | 9.2 | 0.9 | 8.3 | - | - |
| Lc1-Pn1 | 314.60 | 0.8 | 0.8 | - | - | - |
| Mw-Pn6 | 64.7 | 0.5 | 0.5 | - | - | - |
| Pn1 | 23,539.0 | 23.0 | 23.0 | - | - | - |
| Pn1-Lc1 | 252.7 | 0.1 | 0.1 | - | - | - |
| Pn2 | 41,404.9 | 53.4 | 38.1 | 15.3 | 0.02 | <0.1 |
| Pn4 | 9,813.6 | 42.9 | - | 43.0 | 0.03 | 0.4 |
| Pn6 | 1,722.5 | 0.8 | 0.8 | - | - | - |
| Pn7 | 288.2 | 1.2 | 1.2 | - | - | - |
| Wx-Pn6 | 165.4 | 0.2 | 0.2 | - | - | - |
| Total | **90,913.9** | **149.4** | **79.7** | **69.7** | **0.05** | **-** |

**Notes:** [1] RSA area = 132,768.7 ha (the sum of the terrain unit areas in this table does not equal the total RSA area because some units are not crossed by the ROW).

### *Effects on Soil Quality*

Soil quality entails a number of soil chemical and physical components including: soil admixing; soil compaction; erosion; chemical changes during stockpile storage; soil contamination by spills and leaks of chemicals; changes to soil moisture conditions; potential for acidification from environmental sources. A system for assessing soil suitability for reclamation (Saskatchewan Environment 2007) provides a means for assessing some aspects of soil quality which can be used as a benchmark against which effects on quality can be assessed. Some potential effects such as soil acidification were discussed previously and not considered likely to affect soils. Other soil quality factors are discussed herein.

The effects on soil quality are mainly examined qualitatively, being based on general soil conservation and reclamation practices. Some information is based on studies reported in the literature. Dust effects on soils are examined semi-quantitatively.

#### *Soil Admixing*

Admixing of surface soil and subsoil components during soil lift and salvage operations may cause soil profile integrity to be compromised (particularly the A horizon), especially if clear distinctions cannot be maintained between the topsoil and subsoil. This is most problematic where topsoil thickness is highly irregular over the area of soil salvage. The depth of the surface layer that will be salvaged from mineral soils will vary according to landscape position and soil drainage conditions. The primary concern of soil profile admixing is change in texture and structure, which can directly affect soil physical and chemical characteristics. Admixing may occur where topsoil (i.e., A horizon) thickness is less than the average depth specified for the soil type, such that subsoil components (e.g., B horizon) would then be incorporated into the surface lift. This may lead to textural discontinuities, dilution of nutrient status, and reduction in the content of organic matter in A horizon materials. Changes in soil texture could arise from admixing, particularly in those soils with large textural differences between A and B horizons. However, in the LSA, differences in texture among the soil horizons do not occur, except in some localities, because the predominant soils (Pine soil associations) are sand or loamy sand textured throughout their profiles. Consequently, the main concern regarding admixing is the dilution of nutrients and organic matter of the topsoil. In some cases, the incorporation of clayey textured subsoil with silty or sandy topsoils can improve soil quality. Incorporating a clayey material can contribute to particle aggregation and improved water holding capacity, thereby reducing susceptibility to wind and water erosion. Admixing of peat materials with mineral soil material that is deficient in organic matter can also result in a positive change to on soil quality. For example, peat materials can be admixed with topsoil materials during soil salvage, resulting in improved organic matter and nutrient content.

The reclamation plan does not include salvage of sandy soils, except for selected areas of the facility footprint and where direct placement is feasible. Salvage will focus on materials of more favourable reclamation suitability as compared to the predominant sandy Brunisols in the LSA. These include Alluvium, La Corne and Porcupine Plain soils. With careful salvage and transport of these soils, admixing will be minimal. In the case of Organic soil materials mixed with mineral topsoil materials to improve quality, the small area of Organics that will be disturbed (Table 6.2.1-7) can be applied as an amendment to reclaimed topsoils over a large area relative to the source area of the Organics. This is a positive effect, which would tend to counteract negative effects of any small areas of admixing. The admixing effect is therefore assessed as being neutral.

#### *Soil Compaction*

Compaction of soil influences its drainage, structure, porosity, aeration, and potential susceptibility to erosion, all of which ultimately affect soil quality. Compaction by heavy equipment or by repeated passes of lighter equipment compresses the soil mass and breaks down soil aggregates, thereby decreasing macro-pore volume and increasing the volume proportion of solids.

The susceptibility of soils to compaction depends on a number of factors including soil texture, organic matter content, and moisture status. In general, the higher the clay content, the higher the susceptibility to compaction, especially when soils are moist. Conversely, the higher the organic matter content, the less susceptible soils are to permanent compaction. Variability in soil particle size tends to offset compaction, such that soils with homogenous texture (i.e., clay, silt) are more prone to compaction than are soils of mixed particle size (Fisher et al. 2000). Sandy soils are less prone to compaction than silty or clay soils, and soils with a high content of coarse fragments are less susceptible to compaction than stone-free soils (Archibald et al. 1997). The soils most susceptible to compaction in the LSA are limited to low lying, poorly drained areas where the clay content of soils might be slightly higher than in upland soils. The Alluvium, La Corne and Porcupine Plain soils will also be prone to compaction upon wetting due to precipitation. With appropriate mitigation measures such as avoiding work on these soils when wet, and avoiding repeated passes over the same soil areas with equipment, the compaction effect is anticipated to be adverse, reversible, low in magnitude, short-term in duration, local in geographic extent, and intermittent during Project life. Overall, compaction is considered to have little influence on soil quality and suitability for reclamation.

#### *Soil Susceptibility to Water and Wind Erosion*

Wind and water erosion are a concern mainly in terms of loss of soil, and as such these are discussed as part of soil quantity effects in a following section. Soil quality can be affected if erosion preferentially removes finer particles and organic materials from bulk soil. Thus, removal of organic particles and clays from soil can reduce its overall nutrient content and water holding capacity. This may be a concern mainly in the case of soil stockpiles. Appropriate mitigation measures such as providing vegetation cover or other means such as erosion control mats can reduce this effect to a negligible level (Section 7.5, Closure and Reclamation Plan).

#### *Soil Reclamation Suitability*

Soil reclamation suitability can be considered as an integration of various soil quality parameters. Reclamation suitability is defined by a set of soil quality parameters that define a soil’s capability to support ecosystems. Criteria to determine soil suitability for reclamation for strip mine coal lands are presented by Saskatchewan Environment (2007). These criteria are those applicable to prairie soils, as adapted from Alberta Soils Advisory Committee (1987). As the Project is located in boreal forest, the criteria for forest soils by Alberta Soils Advisory Committee (1987) were applied.

Based on the criteria for upper lift (topsoil) and lower lift reclamation suitability determined for existing conditions, both topsoils and subsoils of the mineral soil associations in the LSA generally have poor suitability for reclamation. The limiting factor in topsoil suitability for reclamation is the coarse texture of the mineral soils in the LSA, which are dominated by the Pine association. The coarse-textured material is associated with low nutrient status and low moisture holding capacity.

The Organic soil associations are not rated for reclamation suitability but rather are classed simply as an organic category. Organic materials can be a valued material in reclamation because of their nutrient content and ability to improve the soil moisture holding capacity of the reclaimed mineral soils.

The reclamation suitability ratings of soils in the LSA and the Project footprint are presented in Table 6.2.1-9. The ratings show that the soils to be salvaged in the footprint area have predominantly poor upper lift and lower lift suitability. Approximately 101 ha of peat is available for salvage, which, as indicated above, can be useful as an amendment for reclamation of the soils. As such, it will be targeted for salvage and for use earlier in the progressive reclamation areas, because loss of peat mass in stockpiles due to decomposition/humification will likely occur continuously over time. The baseline information shows that peat thickness averages about 100 cm. Thus, over a 101 ha area, approximately 1 million banked cubic metres of peat could be salvaged.

The reclamation plan will involve topsoil salvage of some of the sandy Pine soils where direct placement is feasible, but they generally will not be stockpiled for future use due to their poor quality (see Section 7.5, Closure and Reclamation Plan). Small areas of good to fair quality materials are available in the area to be disturbed. These correspond to the poorly drained Arbow soil, as well as small areas of Alluvial, La Corne and Porcupine soils. These good to fair quality topsoils will be salvaged.

***Table 6.2.1-9: Reclamation Suitability Ratings of Soils within the Project Footprint***

| Quality Rating | Topsoil | | Subsoil | |
|---|---|---|---|---|
| | Baseline Area (ha) | Disturbed Area (ha) | Baseline Area (ha) | Disturbed Area (ha) |
| Good | 781.1 | 31.1 | - | - |
| Good-Fair | 297.8 | - | - | - |
| Fair | - | - | 1,473.2 | 98.3 |
| Poor | 7,688.0 | 3,320.0 | 7,688.0 | 3,320.0 |
| Poor-Fair | 2,170.8 | 270.0 | 2,170.8 | 270.0 |
| Organic | 621.5 | 101.2 | 227.2 | 34.0 |
| Disturbed Land | 251.0 | 158.8 | 251.0 | 158.8 |
| Water | 407.5 | 1.1 | 407.5 | 1.1 |
| Total | 12,217.7 | 3,882.2 | 12,217.7 | 3,882.2 |

It is desirable in reclamation to restore topsoil quality to the same level as pre-existing conditions or better. Although rated as poor in terms of reclamation suitability, native soils have organic matter in the LFH horizon, which is important in cycling of nutrients and providing sandy soils with some water holding capacity. Where topsoil quantities are insufficient for reclamation, alternative sources of organic materials may be required. Research regarding applicable soil amendments is currently being conducted by Shore Gold and the University of Alberta (Section 7.5).

Given the generally poor quality of existing soils as determined by reclamation suitability analysis, soil materials in the LSA cannot diminish greatly in overall quality and the overall effect is considered to be neutral. Admixing of topsoil with subsoil, compaction, erosion, and changes during storage would have negligible effects on soil quality relative to baseline conditions. In fact, soil quality can be improved to some extent by addition of organic material from salvaged peat and from placement of clay rich till on the surface of the overburden and rock storage pile. To facilitate reclamation, material with higher clay content than that of the existing soils could be useful as an amendment, provided the chemical characteristics are suitable (i.e., non-alkaline, non-saline, non-sodic).

#### *Effect of Air Emissions – Dust Effects on Soil*

Processes that could generate dust at the Project site include blasting, excavating, machinery operation, plant operation, and traffic. The dust can then be deposited on soils, possibly resulting in changes in content of trace elements. Dust originating from roads or other facilities constructed from overburden materials is not of concern because it will generally have elemental composition similar to that of native subsoils. Dust originating from mine pit areas, being composed of kimberlite and kimberlite bearing bedrock materials, may contain high concentrations of some elements, which could elevate levels in native soils if the material is deposited beyond the Project footprint. Kimberlite chemistry was compared with Canadian Council of Ministers of the Environment (CCME) (2007) '*Soil Quality Guidelines for the Protection of Environmental and Human Health'* to determine if there are elements of possible concern. Data from Section 5.2.3 (Metal Leaching and Alkaline/Acid Rock Drainage Geochemistry) are presented in Table 6.2.1-10. Chromium and nickel concentrations are considerably higher than guideline levels, and they could increase soil concentrations to guideline levels or higher.

The assessment of potential effect of dust on undisturbed soils considers the above possible elements of concern as well as the area of deposition of dust and potential increase in soil concentration of the elements of concern. The highest annual deposition rate of dust is predicted to be about 40 $mg/m^2/yr$, in an area adjacent to the mines and extending away about 400 m (see Section 6.2.2, Air Quality). This area lies within the Project footprint, and extends slightly beyond the footprint to the southeast from the Star pit.

An analysis of dust deposition suggests that if the deposition consisted only of kimberlitic dust, and if all Cr and Ni were deposited only onto the LFH horizon, both Cr and Ni would considerably exceed the guideline (calculations not shown). If the dust infiltrates into a 10 cm Ae horizon, the concentrations after Cr and Ni addition by dust would be well within the CCME guidelines.

It is concluded that dust deposition will have a minimal effect on soils adjacent to the Project footprint for the following reasons:

- The considerations above assume that all dust originates from kimberlitic materials. As such, the analysis represents a worst case scenario, because dust with trace element content similar to that of soils will constitute a large portion of deposition;
- Ni and Cr exceedance occurs if it remains in the LFH layer. It is expected that dust will be washed into the underlying mineral layer (the Ae horizon), where it will be diluted to below guideline levels; and
- The affected area is mainly within the Project footprint, and is very small beyond the footprint (see Section 6.2.2, Air Quality).

The effect of dust arising from Project activities on soils is thus considered to be adverse in direction, low in magnitude, long-term in duration, of local geographic extent, and intermittent in frequency over the life of the Project.

***Table 6.2.1-10: Total Elemental Analysis of Star and Orion South Kimberlite***

| Element | Unit | Guideline [1] | Kimberlite (Range) |
|---|---|---|---|
| Aluminum | % | - | 1 to 1.4 |
| Cadmium | mg/kg | 1.4-10 | 0.1 |
| Calcium | % | - | 2 to 4.8 |
| Chromium | mg/kg | 64 | **460 to 518** |
| Copper | mg/kg | 63 | 29 to 42 |
| Iron | % | - | 4.8 to 5 |
| Lead | mg/kg | 70-140 | 6.5 to 9.0 |
| Magnesium | % | - | 9 to 10 |
| Manganese | mg/kg | - | 858 |
| Molybdenum | mg/kg | 5-40 | 0.5 to 0.6 |
| Nickel | mg/kg | 50 | **809 to 1,000** |
| Potassium | % | - | 0.2 to 0.3 |
| Selenium | mg/kg | 1 | 0.3 |
| Silver | mg/kg | 20 | 0.2 |
| Sodium | % | - | 0.2 to 0.3 |
| Zinc | mg/kg | 200-360 | 44 to 52 |

**Notes:** Guideline is based on the 2007 Canadian Environmental Quality Guidelines. The range reported encompasses guidelines for agricultural and residential/park areas.

Bolding indicates elements that are above CCME guideline levels.
Data from Tables 5.2.3-3 and 5.2.3-5 in Metal Leaching and Acid/Alkaline Rock Drainage (Section 5.2.3).

### *Effects on Soil Moisture Regime*

Project construction activities may result in alteration of soil drainage regimes. Changes can be site-specific, such as blockage of drainage ways by roads or other facilities, or of broad scope due to local or regional changes in water table levels arising from pit excavation and dewatering. Site-specific changes can be readily mitigated and effects are expected to be minimal. The following focuses on broad scale effects, which could affect soils in different ways depending on the soil moisture regime and on the extent of water table lowering.

#### *Description of Soil Moisture Regimes*

Soil moisture regimes are discussed herein in terms of drainage classes, which are related to moisture regime categories used in describing ecosite conditions. In the following discussion, reference is made to *Field guide to the ecosites of Saskatchewan's provincial forests* (McLaughlin et al. 2010) for drainage classes, soil moisture regimes and associated ecosites. The drainage classes are defined below, with definitions based on McLaughlin et al. (2010) and on Expert Committee on Soil survey (1982).

> Very poor drainage: refers to organic or mineral soils with pronounced gleying above the 50 cm soil depth. Water is removed from the soil so slowly that the water table remains at or on the surface for the greater part of the time the soil is not frozen.
>
> Poor drainage: refers to any soil texture class associated with mottles and gleying above the 50 cm soil depth. Water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen.
>
> Imperfect soil drainage: refers to any soil texture class associated with mottles above 50 cm. Water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season.
>
> Moderately well drained: a drainage regime associated with fine textured soils (silty clay, sandy, clay, clay), or with mottles present below 50 cm. Water is removed from the soil somewhat slowly in relation to supply, and excess water is removed somewhat slowly due to low perviousness, shallow water table, lack of gradient, or some combination of these.
>
> Well drained: a drainage regime associated mainly with medium to fine textured soils (sandy loam to clay loam). Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow.
>
> Rapidly drained: a regime associated with coarse textured soils (loamy fine sand to coarse sand), generally with few particles larger than 2 mm. Water is removed from

the soil rapidly in relation to supply. Excess water flows downward if the underlying material is pervious.

Very rapidly drained; a regime associated with coarse textured soils (loamy fine sand to coarse sand), generally with greater than about one-third of particles larger than 2 mm. Water is removed from the soil very rapidly in relation to supply. Excess water flows downward very rapidly if the underlying material is pervious.

The wettest drainage classes (very poor, poor, and imperfect) have some degree of water saturation within the soil profile and show evidence of gleying. Gleying is a soil condition resulting from prolonged soil saturation, which is indicated by the presence of bluish or greenish colors through the soil mass or by mottles (spots or streaks) among the colours. Gleying occurs under reducing conditions, by which iron is reduced predominantly to the ferrous state (Gregorich et al., 2002). Water saturation occurs where the water table occurs within the soil profile, as in low-lying areas such as depressions and floodplains. Where the soil contains a relatively impermeable layer, a perched water table may develop above the main water table, and this can lead to gleying in soils.

The wettest drainage regimes typically support wetland ecosites. Ecosites with these drainage regimes that occur in the FalC forest consist of: black spruce – tamarack treed swamp (BP18); deciduous mixedwood swamp (BP18a); black spruce treed bog (BP19); tamarack treed fen (BP23); leatherleaf shrubby poor fen (BP24);willow shrubby rich fen (BP25); graminoid fen (BP26); and, seaside arrow-grass marsh (BP28). The drainage characteristics of these ecosites are indicated in Table 6.2.1-11 below.

The drier soil moisture drainage classes (moderately well drained to very rapidly drained) are not directly connected to groundwater, and are related to moisture holding capacity as determined by soil texture. The LSA and RSA are dominated by rapidly drained, sandy textured soils. The ecosites and their associated drainage regimes are indicated in Table 6.2.1-11.

***Table 6.2.1-11. Ecosites and Their Drainage Regimes in the Fort a la Corne Forest***

| Ecosite | Description | Dominant Drainage | Drainage Range | Mean Depth to Water (cm) | Confidence Interval |
|---|---|---|---|---|---|
| BP01 | June grass - mountain goldenrod grassland | Rapid | Rapid - Imperfect | -[3] | - |
| BP01a | Dry shrubland | Rapid | Rapid - Imperfect | - | - |
| BP02 | Jack pine - lichen | Rapid | Rapid - Moderately Well | - | - |
| BP03 | Jack pine - feathermoss | Rapid, Well, Moderately Well | Rapid - Imperfect | - | - |
| BP04 | Jack pine - trembling aspen - feathermoss | Rapid | Rapid - Imperfect | - | - |
| BP05 | Trembling aspen - prickly | Rapid | Rapid - Imperfect | - | - |

| Ecosite | Description | Dominant Drainage | Drainage Range | Mean Depth to Water (cm) | Confidence Interval |
|---|---|---|---|---|---|
| | rose - grass | | | | |
| BP06 | Trembling aspen - beaked hazel - sarsaparilla | Well, Moderately Well | Rapid - Imperfect | - | - |
| BP07 | Trembling aspen - white birch - sarsaparilla | Rapid, Moderately Well | Rapid - Imperfect | - | - |
| BP09 | White spruce - trembling aspen - feathermoss | Rapid, Well | Rapid - Imperfect | - | - |
| BP10 | Trembling aspen - white spruce - feathermoss | Rapid, Moderately Well, Imperfect | Rapid - Imperfect | - | - |
| BP11 | White birch - white spruce - balsam fir | Well, Imperfect | Rapid - Poor | - | - |
| BP12 | Jack pine - spruce - feathermoss | Imperfect, Moderately Well, Well | Very Rapid - Imperfect | - | - |
| BP13 | White spruce - balsam fir - feathermoss | Well, Moderately Well, Imperfect | Rapid - Imperfect | - | - |
| BP14 | Black spruce - Labrador tea - feathermoss | Imperfect, Moderately Well | Moderately Well - Very Poor | - | - |
| BP15 | Balsam poplar - white spruce - feathermoss | Imperfect | Rapid - Poor | | - |
| BP16 | Balsam poplar - trembling aspen - prickly rose | Imperfect, Well | Rapid - Poor | - | - |
| BP18 | Black spruce - tamarack - treed swamp | Very Poor | Poor - Very Poor | 44.3 [2] | 10.4 |
| BP18a | Deciduous -mixedwood swamp | Very Poor | Poor - Very Poor | - | - |
| BP19 | Black spruce - treed bog | Very Poor | Very Poor | 50.4 | 10.6 |
| BP23 | Tamarack - treed fen | Very Poor | Poor - Very Poor | 23.1 | 13.6 |
| BP24 | Leatherleaf - shrubby poor fen | Very Poor | Very Poor | 20.6 | 30.6 |
| BP25 | Willow - shrubby rich fen | Very Poor | Poor - Very Poor | 30.1 | 19.6 |
| BP26 | Graminoid fen | Very Poor | Poor - Very Poor | 21.1 | 22.5 |
| BP28 | Seaside arrow-grass - marsh | Poor, Very Poor | Poor - Very Poor | 32.8 | 21.2 |

**Notes:** [1] Ecosites in LSA and RSA based on Section 6.3.2 Vegetation and Plant communities.
[2] Water level data provided by M.S. McLaughlin (personal communication).
[3] Blank cells refer to upland sites, which do not have water table data.

### *Potential Effects on Organic and Gleysolic Soil (Wetland) Moisture Regimes*

Site-specific changes in drainage may lead to intermittent or permanently waterlogged conditions (i.e., gleying conditions) in normally well-drained mineral soils such as the Pine, La Corne and Porcupine Plain soils, particularly if they are found in a continuum with gleyed soil phases and Gleysols. Such localized changes can be managed by well accepted practices such as installation of culverts. Consequently, possible changes due to very localized obstructions to drainage are considered to be of minor magnitude.

The potential effect on soil moisture regime, as a result of the water table drawdown, will be drying of poorly drained Organic and Gleysolic soils. These are soils of depressions or potholes, meadows, bogs, fens and swamps, which support ecosites BP18 to BP28 (Table 6.2.1-11). Possible changes due to water level lowering in bogs, fens and peaty swamps include subsidence, increase in woody species growth, and increased decomposition and loss of carbon due to increased exposure to oxygen (Weltzin et al. 2000; Hillman and Roberts 2006). However, carbon loss and subsidence lower the peat surface, resulting in depths to water table similar to that prior to disturbance (Dise, 2009; Weltzin et al., 2000). With lowering of the peat surface, the effect on bogs and fens may involve drying of the edges of these systems, resulting in reduction of their overall area. This effect will be least with a relatively shallow lowering of the water table, possibly as much as 50 cm, but greater drying and shrinkage in area would occur with greater water table lowering. Marsh wetlands in the prairie region are commonly characterized by natural changes in water table levels, and vegetation changes occur in response to these (van der Valk, 2005).
Table 6.2.1-11 indicates the water level ranges of wetland ecosites, as well as the confidence intervals around the average water levels. There is overlap in the water levels among the different ecosites, and the overall range of approximately 20 to 60 cm suggests there could be little effect due to the above mechanism if the water table lowering is limited to about 0.5 m or less. However, the drying effect would be greater with increased lowering of the water table.

Hydrogeological assessment after closure suggests that water level lowering will extend from the pit lakes into the LSA, with 1 m and 2 m depressions extending a short distance into the RSA to the north of the Orion South pit. Lowering to 0.5 m will extend well into the RSA. The area of wetland ecosites that would be affected by water table lowering of 50 cm or more is examined in Section 6.3.2 (Vegetation and Plant communities). The area affected to the end of mining is estimated at about 400 ha in the undisturbed portion of the LSA, and about 3,900 ha in the RSA.

In terms of soil map units, Organics and Gleysols in the LSA are identified as Arbow, Meadow, Bog, Fen and Wetland Complex soils. There are also inclusions of Gleysols within areas mapped as predominantly well drained soils; these are the Pn4, Pn5, Pn6, Pn7, Pn9, Hw1-Wx, and Hw3-Wx soil map units. The poorly drained component generally represents 15-30% of these map units. The summation of these poorly drained soils corresponds to the above area of wetland ecosites in the LSA (about 400 ha) and the RSA (about 3,900 ha). These areas represent 3.3% of the LSA and 2.9% of the RSA. The soil drying would develop gradually during the Project and remain after Project completion with groundwater levels returning to near pre-mining levels relatively rapidly in the RSA and parts of the LSA, and gradually with pit infilling in the LSA (Section 6.2.6, Regional Geology and Hydrogeology). The effect is therefore estimated as being low, and possibly moderate, in magnitude within the LSA, and likely minor in the RSA. It is regional in extent and reversible.

*Potential Effects on Well Drained Soils*

The water source for vegetation on moderately well to very rapidly drained soils relies on precipitation and soil moisture holding capacity. The rapidly drained class is dominant in the LSA and RSA due to the coarse (sandy) texture of the soils (Table 6.2.1-11). Upland species generally extract water from the unsaturated soil zone, which is the soil layer between the surface and the water table. The water table itself is considered to be a barrier to root growth (Armson, 1977). If the unsaturated zone is not replenished with water from precipitation, droughty conditions develop with continued water extraction and evapotranspiration. Theoretical explanation of groundwater dynamics in relation to vegetation can be found in Laio et al. (2009). In imperfectly drained soils, and likely to some extent in moderately well drained soils, the water table is likely sufficiently close to the soil surface (within 1 to 2 m) to replenish the unsaturated zone through capillary rise from the water table. In well to rapidly drained soils, the water table is too deep for such replenishment.

Some vegetation types have adaptive strategies, particularly in water limited ecosystems, wherein water is redistributed between wet and dry soil layers, from shallow to deep layers or vice versa. The term ‘hydraulic lift’ refers to the passive movement of water via plant roots from deep, moister soil layers to shallow, drier soil layers. This process has been examined in southern United States mountain ecosystems dominated by lodgepole pine and Ponderosa pine. Root systems of some species in these ecosystems are known to extend vertically into the soil for considerable depths and to extract water and nutrients from both deep and shallow soil layers (Amenu and Kumar, 2008). There appears to have been research on this aspect of plant water uptake on only a few plant community types. However, jack pine is known to be able to develop tap roots, with extension to 3 m having been recorded in Alberta (Stone and Kalisz, 1991). Such roots may simply draw water from this depth, or may be involved in the more complex mechanism of redistributing water thorough hydraulic lift.

The potential effects of lowering water tables where they already are quite deep are twofold. In one scenario, water availability may be reduced even to the deep rooting species, assuming that the water table is within 3 m. In the LSA, surficial groundwater depths vary greatly with topography. Depth to water table varies from more than 10 m in crest, upper and mid slope positions, to 3 to 5 m in lower slope and more level areas in well drained soil. Another scenario may involve ability of deep rooted species to adapt to water table lowering by further extension of roots. Specific effects are dependent on specific site conditions, (e.g., the interaction between micro-site topography, depth to water table pre and post mining, and the specific vegetation community established). As such, there is uncertainty in attempting to quantify the potential effect on a landscape scale.

It is concluded that imperfectly drained and moderately well drained soils will likely change to drier conditions as a consequence of water table lowering. These moisture regimes mainly occur as narrow bands surrounding very poor and poor drainage regimes, and are therefore considered to be low in extent. The magnitude of change in poorly and very poorly drained soils was considered to be low to moderate. With grouping of imperfectly drained and moderately well drained soils with the poorly drained categories, the magnitude is considered to remain low to moderate. The direction of impact is considered to be both positive and negative, duration will be long-term, during all Project phases and beyond closure. The effect develops gradually, but occurs once. The geographic extent will be regional until post mining, and local after a predicted quick recovery period in the RSA and parts of the LSA. In the case of well drained and, to an extent, rapidly drained soils, changes would depend on specific microsite conditions; however it is possible that species adapted to droughty conditions can further adapt to small changes in the water table. Very rapidly drained soils would not become drier than baseline, so no effect is anticipated. Monitoring of the surface water table and associated soil and vegetation attributes (Section 6.2.1.6) during construction and operations will be conducted.

#### *Effects on Soil Quantity*

Soil erosion reduces soil mass, which is an adverse effect particularly in terms of loss of topsoil. Erosion is caused by accelerated removal of soil materials by running water, wind, or gravitational creep (Fisher et al. 2000). Erosion involves loss of soil volume at origin and gain at endpoint of deposition, and it can deplete nutrient status and reduce overall soil quality through degradation of structure, change in texture, loss of organic matter, reduction of water holding capacity, and reduction in particle aggregation. Soil erosion reduces the amount and suitability of soil material available for use in reclamation.

Topsoils consisting of thin Ahe or Ae horizons characterized by coarse textures and low or absent organic matter content are very susceptible to wind erosion. Thus, an erosion management concern is anticipated for stockpiles of Pine association soils because both their Ae (topsoil) and B (upper subsoil) horizons are sandy-textured. Forest soils of the LSA are generally not well aggregated due to lack of organic matter, which functions as a binding agent between mineral particles and increases the strength of soil particle aggregation (Acton and Gregorich 1995). Frost action, freezing and thawing, and detachment by flowing water will also influence soil susceptibility to water erosion. Naturally occurring wet, organic soils are generally rated as having a negligible risk of erosion. When organic soils become desiccated, the peat fibre structures become brittle, easily break apart and pulverize. Under this condition, the risk rating for organic soils increases to high.

The highest water erosion risk occurs during spring melt and runoff or heavy rainfall events. Wind erosion risk is anticipated to be greatest during periods of hot, dry weather, over the summer months, but can occur even during winter under snow-free conditions. Well established mitigative measures are available to prevent erosion of salvaged soils and in situ soils exposed by vegetation removal. The effect is considered reversible because erosion resistance can be restored over time by organic soil matter accumulation in association with maintaining vegetative cover. Consequently, the direction of impact due to erosion is considered to be adverse, with magnitude anticipated to be low. The duration of the impact will be medium-term, during all Project phases, and intermittent on a seasonal basis. The geographic extent will be local.

### *Project Effects on Soil Capability for Forestry*

The Project impacts on the baseline CLI forest capability ratings are summarized in Table 6.2.1-12. Classes 5 through 7 are lands that have severe limitations to forest growth. The large proportion of Class 6 lands are mainly Pine association soils, which are limited by moisture deficiency and low fertility. Class 6 lands also include the Arbow and Hillwash soils. With reclamation, equivalent forestry capability can readily be restored for these soils. Class 5 soils consist of Pine soils having slightly moister drainage regimes than the norm, along with Alluvium and Wetland soils. Class 4 soils are the finer textured Porcupine, La Corne, Porcupine Plain, and Alluvium soil associations. These classes may be difficult to restore through reclamation. Disturbed soils and landscapes reclaimed to soils with similar properties and overall quality as baseline conditions are expected to support ecosites similar to those present prior to disturbance. Due to the possibility of mixing peat with mineral soil materials, the quality of topsoil can be improved as compared to baseline soils, although the peat quantities will be sufficient for only part of the area.

The proportions of land capability classes for forestry could change as compared to baseline conditions. There will also be areas with texture finer than the typical sand texture of the Pine association. For example, the overburden and rock storage pile will include an area of moderately fine textured glacial till. Because of the relatively higher moisture holding capacity of this material, this area could be reclaimed to CLI Class 4. Till chemistry is expected to be suitable for reclamation (pH ranges from 7.4 to 7.5, SAR typically less than 4); however, further testing of the till may be required to confirm that it is not calcareous, or have other limiting factors for use as a reclamation soil. Sandy soils can be improved by adding organic matter to the topsoil, as discussed previously. A net increase in CLI Class 4 area could result. Lower CLI classes are expected on the steeper slopes of the overburden and rock storage pile and reclaimed PK facilities, particularly on north facing slopes.

It is difficult to assess the above effects quantitatively. Improvement of CLI rating is possible for some soils with poor baseline ratings, but limitations such as unsuitable soil chemistry and topographic conditions (i.e., 4H:1V slopes) could offset improvements. The reclamation plan considers the CLI ratings such that the proportions of closure CLI classes will remain similar to the pre-disturbed conditions. Consequently, project specific effects in terms of impact on land capability for forestry are anticipated to be neutral. The effect on CLI forestry capability does consider land removed from forestry use through development of mine pit lakes. This aspect is treated as loss of terrain, which is discussed in a previous section.

***Table 6.2.1-12: Canada Land Inventory Classification for Forestry in Disturbed Areas***

| Forest Capability | Baseline Area (ha) | Project Disturbance (ha) | Project Disturbance (% of LSA) | Project Disturbance (% of Map Unit Area) |
|---|---|---|---|---|
| 4 | 1,079 | 24.8 | 0.2 | 1.5 |
| 5 | 4,169 | 1,596.8 | 13.1 | 38.3 |
| 6 | 5,822 | 2,062.2 | 16.9 | 35.4 |
| 7 | 489 | 38.4 | 0.6 | 7.9 |
| Disturbed Land | 251 | 158.9 | 0.3 | 63.3 |
| Water | 407 | 1.1 | 0.01 | 0.3 |
| Total | 12,218 | 3,882.2 | 31.1 | - |

**Note:** Calculations are based on the dominant CLI class of soil map units. CLI Classes 1 to 3 do not occur in the Project area.

### *Project Impacts on Soil Capability for Agriculture*

As with forestry capability, various Project related changes in soil chemical and physical properties could affect the ratings for soil capability for agriculture. The percentages of lands in the different class are the same for agriculture and forestry capability, except for classes 6 and 7 (Table 6.2.1-13). Agricultural capability is generally low, with Classes 5 and 6 being predominant. The discussion for forestry in the previous section is also pertinent to agricultural capability, and the Project effects in terms of impact on land capability for agriculture are also anticipated to be neutral. As with forestry, the effect on CLI agriculture capability does consider land converted to mine pit lakes. This aspect is treated as loss of soil cover, which is discussed in a previous section.

***Table 6.2.1-13: Canada Land Inventory Classification for Agriculture in Disturbed Areas***

| Agricultural Capability | Baseline Map Unit Area (ha) | Project Disturbance (ha) | Project Disturbance (% of LSA)(ha) | Project Disturbance (% of MU Area) |
|---|---|---|---|---|
| 2 | 298 | - | - | - |
| 3 | 163 | 31.1 | 0.3 | 19.1 |
| 4 | 618 | - | - | - |
| 5 | 4,169 | - | - | - |
| 6 | 5,822 | 3,653.2 | 29.900 | 62.7 |
| 7 | 262 | 3.9 | 0.032 | 1.5 |
| Organic | 227 | 34 | 0.3 | 15.0 |
| Disturbed Land | 251 | 158.9 | 1.3 | 63.3 |
| Water | 407 | 1.1 | 0.009 | 0.3 |
| Grand Total | 12,218 | 3,882.2 | 31.8 | - |

**Note:** Based on the dominant CLI class of map units. Class 1 does not occur in the Project area.

### 6.2.1.6 Mitigation

During the development of the Project, many design features, environmental best practices, and management policies and procedures were developed in order to reduce or eliminate potential environmental effects. Many of these features are presented in the Project Description (Section 2.0) and in the Closure and Reclamation Plan (Section 7.5). General approaches to impact management and mitigation of surface disturbance during construction, operations and closure of the Project will include:

- reducing the extent of surface disturbance where possible;
- restoring the site to a condition that is similar to the conditions that existed prior to disturbance ;
- preventing and treatment of soil admixing;
- preventing and treatment of soil compaction;
- management of soil erosion risk;
- management of dust and chemical emissions; and
- amelioration of soil contamination.

#### *Terrain Distribution and Topography*

A clearly defined, compact Project footprint will limit overall effects on terrain and landscape features. The ability to develop a compact footprint for the Project site is limited to some extent by the locations of the two main kimberlite deposits. The processing plant and other facilities will be closely grouped together to limit aerial extent. The PKCF, the Coarse PK pile and the overburden and rock storage pile have been located in close proximity to the

Star Pit and processing plant to limit the overall Project footprint in the landscape. These will result in residual features with greater relief than the surrounding area, but with reduced disturbance. Likewise, road infrastructure will be limited, and areas between infrastructure, pits, piles and facilities will remain undisturbed.

Instability associated with steeply sloping valley sides within the footprint will be related to construction activities such as over-steepening or undercutting of slopes. Management of risks associated with unstable terrain will entail employment of relevant engineering and construction best practices during design and construction of Project facilities. For example, the over-steepening of slope gradients can be mitigated with proper back slope grading, and to the extent possible, slope gradients will be decreased along road cuts and disturbance features to gradients at or below the angle of repose of those disturbed sediments. Where appropriate, stability of steep slopes will be managed by drainage control measures and culverts to control runoff and subsurface water flow.

### *Soil Cover and Distribution*

The loss of soil cover is linked to terrain disturbance and the same mitigation measures suggested to limit the loss of terrain apply to the net change in soil associations. These measures include the development of a clearly defined compact, footprint in which facilities are grouped into centralized areas to the extent possible. During the Project lifespan, secondary features will be preferentially constructed in areas that have been previously disturbed.

Replacement of soil cover is the principal mitigation measure with respect to soil cover. The objective of reclamation is to restore the mining site to a condition that is similar to the conditions that existed prior to disturbance by mining operations (SMOE 2008). Salvaged reclamation material will be re-distributed, graded and contoured as part of reclamation activities. To the extent possible, concurrent reclamation activities will take place within the operations phase of the Project (i.e., direct placement). Most soil reclamation will take place throughout operations (progressive reclamation of the overburden and rock storage pile) and is considered in the closure phase of the Project. The Closure and Reclamation Plan (Section 7.5) and the Project description (Section 2.0) provide detailed descriptions of reclamation activities as they pertain to salvage and re-distribution of soils. The reclamation objectives and principles will adhere to *Guidelines for Northern Mine Decommissioning and Reclamation* (SMOE 2008).

### *Soil Quantity*

Erosion control measures will be considered on a site-specific basis throughout the Project life span, to limit the effects of wind erosion on the soils and vegetation.

Prevention of soil loss by erosion can involve various commonly applied methods. Grading, site contouring, and the maintenance of slope lengths and gradient parameters will be undertaken to reduce wind and water erosion of stockpiled soil materials. During the construction and operations phases, stabilization of topsoil stockpiles with erosion control measures and management of surface runoff (snow melt, rainfall) will reduce the potential risk of water erosion. Erosion control materials (mats, netting, straw, and mulches) will be used to reduce soil surface exposure. Where practicable, long term re-vegetation of stockpile surfaces will be conducted. The incorporation of organic material (duff or peat) into coarse-textured (sandy) soils or those deficient in organic matter at the time of salvage, will serve as a preventative measure against wind erosion, as well as contribute to the improvement of water-holding capacity.

Loss of soil by burial and admixing involves preventative measures during soil stripping. Selected areas of fair and good suitability topsoil and areas of deep organic soils will be salvaged for use as reclamation material. Minor spills of soil during transport to stockpiles are inevitable; however, large spills should be recovered as soon as possible, prior to contouring and placement of fill materials.

### *Soil Quality*

Soil quality is based on a number of factors, which, when individually affected, can result in a measurable change in overall quality and reclamation capability. Mineral and organic soils will respond differently to disturbances and therefore require specific mitigation strategies during salvage and reclamation operations.

Admixing can be limited by utilizing the pre-construction information to determine appropriate soil thicknesses to salvage. During salvage operations, site-specific soil checks will be conducted within the disturbance area to determine soil horizon characteristics and to identify specific concerns that could influence the soil stripping and salvage procedures on site. To the extent practicable, soil storage piles will be located on higher ground to limit the potential for groundwater saturation that would adversely affect the quality of the stored soil materials. Stockpiling and direct placement of topsoils will conform to requirements specified in *Guidelines for Northern Mine Decommissioning and Reclamation* (SMOE 2008). Because of its beneficial properties as a topsoil amendment, peat (i.e., organic soil) will be salvaged as described in Section 7.5. Salvaged peat materials will be stockpiled or direct-placed together with mineral topsoils.

Protocols and procedures for waste hazardous materials management include prevention of soil contamination (see Section 2.0, Project Description). For example, hazardous materials will be stored and transported under appropriate and regulated practices. Protocols for safe handling, storage and transport of chemicals, including fuels and other hydrocarbons, include measures to prevent contamination of soils, including soil stored for later use. In the event of accidental contamination, the Spill and Emergency Response Plan (see Section 7.2, Environmental Risk Management) outlines the immediate leak or spill response, and suggested mitigation. Documentation of hazardous material and potential spills will be reported to the on-site environmental team. In advance of Project closure, approaches to contaminant management will follow guidelines of Saskatchewan Ministry of Environment (2008).

Soil compaction is a function of soil moisture content, texture, organic matter content, and traffic. A number of prevention and mitigation measures will be applied to prevent and mitigate compaction, to the extent practicable. Scheduled construction activities will not be carried out on wet soils that are compactable. During construction, efforts will be made to limit the number of repeated passes over areas prone to compaction (e.g., Gleysols and alluvial soils).

Drainage management will assist in decreasing the area of moist and wet soils on site, and thereby limit compaction effects on soils. Roads and other corridors will be designed and constructed to limit alteration of natural drainage patterns. Culverts and drainage ditches will be installed, as required, to maintain drainage. This will include consideration of the prevention of water build-up and flooding in wetland areas due to road construction.

Dust will be generated in a number of ways at the Project site, with the main sources being blasting and wind-blown dust from traffic and activities associated with the overburden and rock storage pile. Mine and plant design and operation will incorporate dust prevention measures. The roads will have dust control measures applied as required, consisting mainly of water application to surfaces. The overburden and rock storage pile and other areas with bare soil will be managed to control wind erosion through direct placement of reclamation material and re-vegetation as practical. Other measures may include use of geotextile, armouring of exposed surfaces, and installation of sediment fences in specific situations. Monitoring of soils adjacent to the Project area will be carried out to track level of trace elements.

### *Soil Moisture Regime*

Potential moisture regime changes at a local scale resulting from alteration of drainage patterns can be minimized by installing drainage and erosion control materials to ensure soil stability, designing access roads and structures to minimize alteration of drainage patterns, and where necessary, promoting adequate surface drainage through use of culverts, diversion ditches and other means.

There are no recommended mitigation measures for effects of water table lowering effects on soil moisture regimes. The effect is reversible, but occurs over a long time period, during which vegetation may adapt to changes in moisture regime. However, the degree and extent of changes cannot be predicted with confidence during construction, operation and closure, due to complex site specific interactions, and therefore water table depths and soil moisture characteristics will be measured in association with vegetation monitoring. Once water levels recover post-closure, the area of effect is greatly reduced.

The monitoring program would apply to undisturbed areas of the FalC forest, and with approval of Saskatchewan Ministry of Environment, could co-locate and take advantage of existing information from long term monitoring plots of the Forest Service. Both wetland and upland systems will be included in the monitoring program. The monitoring program would be initiated early in the construction phase of the Project to potentially enable prediction of long term changes with somewhat greater confidence than currently possible, and it may then be possible to develop mitigation strategies.

### *Land Capability for Forestry and Agriculture*

The current land use is native forest and there is no agriculture within the LSA. However, mitigation measures with respect to capability for forestry are generally also applicable to potential agricultural use. Restoration of land capability for agriculture and forestry is dependent on reclamation. The construction of new landscapes and soil profiles is expected to replace capability so that the growth of forests or crops will be sustainable with normal land management practices. Consequently, all measures indicated above for mitigation of terrain distribution and topography, soil cover and disturbance, soil quantity and soil quality are pertinent to mitigation and restoration of land capability as well.

### *Summary of Mitigation Measures*

Mitigation measures are summarized in tabular format below in Table 6.2.1-14.

***Table 6.2.1-14: Summary of Mitigation Strategies for Soil, Terrain and Surficial Geology***

| Potential Effect | Valued Component | Project Phase | Mitigation Strategy |
|---|---|---|---|
| Removal of soil profiles ( A, B, LFH and O horizons) from the landscape for the mine and facilities | Soil cover<br>Agricultural capability<br>Forestry capability<br>Unique soil or terrain | Construction<br>Operations | Minimize footprint.<br>Strip and salvage soil, including areas of peat, for reclamation.<br>Replace surface soil cover at reclamation (see Section 7.5 Closure and Reclamation Plan) |
| Admixing (by over-stripping, mixing during soil transport and placement) | Soil quality | Construction<br>Closure and Decommissioning | Avoid over-stripping.<br>Stockpile topsoil separately or use direct placement |
| Burial of topsoil (by incomplete salvage, spillage and trampling) | Soil quantity<br>Soil quality | Construction<br>Closure and Decommissioning | Avoid under-stripping.<br>Avoid over-filling loads to limit spillage.<br>Recover larger spills. |
| Soil compaction<br>(by machinery, equipment) | Soil quality | Construction<br>Operations<br>Closure and Decommissioning | Surficial materials are mainly coarse textured, and not prone to compaction.<br>Some areas have finer textures (Alluvium, Gleysols); in these areas:<br>- avoid work in wet conditions<br>- minimize number of repeated passes.<br>De-compact soils at reclamation as necessary. |

| Potential Effect | Valued Component | Project Phase | Mitigation Strategy |
|---|---|---|---|
| Chemistry changes during storage (pH, organic matter, nutrients) | Soil quality | Construction<br>Operations | Develop shallow (<2 m) topsoil piles or used direct placement as practicable.<br>Vegetate any long term piles to maintain biological activity in surface and near-surface layers.<br>Place soil stockpiles only in well drained locations to avoid saturation of soil. |
| Soil acidification due to seepage of potentially acidic substances from PKCF to adjacent soils | Soil quality | Operations<br>Closure and Decommissioning | Likely not an issue. Should issues arise, develop plan for containment and treatment.<br>See Metal Leaching/Acid Rock Drainage Geochemistry (Section 5.2.3). |
| Soil contamination by spills and leaks | Soil quality | Construction<br>Operations<br>Closure and Decommissioning | Follow preventative measures and safe handling protocols.<br>Contain, control and recover spillage or leakage of chemicals or hydrocarbons on the ground surface as soon as possible upon detection (According to Spill and Emergency Response Plan).<br>Evaluate and implement measures for ameliorating contaminated soil, based on the extent of disturbance, chemical characterization of unaffected soil, and remediation criteria. |
| Dust generation and trace element deposition on adjacent soils | Soil quality | Construction<br>Operations<br>Closure and Decommissioning | Apply wind erosion control and dust control measures.<br>(See Climate and Air Quality, Section 5.2.4).<br>Conduct soil trace element monitoring program. |
| Acid deposition on soils in surrounding area | Soil Quality | Construction<br>Operations<br>Closure and Decommissioning | Optimize efficiency in motorized vehicle/ equipment use.<br>(See Climate and Air Quality, Section 5.2.4). |
| Erosion of exposed soil, stockpiles, sloping areas<br>Loss of soil due to wind and water erosion | Soil quantity<br>Soil quality | Construction<br>Operations<br>Closure and Decommissioning | Apply erosion control measures to soil stockpiles to limit erosion (vegetating with appropriate seed mix, use of erosion mats, netting, mulches, straw, slash<br>Manage surface runoff (snow melt, rainfall) to reduce the risk of wind and water erosion.<br>Design, grade and contour stockpiles such that slope lengths and gradients minimize wind and water erosion of soil materials.<br>Monitor for erosion; follow up on any problems with remedial work to restore affected areas. |

| Potential Effect | Valued Component | Project Phase | Mitigation Strategy |
|---|---|---|---|
| | | | Consider use of cross berms, ditches or other methods for slopes greater than 30%, based on geotechnical considerations and design. |
| Surficial material redistribution and alteration of topography by excavation, cut, fill, and development of waste piles | Terrain, surficial material distribution<br>Unique soil/terrain<br>Topography | Construction<br>Operations | Re-contour materials at closure, in conformance with local topography. |
| Changes in soil drainage regime in areas adjacent to disturbed area | Soil quality | Construction<br>Operations<br>Closure and Decommissioning | Install drainage and erosion control materials, as required, to ensure soil stability, facilitate adequate surface drainage and promote revegetation.<br>Design and construct access roads and other earth structures so as to limit alteration of natural drainage patterns. Install culverts as required to manage drainage.<br>Re-contour decommissioned infrastructure and roads to restore natural drainage patterns and topography.<br>Carry out a regional soil moisture monitoring and water table monitoring program, in conjunction with vegetation monitoring. |
| Change to drier soil conditions due to water table lowering | Soil moisture regime | Operations<br>Closure and Decommissioning | Monitor changes beginning early in the Project to potentially facilitate modelling to predict long term effects |
| Seismic activity - effects on geology/terrain,; possible Project damage | Effect on Project (mine, infrastructure damage)<br>Surficial Material Distribution | Construction<br>Operations<br>Closure and Decommissioning | None |
| Landscape instability (landslides, slumps, rock falls in mine) – possible changes to geology/terrain; possible Project damage | Effect on Project (mine, infrastructure damage)<br>Surficial Material Distribution | Construction<br>Operations<br>Closure and Decommissioning | Avoid over-steepening of gradients such as road cuts, and grade back slopes to suitable gradients.<br>Manage drainage to prevent saturated conditions that could initiate land sliding and slumping.<br>Apply prevention measures based on mine design and best practices, including appropriate blasting techniques. |

### *Summary of Residual Effects*

The residual effects expected from Project development were assessed using a classification system based on the rating criteria of direction, magnitude, duration, geographic extent, frequency, reversibility, probability and confidence in the assessment. These rating criteria were then considered to ascertain the overall significance of an impact on the landscape. The definitions of impact criteria and the approach to determining significance are presented in Section 6.1 (Overview and Methods). The predicted impacts of the Project on soils and terrain are summarized in Table 6.2.1-14.

All VCs for soil, terrain and surficial geology had effects rated as ‘not significant’. Some VCs had a moderate magnitude rating in relation to the LSA, but these were assessed as being of low magnitude in relation to the RSA. These VCs consisted of: surficial material distribution and topography, specifically regarding development of new topographic features and loss of terrain to mine pit lakes; soil distribution and cover, specifically regarding loss of soil cover to mine pit lakes; and change in soil quality due to alteration of drainage regime due to water table drawdown. As indicated, each of these effects had a low magnitude at the RSA level.

The soil moisture regime VC was rated as ‘not significant’. While the magnitude and geographic extent are predicted to be ‘Moderate’ during Operations, the effect in the RSA and part of the LSA is expected to diminish soon after mining ends, and the residual effect will then be localized within the LSA. It is expected that moisture regime will return to a state similar to that of the surrounding terrain, but complete water table rebound could require a long time (see Section 6.2.6 Regional Geology and Hydrogeology). Monitoring moisture regime and developing measures as necessary are recommended in order to manage this potential effect.

*Table 6.2.1-15: Summary of Residual Effects*

| Nature of Impact/Indicator | Direction | Magnitude | Duration | Geographic Extent | Frequency | Reversibility | Ecological Context | Probability | Confidence | Significance Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| Terrain Distribution and Topography | | | | | | | | | | |
| Surficial material distribution | Neutral | | | | | | | | High | Not Significant |
| Topography | Neutral | | | | | | | | High | Not Significant |
| Loss of Upland Terrain | Adverse | Low | Long-term | Local | Intermittent | Irreversible | Low | High | High | Not Significant |
| Terrain stability | Adverse | Low | Short-term | Local | Intermittent | Reversible | Low | Unknown | Low | Not significant |
| Soil Distribution/Cover | Adverse | Low | Long-term | Local | Intermittent | Irreversible | Low | High | High | Not Significant |
| *Soil Quality* | | | | | | | | | | |
| Admixing | Neutral | | | | | | | | High | Not Significant |
| Compaction | Adverse | Low | Short-term | Local | Intermittent | Reversible | Low | High | Moderate | Not Significant |
| Contamination (Dust) | Adverse | Low | Long-term | Local | Intermittent | Reversible | Low | Unknown | Low | Not Significant |
| Change in Moisture Status | Adverse & Positive | Low - Moderate [1] | Long-term | Local [1] | Single Occurrence | Reversible | Low | Unknown | Low | Not Significant |
| Soil Acidification | Neutral | | | | | | | | High | Not Significant |
| Soil Quality Relative to Reclamation | Neutral | | | | | | | | High | Not Significant |

| Nature of Impact/Indicator | Direction | Magnitude | Duration | Geographic Extent | Frequency | Reversibility | Ecological Context | Probability | Confidence | Significance Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Soil Quality | Adverse and Neutral | Low to Moderate | Short-term to Long-term | Local to Regional | Intermittent to continuous | Reversible (Irreversible)[1] | Low | Unknown to High | Moderate | Not Significant |
| *Soil Quantity* | | | | | | | | | | |
| Water Erosion | Adverse | Low | Medium-term (Seasonal) | Local | Intermittent | Reversible | Low | High | Moderate | Not Significant |
| Wind Erosion | Adverse | Low | Medium-term (Seasonal) | Local | Intermittent | Reversible | Low | High | Moderate | Not Significant |
| Land Capability for Forestry | Neutral | | | | | | | | High | Not Significant |
| Soil Capability for Agriculture | Neutral | | | | | | | | High | Not Significant |
| Unique Soils and Terrain | Neutral | | | | | | | | High | Not Significant |

**Note:**[1] The magnitude is predicted to extend into the RSA to the end of mining, and to be localized after mining ceases.

[2] Irreversible for one of the indicators.

### 6.2.2 Air Quality

The assessment presented in this section predicts the emissions to the atmosphere from construction and operation activities of the Project, estimates the resultant ambient concentrations, and then compares these estimates to relevant guidelines or objectives.

#### 6.2.2.1 Introduction

Project activity and resulting air emissions will vary almost continuously throughout the duration of the Project. Therefore, the only practical approach for quantifying air quality is to define representative levels of activity during selected periods of time. To avoid the complication and potential confusion of numerous scenarios, a near worst case scenario has been analyzed for the year during which the largest amount of material will be mined and processed. This is predicted to occur in Year 6 when the Star pit is in operation phase 1 and waste stripping is in phases 1a to 4.

Several Project components will be sources of air emissions including mobile and stationary diesel engines, an incinerator, and natural gas heating. Mining activities will generate dust composed of inert soil and kimberlitic materials. The main potential sources of dust are blasting, excavation, materials hauling, crushing and sizing, stockpiling, and overburden and rock disposal. The processing plant will not generate dust since the processed kimberlite will be wet.

Dispersion modelling was undertaken to assess the impact of atmospheric emissions associated with the Project on air quality. Ground level concentrations of Criteria Air Contaminants (CACs) were predicted across a 30 km by 30 km study area centered on the Star pit. The area within the mine boundary was excluded for assessment purposes as this area is restricted to the general public and subject to work place safety standards rather than ambient air quality objectives.

#### 6.2.2.2 Scoping, Issues Identification and Confirmation

The analysis of the Project effects on the atmosphere takes into consideration two categories of contaminants: CACs and greenhouse gases (GHG). Criteria air contaminants relevant to this Project include particulate matter, nitrogen dioxide and sulphur dioxide. These are primary indicators of air quality and are associated with human health impacts (primarily through inhalation) and environmental impacts, including aesthetic, visibility, and depositional effects.

Greenhouse gases such as carbon dioxide, methane and nitrous oxide potentially contribute to climate change. GHG are any gases in the atmosphere that absorb radiation, particularly outgoing terrestrial infrared radiation, contributing to global warming. For the Project, carbon dioxide will be the only GHG emitted to the atmosphere as a product of natural gas and diesel combustion. Emissions of carbon dioxide were quantified and assessed in the context of provincial and national GHG emission totals.

### *Air Quality Objectives*

Air quality objectives provide quantitative criteria useful for assessing significance of air quality related effects. National and/or provincial standards and guidelines suggest thresholds, where, if exceeded, Project effects can be considered significant. Conversely, effects can be considered not significant if these standards and guidelines are not exceeded.

The primary aim of establishing ambient air quality objectives (AAQO) is to protect public health and the environment from the effects of air pollution. Ambient air quality in Saskatchewan is regulated by the provincial government (CAA 1996). The federal government has also set objectives for air quality shown in Table 6.2.2-1: Ambient Air Quality Objectives are AAQO for other provinces to provide a comparison.

For National Ambient Air Quality Objectives (NAAQO), three levels of concentration have been defined:

- Maximum Desirable Level (Level A) defines the long-term goal for air quality and provides a basis for an anti-degradation policy for unpolluted parts of the country and for the continuing development of control technology;
- The Maximum Acceptable Level (Level B) is intended to provide adequate protection against adverse effects on soil, water, vegetation, animals, visibility, personal comfort and well-being; and
- The Maximum Tolerable Level (Level C) denotes the concentration of an air contaminant that requires abatement without delay to avoid further deterioration to air quality that would endanger the prevailing Canadian life-style or ultimately, lead to a substantial risk to public health.

***Table 6.2.2-1: Ambient Air Quality Objectives***

| Jurisdiction | Substance | Level | Concentration[1] µg/m³ | Averaging Time |
|---|---|---|---|---|
| Saskatchewan | $SO_2$ | Acceptable | 450<br>150<br>30 [2] | 1 Hour<br>24 Hours<br>Annual |
| | CO | Acceptable | 15,000<br>6,000 | 1 Hour<br>8 Hours |
| | $NO_2$ | Acceptable | 400<br>100 [3] | 1 Hour<br>Annual |

| Jurisdiction | Substance | Level | Concentration[1] $\mu g/m^3$ | Averaging Time |
|---|---|---|---|---|
| | TSP | Acceptable | 120<br>70[3] | 24 Hours<br>Annual |
| ON, NF, BC | $PM_{10}$ | Acceptable | 50 | 24 Hours |
| BC | $PM_{2.5}$ | Acceptable | 25<br>8 | 24 Hours<br>Annual |
| Canada Wide Standards (CWS) | $O_3$ | Desirable | 100 | 1 Hour |
| | | | 30 | 24 Hours |
| | | Acceptable | 160 | 1 Hour |
| | | | 50 | 24 Hours |
| | | | 30 | Annual |
| | | Tolerable | 300 | 1 Hour |
| | $PM_{2.5}$ | Acceptable | 30 | 24 Hours |
| | TSP | Desirable | 60 | 24 Hours |
| | | Acceptable | 120 | 24 Hours |
| | | | 70[3] | Annual |
| | | Tolerable | 400[3] | Annual |
| | $NO_2$ | Desirable | 60 | Annual |
| | | Acceptable | 400<br>200<br>100 | 1 Hour<br>24 Hours<br>Annual |
| | | Tolerable | 1,000<br>300 | 1 Hour<br>24 Hours |
| | CO | Desirable | 15,000<br>6,000 | 1 Hour<br>8 Hours |
| | | Acceptable | 35,000<br>15,000 | 1 Hour<br>8 Hours |
| | | Tolerable | 20,000 | 8 Hours |

**Note:** [1] At a temperature of 25°C and pressure of 101.3 kPa
[2] Geometric mean
[3] Arithmetic mean
ON: Ontario, NF: Newfoundland and Labrador; BC: British Columbia.

Selection of the appropriate level will depend upon the receptors, and the degree of appropriate protection. Maximum tolerable levels are used for evaluation purposes to identify the severity of an anthropogenic or natural phenomenon in order to protect human health and institute appropriate corrective action. In general, maximum acceptable levels are not to be exceeded in any urban centre including industrial areas releasing atmospheric emissions. Within rural areas, the goal is typically to maintain pollutant concentrations at or below maximum desirable levels.

In keeping with the Canadian Council of Ministers of the Environment (CCME) concepts of Continual Improvement and Keeping Clean Areas Clean (CI/KCAC), the Project will strive to reduce emissions whenever feasible, with the goal of meeting or exceeding the ambient air quality standards.

### *Emission Sources*

The primary emission sources will consist of the following:

- vehicles and stationary equipment exhaust emissions resulting from internal combustion of diesel fuel;
- fugitive dust emissions from blasting, ore mining, materials handling, overburden removal, and waste disposal; and
- fugitive dust generated by vehicles in the open pit and on haul roads.

The secondary sources emitting infrequently will include:

- shop vents relating to welding hoods and general shop and plant ventilation outlets;
- natural gas fired heaters installed at some buildings operating during winter months;
- waste incinerator running daily during an 8-hour shift; and
- construction equipment operating at frequently changing locations depending on the construction schedule over a 2-year period.

Anticipated pollutants generated by the primary and secondary sources will likely include:

- total suspended particulate (TSP);
- particulates with diameter 10 µm or less ($PM_{10}$);
- particulates with diameter 2.5 µm or less ($PM_{2.5}$);
- sulphur dioxide ($SO_2$);
- nitrogen dioxide ($NO_2$);
- carbon monoxide (CO);
- carbon dioxide ($CO_2$); and
- metal elements in dust including cadmium, arsenic, chromium, cobalt, lead, nickel, and molybdenum.

Not all of the above substances are considered to have the potential to pose a risk to human health or to the environment. Air pollutants of concern or Valued Components (VCs) have been selected for detailed impact assessment involving dispersion modelling using the following criteria:

- the level of concern with reference to health effects (relates to ambient air quality objectives);
- probability of occurrence of the substance at higher concentrations;
- emission periods;
- expected ground level concentrations with reference to the monitor detection limit; and
- availability of suitable monitors for contaminants in terms of cost, accuracy, detection limits and suitability for unsupervised continuous operation in open remote terrain.

Considering the above factors the following substances (or VCs) have been selected for the detailed effects assessment which included dispersion modelling:

- particulate matter (TSP, $PM_{10}$ and $PM_{2.5}$);
- metal elements in dust such as lead, cadmium and mercury;
- sulphur dioxide; and
- nitrogen oxides.

Particulate matter, sulphur dioxide and nitrogen oxides are classified by Environment Canada as criteria air contaminants (CACs). They are tracked by Environment Canada to measure the effectiveness of emission reduction programs and to support scientific research (Environment Canada 2010). Heavy metals such as lead (Pb), cadmium (Cd) and mercury (Hg) are of particular interest in the metal elements group due to their toxicity.

In addition, carbon dioxide emissions are selected as a VC and quantified in order to address greenhouse gas emissions.

#### 6.2.2.3 Project Emission Sources Description

General characteristics of potential emission sources of air pollutants of concern are discussed in the following paragraphs.

In-pit crushing and conveying of kimberlite can generate particulate emissions. Uncontained processing operations like these can produce large amounts of dust.

Haul truck exhaust will be the dominant gaseous air contaminant at the site. The main components of diesel engine exhaust are carbon dioxide, nitrogen oxides, and small particulates ($PM_{10}$ and $PM_{2.5}$). Truck loading / unloading will be a source of fugitive dust emissions. There also will be emissions of gases from light vehicles on-site (gasoline and diesel internal combustion engines), but these are considered negligible compared to the large equipment emissions.

Winter heating of buildings will result in emission of carbon dioxide and water vapour due to the use of natural gas as fuel. The annual energy requirement for heating is estimated at

87,495 GJ. However, small heaters will be distributed over the plant area resulting in dispersion of gas combustion products, and are not likely to create a high concentration of contaminants.

Dust may be generated on un-reclaimed areas of the overburden and rock storage pile and other areas of exposed mineral soil. Dust can also be mobilized during material handling, including material loading onto the pile, disturbances by strong wind currents, and potentially removing loads from the pile. The potential drift distance of particles caused by wind is determined by the initial injection height of the particle, the terminal settling velocity of the particle, and the degree of atmospheric turbulence.

Emissions from the waste incinerator will be limited to the products of complete combustion of organic matter (i.e., carbon dioxide and water vapour). Clean burning natural gas will be used as an auxiliary fuel to assure complete combustion in two sequential chambers at high temperatures.

Blasting produces similar emissions to vehicle exhaust, but also produces dust, and small quantities of sulphur dioxide and other substances. Blasting gases readily dissipate in the atmosphere following detonation. Much of the material in the initial plume is larger than the aerodynamic diameter of particles that can remain suspended in the air and is therefore deposited within the pit area.

The Project emissions that can be quantitatively assessed for Star Pit Phase 1 in Year 6 are shown in Table 6.2.2-2. Sources of less than 10% usage are not shown because of their insignificant contribution to total emissions.

*Table 6.2.2-2: Characteristics of Project Emission Sources in Year 6*

| Type | Model | Engine HP | Work Area | QTY | Operation Time (h/d) | Usage (%) | Source Type | Mobility | Contaminant |
|---|---|---|---|---|---|---|---|---|---|
| Off Highway Truck | Komatsu HD 1500-7 | 1406 | In pit & roads | 34 | 20 trucks / 24 | 85 | Volume | Mobile | Exhaust, dust |
| Shovel | Komatsu PC 4000-6 | 1875 | In pit | 3 | 24 | 85 | Volume | Mobile | Exhaust, dust |
| Bulldozer | Komatsu D275AX | 452 | In pit & piles | 5 | 24 | 85 | Volume | Mobile | Exhaust, dust |
| Grader | CAT 16M | 297 | In pit | 2 | 24 | 85 | Volume | Mobile | Exhaust, dust |
| Wheel Loader | Komatsu WA1200-6 | 1765 | IPCC | 1 | 24 | 75 | Volume | Mobile | Exhaust, dust |
| Wheel dozer compactor | Terex TC 550 | 525 | IPCC | 5 | 24 | 50 | Volume | Mobile | Exhaust, dust |
| Production drill | Sandvik D55SP | 800 | In pit | 2 | 24 | 40 | Volume | Mobile | Exhaust, dust |
| Mine water truck | CAT 730 | 330 | In pit | 1 | 24 | 20 | Volume | Mobile | Exhaust, dust |
| Road Sander | CAT 16H | 375 | Roads | 1 | 4 | 15 | Volume | Mobile | Exhaust, dust |
| In Pit Fuel Truck | Kenworth T800 | 600 | In pit | 1 | 18 | 75 | Area | Stationary | Exhaust, dust |
| Heavy service truck | International | 300 | In pit | 3 | 2 | 10 | Volume | Stationary | Exhaust |
| Light service truck | International | 300 | In pit | 4 | 2 | 10 | Area | Mobile | Exhaust, dust |
| Lube truck | International | 600 | In pit | 1 | 18 | 75 | Area | Mobile | Exhaust |
| Weld truck | International | 600 | In pit | 1 | 3 | 10 | Point | Stationary | Gas, exhaust |
| Incinerator | E180 | N/A | Plant | 1 | 8 |  | Point | Stationary | Gas |
| Ore stockpile |  | N/A | Plant | 1 | 24 |  | Area | Stationary | Dust |

### *Emission Rates*

Emission rates of the Project sources have been calculated with AP-42 emission factors published by the US Environmental Protection Agency (EPA 1995). An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category.

The relevant document for stationary sources is the Compilation of Air Pollutant Emission Factors, Volume I – Stationary Point and Area Sources – 5th Edition (EPA 1995). Sequential annual supplements have been published for the AP-42 document as new information becomes available. The current supplement of July 2010 was incorporated into this Project as needed. Emission factors for non-road mobile equipment have been computed using the NONROAD inventory model developed by EPA (EPA 2008). In addition to emission factors, the estimates included the power rating (hp) and utilization factors for each piece of equipment.

Emission rates for Komatsu off highway trucks and shovels have been received from California Environmental Protection, Air Resources Board, Mobile Source Operations Division, which certified Komatsu engines emissions in g/kWh. Their values are below Tier 2 Emission Standard Category.

#### *Construction Phase*

During the early site preparation and construction phases of the project, fugitive emissions resulting from earthwork and vehicle movement on temporary dirt roads will increase particulate concentrations. In addition, fugitive dust will be created by construction activities, exposed topsoil, moved overburden, and stored dusty construction material. The fugitive dust emissions will increase when the initially wet material dries.

Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. The temporary nature of the construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected (1) to have a definable beginning and an end, and (2) to vary substantially over different phases of the construction process. This is in contrast to operational fugitive dust sources, where emissions are either relatively steady or follow a discernable temporal cycle.

The overburden at the first open pit to be mined (i.e., Star Pit Phase 1a) will initially be stripped by an earthmoving contractor(s) using conventional earthmoving equipment including hydraulic excavators, haul trucks and scrapers as shown in Figure 6.2.2-1.

Shore will concurrently procure and commission the in-pit crush and convey (IPCC) system and complete the Phase 1a overburden stripping to expose ore. The IPCC equipment will then be relocated to the Phase 1b pushback to recommence stripping. This general approach of using the IPCC system to strip to ore and then moving it to the next scheduled pit phase will be repeated over the life of the mine.

A detailed construction schedule is not yet available for the Project; therefore, a general approach to estimate area-wide construction fugitive dust emissions is appropriate for the air quality effect assessment. The following subsections describe the methods where wide-spread or site-specific emissions are estimated.

### Engine Exhausts

Heavy-duty diesel vehicles and stationary construction equipment will generate diesel exhaust during the construction phase. Chemical analysis of exhaust has shown that diesel exhaust contains hydrocarbons, carbon monoxide, nitrogen oxides, and particulates. Emission levels of hydrocarbons, carbon monoxide, nitrogen oxides, and particulates are measured in grams per kilometre driven for a heavy truck moving at an average speed of 22.9 km/h (Westerholm et al. 1991). These pollutants are dispersed into the surrounding air while the vehicle is in motion. Usually, humans object to smoke and odorous exhausts from the diesel engines near slow-moving vehicles and stationary equipment. Because this phenomenon occurs near individual operating units, the nuisances could be severe at a construction site but normally would not extend beyond the Project fence line. No emissions inventory has been completed because the equipment data is not yet available as some part of the construction will be done by contractors yet to be selected in the bidding process.

### Fugitive Dust

The quantity of fugitive dust emissions (dust picked up by wind or moving vehicles from the ground) from construction operations are proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources (Cowherd et al. 1974), emissions from heavy construction operations are expected to be positively correlated with the silt content of the soil (that is, particles smaller than 75 micrometers (μm) in diameter), as well as with the speed and weight of the average vehicle, and to be negatively correlated with the soil moisture content.

Based on field measurements of total suspended particulate (TSP) concentrations at construction sites (Cowherd et al. 1974; Jutze 1974), the approximate emission factors for construction activity operations are:

E = 2.69 megagrams (Mg) / hectare / month of activity

E = 1.2 tons / acre / month of activity

These values are most useful for developing estimates of overall emissions from construction scattered throughout a geographical area. This emission factor is most applicable to construction operations with: (1) medium activity level, (2) moderate silt contents, and (3) semiarid climate. Test data were not sufficient to derive the specific dependence of dust emissions on correction parameters. The emission factor is applicable to TSP, therefore it is not suitable for estimating particulate matter (PM) no greater than 10 µm in aerodynamic diameter ($PM_{10}$) because the results would be greatly overestimated. . Derivation of this emission factor assumes construction activity occurs 30 days per month. TSP emissions over an area of 10 acres in one year period will be 144 tons (130 tonnes). This is a very conservative estimate as precipitation (rain and snow) will greatly reduce the emissions and confine them to the activity area.

Fugitive dust may appear at higher concentrations during dry summers and windy weather. Some land will be cleared, grubbed, and regraded, according to highway construction requirements. Also, exposed topsoil and some stored dusty construction materials may generate fugitive dust. The US EPA AP-42 emission factor documentation (EPA 2004) gives the following empirical equation for fugitive TSP emissions from active storage piles, as a result of wind erosion and pile maintenance:

$$TSP = 1.8\,u \quad \text{(kilograms / hectare / hour)}$$

Where u is the average wind speed in m/s.

Calculation of TSP for 10 acres area and 1-hour average with wind speed of 3 m/s and 245 days with precipitation (site average for 2000 – 2005 period) will result in an estimate of 7.2 kg TSP/hour.

*Operations Phase*

Operations phase emissions are estimated for stationary and mobile sources using AP-42 emission factors, equipment manufacturer specifications, materials properties and throughput rates. Frequently used supporting data needed for particulate matter emissions estimates for Star Pit operation in Year 6 are presented in Table 6.2.2-3.

***Table 6.2.2-3: Supporting Data for Particulate Matter Emissions Estimates for Star Pit***

| | |
|---|---|
| Ore throughput | 45,000 t / d or 520 kg / s) |
| Overburden stripping Phase 1a | 28,000 t / d |
| Overburden stripping Phase 1b | 165,000 bcm / d |
| Overland conveyors capacity | 20,000 t / h |

| | |
|---|---|
| Material moisture content | 10% |
| Pit operational time | 7,300 h / a |
| Plant operational time | 8,520 h / a |
| Ore dust specific gravity (median) | 2.2 |
| Wet material bulk density | 2.27 t / m$^3$ |
| ANFO explosives usage | 70 t / wk |
| Coarse ore stockpile diameter / height | 80 m / 36 m |
| Conveyor to stockpile drop height (average) | 1.5 m |
| Annual average wind speed | 3 m/s |
| Silt content in ore | 8.6% |
| Silt content in road material | 9.2% |

### *Fugitive Sources*

The fugitive dust generation process is caused by two basic physical mechanisms:

- pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.; e.g., in-pit crusher/sizer); and
- entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 19 km/h. Examples include PKCF berm wind erosion and stockpile fugitive emissions.

The potential drift distance of particles is governed by the initial injection height of the particle, the terminal settling velocity of the particle, and the degree of atmospheric turbulence. Dispersion models have computed theoretical drift distance, as a function of particle diameter and mean wind speed for fugitive dust emissions. Results indicate that for a wind speed of 16 km/h, particles larger than about 100 μm are likely to settle within 6 to 9 m from the point of emission. Particles that are 30 to 100 μm in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within tens to hundreds of meters from the point of release. Smaller particles have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence (EPA 1995).

For air quality impact assessments, the most important are suspended particulates (SP) consisting of fractions no greater than 30 micrometers in aerodynamic diameter. The following definitions apply to particulate classes in the ≤ 30 μm range:

- suspended particulate (SP), which is often used as a surrogate for TSP, is defined as particulate matter (PM) with an aerodynamic diameter no greater than 30 μm. SP may also be denoted as $PM_{30}$. An effective cut point of 30 µm aerodynamic diameter is frequently assigned to the standard high volume sampler;

- particulate matter no greater than 10 µm in aerodynamic diameter ($PM_{10}$). Because $PM_{10}$ is the size basis for the current primary Ambient Air Quality Standards (AAQS) for particulate matter, it represents the particle size range of regulatory interest in some Canadian jurisdictions (see Table 6.2.2-1) and in the US; and
- particulate matter $PM_{2.5}$ refers to particulate with an aerodynamic diameter no greater than 2.5 µm ($PM_{2.5}$). Some provinces and the Northwest Territories have introduced AAQS for this group of particles. There are also Canada Wide Standards for $PM_{2.5}$.

The quantity of fugitive dust emission depends on several factors, the most important being wind speed, moisture content and dust density. Maximum fugitive emissions will take place during windy weather with small and light particles present in dry active surface materials.

### *Primary Crusher / Sizer*

Initial sizing is required to place suitably sized kimberlite pieces on the conveyor transporting to the processing plant. A semi-mobile sizer, located in pit, was selected to provide this function. Predicted SP and $PM_{10}$ emissions were calculated with AP-42 emission factors for high-moisture ore and maximum throughput of 45,000 tpd. Calculated emissions are presented in Table 6.2.2-4. Annual emissions include 355 operational days and 120 days with dry weather when dust can be dispersed.

***Table 6.2.2-4: Estimated Emissions for the Primary Crusher / Sizer***

| Parameter | | TSP | SP | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| Emission rate | g/s | 7.03 | 5.20 | 2.08 | 0.83 |
| | kg/d | 607.39 | 449.28 | 179.12 | 71.71 |
| | t/a | 70.89 | 52.44 | 20.91 | 8.37 |

### *Processing Plant Stockpile*

Dust emission from an open surface of a particular conical storage pile caused by wind erosion depends on the following factors:

- age of the pile,
- moisture content,
- proportion of aggregate fines and
- wind speed.

The following section contains discussion of the main factors affecting wind erosion from stockpiles; however, other fugitive dust area sources such as open yards and waste aggregate disposal facilities are also affected by these factors.

Age of Storage Pile

When freshly processed aggregate is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself (including conveyor transfer) or from high winds. As the aggregate pile weathers, the potential for dust emissions is greatly reduced. However, the coarse ore storage pile will be continuously active and turnover time will be short. Consequently, the pile-aging factor has not been considered in this project.

Precipitation

Any significant rainfall soaks into the interior of the pile, and any drying of the interior of the pile is very slow. Based on measurements taken for the period of 1971 to 2000 at the Prince Albert meteorological station (see Table 5.2.4-5, Section 5.2.4.7) the lowest precipitation has been observed in winter months (November - March). However, stockpile fugitive emission caused by wind erosion will cease when the surface of the active pile is frozen.

Wind Speed

Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that threshold wind speeds for dust becoming airborne exceed 5 m/s (18 km/h at 15 cm above the surface or 10 m/s (36 km/h) at 7 m above the surface (EPA 1995). As wind speed increases, more aggregate materials will become airborne. However, wind gusts may quickly deplete a substantial portion of the fugitive potential. Also, increased wind speed will provide better ventilation with consequent dilution of suspended particulates and lower concentration. Higher wind speeds (more than 52 km/h) have been recorded at the FalC meteorological station. Most frequent annual directions are from the west. For fugitive emissions the threshold value of 5 m/s is higher than the annual average 3 m/s.

Stockpile fugitive dust emission resulting from wind erosion was predicted by computer simulation with the STOCKPILE Version 1.01 commercial computer model (Beer 1989). This model was developed by F.W. Parrett Limited, London, UK, a company specializing in dust measurement and control. STOCKPILE was written based on field observations and the wind tunnel measurements carried out by the Warren Springs Laboratory at Cambridge University, UK. The US EPA has adopted the Warren Springs Laboratory findings in developing AP-42 fugitive dust emission factors (Parrett 1992).

STOCKPILE model input parameters were as follows:

- stockpile dimensions: diameter 80 m and height 36 m;
- wind speed: 5 m/s;
- roughness surface coefficient: 0.03 for open flat terrain with few obstacles;
- dust particle density: 2.2 g/cm$^3$;
- threshold friction velocity of stockpile surface from references for similar material: 0.35 m/s; and
- the Ksa constant which depends on the surface and moisture content: typical value of 0.0002 was used.

For the above input data, the model dust loss from the stockpile was computed for four sizes. The results are summarized in Table 6.2.2-5. Annual emissions are factored for a mitigation effect caused by 245 days with measurable precipitation. Terminal settling velocities were also calculated. The results were used as dispersion model input data to calculate particulate concentrations in ambient air.

***Table 6.2.2-5: Coarse Ore Stockpile Emissions***

| Parameter | | Particle Diameter | | | |
|---|---|---|---|---|---|
| | | 50 µm | 30 µm | 10 µm | 2.5 µm |
| Emission rate | g/s | 0.240 | 0.197 | 0.116 | 0.058 |
| | kg/d | 20.78 | 17.04 | 10.06 | 5.04 |
| | t/a | 2.494 | 2.045 | 1.207 | 0.605 |
| Settling velocity m/s | | 0.164 | 0.059 | 0.006 | 0.000 |

*Conveyor Emissions*

Dust emissions caused by ore dropping from conveyor to stockpile:

- dropping SP emission factor E:

$$\mathrm{E}\ (\mathrm{kg/m^3}) = \frac{0.0046(\mathrm{d})^{1.1}}{(\mathrm{M})^{0.3}}$$

where: d = drop height (m)
M = moisture content in ore (%)

$$\mathrm{E}\ (\mathrm{kg/m^3}) = \frac{0.0046(1.5)^{1.1}}{(10.0)^{0.3}} = 0.0036$$

Equation taken from AP-42, Table 11.9-1:

- conveyor dropping daily SP emission:

$$\mathrm{SP} = \left(\text{Emission Factor}\right) \times (\text{Density})^{-1} \times \ (\text{Daily Removal}) \times 1000\,\frac{\mathrm{kg}}{\mathrm{t}}$$

$$\mathrm{SP} = 0.0036\,\frac{\mathrm{kg}}{\mathrm{m}^3} \times \frac{1}{2200}\,\frac{\mathrm{m}^3}{\mathrm{kg}} \ \times 45,000\,\frac{\mathrm{t}}{\mathrm{day}} \ \times 1000\,\frac{\mathrm{kg}}{\mathrm{t}} = \ 73.6\,\frac{\mathrm{kg}}{\mathrm{day}}$$

The above calculation yields an instantaneous emission rate of SP at 0.852 g/s (Table 6.2.2-6). According to the EPA emission factors AP-42, the $PM_{2.5}$ emissions are 1.7% of the SP emissions for conveyor drops which is equal to 0.0145 g $PM_{2.5}$ /s. No data for the $PM_{10}$ fraction is available. These values are added to relevant wind erosion emissions to be used in dispersion modelling.

***Table 6.2.2-6: Conveyor Emissions***

| Parameter | | SP | $PM_{2.5}$ |
|---|---|---|---|
| Emission rate | g/s | 0.852 | 0.0145 |
| | kg/d | 73.610 | 1.252 |
| | t/a | 8.592 | 0.146 |

### *Overburden and Rock Storage Pile Emissions*

The wind erosion emission factor for the active storage area was calculated using the following equation (AWMA 1992):

$$E = 1.9\left(\frac{s}{1.5}\right)\left(\frac{365 - p}{365}\right)\left(\frac{f}{15}\right)$$

where: E = SP emission factor (kg/day/hectare)
s = silt content in aggregate
p = number of days with > 0.25 mm of precipitation per year
f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s at the mean pile height

For $PM_{10}$ the emission factor is multiplied by 0.50 and for $PM_{2.5}$ the multiplier is 0.20. The silt content is assumed to be 8.6%. The climate normals for Prince Albert show that there are on average 245 days per year with measurable precipitation (denoted by “p” in the above equation). An analysis of the wind data from the Project site shows that wind speeds are greater than 5.4 m/s at 6.5% of the time. As the aggregate pile weathers, the potential for dust emissions is greatly reduced. A realistic assumption is made that the refresh and active area of waste tailing / stacking will be 20 ha. The remaining area will be weathered to the level of no or negligible fugitive emissions. These values yield the emissions set out in Table 6.2.2-7.

***Table 6.2.2-7: Overburden Pile Emissions***

| Parameter | | TSP | SP | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| Emission factor | kg/day/hectare | 2.218 | 1.552 | 0.776 | 0.3104 |
| Emission rate | g/s | 0.513 | 0.359 | 0.179 | 0.072 |
| | kg/d | 44.35 | 31.04 | 15.52 | 6.21 |
| | t/a | 16.19 | 11.33 | 5.66 | 2.27 |

*In-Pit Materials Hauling*

A mixed fleet of front-end wheel loaders and hydraulic excavators will be employed to load the blasted ore onto off-road haulage trucks. The materials will be dumped to a mobile mining sizer / crusher hopper for conveying into the stockpile at the processing plant. Also, in pit material bulldozing will generate fugitive dust.

The material handling emission factors and total daily emissions were calculated with the AP-42 empirical equations given in Section 13.2.4 (EPA 1995). Following equation constants were applied:

- average wind speed 3 m/s;
- ore moisture constant 10%; and
- daily ore load 45,000 t.

The results are summarized in Table 6.2.2-8.

***Table 6.2.2-8: In-Pit Materials Hauling Emissions***

| Parameter | | SP | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|
| Emission factor | kg/Mg | 0.00068 | 0.00032 | 0.00010 |
| Emission rate | g/s | 0.354 | 0.168 | 0.053 |
| | kg/d | 30.60 | 14.19 | 4.54 |
| | t/a | 3.571 | 1.691 | 0.530 |

*PKCF and Coarse PK Tailings*

No emissions are anticipated from PKCF and coarse PK areas. Fine processed kimberlite will be discharged as a slurry with water content roughly 70% and as such is not considered to be a potential source of fugitive dust. The coarse PK pile will consist of material greater than 1 mm in diameter, and is therefore not considered a source of dust.

*Blasting*

The emissions from blasting are influenced by many factors such as explosive composition, product expansion, method of priming, length of charge, and confinement. These factors are difficult to measure and control in the field. The Project explosive will be ANFO (ammonium nitrate – fuel oil) loaded in water-proof plastic liners. The load per blasthole will be 295 kg and the weekly usage will be 70 tonnes. A powder factor of 0.28 kg/$m^3$ (0.13 kg/t) is anticipated. Fragmentation will generate materials, on average, less than 600 mm in size. On average, blasting will be conducted every two days at a regular time providing approximately 2,300 tonnes of broken rock per blasthole.

TSP emissions induced by ore and overburden blasting are estimated with the AP-42 emission factor (EPA 1995). It is dependent on the area of the blast, according to the relationship:

$$TSP = 0.00022 A^{1.5}$$

The scaling factor for $PM_{10}$ is 0.52 and $PM_{2.5}$ is 0.03.

The assumed blasting area is 60 m x 30 m. With this area of 1,800 $m^2$, the TSP emission would be 16.8 kg/blasting event. Predicted particulate emissions for the Star pit during the operations phase are presented in Table 6.2.2-9.

***Table 6.2.2-9: Star Pit Blasting Particulate Emissions***

| Particulate size, µm | | < 30 | < 10 | < 2.5 |
|---|---|---|---|---|
| Emission per blast | kg | 16.8 | 8.74 | 0.50 |
| Annual emission | t/a | 0.861 | 0.448 | 0.025 |

The wet weather coefficient is included in the yearly estimate. Blasting dust will be airborne regardless of precipitation, but if rain is present the dust will be washed out and no dispersion will take place.

In addition to dust emissions, blasting will generate various gases which are products of extremely rapid combustion of fuel oil and oxygen released by ammonium nitrate. Carbon monoxide (CO) is the pollutant produced in greatest quantity. Nitrogen oxides (both nitric oxide (NO) and nitrogen dioxide ($NO_2$)) are formed, but only limited data are available on these emissions. Sulphur dioxide ($SO_2$) will be also emitted but only in small quantities. Traces of hydrogen sulfide, hydrogen cyanide, and ammonia all have been reported as products of explosives use. Gaseous emissions are summarized in Table 6.2.2-10 take into account the ANFO usage detailed above.

*Table 6.2.2-10: Star Pit Gaseous Emissions*

| Contaminant | | CO | $NO_x$ | $SO_2$ |
|---|---|---|---|---|
| Emission factor | kg/Mg | 34 | 8 | 1 |
| Emissions per blast | kg | 793 | 186 | 23 |
| Annual emission | t | 123.708 | 28.548 | 3.588 |

As shown above, blasting can result in a concentrated plume of particulate matter and gases, but the volume and time duration of such plumes are constrained. Blasts will last less than one minute every second day. Even when blasts result in a visible plume, the contribution to 1-hour and 24-hour averages, as in the Ambient Air Quality Regulations, will be negligible. Much of the solid material in the initial plume is larger than the aerodynamic diameter of particles that can remain suspended in the air, and deposits within a relatively short distance (e.g., 100 m) of the blast site.

### *Wheel Entrainment Emissions*

Road particulate emissions result from dust entrainment by vehicle wheels and the wake created by moving vehicles. The force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. As well, dust emission from unpaved roads is proportional to the fraction of silt (particles smaller than 75 µm in diameter) in the road surface materials. In the Project a fleet of 145 t capacity haul trucks will transport the ore and associated waste rock to mobile sizers located in the pit. The trucks will also be used for the cross-bench material transfer.

The particulate hauling emission factor, described as fugitive dust quantity released per one kilometre travelled by the vehicle (kg/VKT) as per AP-42 (EPA 1995) for unpaved roads, is given by the following empirical equation:

$$E = k\ (s / 12)^{a} (W / 3)^{b} / (M / 0.2)^{c}$$

Equation constants used in estimating E included:

- average road surface silt loading (s) = 9.2%;
- average weight of vehicles (W) = 177 t (250 t gross vehicle weight and 105 t empty truck weight yielding an average of 177 t, which accounts for empty runs); and

- surface material moisture content (M) = 10%.

The remaining constants k, a, b and c are specific for SP ($PM_{30}$), $PM_{10}$ and $PM_{2.5}$ and are detailed in AP-42 Section 13.2. Considering short trips taken by haul trucks and the average speed of 35.4 km/h of sand and clay trucking and 32 km/h of ore trucking, average daily (24-hour) travel of each truck will be approximately 480 km which totals 9,600 km for the whole fleet. Wheel entrainment emissions will be suppressed during wet precipitation periods (average 245 days/year) and by road watering (average 74% efficiency) during dry weather. Therefore estimated wheel entrainment emissions will be as shown in Table 6.2.2-11 below.

***Table 6.2.2-11: Wheel Entrainment Emissions***

| **Parameter** | | **SP** | **$PM_{10}$** | **$PM_{2.5}$** |
|---|---|---|---|---|
| Emission | g / VKT | 477.6 | 121.4 | 17.8 |
| | g / s | 53.1 | 13.5 | 2.0 |
| | kg / d | 4,588 | 1,166 | 171 |
| | t / a | 1,675 | 426 | 62 |

### *Point Source Emissions*

A point source is a single, identifiable source of air pollutant emissions which has fixed effluent (gas or/and aerosol) outlet diameter and effluent exit velocity. Point sources are also characterized as being either elevated or at ground-level. In this Project, point emissions sources consist of the waste incinerator, fuel tanks vents, and heaters.

#### *Waste Incinerator*

A natural gas fired incinerator model E-180 manufactured by Pennram Diversified Manufacturing Corporation, Williamson, PA, USA, is anticipated at this stage of the Project. The incinerator is provided with the primary and secondary combustion chambers. The former will operate within a temperature range of 650°C – 700 °C and the latter at 1010°C – 1050°C, with at least one second retention time. This will assure complete waste combustion and the average 99% reduction by weight. The E-180 Incinerator meets EPA standards for smoke free operation and carbon monoxide emissions as well as the World Bank and World Health Organization (WHO) emission standards. The capacity is calculated to be at least 180 kg/h in order to combust daily refuse generated during an 8 hour shift. The incinerator building will be 12 m by 10 m with a height of 5.4 m, and located 1000 m away and downwind from the main site infrastructure. The stack height will be approximately 10.8 m high. Prior to combustion, plastics will be separated for recycling and kept away from the incinerator. Non-combustibles (e.g., waste metal) and other incombustible products will be stored onsite and may be transported offsite either upon final reclamation, or on an annual basis, depending on the quantities generated. Ash will be hauled periodically to the landfill in Prince Albert.

Incinerator emission parameters (corrected to 7% oxygen), as per manufacturer specifications, will be:

- particulate < 0.08 g/ft3 (dry, standard);
- carbon monoxide < 30 ppm;
- opacity 5% (no smoke);
- nitrogen 68.4%;
- carbon dioxide 13.6%;
- oxygen 12.4%;
- water vapour 5.5%;
- sulphur dioxide < 1 ppm;
- hydrogen chloride < 1 ppm;
- $PM_{10}$ < 0.0001% (by weight); and
- dioxins < 0.1 ppb (no incineration of plastics).

Because of very low concentration of contaminants in the exhaust gas, short term of operation (8 h daily) and use of clean burning natural gas, dispersion modelling of the incinerator is not warranted.

*Diesel Fuel Storage Tanks*

In order to provide the mine with adequate fuel, oil and lubricants to operate equipment and infrastructure, a tank farm will be established near the processing facility. The tank farm will have a manifold/valve and a vapour control system in order to feed the tanks for bulk products and to mitigate emissions. Storage of all bulk products will be in double wall fixed roof Envirotanks. The plant site will have a 150,000 liter diesel fuel storage tank and 10,000 liter gasoline storage tank. A 60,000 liter diesel fuel tank will be installed in Star pit. Intermittent emissions of fuel vapours associated with evaporative losses during storage (known as breathing losses or standing storage losses) and evaporative losses during filling and emptying operations (known as working losses) will be insignificant due to the very low vapour pressure of diesel (0.4 mm Hg at 20°C) and low volume of the gasoline tank. Therefore, tank emissions are considered to be negligible and are not expected to introduce perceptible changes to ambient air quality.

*Heaters*

Heating emissions are associated with products of natural gas combustion containing mainly carbon dioxide and water vapour. Their locations and stack/vent specifications are not yet available at this early stage of the Project design. However, heating gas demand for plant facilities has been specified in the preliminary feasibility study (PFS). This enabled calculation of annual emissions of CACs, which are shown in the Table 6.2.2-12.

***Table 6.2.2-12: Estimated Natural Gas Fired Heating System Emissions at the Star-Orion South Mine***

| Building | Emissions (kg/a) | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | CO | $NO_x$ | $SO_2$ | PM |
| Administration Offices | 16,294 | 6 | 13 | 0 | 1 |
| Administration Dry | 26,130 | 9 | 21 | 0 | 2 |
| Utilidors | 17,858 | 6 | 14 | 0 | 1 |
| Interpretive Centre | 5,962 | 2 | 5 | 0 | 0 |
| Main Warehouse - Storage | 133,298 | 46 | 105 | 1 | 8 |
| Main Warehouse - Offices | 4,097 | 1 | 3 | 0 | 0 |
| Fuel/Lube Building | 15,136 | 5 | 12 | 0 | 1 |
| Maintenance - Shops | 1,718,495 | 588 | 1,351 | 15 | 103 |
| Maintenance - Dry/Offices | 82,951 | 28 | 65 | 1 | 5 |
| Wash/Emergency Response - Wash Bay | 409,872 | 140 | 322 | 4 | 25 |
| Wash/Emergency Response - Parking | 30,610 | 10 | 24 | 0 | 2 |
| Wash/Emergency Response - Offices | 5,498 | 2 | 4 | 0 | 0 |
| Site Incinerator | 8,649 | 3 | 7 | 0 | 1 |
| Security Building | 3,493 | 1 | 3 | 0 | 0 |
| Process Plant – Main Building | 1,647,956 | 563 | 1,296 | 14 | 99 |
| Process Plant – Building 2 | 162,570 | 56 | 128 | 1 | 10 |
| Process Plant – Recovery Building | 54,296 | 19 | 43 | 0 | 3 |
| Totals | 4,351,813 | 1,488 | 3,422 | 37 | 260 |

### *Mobile Sources*

The mobile sources consist of the various vehicles used at the mine site. These include ore trucks used to transport materials in the pit from the ore shovel to the semi mobile crusher, dozers, front-end loaders, transport trucks, and pickup trucks. A partial list of Project equipment is shown in Table 6.2.2-2. Some of the vehicles travel along the roads at the mine site while others remain in one general location such as the mine pit. The vehicles produce both exhaust emissions and fugitive dust emissions.

Most of the pollutants from internal combustion (IC) engines are emitted through the exhaust. Evaporative losses are insignificant in diesel engines due to the low volatility of diesel fuels. Combustion of diesel fuel involves emissions of nitrogen dioxide, sulphur dioxide, carbon monoxide, carbon dioxide, water vapour and some small quantities of unburned hydrocarbons, particulate matter and other compounds.

Emissions of Komatsu haul trucks and shovel were calculated based on certificates issued by California Environmental Protection, Air Resources Board, Mobile Source Operations Division, which includes measured Komatsu engines emissions in g/kWh.

Emissions of the remaining equipment units were calculated with emission factors developed for non-road vehicles using the NONROAD model developed by the EPA. As public domain software it can be downloaded on the Internet (EPA 2008). Emission predictions from the diesel engines were based on the horsepower (hp) rating (shown in Table 6.2.2-2), utilization factor for each equipment unit and NONROAD emission factors. Summary of diesel engine emissions for each criteria contaminant are shown in Table 6.2.2-13. A relatively low emissions of $SO_2$ are attributed to introduction of low sulphur diesel fuel ($\leq$15 mg sulphur / kg fuel) for the off road mobile equipment including haul trucks. Such concentration was assumed for the NONROAD estimates. Annual emissions refer to assumed 355 working days.

***Table 6.2.2-13: Mobile Sources Total Emissions***

| Compound | Instantaneous Emissions, g/s | Daily Emissions, kg/d | Annual Emissions, t/a |
|---|---|---|---|
| $PM_{10}$ | 1.425 | 123.124 | 44.94 |
| $PM_{2.5}$ | 1.354 | 116.970 | 41.52 |
| Nitrogen Oxides ($NO_2$) | 37.636 | 3251.750 | 1,186.89 |
| Sulphur Dioxide ($SO_2$) | 0.052 | 4.537 | 1.59 |

### *Greenhouse Gases*

Greenhouse gases (GHG) such as carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are produced during fuel combustion in diesel engines. Nearly all of the fuel carbon is converted to $CO_2$ during the combustion process. This conversion is relatively independent of firing configuration. Formation of another greenhouse gas, carbon monoxide (CO) will also take place, but its amount is negligible compared to the amount of $CO_2$ produced. Formation of $N_2O$ during the combustion process is governed by a complex series of reactions and is dependent upon many factors. However, the formation of $N_2O$ is minimized when combustion temperatures are kept high (above 800ºC) and excess air is kept to a minimum.

The emissions of $CH_4$ and $N_2O$ are related to vehicle miles traveled rather than fuel consumption, and quantifying their emissions is not as easily estimated from a vehicle as for $CO_2$. On average, their emissions represent roughly 5 - 6 percent of the GHG emissions from passenger vehicles, while $CO_2$ emissions account for 94-95 percent, accounting for the global warming potential of each greenhouse gas (EPA 2010). To simplify this estimate, it is assumed that $CH_4$ and $N_2O$ account for 5 percent of diesel engine emissions (in terms of $CO_2$ equivalent), and the $CO_2$ estimate should be multiplied by 100/95 to incorporate the contribution of the other greenhouse gases. This multiplier incorporates global warming potential (GWP) for $CH_4$ which is 21 and for $N_2O$ equal to 310 (EPA 2010).

With these assumptions, annual GHG emissions consist of $CO_2$ associated with combustion of natural gas and diesel fuel. Estimated emissions for natural gas fired heaters will be 4,352 tonnes per year as shown in Table 6.2.2-12. Carbon dioxide emissions for diesel engines are estimated with reference to the Intergovernmental Panel on Climate Change guideline. It requires that an oxidation factor be applied to the carbon content to account for a small portion of the fuel that is not oxidized into $CO_2$. For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains un-oxidized). To calculate the $CO_2$ emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of $CO_2$ (m.w.44) to the molecular weight of carbon (m.w.12): 44/12. Therefore, the equation for calculating $CO_2$ emissions (E) from a gallon of diesel is defined as:

$$E = 2{,}778 \text{ grams} \times 0.99 \times (44/12) = 10{,}084 \text{ grams} = 10.1 \text{ kg / gallon (US)}$$

Annual diesel fuel consumption will be:

- ore mining $1.508 \times 10^6$ gallons; and
- overburden and waste rock removal $1.101 \times 10^6$

Therefore $E = 10.1 \text{ kg/gal} \times 2.609 \times 10^6 \text{ gal/a} \times 1 \text{ t/1000 kg} = 26{,}351 \text{ t } CO_2 \text{ /a}$.

The addition of $CH_4$ and $N_2O$ yields total diesel fuel emissions of 27,738 t $CO_2$ eq /a.

In summary, the total annual GHG emissions resulting from combustion of natural gas and diesel fuels will be 32.090 kilotonnes (kt) of $CO_2$. The reported GHG emissions in Saskatchewan in 2008 were 21,855 kt and in Canada they were 263,000 kt. Therefore, the Project GHG emission estimates are 0.15% of the provincial and 0.0122% of national emissions. During mine operations, Shore will review initiatives to control GHG emissions including development and implementation of energy saving plans, purchasing energy-efficient equipment, land reforestation, and other means.

### 6.2.2.4 Boundaries of the Study Area

Spatial and temporal boundaries for the air quality study area are described below.

### *Spatial Boundaries*

The air quality assessment was completed for the Regional Study Area (RSA) and Local Study Area (LSA). The RSA for the cumulative air quality assessment was defined in preliminary dispersion modelling with the AERMOD model and resulted in the selection of a 10 km zone around the emission sources. The RSA is a 30 km by 30 km domain extending by 5 km on each side beyond the defined RSA. The LSA covers a 3 km belt around the Project boundary where the maximum ground level concentrations will occur due to mining equipment, mobile sources and plant activities. The extent of the LSA was also determined by provincial dispersion modelling guidelines advising selection of a refined (< 250 m spacing) Cartesian receptor grid within 2 km from the Project area.

### *Temporal Boundaries*

The establishment of temporal boundaries is based on a scenario when air quality impacts would be highest throughout the life of the project. This is predicted to occur in Year 6 when the Star pit is in Phase 1 with the maximum ore mining rate of 14.7 million tonnes per annum (Mtpa), and when the highest material quantities will be disposed of into the mine materials stockpile, with 8.5 million bank cubic meters ($m^3$) in Phase 1a and 67.5 million $m^3$ in Phase 1b, 33.9 million $m^3$ in Phase 2.

### *Effects Assessment*

The effects assessment for the Project is based on a dispersion modelling exercise. The model uses the emissions sources outlined in section 6.2.2.3 and the spatial and temporal boundaries outlined in section 6.2.2.4.

### *Dispersion Model Overview*

The modelling was performed with the AERMOD View 6.8.6 modelling system that includes two preprocessors (AERMAP for terrain data, and AERMET for meteorological data). The model features include:

- the ability to mode dispersion of primary pollutants and toxic and hazardous waste pollutants;
- the ability to handle multiple sources in an industrial complex (point, area, volume and pit types) with no buildings or single or multiple buildings with building downwash
- constant or time-varying emissions;
- gas and particle depositions;
- concentration estimates for all terrain locations, except in lee areas
- predictions at distances up to 50 km from the source;
- specification of receptors locations as gridded and/or discrete receptors in Cartesian or polar coordinates; and

- use of real-time meteorological data to account for the atmospheric conditions that affect the dispersion of air pollutants.

AERMOD is intended to use hourly averaged meteorological data sequentially for at least one year if site specific and preferably 5-year regional data. For this Project, a 5-year surface and profile meteorological data for the Prince Albert region was purchased from SDA Weather Services, Winnipeg, MB. This electronic data was pre-processed with AERMET computer program prior to running the AERMOD.

Three types of emission sources were considered for modelling: area, volume and open pit:

- An area source is an emission into the atmosphere that is distributed over a stationary spatial area. Parameters normally required for area sources include the coordinates of the area perimeter, the release height, and the mass emission flux rate of the pollutants of concern (i.e., mass emission rate per unit of area, g/(s-m$^2$);
- A volume source is an emission to the atmosphere that has an initial width and depth at a stationary release point. Parameters normally required for volume sources include the coordinates of the volume dimensions and the mass emission rates; and
- Open pit sources are used to simulate fugitive emissions from below-grade open pits, such as surface mines and stone quarries. The open pit algorithm uses an effective area for modelling pit emissions, based on meteorological conditions, and then utilizes the numerical integration area source algorithm to model the impact of emissions from the effective area sources. The models accept rectangular pits with an optional rotation angle specified relative to a north-south orientation.

*Modelling Outline*

The AERMOD dispersion modelling options selected for this project included:

- pit, area, volume and point emission sources
- concentration output for gases, $PM_{10}$ and $PM_{2.5}$;
- monthly and annual dust dry deposition on and beyond the Project fence line;
- rural area;
- elevated terrain calculation algorithms with uploaded GridASCII terrain data;
- no exponential decay;
- the 1 h, 8 h, 24 h, monthly, and annual averaging time, depending on AAQO for a particular contaminant;
- no building downwash effect;
- exclusion of the Project area within the fence line;

- a refined Cartesian receptor grid with 250 m spacing in three levels on and beyond the fence line;
- a 1 km discrete receptors grid within 30 km x 30 km modelling area;
- 5-year surface and profile meteorological data;
- all wind speed and stability classes; and
- the first highest concentration values.

*Assessment Scenarios*

Dispersion modelling was conducted for three assessment scenarios:

- Base case: existing environmental conditions and existing projects and facilities;
- Project case: Project emissions plus baseline; and
- Cumulative case: Project emissions plus baseline plus approved and planned projects reasonably foreseeable in the region.

In the receptor pathway of the model, the Cartesian grid network with uniform grid spacing was used. After defining the plant boundaries the model was first run with a coarse grid of 1000 m. After determining the areas of maximum impact it was re-run with finer grids defined as the plant boundary (fence line) receptors. The modelled study area depended on expected ground-level concentrations from the Project which should allow not only to assess compliance with AAQO but also to assess impacts on other components of the environment such as soil, plants and surface water.

Models are typically used to predict the highest ambient concentrations, which in turn are compared to ambient air quality objectives. The areas of applicability of the AAQO are not defined, however, usually they are applied to areas where there is public access (i.e., beyond the plant boundary). Within the plant boundary, meeting occupational health and safety criteria are of primary importance. The plant boundary is determined by the facility fence line or the perimeter of disturbed area that defines where public access is restricted. For that reason, the modelling results do not show concentrations within the Project area.

Temporal boundaries for dispersion modelling have been developed in consideration of those time periods during which Project air emissions have the potential to degrade ambient air quality. In general, emissions that could affect air quality will be relatively short-term from such operations as blasting, fuelling, welding, tire service, etc. Therefore, they were not included in the model. However, emissions from such sources as haul trucks, waste disposal, grading, and backfilling will be fairly regular so they were modelled.

### *Modelling Results and Assessment*

Modelling results consist of graphical and tabular maximum ground level concentrations (in μg/$m^3$) for TSP, $PM_{10}$, $PM_{2.5}$, $NO_2$ and $SO_2$. Modelling of particulates deposition (in g/($m^2$-month) was also completed. The model predictions in a graphical form are shown in Figures 6.2.2-2 to 6.2.2-9. Because of low concentrations of $SO_2$, $NO_2$ (annual) and $PM_{2.5}$ (annual), the respective graphs are not shown and the modelling results have been saved in the model-generated tables.

The predicted hourly, daily and annual maximum ground level concentrations (GLC) for each of the modelled contaminants (model prediction plus baseline), the location of impacts and their relevant AAQO are summarized in Table 6.2.2-14. The baseline concentrations measured at the Project site are discussed in detail in Section 5.2.4.

***Table 6.2.2-14: Summary of Dispersion Modelling Results***

| **Substance** | **Averaging Time** | **Max GLC μg/$m^3$** | **AAQO μg/$m^3$** | **Compliance %** | **Receptor Location, m** | |
|---|---|---|---|---|---|---|
| | | | | | **UTM E** | **UTM N** |
| Sulphur dioxide ($SO_2$) | 1 h | 0.460 | 450 | < 1 | 515845 | 5895855 |
| | 24 h | 0.108 | 150 | < 1 | 515845 | 5895855 |
| | Annual | 0.0127 | 30 | < 1 | 516500 | 5896500 |
| Nitrogen oxides (as $NO_2$) | 1 h | 399 | 400 | <100 | 517532 | 5893794 |
| | 24 h | 55 | 200 | 27 | 521250 | 58973335 |
| | Annual | 5 | 100 | 5 | 521250 | 898167 |
| Total suspended particulate (TSP) | 24 h | 30 | 120 | 25 | 507650 | 58965500 |
| | Annual | 12 | 70 | 17 | 520350 | 5900000 |
| Particle matter<br>< 10 μm ($PM_{10}$) | 24 h | 35 | 50 | 70 | 518253 | 5894294 |
| Particulate matter <2.5 μm ($PM_{2.5}$) | 24 h | 10 | 25 | 40 | 518253 | 5894294 |
| | Annual | 5 | 8 | 62 | 521250 | 5898167 |

**Note:** GLC - Ground Level Concentration; AAQO - Ambient Air Quality Objective; < - less than

Predicted monthly deposition of particulate matter on the ground in the Star pit area reveals the highest dry deposition rate at 0.636 g/$m^2$ at UTM coordinates 509045 mE and 5878628 mN, which is well below the Saskatchewan provincial guideline of 20 g / ($m^2$ month) and a mining industry standard of 4 g / ($m^2$ month) (Figure 6.2.2-4). The annual dust dry deposition rate is predicted at 14.556 g/$m^2$ at UTM coordinates 507650 mE and 5896500 mN. The annual dust deposition guideline has not been established.

The dispersion model predictions indicate that with a new type of hauling truck the Project will comply with relevant ambient air quality objectives. The 1-hour maximum $NO_2$ concentrations shown in Figure 6.2.2-6 will be at the permissible levels with the highest concentration occurring at the immediate vicinity of the southeastern Project fence line. The 24-hour (Figure 6.2.2-7) and annual (Table 6.2.2-14) maximum GLC of $NO_2$ will be well below the respective AAQO.

Concentrations of $SO_2$ are predicted to be very low for all regulated averaging times. The 24-hour $PM_{10}$ maximum GLC shown in Table 6.2.2-14 is at the level approximately 2/3 of AAQO. The maximum GLC concentrations of TSP and $PM_{2.5}$ are predicted to be well below the relevant AAQO.

Within the open pits, there will be short periods of maximum 1 to 2 days when the atmosphere is very stable and a low-level inversion will be present. During these conditions emissions can be trapped in the pit and ambient concentrations of exhaust gases and particulate matter can increase to high levels. The operations supervisor or the designated person will monitor these conditions and in the event that pollutants accumulate in the pit, mining operations will be scaled down for some time until it is safe as per appropriate occupational health and safety regulations to continue with pit work.

### 6.2.2.5 Mitigation

Mitigation measures for the construction and operations phases are described below.

#### *Construction Phase*

Early site preparation and construction phase mitigation measures that will be implemented to minimize air quality impacts include the following:

- implement fleet maintenance program ensuring that all diesel-powered equipment will operate efficiently, thereby reducing air emissions;
- impose vehicle speed limits to mitigate fugitive dust;
- apply water as dust suppressant to construction roadways during dry summer weather (June to September) and calcium chloride or other liquids during cooler weather when ground is not covered with snow, as needed;
- reduce vehicle emissions by not allowing motors left to idle, except when necessary;
- avoid spills during vehicles and stationary power equipment refueling to avoid releases of hydrocarbons to the atmosphere; and
- use water spray instead of pneumatic flushing when removing dust whenever possible.

***Operations Phase***

To mitigate potential atmospheric impacts of the proposed project during operation, the following measures will be implemented:

- implement a fleet maintenance program ensuring that all diesel-powered equipment will operate efficiently, thereby reducing air emissions;
- impose vehicle speed limits within the Project fence line and outside with Project related traffic to mitigate fugitive dust and reduce engine emissions;
- apply dust suppressants (water, calcium chloride) to haul and service roads during dry weather to mitigate fugitive dust as needed (see Figure 6.2.2-2);
- to reduce vehicle emissions, motors will not be left to idle, except when necessary;
- upgrading road-surfacing materials using local coarse rocky aggregates; and
- keep PFCF wet enough to avoid wind erosion.

In terms of blasting:

- use delay blasting techniques whenever possible to avoid long distance dust dispersion; natural mitigation will take place as mining pits will operate below the ground level (note that ore and waste will be coarse run-of-mine muck not prone to generating excessive dust).

Miscellaneous items:

- use water spray instead of pneumatic flushing while cleaning equipment and working areas when temperature is above the freezing point ; and
- apply vegetation cover on stripped areas and long-term stockpiles

Additional mitigation measures will be implemented on an on-going basis when an opportunity for emission reduction is identified and technology development offers new tools for emission reduction.

### 6.2.2.6 Residual Effects

A residual effect is any measurable or demonstrable environmental effect remaining after mitigation. From an air quality perspective, if the level of a residual effect is less than the ambient air quality objective, it is not significant. If, on the other hand, it exceeds the objective it may be significant. In this Project it is unlikely that any residual effects will occur as the maximum concentrations comply with the appropriate air quality criteria. Only the concentrations of $NO_2$ 1-hour average are likely to have any residual air quality impacts. $NO_2$ concentration at longer averaging times are predicted to meet the relevant air quality objectives. The affected area is small and is adjacent to the Project fence line at the southeast site. It is not suitable for development of permanent residences and not easily accessible by the general public. These effects have been classified in terms of CEAA criteria (see Section 6.1) and are summarized in Table 6.2.2-15.

***Table 6.2.2-15: Summary of Residual Effects for Air Quality***

| | |
|---|---|
| Nature: | Negative |
| Magnitude: | Low |
| Spatial: | Immediate |
| Timing: | Operation |
| Duration: | Short-term |
| Reversibility: | High |
| Likelihood: | Low |
| Significance: | Not Significant |

#### 6.2.2.7 Cumulative Effects

The cumulative effects assessment (CEA) includes all of the existing, approved and planned projects and activities associated with atmospheric emissions which could negatively impact air quality in the region of Fort a la Corne. Projects are typically some form of commercial or industrial development that is planned, constructed, and operated – a refinery development or resource access road, for example. Activities may either be part of a project or may arise over time because of ongoing human presence in an area (CEAA 1999).

A study of inventory data of existing and planned facilities and operations in the area east of Prince Albert has shown that no significant emission sources exist or are anticipated in the 30 km radius from the centre of the Project area. Usually a 30 km distance is sufficient to disperse emitted contaminants to concentrations at the background levels. An aerial view of the modelled area, TSP isopleths (blue lines) and rural / forestry surroundings showing lack of industrial emission sources is depictured in Figure 6.2.2-10.

The nearest industrial facility is Nipawin Ethanol Plant located 40 km east of the Project. Some activities such as highways traffic and commercial timber harvesting do not contribute to the Project cumulative impacts because their low emissions, short dispersion range and distant location. Therefore, cumulative effects and a cumulative impact of the Project are not expected.

### 6.2.3 Noise Impact Assessment

This Section addresses environmental noise levels that will result from the Project in order to identify and assess adverse impact on receptors such as workers, other individuals, and wildlife, if any. Also, predicted noise levels will be evaluated with reference to relevant guidelines and objectives.

#### 6.2.3.1 Introduction

Project activity and resulting noise levels will vary almost continuously throughout the duration of the Project. Therefore, the only practical approach for quantifying noise levels is to define representative levels of activity during selected periods of time. To avoid the complication and potential confusion of numerous scenarios, a near worst case scenario has been analyzed for the year during which the largest amount of material will be mined and processed. This is predicted to occur in Year 6 when the Star pit is in operation phase 1 and waste stripping is in phases 1a to 4.

Noise generation during construction and operation phases will fall into three categories that include (a) instant, (b) intermittent or (c) continuous periods, with levels that vary from low to high. Mining operation, including blasting, crushing, hauling, and waste disposal will be the main sources of instant or intermittent noise. Ore processing and the diamond recovery plant will generate continuous noise associated with ore crushing, grinding, classifying and screening.

Prediction of the Project environmental noise levels was accomplished with an established noise mapping model. The model addresses outdoor sound propagation which is a complicated interaction between sound waves and the environment through which they pass. Sound is attenuated by absorption in the air and it is bent (refracted) by winds and by thermal gradients. It is blocked by barriers, diminished with distance, and can be cancelled or amplified by reflections due to the ground. All these features are considered by the model.

The following topics related to noise assessment are not addressed in this section:

- No consideration is given to highway traffic. Vehicle traffic noise on the access highways will be present on an irregular basis and will be of short duration and low volume. Traffic will add little to background noise levels;
- Project details which are related to noise impacts, such as a description of sensitive wildlife areas and habitation within the study area, are presented in other sections of this report;
- The baseline setting of ambient noise is discussed in Section 5.2.5 (Noise) and includes detailed descriptions of surveyed daytime and nighttime noise levels, sound statistical descriptors, and an introduction to environmental acoustics; and
- Although the majority of noise issues are dealt with in this report, hearing damage risk associated with occupational noise exposure is not discussed in this section (see Section 5.4.4).

### 6.2.3.2 Boundaries of the Study Area

Spatial and temporal boundaries of the study area are described below.

*Spatial Boundaries*

The LSA for noise was defined by the location of a targeted sound level specified by a Noise Control Directive described in the next Section, which is the Project footprint plus an additional 1,500 m. The area within the LSA includes the plant site, overburden and rock storage and process kimberlite piles, pits and infrastructure.

The regional study area (RSA) overlaps the proposed Project footprint by 3 km. This distance is approximately the maximum extent required for attenuating the unmitigated high level blasting noise to the permissible levels in the surrounding environment. This is based on similar assessments of pit mines and empirical estimates such as that shown in section 6.2.3.5 (Operations Blasting Noise and Vibration).

*Temporal Boundaries*

The establishment of temporal boundaries is based on the worst-case scenario, when noise impacts would be highest throughout the life of the Project. This is predicted to occur in Year 6 when the Star pit is in Phase 1 with the maximum ore mining rate of 14.7 million tonnes per annum (Mtpa), and when the highest material quantities from the Star Pit will be disposed of, into the mine materials stockpile, with 8.49 million bank cubic meters (Mbcm) in Phase 1a, 67.5 Mbcm in Phase 1b, and 33.9 Mbcm in Phase 2. No distinction is made between daytime and nighttime periods as both construction and operation activities will continue on a 24/7 basis. Noise will be present all the time during construction and operations phases and will cease when the Project is decommissioned.

### 6.2.3.3 Noise Criteria and Standards

Equivalent sound pressure level ($L_{eq}$) is used as a noise criterion. $L_{eq}$ refers to an energy equivalent sound level. It is a time-averaged sound level; a single-number value that expresses the time-varying sound level for the specified period as though it were a constant sound level with the same total sound energy as the time-varying level. A one-hour time averaged energy equivalent sound level is referred to as a one-hour $L_{eq\ 1h}$ and is expressed in decibel (dB). A-weighting is the filter used for measuring sound to approximate human hearing. Therefore, for the purpose of environmental compliance assessment by comparison with relevant standards the $L_{eq}$ is expressed in A-weighted decibel (dBA).

There are no Saskatchewan or Canadian noise standards, criteria or objectives that are applicable to the area of the proposed Project. Therefore, three relevant noise guidelines are discussed:

- The Irish Environmental Protection Agency (IEPA) Guideline Note for Noise in relation to Scheduled Activities (IEPA 2006);
- The Alberta Energy Resources Conservation Board Directive 038: Noise Control (ERCB 2007); and
- The World Bank. The Pollution Prevention and Abatement Handbook (1999).

The IEPA has produced a guidance note for noise in relation to Scheduled Activities. It describes in general terms what the approach to be taken in the measurement and control of noise, and provides advice in relation to the setting of noise emission limit values and compliance monitoring.

In relation to mine developments and ancillary activities, the IEPA recommends that noise from the activities on site shall not exceed the following noise emission limits at the nearest noise sensitive receptors:

- daytime: 08:00 – 20:00 hrs $L_{eq}$ (1 hour) = 55 dBA
- nighttime: 20:00 – 08:00 hrs $L_{eq}$ (15 minutes) = 45 dBA

In addition, the IEPA recommends that no noise level shall exceed the limit value by more than 2 dBA, and that on-site activities should be permitted during nighttime hours only when they comply with the noise emission limit values (e.g., loading and moving of materials). Audible tones or impulsive noise should be avoided at night. It is also appropriate to permit higher noise emission limit values for short-term temporary activities such as construction of screening berms or noise prevention walls, where these activities will result in a considerable environmental benefit.

In relation to blasting activities within pit developments, IEPA recommends that the 125 dBA (Linear maximum peak value) with a 95% confidence air overpressure emission limit be adopted and applied at the nearest sensitive location.

The IEPA suggests that normal hours of blasting should be defined (e.g., 08:00 – 19:00 hrs), and provision should be included to permit blasting outside these hours for emergency or safety reasons beyond the control of the pit operator. In addition, the IEPA advises that pit operators should provide advance notification of blasting to nearby residents through use of written notes, signage at site entrance, or warning sirens (or a combination of these methods).

The Alberta Energy Resources Conservation Board has clear guidelines outlined in Directive 038: Noise Control on regulating noise at underdeveloped areas, such as the Fort à la Corne (FalC) area. The Directive defines the permissible sound level (PSL) as the maximum sound level which a noise source should not exceed at a point 15 m from the nearest or most impacted dwelling unit, or at 1500 m from the Project fence line if a closer dwelling does not exist.

The PSL is calculated as follows:

Permissible Sound Level = Basic Sound Level + Daytime Adjustment + Class A Adjustment + Class B Adjustment

The Classes A and B adjustments include a tonal and impulse/impact components of noise, an ambient monitoring adjustment, the duration of noise generating activity, and presence of seasonally occupied dwellings including hunting or recreational cabins. For this Project, the calculated PSL are:

- daytime 07:00 – 22:00 hrs $L_{eq}$ (15 hours) = 55 dBA
- nighttime 22:00 – 07:00 hrs $L_{eq}$ (9 hours) = 45 dBA

On a global scale, the most common noise objective adopted for environmental assessments of projects financed by the international financial institutions (IFIs) is the World Bank noise standard for large projects (IFIs Category A projects with significant environmental impacts, e.g., mining projects). The standards are given in *The Pollution Prevention and Abatement Handbook* (World Bank 1999) and are summarized in Table 6.2.3-1.

***Table 6.2.3-1: Daytime and Nighttime Standards for Noise Receptors***

| **Receptor** | **$L_{eq}$ (dBA) Daytime (07:00 – 22:00)** | **$L_{eq}$ (dBA) Nighttime (22:00 – 07:00)** |
|---|---|---|
| Residential, institutional, educational | 55 | 45 |
| Industrial, commercial | 70 | 70 |

The guidelines state that noise abatement measures should achieve either the levels given in the above table or increase in background levels by no more than 3 dBA. Measurements are to be taken at noise receptors located outside the project boundary. Although this Project is not financed by the IFIs, this reference is provided here to show that the EPA and ERCB adopted nighttime noise criteria of 45 dBA are the same as the World Bank allowable levels.

#### 6.2.3.4 Noise Sources

Noise sources at the Project site for the construction and operations phases are described below.

***Construction Noise***

During the early site preparation and construction phases of the Project, different types of construction equipment would be utilized. This equipment will include a number of machines and devices varying in physical size, horsepower rating, and mode of operation. Consequently, the noise produced can be expected to vary widely. Even for equipment of a single model, variations in sound level at a fixed distance can be expected (Harris 1979).

Construction activities will proceed through a number of phases. Each construction phase will have both generic and phase-specific noise sources associated with it. Construction noise emissions are expected to occur during the following activities:

- leveling and grading;
- vehicle/heavy equipment traffic;
- excavation;
- pile driving;
- concrete pouring;
- steel erection;
- mechanical installation; and
- commissioning and start-up.

A list of construction equipment classified as noise sources typically found at the large industrial construction sites is provided in Table 6.2.3-2 (Holland and Attenborough 1981). The predominant sources of construction equipment noise are associated with internal combustion engines and impacting equipment. The table also provides typical maximum A-weighted sound levels for each type of construction noise source.

***Table 6.2.3-2: Typical Maximum Construction Equipment Sound Levels at 15 Meters***

| Noise Source | A-Weighted Sound Level (dBA) |
|---|---|
| **Earth Moving** | |
| Crawler Trackers, Dozers | 81-85 |
| Front End Loaders | 81-86 |
| Graders | 79-83 |
| Earth Haulers | 88-90 |
| Dump Trucks | 88 |
| **Material Handling** | |
| Mobile Cranes | 83 |
| Concrete Mixers (Truck) | 85 |
| Concrete Pumps | 82 |
| **Impact Equipment** | |

| Noise Source | A-Weighted Sound Level (dBA) |
|---|---|
| Jackhammers | 88 |
| Pneumatic Tools | 86 |
| **Auxiliary Tools** | |
| Pumps | 76 |
| Generators | 78 |
| Compressors | 87 |
| Paging Systems | 80-92 |
| Warning Horns | 98-102 |
| **Other Equipment** | |
| Saws | 78 |
| Vibrators | 76 |

Internal combustion engines are used to provide propulsion for trucks and/or operating power for working mechanisms such as buckets, dozers, etc. Exhaust noise is usually the most important component of engine noise. However, noise associated with the air intake, cooling fans, and the mechanical and hydraulic transmissions and control systems also can be significant.

Impacting equipment typically includes pile drivers, rock drills, and small hand-held pneumatically, hydraulically, or electrically powered tools. The primary noise source for conventional pile drivers is the impact of the hammer striking the pile. Engine-related noise sources, such as combustion explosion or release of steam at the head of some equipment, are usually secondary. The predominant sources of noise in pneumatic tools are the high-pressure exhaust and the impact of the tool bit against the material on which it acts.

For the conservatively assumed sound levels given in the above Table 6.2.3-2, a cumulative noise of 90 dBA at 15 m from sources will dissipate to 55 dBA level (recommended daytime objective) at a distance of approximately 1000 m assuming typical loss of 6 dBA with the doubling of distance. It means, that if 90 dBA noise is at 15 m, than it will be 84 dBA (90 minus 6) at 30 m (double 15 m), 78 dBA at 60 m, etc.

#### *Operations Noise*

For the operations phase, Project noise and vibration are associated with pit mine infrastructure, the processing plant, access and haul roads, material hauling and waste disposal. During full scale kimberlite mining in Year 6, the equipment will be operating in Star Phase 1 with a mining rate of 14.7 Mt. Trucks engaged in hauling ore and waste rock material will be the predominant noise source. Other noise sources will include diesel-powered hydraulic excavators, shovels, loaders, crushers, conveyors, bulldozers, compactors, and blasthole drills. However, the equipment counts and types will not change frequently. Consequently, overall noise levels will not change dramatically as the pit is developed. The pit walls will offer substantial shielding to horizontal sound propagation. Noise from the plant buildings will be relatively constant throughout the life of the project.

Typical maximum sound pressure levels ($L_{max}$) at a pit mine from various quarry noise emission sources at different distances are given in Table 6.2.3-3 (Environment Australia 1998).

***Table 6.2.3-3: Typical Mining Noise Levels***

| Noise Source | Operating Condition | Noise Level (dBA) | Distance (m) |
|---|---|---|---|
| Haul Truck | Laden Passby | 91 | 7 |
| Haul Truck | Empty Passby | 87 | 7 |
| Haul Truck | Laden/Uphill | 98 | 7 |
| Product Truck | Laden Passby | 88 | 7 |
| Front-end Loader | Loading | 85 | 7 |
| Primary Jaw Crusher | Crushing | 104 | 4 |
| Rock Breaker | Breaking | 100 | 7 |
| Hydraulic Drill | Maximum | 100 | 7 |
| Excavator | Scraping | 90 | 7 |
| Reversing Alarm | | 92 | 4 |
| Production Blast | | 110 | 100 |

Sound power levels (PWL) over the 1/1 octave frequency spectrum for equipment scheduled to operate at the Project site in Year 6 is shown in Table 6.2.3-4.

***Table 6.2.3-4: Sound Power Level Frequency Spectrum for the Project Noise Sources***

| Source | Sound Power Level (dB) per Frequency Spectrum | | | | | | | | | Overall dB(Lin) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 31.5 | 63 | 125 | 250 | 500 | 1k | 2k | 4k | 8k | |
| Haul Truck | | 90 | 96 | 104 | 115 | 113 | 112 | 108 | 99 | 119 |
| OB / Ore Shovel | | 104 | 108 | 98 | 99 | 97 | 92 | 86 | 80 | 110 |
| Wheel Loader | | 102 | 110 | 101 | 102 | 99 | 93 | 89 | 82 | 112 |
| Wheel Dozer Compactor | 70 | 87 | 99 | 106 | 111 | 113 | 108 | 101 | 93 | 121 |
| Bulldozer | | 103 | 115 | 106 | 107 | 103 | 101 | 97 | 87 | 117 |
| Production Drill | 98 | 107 | 114 | 114 | 114 | 119 | 119 | 121 | 118 | 126 |
| Crawler | | 103 | 115 | 106 | 107 | 103 | 101 | 97 | 87 | 117 |
| Grader | | 103 | 115 | 106 | 107 | 103 | 101 | 97 | 87 | 117 |

| Source | Sound Power Level (dB) per Frequency Spectrum | | | | | | | | | Overall dB(Lin) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 31.5 | 63 | 125 | 250 | 500 | 1k | 2k | 4k | 8k | |
| Excavator | | 104 | 109 | 112 | 107 | 105 | 102 | 86 | 80 | 116 |
| Telehandler | | 103 | 115 | 106 | 107 | 103 | 101 | 97 | 87 | 117 |
| Skid Steer Loader | | 103 | 115 | 106 | 107 | 103 | 101 | 97 | 87 | 117 |
| Transfer Hopper | | 105 | 97 | 93 | 95 | 97 | 93 | 87 | 75 | 107 |
| Crusher | 111 | 120 | 121 | 121 | 120 | 117 | 115 | 111 | 105 | 127 |
| Overburden Stacker | 70 | 87 | 99 | 106 | 111 | 113 | 108 | 101 | 93 | 117 |
| Conveyor | 75 | 97 | 107 | 113 | 116 | 121 | 112 | 110 | 101 | 123 |
| AG Mill | | 118 | 117 | 118 | 114 | 111 | 108 | 110 | 95 | 124 |
| Classifiers and Screens | | 113 | 113 | 115 | 119 | 111 | 106 | 98 | 93 | 122 |

The PWL data is an indicator of noise emission intensity of the source. The sound power is used by computer models to predict ambient noise levels in the surrounding area.

When the processing plant commences operation, the major noise sources will be located in the grinding and screening building accommodating high-level noise sources comprising two autogenous grinding mills, spiral classifiers and screens. Noise generated by each unit will be cumulated and transmitted through the building walls made of corrugated steel panels. In this way, the building will become a secondary emitter. The noise transmission loss (TL) depends on thickness of the wall panels and structural properties. The TL can be computed for a particular material over octave band sound power levels (Hansen and Qiu 2004). The calculations are summarized in Table 6.2.3-5.

***Table 6.2.3-5: Sound Power Level of the Grinding and Screening Building***

| Source | Sound Power Level (dB) in Frequency Spectrum (Hz) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1k | 2k | 4k | 8k |
| AG Mill #1 | 118 | 117 | 118 | 114 | 111 | 108 | 110 | 95 |
| AG Mill #2 | 118 | 117 | 118 | 114 | 111 | 108 | 110 | 95 |
| Spiral Classifier and Screens | 113 | 113 | 115 | 119 | 111 | 106 | 98 | 93 |
| Indoor Cumulative PWL | 122 | 121 | 122 | 121 | 116 | 112 | 113 | 99 |
| PWL Transmission Loss | 13 | 19 | 21 | 23 | 27 | 31 | 35 | 38 |
| Outdoor PWL (Noise Model Input) | 109 | 102 | 101 | 98 | 89 | 81 | 78 | 61 |

### 6.2.3.5 Noise Effects

The effects assessment for noise is presented here in terms of blasting (intermittent noise) and noise modelling (continuous noise). Effects on humans and wildlife are presented in section 6.2.3.6.

#### *Blasting*

Effects from intermittent noise as a result of blasting during the construction and operations phases are described here.

*Construction Blasting Noise*

The effects from blasting activities fall under three categories, noise, dust, and vibration. The noise from a blast can be loud if the listener is within a few hundred meters of the blast. Airborne pressure waves can cause annoyance because of hearing and feeling (particularly the low frequency component) the noise at levels above peak linear values of around 115 dBA. However, at a distance it is usually heard as a low rumble or "popping" sound that lasts one or two seconds. If the wind is blowing away from the listener, there may be no audible sound. Some atmospheric conditions, such as low cloud cover, cause the sound waves to propagate over a greater distance and results in a more noticeable "bang" referred to as an "air blast".

*Operations Blasting Noise and Vibration*

Blasting will not be regularly used for initial development of the pit, as the surficial glacial material is expected to be easily excavated. Blasting may occur to remove large boulders, or to loosen heavily compacted till as needed. Boulders and compacted till will not be encountered until a depth of at least 40 m. As the pit deepens, the pit walls will act as sound barriers and will attenuate blast noise outside the perimeter of the pit depending upon the depth of the pit. According to Griffiths and Oates (1978), the attenuation to be expected for blast noise originating at a depth of 15 m and at a depth of 30 m below original ground level would be about 2 dB and 6 dB, respectively. Although additional shielding can be expected for blasts on lower benches, it is unlikely that the additional attenuation would ever exceed 15 dB even for very deep pits because of reflection of sound off the opposing faces of the pit.

Several empirical formulas have been developed for predicting the unweighted peak noise level from a blast. The prediction formula adopted for this project is one derived by Linehan and Wiss (1980) for the US Bureau of Mines. The constants derived for the formula vary somewhat between mine sites, so to take a conservative approach, those constants that result in the highest predicted noise levels have been used for this project. The prediction formula is as follows:

$$P = 6.31\, e^{-B}\, (D/W^{1/3})^{-1.16}$$

where:

P = peak overpressure, kPa
e = base of natural logarithm (e = 2.7183)
D = distance from blast to receiver
W = maximum charge weight per delay (TNT equivalent), kg
B = scaled depth of burial ($C/W^{1/3}$), $m/kg^{1/3}$
C = depth to center of gravity of charge, m

The peak overpressures predicted by the formula above can be converted to unweighted peak sound pressure levels (SPL), in decibels, using the following equation:

$$SPL = 20 \log P + 154$$

The maximum charge weight per delay represents the equivalent weight of TNT. As per typical mining practice, the ANFO explosive will be about 70% ammonium nitrate and 30% fuel oil. An actual charge weight of 1,000 kg of ANFO is equivalent to about 411 kg of TNT, so for typical blasting in ore (using 0.19 to 0.24 kg explosives per ton, and an assumed yield of 880 tonnes per blast hole; Section 2.6.2.1) the equivalent TNT would range from 68.7 to 86.8 kg TNT. The SPL formula was derived from blast noise measurements ranging from 30 to 3,000 m.

The Linehan and Wiss (1980) equation has been used to predict blast noise at distances up to 3 km. The primary predictions assume sound propagation over ground. Table 6.2.3-6 shows unweighted peak sound pressure levels at different distances caused by the explosion of 211 kg of ANFO charge at a depth to the center of gravity of 7.5 m and 15 m.

***Table 6.2.3-6: Predicted Blasting Noise Levels***

| **Distance (m)** | 30 | 100 | 500 | 600 | 1,000 | 1,500 | 2,000 | 3,000 |
|---|---|---|---|---|---|---|---|---|
| **SPL (dBA) @ 7.5 m** | 136 | 124 | 108 | 106 | 101 | 97 | 94 | 90 |
| **SPL (dBA) @ 15 m** | 121 | 109 | 93 | 91 | 86 | 82 | 79 | 75 |

In addition to noise, blasting will cause ground vibration caused by shock waves emanating from the blast point. The vibrations can be felt easily close to the blast but decrease in strength as they radiate outwards. There are no structures in the vicinity of the Project that could be subjected to damage by vibration in the blasting zone.

### *Noise Modelling*

The predicted changes to environmental sound levels from the project during operation were determined using the SPM9613 noise prediction model developed by Power Acoustics, Inc. (2010), Orlando, Florida. The model includes two subroutines: ISO 9613-1 specifically addressing atmospheric attenuation and ISO 9613-2 which specifies an engineering method for calculating environmental noise from a variety of noise sources by prescribing methods to determine the various attenuation effects observed during outdoor sound propagation. The model incorporates the following parameters:

- geometric spreading;
- barrier effects;
- atmospheric absorption;
- ground attenuation;
- specific wind speed/direction;
- source size and location; and
- acceptance of sound power level and sound pressure level spectrum data.

The operation noise modelling is based on the following assumptions:

- noise sources used in this study include the primary in-pit crusher, screens, excavators, dozers, compactors, hydraulic drill, haul trucks, and the process plant;
- maximum noise generated during mining at the Star open pit will occur during Phase 1 operation in Year 6, with sources located across the pit area;
- the facility will operate continuously at the same level on 24/7 basis;
- the processing building noise is presented as a computed combined source;
- over thirty 160-tonne ore/overburden trucks will operate continuously, mainly in the pit;
- octave bands spectrum provided for similar equipment are used for each type of noise source;
- all model input noise levels are in sound power level spectrum dB Linear;
- the terrain is considered flat for noise propagation with no major barriers;
- atmospheric conditions that would minimize sound attenuations are not taken into account (conservative approach); and
- the grid size was selected to include both the local study and regional areas to include near-by and distant noise levels.

The model input data included octave sound power level for each noise source, their locations, 3D dimensions of each source, meteorological parameters, ground attenuation, and the pit geometry. A total of 42 noise sources presented in Table 6.2.3-4 (included multiple units) were modelled, with 28 sources in the pit (below the ground level).

The sound level modelling results are shown in Figures 6.2.3-1 as noise level contour plots for the project area of 7 km x 7 km. Arbitrary selected X-Y axes have the 0-0 point located in the center of the Star pit with the UTM NAD 27, Zone 13 coordinates 515000 mE, 5897000 mN. Replacing the UTM with the project related coordinates improved understanding of the spatial aspect of noise propagation as direct distances to the mining centre are shown on the graphs.

The results show that the noisiest sources within the proposed Project area will be inside the pit where equipment will be simultaneously removing overburden and extracting kimberlite (e.g. shovels, loaders, trucks, drills, etc.). Due to the proximity of the major pieces of equipment, the combined noise levels will be higher than the individual equipment noise levels. The highest noise levels could exceed 80 dBA within the pit. However, due to the mitigation effect of the pit walls, the noise levels on the surface near the pit will be much lower, in the range of 60 to 65 dBA, descending outward. On a larger scale representing the local and regional study areas, noise levels will be distributed evenly because noise generating equipment will be operating across the whole area within the Project fenceline and noise will propagate freely subject to attenuation in air. This is shown in Figure 6.2.3-2.

Overall, the model output shows elevated (over 60 dBA) noise levels close to the sources mainly within the overburden pile, the pit, and the processing plant areas where more equipment units and noisy operations are located. Noise predictions within the Project area falls under occupational health and safety regulations. Environmental compliance concerns, and subsequent environmental effects, are considered in the area beyond the Project fence line. The model predicts that levels outside the fence line are at 45 dBA or lower (Figure 6.2.3-2). Therefore the Project will not generate noise levels in excess of the recommended levels ($L_{eq\ night}$=45 dBA and $L_{eq\ day}$ = 55 dBA) as summarized in Section 6.2.3.3.

There are inherent uncertainties regarding the use of results from any predictive model. The SPM9613 model selected for impact prediction is based on advanced algorithms and assumptions taken from European Union standards ISO 9613. The model is based on current research, and has been refined using many years of field calibration and experience. The quality and relevance of the noise model predictions from the noise model are only as good as the quality and relevance of the data inputs. Sound emissions and site data used for the assessment were established with a high level of professional care to ensure the simulations were representative of the Project case. Rate prediction confidence depends on quality of baseline data, confidence in analytical techniques and confidence in mitigation measures. The overall prediction confidence for this assessment is moderate. There is high confidence in all acoustic measurements taken for this project (i.e., baseline survey) and the capability of the noise prediction model. Low to moderate confidence is assigned to noise input parameters, due to assumptions made about equipment locations, timing of maximum noise generation, and atmospheric and topographic attenuation.

This uncertainty can only be improved or eliminated by direct field monitoring when the Project is fully operational.

#### 6.2.3.6 Effects on Humans and Wildife

There are a number of potential effects of noise on health, ranging from psychological well being (i.e., bother or annoyance) to potential physical effects (e.g., sleep disturbance, hearing damage). It has been shown that animals are also impacted by noise. Existing standards and regulations usually take the results of health impact research into account, but social, political and historic factors are at least as important.

### *Impact on Humans*

Quantitative information on the effects of noise on people is well documented. If sufficiently loud, noise may adversely affect people in several ways. For example, noise may interfere with human activities, such as sleep, verbal communication, and tasks requiring concentration or coordination. It may also cause annoyance, hearing damage, and other physiological problems. These factors lead to irritability which is the first sign of the psychological impact of noise.

The effects of noise are seldom catastrophic, and are often only transitory, but adverse effects can be cumulative with prolonged or repeated exposure. In addition, noise can interfere with the teaching and learning process, disrupt the performance of certain tasks, and increase the incidence of antisocial behaviour. There is also some evidence that noise can adversely affect general health and wellbeing in the same manner as chronic stress (WHO 1999, Passchier-Vermeer and Passchier 2000).

Several noise scales and rating methods are used to quantify the effects of noise on people. These scales and methods consider such factors as loudness, duration, time of occurrence, and changes in noise level with time. However, all the stated effects of noise on people vary greatly with the individual.

Generally, changes in noise levels less than 3 dBA are barely perceptible to most listeners, whereas 10 dBA changes are normally perceived as doublings (or halvings) of noise levels. These numbers permit direct estimation of an individual's probable perception of changes in noise levels. It is also possible to characterize the effects of noise by studying the aggregate response of people in communities. The rating method used for this purpose is based on a statistical analysis of the fluctuations in noise levels in a community, and integrating the fluctuating sound energy during a known period of time, most typically during 1 hour or 24 hours. Commonly applied criterion for estimating response is incorporated into the community response scale proposed by the International Standards Organization (ISO) of the United Nations as shown in Table 6.2.3-7. This scale relates changes in noise level to the degree of community response and permits direct estimation of the probable response of a community to a predicted change in noise level.

*Table 6.2.3-7: Community Response to Increases in Noise Levels*

| Change (dBA) | Category | Description |
|---|---|---|
| 0 | None | No observed reaction |
| 5 | Little | Sporadic complaints |
| 10 | Medium | Widespread complaints |
| 15 | Strong | Threats of community actions |
| 20 | Very strong | Vigorous community action |

**Source:** International Standards Organization, Noise Assessment with Respect to Community Responses, ISO/TC 43. (New York: United Nations, November 1969).

There are no human receptors residing within the LSA or RSA (within 1,500 m of the Project) and hence chronic off-site human impacts are not considered as an issue.

### *Impact on Animals*

Noise can adversely affect wildlife by interfering with communication, masking the sounds of predators and prey, cause "stress" or avoidance reactions and, in the extreme, result in temporary or permanent hearing damage. Experiments have also shown that exposure to noise impulses throughout the night-time sleep period resulted in poorer daytime task performance by animals (Fletcher and Busnel 1978).

It is known that a large number of animals have adapted to the presence of humans and the noise generated by humans. In fact, many animals have demonstrated an ability to live in extremely noisy environments for example, rodents in factories, ships and subways, fish in waters with constant shipping activity and birds and mammals on and around airfields. Although there have been reports of panic and similar "startle" reactions in animals to both fixed and rotating wing aircraft activity, the difference between these reports and field observations around military and commercial airfields may be explained by the learning process and habituation of many animal populations.

Studies conducted on arctic wildlife suggest that the same animal population should be observed over an extended time period at the same location. Busnel (1978) believes that unusual noise, in combination with close proximity visual stimulation, is enough to disturb any animal, including man, and cause panic. He also points out that any sudden and unexpected intrusion, whether acoustic or otherwise, can produce a startle or panic reaction. What is due specifically to noise alone is not always known.

Experimentation with the sonic boom (equivalent to quarry blasting), which is a purely acoustic stimulus (with no associated visual or odour stimuli), shows that the behaviour of domestic and also some traditionally shy wild species was unaffected as the result of repeated sonic booms (Casaday and Lehmann 1967, Welch and Welch 1970). Bird scare guns are also an acoustic source producing similar results.

The learning ability of many animal species is discussed by Busnel and Molin (1971). The animal's initial reaction to a new noise source is fright and avoidance but if other sensory systems are not stimulated (for instance optical or smell), the animal learns quite quickly to ignore the noise source.

#### 6.2.3.7 Mitigation

Mitigation measures for the construction phase, operations phase and blasting are described in this Section.

##### *Construction*

The following mitigation measures will be implemented to reduce effects associated with increases in noise levels during construction of the Project:

- noisy construction activities will be scheduled during daytime hours, to the extent possible;
- OH and S noise guidelines will be enforced at all times;
- regular inspection and maintenance of construction vehicles and equipment will be performed to ensure that they have quality mufflers and that worn parts are replaced;
- speed limits on site will be enforced;
- equipment will be turned off when not in use, if practicable;
- project roads will be maintained to reduce noise associated with vibration and vehicle noise; and
- faulty parts generating excessive noise will be replaced or repaired.

##### *Operations*

The following mitigation measures will be implemented to address increases in noise levels during operations:

- OH and S guidelines will be enforced at all times;
- electric motors and diesel engines will meet acoustic industrial standards;
- the process plant will be enclosed and to provide effective noise absorption by walls and roof material;
- equipment will be maintained to ensure that designer noise-output specifications continue to be met; and
- a noise survey will be conducted at the property line and at the location of critical receptors when the project attains full production capacity to confirm compliance with

PSL during daytime and nighttime hours. The results of this survey will determine if any additional work is required.

### *Blasting*

The following measures will be implemented to reduce the effects of blasting:

- optimize and revise blast design, as required, with the goal of minimizing the amount of blasting conducted;
- blasting will occur on day shift only during daylight hours; and
- where relevant, Shore will endeavour to inform the public of the revised blasting timetable.

### 6.2.3.8 Residual Effects

A residual effect is any measurable or demonstrable environmental effect remaining after mitigation. Residual impacts criteria for noise and impacts classification are defined in Table 6.2.3-8.

***Table 6.2.3-8: Definitions of Impact Criteria for Noise***

| | |
|---|---|
| **Direction** | Neutral:<br>No change compared to ambient sound levels.<br>Negative:<br>An increase in noise |
| **Magnitude** | Negligible:<br>≤ background noise (30 dBA $L_{eg}$).<br>Low:<br>> background noise, and ≤ 45 dBA $L_{eg}$ at 1.5 km (continuous or intermittent sources).<br>Moderate:<br>> 45 dBA $L_{eg}$ at 1.5 km (continuous or intermittent sources),<br>≤ 55 dBA $L_{eg}$ at 1.5 km (continuous sources 24 hour average sound level), and<br>≤ 65 dBA $L_{eg}$ at 1.5 km (intermittent sources 1 hour average sound level).<br>High:<br>> 55 dBA $L_{eg}$ at 1.5 km (continuous sources 24 hour average sound level),<br>> 65 dBA $L_{eg}$ at 1.5 km (intermittent sources 1 hour average sound level). |
| **Geographic Extent** | Local:<br>Effect is restricted to the LSA (e.g., mine footprint plus 1.5 km).<br>Regional:<br>Effect extends beyond the LSA into the RSA. |
| **Duration** | Short-term:<br>3 years; includes pre-construction and construction phases.<br>Long-term:<br>26 years; includes operation phases. |

| | |
|---|---|
| **Reversibility** | Reversible (short-term):<br>Effects can be reversed at closure of the Project. |
| **Frequency** | Low:<br>Occurs once daily at < 1-h total duration.<br>Moderate:<br>Occurs frequently at < 3-h total duration.<br>High: Occurs continuously. |

Based on the above criteria, the residual effect of noise for construction and operation of the Project is classified in Table 6.2.3-9.

***Table 6.2.3-9: Noise Residual Effects for Construction, Operations and Closure:***

| | |
|---|---|
| Direction: | Negative |
| Magnitude: | Moderate for construction; Low for operation |
| Geographic extend: | Local |
| Duration: | Short term for construction; Long term for operation |
| Reversibility: | Reversible |
| Frequency: | High |

### 6.2.4 Hydrology

#### 6.2.4.1 Project Methodology

Hydrological analyses were conducted to assess the effects of the Project on the surface water flows in tributary streams (see Figure 6.2.4-1) and in the Saskatchewan River.

A water balance model was developed for the life of the Project. The water balance model provides a tool for quantifying the volume of water at various nodes within the mine's water management system at any specific time. Results from the water balance can be used to help determine if there is a risk of having water in excess of what can be managed by the current design and if there is a risk of not having enough water for mine operations. The water balance results were also used to assess the effects of the mining developments on the local study area.

The water balance model developed for the Project tracks the volume of water that is gained and lost on a monthly basis for a period of 24 years. The period modeled begins a year prior to the start of construction to determine the baseline conditions and ends at the stop of operations. The structure of the water balance model is discussed in Appendix 6.2.7-A.

The following water sources or inputs were applied in the water balance:

- Star Pit surficial aquifer Residual Passive Inflow (RPI);
- Star Pit deep aquifer (Mannville) RPI;
- Star Pit Mannville pumping well flow;
- Orion South surfical aquifer RPI;
- Orion South Mannville RPI;
- Orion South Mannville pumping well flow;
- shallow wells for Processing Plant Recovery;
- surface runoff from:
    - Star Pit (upper and lower pit walls);Orion South Pit (upper and lower pit walls);
    - Overburden Stockpile;
    - Fine PK Containment Facility (PKCF);
    - Coarse PK Pile;
    - Processing Plant and other site facilities;
    - roads;
    - undeveloped area of East Ravine Watershed upstream of Star Pit, which is assumed to be diverted to the Runoff Pond; and
- direct precipitation on ponds.

Water losses for the Project will include:

- evaporation from pond surfaces;
- seepage from ponds;
- discharge from the sewage lagoon; and
- infiltration, including that from PKCF, Coarse PK and Overburden Pile

The water balance links all the inflows and outflows to determine the water volume for the following nodes each month:

- Processing Plant bypass water/recycle water;
- PKCF water storage;
- Inflow to wetlands around the PKCF;
- Runoff Pond;
- Star Pit water storage (post operation);
- Discharge to the Saskatchewan River via the diffuser; and
- Discharge to the Saskatchewan River from tributary streams.

Key assumptions made in establishing the water balance model include:

- Water from upstream extents of East Ravine will be used on site or pumped to Duke Ravine beginning during the construction phase of the project;
- The area of East Ravine contributing runoff to the Saskatchewan River will diminish during Star Pit development and at full build out of Star Pit, the area is assumed to be negligible;
- 90% of seepage from the PKCF and runoff from the exterior slopes of the PKCF will be captured in ditches around the toe of the facility and pumped back into the PKCF;
- 10% of seepage from the PKCF will bypass the ditches around the toe of the facility and report to wetlands in Duke Ravine, FalC Ravine and Wapiti Ravine;
- During the Star Mine operation water for operating the plant will be recycled from the PKCF; during the Orion South Mine operation Fine PK will be discharged to the Star Pit and the PKCF will no longer be used, therefore water for operating the plant will be taken from the Mannville dewatering system;
- Runoff from the side slopes and floor of the pits and residual groundwater flow into the pits will be collected and pumped to the Mannville Tank;
- Runoff from the Overburden Stockpile and Coarse PK Pile areas were distributed based on the proportion of the watershed overlapped by each pile (i.e., 47% of the Overburden Stockpile is in the Caution Creek watershed, therefore 47% of the runoff from the Overburden Stockpile will runoff to Caution Creek); and
- Catchment areas for the Overburden Stockpile, Coarse PK Pile and PKCF assumed that the facilities would be at full footprint at the start of Operations.

The water balance computes monthly water volumes from a year prior to the start of construction (Year 0) to the end of operations (Year 24). The following years represent years of interest within the Construction and Operations phases of the Project that have been selected for the effects assessment:

- Construction:
  - Year 3 - final year of stripping prior to initiation of mining in Star Pit in Year 4;
- Operations:
  - Year 12 – production in Star Pit prior to stripping for Orion South Pit;
  - Year 16 – production in Star Pit with stripping for Orion South Pit; and
  - Year 24 - The last complete year prior to end of mining in Orion South Pit in the summer of Year 24.

Three climatic scenarios were examined:

- Mean Case. Mean annual precipitation (468 mm) in all years;

- Wet Case. Mean annual precipitation in all years, except Year 19, when 1:20 year return period (wet) precipitation (656 mm) occurs; this year was selected as it is the year with the highest groundwater contribution and when the expected diffuser outflow is greatest under normal conditions, hence this year represents the minimum required flows to the water management system;
- Dry Case. Mean annual precipitation in all years, except Year 7, when 1:20 year return period (dry) precipitation (318 mm) occurs; this year was selected as it is the year with the lowest groundwater contribution and when the expected diffuser outflow is lowest under normal conditions, hence this year represents the greatest potential demand for process/make-up water supply over the life of the project.

The operating life of the mine will be approximately 20 years, thus the analysis of the 1:20 year dry and wet conditions were considered to be the most reasonable. The effects of the Project were first assessed for the Mean Case, and then changes to the assessment for the other two cases were determined.

#### 6.2.4.2 Potential Effects

***Effects of the Project***

*Tributary streams*

Tributaries to the Saskatchewan River can be affected by the following Project activities:

- Clearing of vegetation;
- Construction of roads and plant site facilities that have compacted surfaces;
- Release of excess Mannville groundwater;
- Capture of groundwater from dewatering wells that would otherwise provide interflow to local streams;
- Excavation of pits;
- Creation of overburden stockpiles; and
- Impoundment of channels to create the Runoff Pond.
-

The results from the water balance model were used to quantitatively assess the effects of mine development and operations activities on the tributary channels.

Table 6.2.4-1 presents changes in the drainage areas reporting to the mouths of tributary streams for Baseline, Construction and Operations phases of the Project.

***Table 6.2.4-1: Effects of the Project on Drainage Areas for Selected Tributary Streams to the Saskatchewan River***

| **Stream** | **Drainage Areas at the Mouth of Creek (ha) and Percent Change from Baseline (%)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***Baseline*** | ***Construction*** | | ***Operations*** | | | | | |
| | **Year 0** | **Year 3** | | **Year 12** | | **Year 16** | | **Year 23** | |
| Caution Creek | 9,319 | 8,611 | -8% | 8,358 | -10% | 8,358 | -10% | 8,358 | -10% |
| Caution Creek South | 916 | 810 | -12% | 766 | -16% | 766 | -16% | 766 | -16% |
| UT-2* | 163 | 163 | 0% | 163 | 0% | 163 | 0% | 163 | 0% |
| 101 Ravine | 2,431 | 1,919 | -21% | 1,419 | -42% | 1,419 | -42% | 1,419 | -42% |
| West Perimeter Ravine | 344 | 334 | -3% | 315 | -9% | 315 | -9% | 315 | -9% |
| West Ravine | 345 | 208 | -40% | 86 | -75% | 86 | -75% | 86 | -75% |
| East Ravine | 1,687 | - | -100% | - | -100% | - | -100% | - | -100% |
| Duke Ravine | 1,169 | 1,169 | 0% | 874 | -25% | 874 | -25% | 874 | -25% |
| FalC Ravine | 81 | 81 | 0% | 45 | -44% | 45 | -44% | 45 | -44% |
| Wapiti Ravine | 375 | 375 | 0% | 154 | -59% | 154 | -59% | 154 | -59% |
| English Creek | 8,124 | 8,124 | 0% | 8,011 | -1% | 8,011 | -1% | 8,011 | -1% |

*UT-2 – Unnamed Tributary 2*elected nd;ow to local streams. greatest potential demand for process/make-up water supply over the life of the project were co

As a result of the construction of the Star Pit, the drainage area of East Ravine is reduced from 1,687 ha to 10 ha; for the purposes of the assessment this has been deemed a 100% loss Other watersheds are impacted by construction to a lesser extent with the reduction of the drainage area ranging from under 1% to 59%. The drainage area of Wapiti Ravine is reduced by 59% due to the development of the PKCF. However, negligible development in the area of Unnamed Tributary 2 results in the reduction of the drainage area being less than 1%.

Table 6.2.4-2 indicates the mean annual flows for each of the tributary channels that were assessed for the Baseline, Construction and Operations phases.

**Table 6.2.4-2:** ***Effects of the Project on Annual Mean Surface Water Discharges in Streams Tributary to the Saskatchewan River for the Mean Climatic Case***

| Stream | Annual Mean Discharge at the Mouth of Creek ($m^3$/s) and Percent Change from Baseline (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Baseline* | *Construction* | | *Operations* | | | | | |
| | Year 0 | Year 3 | | Year 12 | | Year 16 | | Year 23 | |
| Caution Creek | 0.08 | 0.11 | 34% | 0.12 | 44% | 0.11 | 40% | 0.11 | 32% |
| Caution Creek South | 0.01 | 0.01 | 48% | 0.01 | 46% | 0.01 | 42% | 0.01 | 39% |
| UT-2 | 0.00 | 0.00 | 0% | 0.00 | -37% | 0.00 | -46% | 0.00 | -52% |
| 101 Ravine | 0.03 | 0.05 | 70% | 0.05 | 86% | 0.05 | 82% | 0.05 | 76% |
| West Perimeter Ravine | 0.02 | 0.02 | 0% | 0.02 | -3% | 0.01 | -9% | 0.01 | -25% |
| West Ravine | 0.02 | 0.02 | -5% | 0.01 | -11% | 0.01 | -18% | 0.01 | -33% |
| East Ravine | 0.02 | - | -100% | - | -100% | - | -100% | - | -100% |
| Duke Ravine | 0.02 | 0.03 | 33% | 0.10 | 365% | 0.10 | 360% | 0.10 | 348% |
| FalC Ravine | 0.01 | 0.01 | 0% | 0.01 | -3% | 0.01 | -11% | 0.01 | -27% |
| Wapiti Ravine | 0.02 | 0.02 | 0% | 0.02 | -8% | 0.01 | -15% | 0.01 | -30% |
| English Creek | 0.11 | 0.11 | 0% | 0.11 | -1% | 0.11 | -4% | 0.10 | -12% |

The baseflow in each steam discussed above will be reduced over the life of the mine as a result of the Manville aquifer dewatering. The baseflow reduction due to dewatering is taken from groundwater modelling carried out by SRK (SRK, 2011). However, the discharges from Caution Creek, Caution Creek South and 101 Ravine increase, as a result of the increased runoff and reduced evapotranspiration following the development of the Overburden and Rock Storage pile.

The PKCF will capture and store runoff from areas of the Duke Ravine, FalC Ravine, Wapiti Ravine and English Creek watersheds, which will act to reduce the contributing catchment areas. This reduction in contributing catchment areas for FalC Ravine, Wapiti Ravine and English Creek along with the reduction in groundwater baseflow account for the reduction in the stream discharges reported in Table 6.2.4-2.

Flows from East Ravine are virtually eliminated due to the development of the Star Pit in the lower reach of the watershed. Runoff from the upper reach of the East Ravine watershed will be collected in the Runoff Pond and diverted to Duke Ravine. This diversion accounts for a portion of the almost 3-fold increase in the annual mean discharge from Duke Ravine from the baseline rate during operations.

The maximum monthly discharges are expected to change in a manner similar to those for the mean annual flows. Table 6.2.4-3 lists the maximum monthly mean discharges computed for the years of interest.

***Table 6.2.4-3: Effects of the Project on Maximum Monthly Mean Surface Water Discharges in Selected Streams Tributary to the Saskatchewan River for the Mean Case***

| Stream | Maximum Monthly Mean Discharge at the Mouth of Creek ($m^3/s$) and Percent Change from Baseline (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***Baseline*** | ***Construction*** | | ***Operations*** | | | | | |
| | **Year 0** | **Year 3** | | **Year 12** | | **Year 16** | | **Year 23** | |
| Caution Creek | 1.04 | 1.53 | 46% | 1.68 | 61% | 1.67 | 60% | 1.66 | 59% |
| Caution Creek South | 0.10 | 0.18 | 69% | 0.19 | 88% | 0.19 | 87% | 0.19 | 86% |
| UT-2 | 0.02 | 0.02 | 0% | 0.02 | -16% | 0.02 | -19% | 0.02 | -21% |
| 101 Ravine | 0.29 | 0.64 | 120% | 0.72 | 148% | 0.72 | 147% | 0.71 | 146% |
| West Perimeter Ravine | 0.07 | 0.07 | -1% | 0.07 | -5% | 0.07 | -9% | 0.06 | -18% |
| West Ravine | 0.07 | 0.06 | -20% | 0.05 | -38% | 0.04 | -42% | 0.04 | -51% |
| East Ravine | 0.21 | - | -100% | - | -100% | - | -100% | - | -100% |
| Duke Ravine | 0.16 | 0.28 | 78% | 0.83 | 419% | 0.83 | 417% | 0.82 | 413% |
| FalC Ravine | 0.05 | 0.05 | 0% | 0.04 | -10% | 0.04 | -16% | 0.03 | -30% |
| Wapiti Ravine | 0.08 | 0.08 | 0% | 0.05 | -30% | 0.05 | -33% | 0.04 | -42% |
| English Creek | 1.02 | 1.02 | 0% | 1.01 | -1% | 1.00 | -2% | 0.98 | -4% |

Figure 6.2.4-2, Figure 6.2.4-3, Figure 6.2.4-4, Figure 6.2.4-5, Figure 6.2.4-6, Figure 6.2.4-7, Figure 6.2.4-8, Figure 6.2.4-9, Figure 6.2.4-10 and Figure 6.2.4-11 illustrate the computed monthly discharge hydrographs for Caution Creek, Caution Creek South, Unnamed Tributary 2, 101 Ravine, West Ravine, Duke Ravine, Wapiti Ravine and English Creek, respectively for Baseline, Construction and Operations conditions.

White Fox Creek is a stream located north of the LSA and Stream F and Stream G (Peonan Creek) are two streams south of the Saskatchewan River and south of the LSA that are not directly affected by physical disturbance resulting from the construction and operation of the Project. It is predicted that the effects of groundwater pumping will extend to these streams, resulting in a reduction in baseflow. Streams such as English Creek, Stream F and Stream G (Peonan Creek), which have little or no physical disturbance occurring in their watersheds, the effects are expected to be greatest approximately 45 to 60 years after the start of Project construction. After this point in time the groundwater discharge begins to increase towards pre-development levels (SRK, 2011). The effect of groundwater pumping in these streams is most significant in the winter months when there is little to no surface runoff to supplement the flow in the streams. Figure 6.2.4-12, Figure 6.2.4-13 and Figure 6.2.4-14 illustrate the computed monthly hydrographs for White Fox Creek, Steam F and Stream G (Peonan Creek). The total discharge from these streams in the baseline year was based on streamflow monitoring in the region. There were no monitoring data available for the months of November through March; thus, it was assumed that the winter baseflow would be equal to the groundwater discharge.

In summary, for tributary basins not directly affected by physical disturbance resulting from the construction and operation of the Project, the effects on stream discharges are expected to result solely from groundwater pumping.

A 90-10 approach is applied to water withdrawals from tributary streams supporting fish habitat. This means that:

- Withdrawals could conceptually be as much as 10% of the weekly average flow: and,
- Withdrawals can be limited by ensuring that the 90% of the weekly average discharge remains in the steam, meaning that if the natural flow falls below 90% of average, then no withdrawal would be allowed.

The groundwater pumping results in reductions in baseflow to the tributary streams locally and regionally. Results show that in the post freshet period the percentage reduction in baseflow will be less than 10% of the average baseline values for large streams (watersheds greater than about 500 km$^2$), but could exceed the 10% withdrawal limit for small streams (watersheds less than about 500 km$^2$) during the post freshet period. Effects are expected to be greater than 10% of the average baseline values during the winter ice-cover period for those streams that normally have sustained flow during the winter. Such an effect would not be observable on streams that normally cease to flow during the winter. However there are little to no streamflow data available for this period.

The effect of the Project on surface water flows in the Saskatchewan River is the combined effect of:

- Changes in the baseflow due to groundwater pumping;
- Changes in runoff discharges from tributary basins; and
- Addition of water to the river from the diffuser.

The maximum reduction in groundwater discharge to the Saskatchewan River would be approximately 0.028 $m^3/s$, which is equivalent to 0.006% of the baseline annual mean discharge. Based on this information it can be concluded that groundwater pumping for the Project has a negligible direct effect on the Saskatchewan River discharge.

The effects of the Project on runoff discharges to the Saskatchewan River from tributary streams and outfall discharges are presented in Table 6.2.4-4.

*Table 6.2.4-4: Computed Changes to Inflow to the Saskatchewan River*

| Source of Inflow | Annual Mean Discharge ($m^3/s$) and Percent Change from Baseline (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Baseline* | *Construction* | | *Operations* | | | | | | | |
| | Year 0 | Year 3 | | Year 6 | | Year 12 | | Year 16 | | Year 23 | |
| Tributary Streams | 0.39 | 0.43 | 9.9% | 0.52 | 31.2% | 0.51 | 28.8% | 0.49 | 24.4% | 0.45 | 15.5% |
| Facility Runoff | - | 0.24 | N/A | 0.39 | N/A | 0.38 | N/A | 0.36 | N/A | 0.33 | N/A |
| Diffuser | - | 0.02 | N/A | 1.15 | N/A | 1.19 | N/A | 1.23 | N/A | 0.69 | N/A |
| Saskatchewan River | 439.00 | 439.68 | 0.2% | 441.06 | 0.5% | 441.08 | 0.5% | 441.09 | 0.5% | 440.47 | 0.3% |

Notes: 1. Tributary streams includes only the streams within the LSA on the north side of the Saskatchewan River without supplemental flows added to mitigate stream flow reduction due to groundwater pumping..

Reductions in discharge in some catchments are compensated for by increased runoff in other catchments, such that the total inflow to the river from tributary streams is always greater than for Baseline. For example, reductions in baseflow in the tributary streams as a result of groundwater pumping are offset by diffuser flow to the Saskatchewan River. Diffuser outflows average near 1 $m^3/s$ to 2 $m^3/s$. This input together with the small increase in local runoff, amounts to a maximum change of about 2.27 $m^3/s$ in the Saskatchewan River discharge. A change of this small magnitude (0.5%) would not be measurable in the river.

Dry and wet scenarios were also modeled. For the dry scenario, the depth of precipitation was reduced to the 1:20 dry precipitation in Year 7, as this is the year (after the start of operations) with the lowest expected groundwater contribution. Effects on the tributary stream baseflows from groundwater contributions are similar to those for the mean case. However, as precipitation is less, runoff in Year 7 is less than under mean conditions.

Diffuser discharges are directly related to surface water runoff volumes for the contributing watersheds. For Year 7, the reduction in total diffuser flow volume due to reduced surface runoff is 1%. On a monthly basis the greatest change to the diffuser discharge occurs in April of Year 7, with a 5% decrease compared to the mean case. These changes are illustrated on Figure 6.2.4-15.

For the wet scenario, the depth of precipitation was increased to the 1:20 year wet precipitation in year Year 19, as this is the year with the highest groundwater contribution and when the expected diffuser outflow is greatest under normal conditions. Effects on the tributary stream baseflows are similar to those for the mean case. However, as precipitation is greater, runoff in Year 19 is more than under mean conditions.

The increase in diffuser flow volume in Year 19 is approximately 3% compared to the mean case. The increased surface runoff results in the design capacity of the diffuser being exceeded in the months of January and April. On a monthly basis the greatest change in the diffuser discharge occurs in April of Year 19, with a 14% increase compared to the mean case. These changes are illustrated on Figure 6.2.4-16.

### 6.2.4.3 Mitigation

Development of the Project includes the following mitigative measures to reduce the effects of the Project on surface water hydrology:

- Water is re-used within the plant site. Make-up water is provided from the PKCF Polishing Pond;
- Reducing contact water. Where feasible, drainage from sub-catchments upstream of Project facilities will be diverted around the facilities to reduce water volumes that could be affected during Operations;

- Supplemental flows will be provided to mitigate reductions in low flow conditions for English Creek, Duke Ravine, and 101 Ravine and other streams as warranted; and
- Erosion and sediment control will be installed where necessary and practical to control surface flows and limit transport of deleterious substances into watercourses, including Duke Ravine.

#### 6.2.4.4 Residual Effects

The residual effects of the Project on surface water hydrology have been assessed by considering the mitigative measures discussed above for each phase of the Project. For the Construction and commissioning phase, the following activities could affect surface water hydrology:

- Clearing and Stripping;
- Surface infrastructure installations;
- Water source and wastewater management;
- Pit excavation and development;
- Construction of overburden & rock storage and processed Kimberlite containment facilities;
- Construction of Processing Plant and facilities;

- During Operations, the following activities were assessed for surface water hydrology;
- Surface water management;
- Water supply and distribution;
- Mine dewatering;
- Erosion control and soils/till stockpiles management;
- Overburden & rock storage management;
- Fine and coarse processed Kimberlite management;
- Waste water management and drainage control; and
- Processing Plant water consumption

Table 6.2.4-5 summarizes the residual effects of the Project for each receptor at the selected Project phases. Note that closure and reclamation are discussed in Section 7.

*Table 6.2.4-5: Residual Effects of the Project on Surface Water Hydrology*

| Project Phase | Direction | Magnitude | Duration | Geographic Extent | Frequency | Significance | Reversibility |
|---|---|---|---|---|---|---|---|
| **Construction and Commissioning** | | | | | | | |
| **Tributary Streams** | | | | | | | |
| Caution Creek | Positive | High | Short-term | Local | Continuous | Not Significant | Reversible |
| Caution Creek South | Positive | High | Short-term | Local | Continuous | Not Significant | Reversible |
| UT-2 | Neutral | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| 101 Ravine | Positive | High | Short-term | Local | Continuous | Not Significant | Reversible |
| West Perimeter Ravine | Neutral | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| West Ravine | Adverse | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| East Ravine | Adverse | High | Short-term | Local | Continuous | Not Significant | Reversible |
| Duke Ravine | Positive | High | Short-term | Local | Continuous | Not Significant | Reversible |
| FalC Ravine | Neutral | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| Wapiti Ravine | Neutral | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| English Creek | Neutral | Low | Short-term | Local | Continuous | Not Significant | Reversible |
| Saskatchewan River | Positive | Low | Long-term | Regional | Continuous | Not significant | Reversible |
| **Operations** | | | | | | | |
| Tributary Streams | Adverse | High | Long-term | Local | Continuous | Significant | Reversible |
| Caution Creek | Positive | High | Long-term | Local | Continuous | Significant | Reversible |
| Caution Creek South | Positive | High | Long-term | Local | Continuous | Significant | Reversible |

| Project Phase | Direction | Magnitude | Duration | Geographic Extent | Frequency | Significance | Reversibility |
|---|---|---|---|---|---|---|---|
| UT-2 | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| 101 Ravine | Positive | High | Long-term | Local | Continuous | Significant | Reversible |
| West Perimeter Ravine | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| West Ravine | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| East Ravine | Adverse | High | Long-term | Local | Continuous | Significant | Not Reversible |
| Duke Ravine | Positive | High | Long-term | Local | Continuous | Significant | Reversible |
| FalC Ravine | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| Wapiti Ravine | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| English Creek | Neutral | Negligible | Long-term | Local | Continuous | Not Significant | Reversible |
| Saskatchewan River | Positive | Low | Long-term | Regional | Continuous | Not significant | Reversible |

Effects within the LSA are significant, as specific streams will have substantial changes in runoff; e.g., East Ravine, where the lowest reach of the channel will have almost all of its upstream drainage area removed and Duke Ravine, where the catchment area is nearly doubled by the diversion of the upstream extents of the East Ravine catchment. Groundwater contribution to the streams within the LSA, including the Saskatchewan River, will be reduced over time as a result of groundwater pumping. Cumulatively, however, the net change in flow from all local catchments draining to the Saskatchewan River is near zero, and the effects on the Saskatchewan River are deemed not significant as a result. Effects in the RSA are not measurable, and are not significant.

#### 6.2.4.5 Cumulative Effects

The residual effects of the Project on surface water hydrology at the RSA level (Saskatchewan River) have been determined to be not measurable and not significant as a result. As the effects of this project cannot be detected as a part of cumulative effects of other projects, this project does not add measurably to the effects of the other projects.

#### 6.2.4.6 Closure

To assess the hydrologic impacts of the Project beyond the Operations phase a water balance was developed for Closure. The water balance contained two parts. One focusing on mine pit infilling and the other on the changes to local streamflow. Closure was defined as the period commencing at the end of mining (approximately Year 24) during which reclamation is established. The analysis for closure included:

- changes to local streamflow as a result of changes in the reclaimed landscape;
- changes in groundwater baseflow as it recovers; and
- water balance simulation of in-pit lake filling.

The water balance model developed for Closure tracks the volume of water that is gained and lost on an annual basis starting at the end of a period 20 to 25 years after the operations phase. The assumption was made that the vegetation of the reclaimed areas would be fully established and relatively stable after this period.

It was assumed that the PKCF, Course PK Pile, Overburden Pile and all Site Facilities will be reclaimed to the appropriate land use categories, as per provincial regulations, upon mine closure as described in Section 7.5. With the exception of the PKCF, it is assumed that the natural watershed boundaries will be restored as close to the natural conditions (i.e., pre-development conditions) as possible. The PKCF will remain bermed and the runoff from within this area will be discharged into Duke Ravine. The runoff from the outer slopes of the PKCF berms will be directed to the natural watersheds in which they are located (English Creek, Wapiti Ravine and FalC Ravine).

The Orion South Pit is contained within the upstream portions of 101 Ravine and East Ravine. Modeling (SRK 2011) shows that the water level within the Orion South Pit will not reach an elevation of 436 mamsl, and therefore, will not overflow into East Ravine. The Closure plan for Star Pit directs overflow into the downstream reach of East Ravine and subsequently the Saskatchewan River when the water level reaches 378 mamsl. The structure of the water balance model is discussed in Appendix 6.2.7-A.

The following water sources or inputs were applied in the water balance:

- surface water runoff;
- direct precipitation (pond surface and pit walls);
- groundwater seepage;
- evaporation; and
- groundwater infiltration.

Key assumptions made in the creation of the water balance for Closure include the following:

- landscape is fully reclaimed (i.e., selection of runoff coefficients is based on fully reclaimed conditions);
- runoff coefficients for adjacent basins and pit walls were invariant with time;
- groundwater flows into and out of the pits were varied, based on information provided in the groundwater model (SRK, 2011); and,
- extreme events, such as extreme precipitation, droughts and wild fires, were not considered.

The findings of the Closure water balance study are presented in Appendix 6.4.2-A. A high level summary of the water balance findings are listed below:

- As per GW modeling by SRK, the maximum reduction in groundwater contribution to stream flow occurs 25 years after end of mining.
- The maximum reduction in groundwater discharge to the Saskatchewan River would be approximately 0.16 $m^3$/s. This is equivalent to 0.34% of the baseline annual mean discharge
- Creek flows return to between 68% and 92% of baseline at the end of the SRK modeling period which is 350 years after the end of mining.
- Star Pit will spill into East Ravine 326 years after mining ends. The average annual spill volume into East Ravine will be approximately 1.22 $Mm^3$
- Orion South Pit does not spill during the modeling period (1000 years). After 326 years when Star Pit starts to overflow, the water level in Orion reaches 406 mamsl.

*Table 6.2.4-6: Residual Effects of the Project on Surface Water Hydrology for Closure*

| Tributary Streams | Direction | Magnitude | Duration | Geographic Extent | Frequency | Significance | Reversibility |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Caution Creek | Neutral | Low | Long-term | Local | Continuous | Not significant | Reversible |
| Caution Creek South | Neutral | Low | Long-term | Local | Continuous | Not significant | Reversible |
| UT-2 | Negligible | Low | Long-term | Local | Continuous | Not significant | Reversible |
| 101 Ravine | Adverse | Moderate | Long-term | Local | Continuous | Not significant | Reversible |
| West Perimeter Ravine | Adverse | Low | Long-term | Local | Continuous | Not significant | Reversible |
| West Ravine | Adverse | Moderate | Long-term | Local | Continuous | Not significant | Reversible |
| East Ravine | Adverse | High | Long-term | Local | Continuous | Significant | Not Reversible |
| Duke Ravine | Positive | Low | Long-term | Local | Continuous | Not significant | Reversible |
| FalC Ravine | Adverse | Low | Long-term | Local | Continuous | Not significant | Reversible |
| Wapiti Ravine | Adverse | Moderate | Long-term | Local | Continuous | Not significant | Reversible |
| English Creek | Neutral | Negligible | Long-term | Local | Continuous | Not significant | Reversible |
| Saskatchewan River | Positive | Low | Long-term | Regional | Continuous | Not significant | Reversible |

### 6.2.5 Navigable Waters

The *Navigable Waters Protection Act* (NWPA) is a federal law administered by Transport Canada that ensures that works constructed in navigable waterways are reviewed, regulated, and minimize impacts to vessel navigation (Minister of Justice 2009). Thus approval for activities related to the development, operation, and closure of the Project that have the potential to cause direct or indirect effects on navigation will need to be received prior to the commencement of construction activities.

#### 6.2.5.1 Introduction

The LSA of the Project includes nine streams that are tributaries of the Saskatchewan River (SKR), and the SKR from approximately 3 km upstream of Caution Creek to 2 km downstream of English Creek (Figure 6.2.5-1). Recent amendments were made to the NWPA that define classes of minor works and waters that have no significant impact to navigation to enable the government to streamline the approval process for large-scale projects (Public Works and Government Services Canada 2009). The FalC Ravine, Wapiti Ravine and West Perimeter Ravine that flow into the SKR are small, shallow, and contain numerous obstructions to passage, such as beaver dams, log jams, waterfalls, subsurface flow, etc. (refer to Section 5.3.1 for detailed information and photographs). Under Section 11 of the amendment, *Minor Navigable Waters*, these streams are designated as a class of waters that do not require approval prior to work being undertaken. The six remaining tributaries were assessed by Transport Canada, who issued letters on May 18, 2010 (Appendix 6.2.5-A) stating that Caution Creek, 101 Ravine, West Ravine, East Ravine, English Creek and Duke Ravine were not subject to the NWPA. Therefore, these streams require no further discussion regarding potential Project-related effects on their navigability.

The SKR is an important navigable waterway that is utilized for limited recreational purposes (e.g., canoeing and fishing). Project facilities will be located north of the SKR and will not alter navigability on the river. There will be no water intake pipe located in the SKR because all process water required by the plant is expected to come from pit dewatering or from surface run-off collection. The only Project-related development to be located in the SKR is the process and ground water discharge structure, which will consist of a pipe extending from the Water Management Reservoir in the Duke Ravine to the proposed outfall location in the SKR (Figure 6.2.5-1).

The other Project-related development addressed in this section is the access road crossing of the White Fox River. An access corridor is proposed that includes a roadway, communication lines, and a natural gas pipeline extending from Highway 55 near Smeaton south through the FalC forest to the mine site (Figure 6.2.5-1). The alignment was chosen to reduce the number of stream crossings and, by utilizing the same corridor for all these ancillary developments, the environmental impacts are reduced.

The objective of this Section is to evaluate the significance of the water discharge outfall in the SKR and the White Fox River road crossing structure on vessel navigation and to describe proposed mitigation measures.

### 6.2.5.2 Water Discharge Outfall

The proposed site of the water discharge outfall in the SKR is approximately 600 m downstream of the mouth of Duke Ravine (Figure 6.2.5-1). Appendix 6.2.5-B, Photos 1 to 6, illustrate the study area upstream and downstream of the proposed water discharge outfall location. The discharge structure will consist of a submerged pipeline with the outfall occurring approximately 60 m from the north bank of the river[1]. The water depth at the proposed outfall location is approximately 3.5 m. A hydrotechnical modeling study recently completed found that the SKR near the proposed discharge location has a steeper upper reach, with characteristically higher velocities and shallower depths, relatively uniform flow across the channel, and no obstructions such as islands or mid-channel features (AMEC 2010). The width of the river channel varies from a minimum of 260 m to a maximum of 380 m within a 5 km reach downstream of the proposed outfall location. The water discharge rate is designed to be up to 2.3 $m^3$/s or 199,000 $m^3$/day, which represents approximately 0.53% of mean annual flow and 1.2% of the modeled open water 7Q10 flow of the SKR (AMEC 2010). Thus the overall contribution of the discharged water to the river flow will be minimal.

Although empirical documentation of vessel use of the river in the Project LSA has not been recorded, it is assumed that there is limited recreational use due to accessibility and proximity to higher quality sport fishing areas such as Codette Lake, Tobin Lake, the Forks[2], and the numerous fishing lakes to the north. The portion of the SKR in the LSA is relatively difficult to access. The closest public boat launch is located approximately 16 km downstream near Highway 6 at the Wapiti recreational area. It is likely that the SKR could be accessed from private land along the SKR, or from the James Smith Cree Nation near the Project site, however usage would be considered low.

#### *Effects*

During construction, work may occur on the banks of the SRK to armour the discharge pipe from ice damage. During this time, it may be necessary to install a small coffer dam or other water exclusion structure so that the pipe can be installed in the dry. This may temporarily reduce the navigable width of the SRK by up to 2 m (out of a minimum of 260 m width).

As discussed above, the water discharge pipe will be submerged and will extend into the SKR approximately 60 m from the north bank. There are no predicted effects because the

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[1] Approximate coordinates are E519519, N5897340 (NAD83).

[2] The Forks is the area of the river where the North Saskatchewan River meets the South Saskatchewan River and forms the Saskatchewan River.

pipe will be submerged and the river width (260 m) and depth (3.5 m) at the proposed outfall location; this will allow ample room for vessel navigation.

### *Mitigation*

The location of the outfall structure will be marked near shore and the pipeline will also be armoured with rocks to protect it from ice movement, which will further act to mark the structure. During installation and decommissioning of the outfall structure, proper control measures will be taken to ensure that debris or other materials do not accumulate in the SKR and alter navigability at the site. In addition, no tools, equipment, vehicles, materials, or temporary structures used during construction, operation, or removal of the outfall structure will remain at the site after closure and decommissioning of the Project.

### *Significance*

Residual effects on the navigability of the SKR caused by installation, operation, and decommissioning of the water discharge outfall are considered to be not significant and unlikely to occur.

## 6.2.5.3 Access Corridor

The access corridor will cross the White Fox River at the site of the current bridge on the Shipman Trail (Figure 6.2.5-1; Appendix 6.2.5-B, Photos 7 to 10). Since the existing road will be upgraded and widened, a widening of the existing bridge will be required as part of the Project development. Currently there is a 17.93 by 4.9 m wide portable steel bridge spanning the waterway that was constructed in 2007. To widen the existing bridge, one additional bin cell wall would be installed adjacent to each of the existing exterior bin walls at the abutments. The old bridge would be realigned and connected to the new bridge to create a clear width of 11.98 m between the rails and a roadway width of 11.4 m.

Prior to construction of the 2007 bridge, a review of the hydraulic requirements for the crossing structure of the White Fox River was completed and the existing crossing structure was designed to meet the requirements of the Department of Fisheries and Oceans Canada, Transport Canada, and the Saskatchewan Ministry of the Environment (CanNorth 2006).

### *Effects*

Modifications being made to the existing bridge at the White Fox River will alter the width of the bridge, but the height will remain the same, which is the most important factor when considering navigation of the waterway. Considering the current structure was designed to be a sufficient height to allow safe passage of vessels and approval of the design was obtained from Transport Canada, there are no predicted effects from the crossing structure on navigability of the waterway. Section 10 of the NPWA states that "any lawful work may be altered if plans of the proposed alteration are deposited with and approved by the

Minister and in the opinion of the Minister, interference with navigation is not increased by the alteration." Thus, plans of the alteration will be submitted and the appropriate permits will be retained, however, no issues are anticipated in terms of navigability cause by the bridge realignment and upgrade on the White Fox River.

#### *Mitigation*

The current bridge is designed to enable safe navigation of the White Fox River and expansion of the bridge will not change navigability; therefore, no mitigation measures are required during operation of the structure. During the construction phase of the bridge, mitigation measures will include preventing material from entering the water way that could reduce the navigability of the river. This will include the use of proper erosion control measures, if needed, to ensure that sedimentation or the deposition of other material does not occur. In addition, no tools, equipment, vehicles, materials, or temporary structures will remain at the site after construction activities at the bridge are completed. There are no plans to remove the bridge following closure and decommissioning of the Project.

#### *Significance*

Residual effects on the navigability of the White Fox River caused by alterations to the existing bridge are considered to be not significant and unlikely to occur.

### 6.2.6 Regional Geology and Hydrogeology

This Section of the Environmental Impact Statement (EIS) describes the Project specific effects related to the regional geology and hydrogeology. This Section should be read in conjunction with Section 5.2.7 (Groundwater Resources), which describes the regional geological and hydrogeological settings.

The Project will excavate through the surficial aquifers of the shallow groundwater system and through several of the thin aquifer layers within the clay and shale, allowing these aquifers to drain into the mine. The mine will also intercept the deeper aquifers of the deep groundwater system in the Mannville Group, requiring pumping from both this aquifer and the underlying Souris River Formation to maintain dry working conditions. Modelling by SRK (2011a) predicts that most of the groundwater at the mine will be pumped from the deep aquifers, with only a limited contribution coming from the thin aquifers of the shallow groundwater system.

The groundwater model predicts that dewatering from the Mannville Group/Souris River Formation will lower water levels in the deep aquifer unit for some distance away from the mine. However, the effect of dewatering and mine construction on the upper aquifers is expected to be limited and localised to the mine area due to the intervening confining layers of Colorado shale and till between the deep and shallow groundwater systems and the surficial aquifer being regularly replenished by precipitation. Groundwater level declines in thin aquifers within the deeper till units are expected to be intermediate between those in the Mannville Group and the surficial aquifer.

The reduction in groundwater levels is expected to result in two environmental effects: 1) a decrease in groundwater discharge to local creeks and 2) a decrease in the utility of some private wells completed in sand layers within the deeper surficial aquifers. The effect of decreased groundwater discharge to local creeks, along with the mitigation strategies to address the reductions in surface water flows are discussed in Section 6.2.4 (Hydrology).

As discussed in later sections, the effect on local wells will be mitigated through a program of monitoring and provision for alternate water supplies where necessary (e.g., new wells, well improvements, lowering of pump intakes, hook ups to unaffected municipal based systems or cisterns). Approximately 150 wells completed at depths of greater than 25 m, within 30 km of the Site, were identified as potentially vulnerable to the effects of dewatering through the modelling process.

The water taken from the open pits and dewatering wells is expected to be suitable for use at the mine process plant and will reduce the overall water demand of the Project. The water will eventually be discharged to the Saskatchewan River, with some pumped into Star pit in the final years of mining. Additional information on the use of the mine water at the site, and the environmental effects of the eventual discharge of the mine water to the Saskatchewan River are discussed in Section 6.2.7 (Surface Water Quality).

A geological effect arising as a consequence of development of the Star and Orion South pits is the removal of the aquitard (glacial till and Colorado Group sediments). Following mining, the open pits will be allowed to flood with water. This will create a hydraulic connection across the Colorado shales between the deep groundwater system in the Mannville Group and the shallow aquifers in the shallow groundwater system. Upon filling of the pit lakes, small volumes of water are expected to drain from the Star pit lake into the Saskatchewan River through the East Ravine, however surface water inflows into the Star pit are expected to account for 80% of the outflow from the lake (SRK 2011b). Water quality of the pit discharge is modeled in Section 6.2.7. In comparison, no surface water overflow is expected from the Orion South pit lake. Some drainage from the shallow surficial aquifer into the pits is expected.

In summary, a groundwater model has been prepared for Shore to assist in assessing the effect of mine dewatering on the regional groundwater flow systems. The model predicts that water levels will be lowered substantially in the deep groundwater system and to a lesser extent in the overlying aquifers in the shallow groundwater system. The use of some local wells completed in the deeper surficial aquifers within the till may be affected by the dewatering and groundwater discharge to local creeks is also expected to be reduced. Both these effects will be addressed through implementation of mitigation strategies. The mitigation strategy for wells will include monitoring and a program to provide alternate water supplies to affected well owners. The mitigation strategy for the creeks is discussed in Section 6.2.4 (Hydrology).

### 6.2.6.1 Introduction

This Section presents the effects assessment for the regional geology and hydrogeology components of the Project. The effects on surficial soils, terrain and local geology are discussed in Section 6.2.1 (Soils, Terrain and Geology). The purpose of this section is to:

- describe the valued components regional geology and hydrogeology;
- evaluate the potential interactions among Project components;
- identify potential effects arising from those interactions;
- identify avoidance, mitigation and/or compensation measures;
- rate residual effects based on effective application of mitigation measures; and
- identify and assess potential cumulative environmental effects (CEE) from other current or future land use activities.

Hydrogeological changes have the potential to cause indirect impacts to other disciplines and valued components (VCs) such as hydrology, wetlands and streams, and fisheries. Where changes in the hydrogeological setting cause impacts described in other sections of this document, this section refers the reader to those sections. Only the changes created by mining to the hydrogeologic setting are described in this section. The authors of the sections on hydrology and fisheries relied on the information presented by SRK (2011a) when completing their respective sections of this document.

For the purposes of this discussion, the LSA includes the area of the mine site, including the pits, stockpiles and facilities. The RSA for hydrogeological assessment encompasses a larger area that extends more than 50 km from the Project Site. The RSA contains many individual features of interest, including the Saskatchewan River, regional aquifers, a buried bedrock valley and the kimberlites. Descriptions of these features and the sources of information used to derive the descriptions can be found in Section 5.2.7 (Groundwater Resources). The regional geology and hydrogeology baseline section (Section 5.2.7) also describes the conceptual model of the RSA.

### 6.2.6.2 Scoping and Effects Identification

Effects on regional geology and hydrogeology can result from the Project due to dewatering, excavation of the open pits, loss of water at the site, water pumping for water supply and the creation of processed kimberlite (PK). Potential issues relating to the regional geology and hydrogeology were initially identified for detailed examination as follows:

- reduction in groundwater levels and changes in groundwater flow directions during mining and post closure;
- reduction and changes in groundwater discharge to surface water features, including quality and quantity;
- changes to groundwater quality after closure; and
- decrease in the groundwater supply to existing wells reliant on aquifers affected by dewatering.

Issue identification also considered information gathered from community engagement, regulatory engagement, professional judgement and lessons learned from similar projects.

Potential issues that could result in potential geological or hydrogeological effects, as presented in Table 6.2.6-1, were then identified by comparing Project phases and components or activities within those phases (Table 6.1-1 of Section 6.1, Overview and Methods).

Each issue was then assessed and validated in terms of whether or not it would result in a residual effect, based on evidence from other similar assessments, regulatory requirements or guidelines (e.g., Guidelines for Northern Mine Decommissioning and Reclamation, Saskatchewan Ministry of Environment (SMOE 2008)), predictive numerical modelling and professional judgment.

***Table 6.2.6-1: List of Project Components and Activities for Hydrogeology and Groundwater Quality***

| Potential Effect | Project Phase | Component/Activity [1] | Valued Component | Effect Confirmation/ Validation |
|---|---|---|---|---|
| Lowering of groundwater levels and changes in groundwater flow directions due to pit dewatering | Construction and operations | Dewatering of aquifers to allow mining (mine dewatering) | Interference with operation of wells<br>Changes in groundwater discharge to surface water, springs and shallow aquifers | Valid |
| | Closure and Decommissioning | Flooding of pit lakes upon closure (monitoring and maintenance of discharge flow and quality, and groundwater management) | | Valid |
| Water supply for processing plant | Operations | Large quantities of water will be required for the processing plant on site and will be taken from the mine dewatering system (water source and waste water management) | None | Minor |
| Dewatering induced subsidence | Construction and Operations | Dewatering of aquifers to allow mining (mine dewatering) | Ground surface | Minor |
| Lowering of | Construction and | Dewatering of aquifers to provide | Inference with | Minor |

| Potential Effect | Project Phase | Component/Activity [1] | Valued Component | Effect Confirmation/ Validation |
|---|---|---|---|---|
| groundwater levels and changes in groundwater flow directions due to camp water supply | Operations | water supply for accommodations (water source and waste water management) | operation of wells<br>Changes in groundwater discharge to surface water | |
| Changes in groundwater quality from processed kimberlite facilities and upward movement of ground through open pit after closure | Construction and operations | Creation of PKCF, Coarse PK pile (water source and waste water management) | Changes in groundwater quality | Valid |
| | Closure and Decommissioning | PKCF, Coarse PK pile and Open Pit to remain after closure. (surface and groundwater management) | | |

**Note:** [1] from Chapter 2 Project Description.

### 6.2.6.3 Effects Confirmation

The analysis summarized in Table 6.2.6-1 is to assist in the assessment of each of the potential issues relevant to geology and hydrogeology and to determine the validity of each issue after applying mitigation measures and in turn identify which will warrant further assessment. The issues listed above considered valid required further analysis to determine the possibility of a residual effect after mitigation. This approach to pathway validity is based on scientific knowledge, the assessment of similar developments and numerical modelling.

#### *Minor or Not Valid Effects*

The following discusses the reasons for categorizing some potential issues or effects as minor or not valid. Minor and not valid effects are initial issues identified as potentially having an effect on the geology or hydrogeology, but which upon further analysis have no actual effect, or potentially have a minor effect, considered within natural variation, that is readily mitigated. Further assessments are not carried out on the minor or not valid issues.

*Water supply for processing plant*

The processing plant will require large quantities of water; however the water from the plant will be recycled from the mine dewatering system and will not represent an additional withdrawal of water from the environment.

*Dewatering induced subsidence*

Subsidence can potentially result from depressurization during dewatering of unconsolidated materials. In this case, the majority of the depressurization will occur in the consolidated bedrock formations, with limited depressurization in the overlying overburden deposits. Most overburden deposits are also consolidated after having been overridden by one or more glacial advances. Although a formal geotechnical study has not been undertaken to assess this potential issue, dewatering induced subsidence is not expected to be a concern.

*Lowering of groundwater levels and changes in groundwater flow directions due to camp water supply*

Water withdrawal for the camp water supply was identified as a potential issue during one of the community consultations. Shore estimates that the camp water supply will require approximately 50 $m^3$/day of water. This is a small quantity of water, which will be returned to the environmental locally through a septic tile bed. No impacts are expected from the use of groundwater for the camp water supply.

***Confirmed or Valid Issues***

Two issues were confirmed or validated as described below.

*Lowering of groundwater levels and changes in groundwater flow directions due to pit dewatering*

Based on the Project description, dewatering is required during mining and there is a potential for permanent changes to groundwater levels to occur following flooding of the open pits. This may result in changes to the groundwater flow directions leading to reductions in groundwater discharge to surface water features and to interference in the operation of some private drinking water supplies reliant on groundwater in the RSA. Further examination is carried out to assess these effects.

*Changes in groundwater quality from processed kimberlite facilities and open pits*

Based on the Project description, there is potential for changes to the groundwater quality due to the infiltration of slightly brackish groundwater from processed kimberlite facilities constructed at the site and the upward movement of slightly brackish groundwater through the open pits after closure. Further examination is carried out to assess this effect.

#### 6.2.6.4 Effects Assessment

A conceptual groundwater model for the RSA was used by SRK to develop a numerical groundwater model as described in Section 5.2.7. Regional scale hydrogeology effects within the RSA were then investigated using this numerical groundwater model (SRK 2011a; Appendix 5.2.7-A). The investigation included an assessment dewatering required during mine construction and operations, and of the post closure conditions created by the removal of the aquitards by the mining of the open pits.

Local scale hydrogeology effects within the LSA were assessed through a desk top analysis. This included changes to the groundwater quality from the PKCF and the Coarse PK pile.

### *Assessment of Regional Scale Hydrogeology Impacts*

The numerical groundwater model presented in SRK 2011a was also used to investigate the hydrogeology impacts due to dewatering of the open pit and the creation of post closure pit lakes.

#### *2011 Groundwater Model*

The 2011 groundwater model (Appendix 5.2.7-A) represents part of the process to gain an improved understanding of the groundwater flow system in the RSA. This program has included numerical models developed previously in 2005 (HCI 2005a, and 2005b), 2006 (HCI 2006), 2007 (HCI 2007a, 2007b), 2009 (SRK 2009) and 2010 (SRK 2010) and which were updated as new information became available. Additional information on the evolution of the model is described in Section 5.2.7 (Groundwater Resources).

Each stage of the development of the groundwater model has included predictive scenarios to assist in the design of the pit dewatering system on the basis of the latest hydrogeological data. In 2011, the groundwater model was updated to include an updated mining plan, and adjustments to hydraulic conductivity (K) values and boundary conditions following the interpretation of the results of a 20-day pumping test conducted in late 2010. The results for the most recent model form the basis for this component of the EIS.

#### *2011 Mining Scenario*

In 2011, SRK were provided with new yearly mine plans on which to base the proposed pit dewatering plan. There are two proposed pits for the Project, one in the Star Kimberlite and the other in the Orion South Kimberlite. The 2011 mining scenario shows that excavation will commence in the Star pit, to be followed by the Orion South pit. Overburden, country rock and Fine PK material from the Orion South pit and processing can then be used to partially backfill the Star pit. The major changes in the mining plan from 2010 to 2011 were:

1. the timing of excavation work at the two pits, resulting in slightly shorter Mannville dewatering times for the mine due to a slightly later start to Mannville dewatering.
2. decreasing the number of dewatering wells from 44 in 2010 to 30 in 2011 and the addition of five in pit dewatering wells in the Star pit to reflect some optimization work completed in 2011.
3. the timing of the backfilling of the Star pit was adjusted to begin after year 17 with excavation material from the Orion South pit, leading the end of pumping in the in-pit dewatering wells in the Star pit in year 17.
4. the discharge of process water from the Orion South pit into the Star pit beginning year 18 (SRK 2011b).
5. increasing the depth of the Star pit by approximately 75 m.

6. decreasing the depth of the Orion South pit by approximately 45 m.

### *Simulation of Dewatering of the Proposed Pits*

Dewatering of the mine will be accomplished by using collection drains and sumps located within the open pit, by developing a ring of deep dewatering wells around each pit completed within the Mannville Group and some in-pit dewatering wells. Water from the dewatering wells will be used for process water as required with the excess being discharged to the Saskatchewan River through a diffuser. Prior to year 18, process water will be discharged to the PKCF and recycled within the plant. After year 18, process water is discharged to the Star pit at a rate of 67,000 m$^3$/day, with the excess Mannville water being discharged to the Saskatchewan River (SRK 2011b).

The SRK (2011a) model simulated dewatering wells as “pumping centres”. The pumping centres were simulated by applying a high vertical hydraulic conductivity to a column of cells representing the screened interval of the modelled dewatering wells. A total of 30 pumping centres were used to simulate dewatering wells at both of the open pits, including five in-pit dewatering wells in the Star pit (Figure 6.2.6-1).

During excavation of the respective pits, the dewatering wells are simulated as pumping at a constant pumping rate of 5,450 m$^3$/day (1,000 gpm), until the water levels reached a freeboard elevation of 30 m above the top of Souris River Formation for the perimeter wells or 20 m above the top of the Souris River Formation for the in-pit dewatering wells. The freeboard elevation was used to simulate well inefficiencies and to mimic natural hydraulic limits of dewatering.

The maximum simulated amount of water that was pumped from the ring of pumping centres around each pit was 98,000 m$^3$/day for the Star pit alone and a combined 120,000 m$^3$/day for both pits. The reason for the relatively small increase in the pumping rate from one to two pits is because the Star pit will be dewatered first prior to Orion South and hence drawdown will have already been achieved to the desired level within the Mannville aquifer before pumping starts at Orion South. These pumping rates represent a significant decrease from the 2010 model results.

In addition to active pumping from dewatering wells in the Mannville Group, residual passive inflow (RPI) will occur from the shallow groundwater system, particularly early in the mining process, and also from the deep groundwater system towards the end of mining. The RPI, mostly from the surficial aquifer is predicted to be up to 19,000 m$^3$/day for the Star pit and up to 15,200 m$^3$/day for the Orion South pit particularly during the early stages of pit excavation. During the final stages of pit excavation, the RPI for the deep aquifer is predicted to reach up to 3,000 m$^3$/day for the Star pit and up to 2,000 m$^3$/day for the Orion South pit. It should be noted however that while this flow was simulated as RPI into a drain cell, it is assumed that much of the actual flow will be intercepted by separate depressurization systems within the aquifers in order to maintain stable slope conditions and to reduce any uncontrolled inflow down to manageable quantities.

The simulated water budget for the base case scenario at the end of mining indicates that the proportion of groundwater from various sources extracted by the dewatering system is:

| | Star | Orion South |
|---|---|---|
| groundwater from storage (mainly the Mannville Group) | 62% | 58% |
| groundwater inflow from lateral modal boundaries within Mannville Group | 29% | 30% |
| shallow groundwater system (captured by toe drains and ditches) | 8% | 11% |
| capture of additional recharge to the shallow groundwater system | 1% | 1% |

The water budget results indicate that most of the water (>88%) extracted by the dewatering system originates from the deep groundwater system at the model boundaries or from storage.

To investigate the importance of the inflow from the lateral model boundaries, SRK (2011a) ran a model variant replacing the general head boundary conditions in the Mannville aquifers with no flow boundary conditions. Their sensitivity modelling results using this variant indicated that the dewatering rate remained about the same, and that there was a slightly larger decrease in shallow groundwater levels and shallow groundwater discharge to local creeks. SRK (2011a) concluded that based on this analysis, the model predictions are not significantly sensitive to model boundary conditions for the Mannville Group.

SRK (2011a; Appendix 5.2.7-A) also did sensitivity modelling incorporating vertical hydraulic conductivity variants for the Colorado shale units and lower till (confining layer) which were varied by a factor of ±3. SRK (2011a) concluded that groundwater levels in the surficial aquifers and groundwater discharges to the creeks were sensitive to vertical hydraulic conductivity values selected for the confining layer. However, while the model variants affected water levels and the discharge quantities, they did not suggest a change in the mitigation strategies required to address these concerns.

### *Simulation of Regional Groundwater Related Potential Effects*

Regional groundwater related impacts were defined as any substantial changes in groundwater levels, or discharges to affect distinct surface water features such as the

Saskatchewan River and/or nearby creeks and springs. Effects were determined on the basis of changes observed by comparing pre mining, active mining and post mining simulated conditions.

The two main groundwater systems are represented in the groundwater model as distinct numerical model layers. In addition there are a number of thin intermittent aquifers within or beneath the till layers included in the shallow groundwater system that are sometimes used for water supply. The extent of these thin, intermittent intertill aquifers is not known, however it is presumed that they form isolated discontinuous lenses as the presence and depth of these layers vary significantly between boreholes. As such, they are difficult to incorporate into the model as distinct layers. Instead, the bulk parameters for the till layers were adjusted to reflect the higher potential for horizontal flow because of these sand lenses. Therefore, the model predictions for drawdown within the till layers will be a relative approximation of actual drawdown when compared to predictions of the drawdown in the Mannville aquifer and surficial aquifers.

The groundwater model simulates the Saskatchewan River using specified head (or constant head equal to 360 masl) cell values applied to the first model layer along the route of the river. The specified head cells allow surface water to be hydraulically connected to the groundwater without any restrictions (or leakance factor). In practice, however, the degree of hydraulic connection is controlled by the hydraulic conductivity of the till units infilling along the river valley. Smaller creeks were modelled using a combination of drain cells and seepage face cells. Drain cells were used to simulate major named creeks such as English Creek, and Peonan (or Pehonan) Creek. Seepage cells were used to simulate smaller unnamed tributaries and springs.

Impacts to the creeks and rivers were assessed by comparing discharge quantities simulated under pre-mining, active mining and post mining conditions.

### *Simulation of Potential Effects Due to Open Pit Dewatering and Creation of Pit Lakes*

Groundwater impacts due to open pit dewatering and the creation of the pit lakes were simulated using the SRK (2011a) groundwater model which predicts a lowering of ground water levels in some aquifers resulting in: a) potential well interference to private well water supplies; and b) reductions in groundwater discharges to some surface water features.

The Base Case model predicts that the maximum reduction in groundwater level will occur in the deep groundwater system which will be dewatered by the dewatering wells. According to the model, groundwater levels in the Mannville aquifer will be lowered by more than 200 m in the vicinity of the pits but will be lowered by less than 100 m at 10 km distance from the pits (Figure 6.2.6-2). The lowering of the water level in the Mannville aquifer occurs in response to the lack of available recharge through the low permeability shale that overlies the aquifer, the loss of water from storage and the flow of water from the model boundaries.

The reduction in water levels in surficial aquifers however will be attenuated by the underlying shales and till (confining layer) which separates them from the Mannville aquifer. Also the availability of recharge from precipitation and the relatively large release of water from storage within the shallow groundwater system lessens the effect of drawdown in the surficial aquifers.

The impact to surface features such as wells and creeks, which may rely on the shallow groundwater system were determined to be sensitive to the vertical hydraulic conductivity of the Colorado group shale and lower till (the confining layer) used in the groundwater model. SRK (2011a) addressed this sensitivity by using several variants of the vertical hydraulic conductivity value of the confining layer in the model to predict possible outcomes.

Varying the vertical hydraulic conductivity of the shale increases or decreases the amount of water simulated to flow between the shallow groundwater aquifers and the deeper groundwater aquifers. When the vertical hydraulic conductivity of the shale is increased then the water level drop in the shallow aquifers is more, while the water level drop in the Mannville aquifer is less. Conversely when the vertical hydraulic conductivity of the shale is decreased, then the water level drop in the surficial aquifers above the Colorado shale is less and the water level decline in the Mannville aquifer is greater. With less infiltration from surficial sources, more water is required from storage outside the boundaries of the model. However, based on the sensitivity modelling as detailed in SRK (2011a), it was concluded that groundwater discharges to the creeks and wells, while sensitive to the vertical hydraulic conductivity of the confining layer, did not change in the various scenarios enough to warrant different mitigation strategies or contingencies to address the variation.

The predicted reduction in water levels for the base case analysis for the lower till, upper till and surficial aquifers is shown in Figures 6.2.6-3, 6.2.6-4, and 6.2.6-5, respectively. The impact of a drop in water levels in shallow aquifers is increased near to the proposed pits where there is also the influence of horizontal drainage into the open pits through seepage faces.

### *Potential Effects on Local Water Wells*

Section 5.2.7.4 of the baseline report describes the occurrence of water wells in the RSA. Private wells are located in all the Rural Municipalities around the FalC Provincial Forest, and on the First Nation communities to the south of the Saskatchewan River (Figure 6.2.6-6). The closest wells to the Project Site identified either in the SWA database of water wells or in the door to door survey, were located approximately 8 km south of the Project Site on the James Smith First Nation and 12 km west of the site in the Rural Municipality of Kinistro on the south side of the Saskatchewan River (wells shown within the FalC likely have errors in their location information from the SWA database, or are not domestic water sources).

Table 6.2.6-2 summarises the as-constructed details of water wells within 30 km of the proposed pits listed in SWA records. Approximately two thirds of wells are completed at depths of less than 25 m, which likely means they are completed in the surficial sand aquifer that is widespread across the RSA. The remaining wells are completed at depths consistent with till deposits and are assumed to be completed within sand lenses within the till or within layers between till sheets.

***Table 6.2.6-2: Summary of Local Wells Within 30 km of the Proposed Pits***

| Well Depth Interval | Number of wells in this interval | Expected completion unit-model equivalent |
|---|---|---|
| Wells less than 25 m deep | 324 (69%) | Surficial sand |
| Wells between 26 and 50 m deep | 85 (18%) | Sand layer within till.<br>Upper layer of upper till |
| Wells between 51 and 100 m deep | 58 (12%) | Sand layer within till.<br>- Lower layer of upper till |
| Wells greater than 100 m deep | 1 (<1%) | Sand layer within till.<br>- Lower till |
| Total | 468 | |

**Note:** Based on SWA records of completed wells.

The surficial sands are represented as the topmost layer in the groundwater model. The predicted drawdown in this layer in any of the scenarios is less than 1 m at locations outside the FalC forest. The SWA records and field checking indicate that there are no private wells completed in the surficial aquifer within the FalC (Figure 6.2.6-7), with the exception of industrial wells operated by ShoreGold. This is consistent with the immediate area around the open pits being a provincial forest with no private dwellings that would require water wells. In the base case scenario, no impact to any shallow wells is expected. However, in the conservative scenario, there are a few shallow wells that fall in areas were drawdown in the surficial aquifer is predicted to be between two and three metres, which may be enough to impact some shallow wells. The existing water supply wells used by the James Smith First Nation are completed in this aquifer, but outside the area of significant drawdown (<2 m in the conservative scenario) and as such are not expected to be effected by dewatering. Monitoring to confirm the effects of dewatering is recommended for shallow wells completed in areas where the drawdown is predicted to be greater than two metres in the conservative variant. Additional details on the proposed monitoring program are provided later in this section.

The absence of impacts to shallow wells in the RSA is also consistent with the lack of observable drawdown over several years from large scale dewatering at the Nipawin Dam in the 1980’s approximately 50 km east of the Project site (see Section 5.2.7.5). However, during the 2010 door to door survey of wells near the FalC, a number of owners of shallow wells commented that in dry years their wells could not be relied upon to supply water (see Section 5.2.7.4). This will continue to be the case in future dry years. Monitoring will be required to distinguish between climate related changes and mine impacts.

In addition to the surficial aquifer, about one third of local wells are completed at depths of greater than 25 m (Table 6.2.6-2), which would be consistent with sand lenses within the till units.

The groundwater model uses bulk parameters to simulate till layers containing sand lenses and does not explicitly model the individual sand lenses, which are relatively thin and discontinuous. The model however was used to predict drawdowns in the sand lenses of the upper till to provide an approximation of the potential drop in water levels in those wells completed in the upper till between depths of 25 to 50 m. The predicted impact to the shallower wells completed in the upper till is shown in Figure 6.2.6-8 which shows drawdowns in the model domain of generally between five and twenty metres in areas beyond the FalC forest boundary, mostly in areas to the north and east of the Project site. This does not change substantially when higher or lower vertical hydraulic conductivity values are modeled for the Colorado Shale. Given the shallow depth of the wells in the upper till, based on the SRK (2011a) model results, it is expected that declines in groundwater levels resulting from dewatering of the proposed pits will potentially affect the operation of some private wells completed in the upper till sequence.

There are approximately 85 wells completed in the upper till that maybe affected by dewatering. Monitoring of water levels in these wells, as discussed below, is recommended to allow sufficient time to prepare mitigation, should the operation of any of them become affected by dewatering.

Computed drawdowns from the groundwater model for the lower till were used to estimate impacts upon wells completed in the sand layers at depths of greater than 50 m (Figure 6.2.6-9). Using the base case, the predicted drawdown in those wells tapping the lower till due to dewatering of the proposed pits may be in the order of 20 m for those south of the river, and less than 15 m for those north of the FalC forest. These conclusions do not change substantially for the other model variants.

There are 59 identified locations with wells within 30 km of the mine site that are completed at depths of greater than 50 m and may potentially experience drops in water level of the magnitude shown in Figure 6.2.6-9. In most cases, the depth of the well means that there is an adequate water column above the well screen that these wells will not go dry. Therefore they may only be slightly affected by dewatering depending upon the exact depth and location of the well, the pump setting in the well, the performance of the aquifer and the water usage. Monitoring of water levels in these wells is recommended to allow sufficient time to prepare mitigation, should the operation of any of them become affected by dewatering.

*Monitoring and Mitigation of Potential Effects on Local Water Wells*

To address uncertainties in the analysis and to assess the need for possible mitigation measures for potential effects on area wells, a program of water level monitoring in some private wells will be commissioned. The program can utilize existing private wells for monitoring, or can drill dedicated, strategically located, new monitoring wells. Where water level declines are shown to affect private wells, then mitigation can be offered by providing additional above ground storage for water, by lowering the pump setting or by the replacement of existing pumps with more efficient high-lift pumps. In some cases, it may be necessary to provide alternative water supplies in the event that the wells are severely impacted. This is a standard requirement of water licenses issued in Saskatchewan. Mitigation will start during the license process with extensive program to educate local well owners of the proposed works and monitoring. It will also provide them with contact information and a process should problems arise with their wells.

The objectives of the groundwater monitoring program would be to:

- monitor the effects of dewatering on local aquifers,
- confirm model predictions,
- anticipate impacts to local wells before they occur, and
- help resolve well interference complaints by providing sufficient information to distinguish between groundwater level fluctuations due normal seasonal or climate variation or well maintenance issues, and dewatering.

For the groundwater monitoring program, there are approximately 30 onsite monitoring wells which can be used to monitor the response to dewatering in aquifers and aquitards close to the proposed pits. This information can be supplemented with water level data collected from private wells in the region, and it is recommended that local well owners be approached and asked to participate in a well monitoring program. Based on the previously conducted door to door survey, many homeowners in the area were amenable to having their wells monitored, indicating this is a reasonable approach. At least 10 percent of local wells (approximately 50 wells) would need to be included in the monitoring program to build a representative network. The network should include wells completed in different areas to provide sufficient coverage. The program would include wells in the deeper aquifers which are likely to see the effects of dewatering first. If suitable private wells cannot be located in some areas, then the construction dedicated monitoring wells may be required. A number of monitoring wells outside the drawdown cone of the mine in analogous environmental zones will also included to identify seasonal and climate variations.

It is proposed to use pressure transducers to record groundwater levels in an hourly to daily basis, and download the transducers on a quarterly basis, at least until the trends of water level changes experienced in the wells can be established, at which point the frequency of downloads might be changed. It is recommended that monitoring in most wells begin at least one full year prior to the start of dewatering to monitor seasonal changes in groundwater levels without the effect of dewatering. The groundwater level data will be assessed in combination with information from nearby climate monitoring stations and the surface water monitoring program. The monitoring program would be reviewed on an annual basis, and adapted as necessary to achieve the program objectives.

*Potential effects to Surface Water Features*

The SRK (2011a) model includes estimated reductions on groundwater discharges to creeks near the Project site and to the Saskatchewan River. The reduction in groundwater discharge to the Saskatchewan River is negligible compared to the total flow of the river. However, effects on the smaller creeks near the Project are significant, with upwards of 60% reduction in the base flow of some named creeks for the base case scenarios. Some smaller creeks experience base flow losses of more than 70%. The effect of the reduction on base flow in these creeks on fish habitat and the proposed mitigation strategies are further discussed in Section 6.3.1 (Fisheries and Aquatic Resources). During high flow periods, the small reduction in baseflow is unlikely to significantly affect the total stream flow.

Many of the nearby wetlands are within the footprint of the mine infrastructure and the effects on surface water features such as wetlands were not modelled. Given the presence of clay sediments within the surficial sediments, it is likely that the wetlands formed in poorly drained areas that collect water during periods of high flow and snow melt. As such, they will be somewhat protected from the relatively small drawdowns predicted by the SRK (2011a) model for the surficial aquifer.

*Potential effects to Springs along the Saskatchewan River Valley*

The SRK (2011a) model did not assess impacts to springs along the valleys of the Saskatchewan River, but they can be estimated by a comparison to the predicted declines in baseflow for nearby creeks which is included in the model. Based on this comparison, springs along the Saskatchewan River valley within several kilometres of the mine can expect to see a decline in year round discharge.

### *Assessment of Local Hydrogeology Impacts due to Creation of Processed Kimberlite Facilities*

The mining and processing of ore materials will create large quantities of processed kimberlite that, after processing, will be divided into either fine processed kimberlite (Fine PK) or coarse processed kimberlite (Coarse PK) and placed in the PKCF and Coarse PK pile respectively (Figure 6.2.6-1).

Slightly brackish water from the dewatering wells will be used in the process plant and to transport the Fine PK from the plant to the PKCF. Because this water will be elevated above the local water table, infiltration of slightly brackish water from these facilities into the shallow aquifers is possible.

Runoff from the PKCF will be captured by interception ditches in the surficial sand and directed to natural wetlands for treatment or pumped back into the PKCF. No PKCF water is expected to be discharged, however limited infiltration of water from the base of the PKCF into the shallow aquifer is expected during the early stages of operation. Infiltration will decrease greatly once a layer of fine PK is established in the bottom of the PKDF. Water that infiltrates into the shallow aquifer will flow primarily towards the Duke Ravine due to the groundwater gradient created by pit dewatering. The interception ditches will be supplemented by installation of drainage or shallow interception wells to prevent seepage water from diretly entering the Duke Ravine. The assessment of the surface water discharges to the creeks is discussed in Section 6.2.7 (Surface Water Quality).

### *2011 Groundwater Model Predictions for Post Mine Closure Conditions*

The groundwater model includes predictions for post mine closure conditions (SRK 2011b). These predictions address pit flooding and residual groundwater level declines.

Following mining, the open pits will fill with passive inflow from groundwater and from precipitation. Most of the water that fills the open pits will originate from the Mannville aquifer.

After 100 years, the Orion South pit lake is predicted to be 85% filled. The final elevation for the Orion South pit is predicted to be 411 masl. At this elevation, the Orion South pit lake will not overflow. The Star pit will fill to an elevation of 392 masl (more than 30 m below the original groundwater elevation) after 470 years, at which point it will begin to flow into the Saskatchewan River through the East Ravine valley. In the long term, after mining ceases, 80% of the inflow into the Star Pit will come from surface water (SRK 2011b). Closure water quality is discussed in Section 6.2.7.

It is expected that there will be a limited reduction in the water level in the surficial aquifers in the immediate vicinity of the open pit lakes as a result of passive inflow from the shallow surficial aquifers towards the pit lakes, as shown in Figure 6.2.6-10. There are no private wells within this area that would be affected by this small decline.

There will also be some drainage from the intertill sand aquifers towards the Orion South pit lake; however, at the Star Pit, it is likely that water from the lake will flow out of the pit lake towards the lower elevation of the Saskatchewan River valley through one or more deeper intertill aquifers (this is in addition to surface water overflow out of the pit lake through the East Ravine). This water will then reappear at one or more of the existing springs on the pit side of the river, much the same as it does now. Predicted closure water quality of the Star Pit lake is described in Section 6.2.7.

The amount of water expected to be discharged as springs from this Star Pit Lake is expected to be minor due to the limited potential of the thin discontinuous aquifers to mobilize water and the potentially low hydraulic gradient existing between the pit lakes and the spring locations along the Saskatchewan River valley. The placement of backfill material in the Star pit is also likely to reduce groundwater flow away for the pit area. There are no private wells in the immediate area of the proposed pit lakes, and therefore no private wells are expected to be affected by the infilling of the pit lakes.

#### 6.2.6.5 Mitigation Measures

Mitigation measures will be implemented to reduce effects from the proposed mine dewatering. The mitigation of those effects on area creeks related to mine dewatering is discussed in Section 6.2.4 and the mitigation strategy to address the discharge of the Mannville sourced groundwater by the dewatering system is addressed in Section 6.2.7 (Surface Water Quality). The mitigation measures discussed in this section will address well interference.

To address uncertainties in the analysis and assess the need for possible mitigation measures for potential impacts to area wells, a program of water level monitoring in private wells and monitoring wells will be implemented (Table 6.2.6-3). The program will consist of monitoring water levels in existing private wells and drilling dedicated, strategically located, new monitoring wells. Where water level declines are shown to affect private wells, then mitigation can be offered by providing additional above ground storage for water, by lowering the pump setting or by the replacement of existing pumps with more efficient high-lift pumps. In some cases, it may be necessary to provide alternative water supplies in the event that wells are severely impacted and depending upon well use and landowner needs.

***Table 6.2.6-3: Summary of Mitigation Strategies for Regional Geology and Hydrogeology***

| Potential Effect | Valued Component | Project Phase | Mitigation Strategy |
|---|---|---|---|
| Lowering of groundwater levels due to pit dewatering | Well interference | Construction<br>Operations | Monitoring to identify wells that will be affected.<br>Well improvements or providing of alternate water supplies to affected well owners. |

#### 6.2.6.6 Residual Effects

The residual effects expected from Project development were assessed using a classification system based on the rating criteria of direction, magnitude, duration, geographic extent, frequency, reversibility, probability and confidence in the assessment.

These rating criteria were then considered to ascertain the overall significance of an impact on the landscape. The definitions of impact criteria and the approach to determining significance are presented in Section 6.1 (Overview and Methods). The predicted residual effects of the Project on the geology and hydrogeology are summarized in Table 6.2.6-4.

During construction and operation of the mine, the residual effects on the regional geology and hydrogeology are expected to be related to the operation of the dewatering system, and the depressurization of aquifers in the RSA. Smaller local effects are expected to be associated with the infiltration of brackish groundwater into the shallow groundwater system near the PKCF. Most of these effects are expected to reverse themselves at the end of mining over a period of decades, when the dewatering system is turned off and groundwater levels return to near pre-mining levels. Before groundwater levels return to pre-mining levels, some wells and creeks in the local areas will be affected. The effects on area creeks are discussed in Section 6.2.4 (Hydrology) and the effect of the discharge of groundwater from the dewatering system on the Saskatchewan River is discussed in Section 6.2.7 (Surface Water Quality).

Aquitard removal during mining is expected to create a hydraulic conduit for vertical groundwater movement at each of the Star and Orion South pits following the creation of the pit lakes. At both pits, the pit lake elevation will be below the surficial water table, and groundwater drainage from the surficial aquifers towards the pit lakes is expected to occur as a permanent condition immediately surrounding the pits.

Closure water quality is described in Section 6.2.7. At the Orion South pit lake, the direction of groundwater flow upon final closure is expected to be downwards from the surficial aquifers towards the Mannville aquifer, and the brackish water in the lake will therefore be contained within the lake.

At the Star pit, small volumes of water from the lake may move towards the Saskatchewan River valley through thin aquifers within the till and discharge from springs along the walls of the Saskatchewan River valley. Overflow will discharged via surface drainage through the East Ravine. This water moving through existing aquifers is likely to have a similar quality to the Star Pit Lake, which is further discussed in Section 6.2.7. The volume of water moving from the Star Pit Lake as groundwater is expected to be very small due to limited potential for the thin, discontinuous aquifers to move water, the low hydraulic gradient from the lake to the spring locations in the Saskatchewan River valley and likely covering of aquifers by back filled materials in the Star Pit.

470 years after mining, there will also be surface water flow out of the Star pit to the Saskatchewan River. Most of this water is expected to originate as inflow into the pit from the East Ravine in the long term.

*Table 6.2.6-4: Summary of residual effects*

| Nature of Impact/Indicator | Direction | Magnitude | Duration | Geographic Extent | Frequency | Reversibility | Ecological Context | Probability | Confidence | Significance Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| Dewatering[1and2] | | | | | | | | | | |
| • Well interference | Adverse | Low | Long term | Regional | Intermittent | Reversible | Low | High | High | Not Significant |
| • Year round spring discharge | Adverse | Low | Long term | Regional | Intermittent | Reversible | Low | Medium | Medium | Not Significant |
| Infiltration of brackish ground water from PKC | Adverse | Low | Long term | Local | Declining | Reversible | Low | High | High | Not significant |
| Aquitard removal | | | | | | | | | | |
| • Residual drawdown | Adverse | Low | Long term | Local | Continuous | Irreversible | Low | High | High | Not significant |
| • Creation of brackish springs | Adverse | Low | Long term | Local | Continuous | Irreversible | Low | Moderate to High | Moderate | Not significant |

**Notes:** [1] effects on area creeks is discussed in Section 6.2.4 (Hydrology).

[2] effects of dewatering system discharge on the Saskatchewan River is discussed in Section 6.2.7 (Surface Water Quality)

#### 6.2.6.7 Follow-up and Monitoring

A monitoring program of groundwater levels in dedicated monitoring wells and in private water supply wells will be developed to confirm the modelled predictions of dewatering effects. This will include wells located close to and distant from the mines and will include the Mannville aquifer and the deep sand seam aquifers in the lower till. A number of monitoring wells outside the drawdown cone of the mine in analogous environmental zones are also included to identify seasonal and climate variations. Other monitoring will include:

- continuous measurements of the discharge from the dewatering systems;
- periodic sampling of the discharge water;
- stream flow measurements in area creeks and in a reference watershed; and
- collection of climate data.

The monitoring and follow-up programs will be used to confirm that the predictions based on the groundwater model match the observed drawdowns and to incorporate new private wells drilled in the region into the monitoring program. As part of the follow up program, the ground water model will be periodically updated and calibrated to the new data. The monitoring and follow-up programs will continue until a clear recovery trend is established after mine closure.

#### 6.2.6.8 Effects of the Environment on the Project

Changes in the environment are not expected to affect the regional geology and hydrogeology of the Project directly. However, climate change or long term climate variations that leads to drier conditions may make it difficult to distinguish between the effect of mine dewatering on local creeks and wells and dry conditions. Long term monitoring of groundwater, surface water and climate data from the mine site and in area(s) outside the RSA as described will to help distinguish between mine induced dewatering effects and climate related variations.

#### 6.2.6.9 Conclusions

Impacts from the dewatering of the two proposed open pits will result in a measureable decline in the water level in the deep groundwater system. This aquifer is not used as a water supply and does not play a significant role in providing water to local creeks or to the Saskatchewan River, hence no direct significant environmental effects are expected from the dewatering of this aquifer.

Over time, however, the drawdown of the piezometric surface in the deep aquifer will migrate upwards into the shallower aquifers that are used for well water supplies and provide seepage to local creeks. The upward spread of the drawdown will be largely attenuated by the Colorado shale and lower till (confining layer), and will be offset by recharge from precipitation that generally discharges to local creeks. This will result in a reduction in base flow in local streams and creeks, but local wells which are completed in the shallow aquifers are not expected to be affected by the dewatering of the pits. However, the operation of some deeper wells which tap the sand lenses in the tills may be affected. SWA records indicate that there are approximately 150 existing wells within 30 km of the Project Site that are completed at depths that may be affected by the dewatering.

The mitigation strategy to address the decrease in base flows in the creeks is addressed in Section 6.2.4 (Hydrology). The effect on wells will be addressed by a program of groundwater level monitoring, and by the provision of alternate water supplies. For example those affected wells can be mitigated by the installation of new wells, or by improving old wells or by simply changing pump settings. New storage cisterns can be provided, or in some cases hook up to municipal water supplies can be provided depending upon the specific situation of each well.

The water pumped from the dewatering system will be mostly brackish. It is intended to use this water onsite in the process plant, and then eventually discharge it into the Saskatchewan River, with some being discharged to the Star pit in the final years of mining. The mitigation strategy to address the discharge of the water is addressed in Section 6.2.7 of this document (Surface Water Quality).

The Star pit will be partially backfilled with overburden and Fine PK material from the Orion South pit during mining. Following closure of the mine, the open pits will then naturally fill with water. from the Mannville aquifer and from surface runoff. At the Orion South pit lake, the final pit lake elevations will be below the surrounding ground, and overflow from the Orion South pit lake is not expected. The Star pit is located close to the East Ravine, which provides a relatively low elevation outlet for the pit lake, and the Star pit lake will overflow through the East Ravine into the Saskatchewan River.

After the pit lakes are full, there will be limited groundwater drainage into the pit lakes from the shallow aquifers and a small residual drawdown cone will be developed in the surface groundwater system locally around each pit. There may also be a limited amount of groundwater discharge from the Star pit through existing springs along the north side of the Saskatchewan River valley. There are no private wells between the Star pit lake and the Saskatchewan River that would be affected by this groundwater movement.

### 6.2.7 Surface Water Quality

#### 6.2.7.1 Introduction

This Section describes the water quality effects assessment for the proposed Star-Orion South Diamond Project. The assessment is based on five principal studies:

- baseline water and sediment quality studies conducted over a number of years and assessed as part of the current EIA (Section 5.2.4);
- groundwater modelling conducted by SRK which developed predictions of groundwater quality and quantity for the project throughout all phases of mining including construction, operations, closure and post closure;
- diffuser water quality modelling by AMEC which used AQUASEA, a two-dimensional flow and transport model (Appendix 6.2.6-A) to predict effects to the Saskatchewan River;
- surface water quality modelling conducted by AMEC which incorporated process water quality and quantity inputs, the above-referenced groundwater modelling results and geochemical predictions for the ore and mining waste and provided predictions of water quality for the project throughout all phases of mining including construction and operations, closure and post closure; and
- Star and Orion South pit lakes water quality sampling conducted by AMEC and incorporated mine closure plans, groundwater and surface water inputs during pit infilling and spill over water quality upon lakes infilling;

Outputs from the surface water model were used to provide predictions of effluent discharge effects on the Saskatchewan River and potential changes in water quality in affected streams in the study area.

#### 6.2.7.2 Scoping, Issues Identification and Confirmation

The purpose of scoping is to focus the assessment on key issues related to water quality as determined by interactions between the physical project and the natural environmental setting. The scoping process was carried out in the following steps:

- key issues which are associated with each project component were identified by professional judgement, evaluation of issues resulting from the project initial environmental evaluation (formerly project proposal) and results of public engagement activities (Section 4.0), including the public, Aboriginal groups, and government agencies;
- identification of issues specific to the water quality discipline that interact with each project component; and
- determination of the rationale for issues selection.

The issues identification and confirmation process identified two key water quality issues. The relevance of these issues was validated by considering each issue in the context of the baseline conditions, review of the Project Description (Section 2.0), and a consideration of identified stakeholder concerns.

These issues (Table 6.2.7-1) were further validated through historic and current public and regulatory engagement conducted from 2008 through 2012.

*Table 6.2.7-1: Issues Evaluation Table for Water Quality*

| Issue | Interaction with the Project (yes/no) | Identified by Shore (Professional judgement) | Identified by Aboriginal Groups | Identified by Government Agencies | Identified by Public or Other Stakeholders | Included or Not in the EIA | Rationale |
|---|---|---|---|---|---|---|---|
| Surface water quality | Yes | Yes | Yes | Yes | Yes | Yes | Quality changes possible |
| Sediment quality | Yes | Yes | Yes | Yes | Yes | Yes | Quality changes possible |

The water quality issues were identified through engagement with the following groups:

- federal government agencies including: Environment Canada (EC), Fisheries and Oceans Canada (DFO), Canadian Environmental Assessment Agency (CEAA), and Natural Resources Canada (NRCAN);
- provincial government agencies including: Saskatchewan Ministry of Environment (SMOE) and the Saskatchewan Watershed Authority (SWA);
- two cities (Prince Albert and Melfort);
- six towns (Nipawin, Choiceland, Tisdale, Kinistino, Star City, Birch Hills);
- 13 villages (Smeaton, Weirdale, Love, White Fox, Codette, Meath Park, Ridgedale, Albertville, Beatty, Aylsham, Weldon, Valparaiso, Zenon Park);
- James Smith Cree Nation, Muskoday First Nation, Sturgeon Lake First Nation and Red Earth Cree Nation;
- members of the Métis Nation - Saskatchewan Eastern Region II and Métis Nation - Saskatchewan Western Region II; and
- 12 rural municipalities (Tisdale (427), Star City (428), Flett's Springs (429), Connaught (457), Willow Creek (458), Kinistino (459), Birch Hills (460), Prince Albert (461), Nipawin (487), Torch River (488), Garden River (490) and Buckland (491)).

No water licenses were identified in the English Creek to Caution Creek watersheds; all streams are minor (1st or 2nd order) tributaries of the Saskatchewan River which drain the Project site. The following summarizes how water quality resources could be affected by the Project in each of the four phases.

### *Construction Phase*

Without effective controls, sediment could be exported from construction activities potentially affecting receiving water bodies by increasing suspended sediments and turbidity and by adding to bed load sediment which may in turn affect aquatic habitats. In early construction, shallow groundwater may be intercepted by removal of overburden from the Star pit, potentially reducing surface water flows in the tributaries draining the Project site.

### *Operations Phase*

During operations there will be a discharge through a diffuser to the Saskatchewan River. Discharge water will be a combination of precipitation falling into the pit, wall runoff and deep groundwater from dewatering wells. Contact water sources will include water collected in pits including both shallow and deep groundwater, atmospheric precipitation and runoff from pit walls. Both shallow and deep groundwater will be intercepted by dewatering wells and flows in tributaries draining the Project site may be reduced (Section 6.2.4- Hydrology Effects). Flows in the Saskatchewan River will be slightly increased from diffuser discharge and there will be minor changes to Saskatchewan River water quality immediately downstream of the diffuser.

#### *Closure and Decommissioning Phase*

At closure the Star and Orion pits will be allowed to naturally fill with groundwater, surface runoff from adjacent watersheds and precipitation and runoff within the pits themselves. At closure the PKCF berm will be breached at the time when unused storage will be dry or almost dry as no fine PK will be deposited once mining in Star pit has ceased. The reclaimed PKCF will drain to the Duke Ravine and become a part of its watershed. During Orion South mining, processed kimberlite will be directed to Star pit instead of the PKCF. Flows in all streams will follow pre-mining drainage patterns. Runoff from the east Ravine catchment will be diverted into Star Pit.

#### *Post Closure Phase*

During the closure phase, the open pits will fill with water. Post closure, the Orion South pit will not discharge, and water levels will stabilize below the top of the pit. The Star pit water will overflow into the lower reaches of the East Ravine as a result of surface water input, and subsequently discharge into the Saskatchewan River.

### 6.2.7.3 Valued Components

Surface water quality was selected as a valued component (VC) to address the environmental effects of the Project because of its intrinsic importance to health and well being to humans, wildlife and aquatic organisms.

#### *Surface Water Quality*

Maintenance of acceptable water quality is a high priority for communities, government, and Shore. The Project could potentially affect surface water quality; therefore, predictions of potential effects on water quality are required.

*Sediment Quality*

Bottom sediments form one of the links between the abiotic and biotic aquatic systems. Maintenance of sediment quality is therefore an important requirement for maintenance of aquatic ecosystems. Project construction, operation, and closure could result in effects on bottom sediments and thus assessment is required.

### 6.2.7.4 Applicable Regulations, Standards and Guidelines

Regulations pertaining to water and sediment quality that apply to the project are listed in Table 6.2.7-2.

*Table 6.2.7-2: Regulations and Guidelines Governing Water and Sediment Quality for Mining at Star-Orion South*

| Regulation/Guideline | Regulatory Authority |
|---|---|
| Saskatchewan Environmental Management and Protection Act | Saskatchewan Ministry of Environment |
| Water Regulations – 2002 | Saskatchewan Ministry of Environment |
| Saskatchewan Water Quality Guidelines | Saskatchewan Ministry of Environment |
| Concentration of Pollutants in Liquid Effluent | Mineral Industry Environmental Protection Regulations |
| Fisheries Act | Environment Canada |
| Canadian Environmental Quality Guidelines | Environment Canada |

### 6.2.7.5 Surface Water Quality

*Water Quality Assessment Methods*

A quantitative mathematical mass balance modelling approach was used to predict resultant water quality for the Project. The potential effects of mine construction, operation and closure on water quality were assessed using the model.

The model assumes all parameters behave conservatively, that is, do not change concentration in the liquid phase over time. This is a conservative assumption because it discounts several processes that will take metals out of the liquid phase, including sedimentation, precipitation, absorption, and adsorption. Ammonia and nitrite are not converted to nitrate in the model. All three species are considered conservative and calculated independently.

Seepage from the PKCF and the Coarse PK pile is directed to natural wetlands for passive treatment before release to the East Ravine and Duke Ravine watersheds. The treatment efficiencies were determined from a literature review and applied in the model (see Appendix 6.2.7-A).

The water quality model is discussed in detail in Appendix 6.2.7-A.

#### *Waste and Water Management*

Mine facilities, operation, and waste management are discussed in Section 2 (Project Description). The mass balance water quality model is based on the assumption that all management controls are in place and functioning as designed.

#### *Water Effects Assessment*

*Sources*

Loading sources from the Project site include:

- Star Pit – sump (combination of deep and shallow groundwater and wall leach runoff);
- Orion South Pit – sump (combination of deep and shallow groundwater and wall leach runoff);
- deep well pumps (Mannville Formation Water);
- shallow groundwater;
- vehicle wash facility (through oil-water separator; minor source);
- site facilities runoff (minor source);
- sewage lagoon (minor source);
- PKCF seepage and berm exterior slopes runoff;
- coarse PK pile seepage and runoff ;
- overburden storage runoff; and
- watershed drainage and runoff (all watershed runoff above site facilities will be diverted either around the facility to the same watershed downstream, with the exception of excess water in the East Ravine drainage collected in the runoff pond, which would be pumped to the Duke Ravine, 101 Ravine or English Creek as part of low flow supplementation, or through the plant).

The collective effects of all sources were modelled using a standard mass balance box mixed model whereby source loadings were input from source characterization and a resultant concentration in all streams in the study area predicted. Figure 6.2.7-1 represents all watersheds and streams assessed in the model and sources locations.

The modelling results were compared to applicable guidelines and summarized in Table 6.2.7-3. It includes both effluent discharge guidelines and receiving waterbodies guidelines.

*Table 6.2.7-3: Summary of Water Quality Criteria*

| Parameter | Units | Guidelines | | | |
|---|---|---|---|---|---|
| | | Liquid Effluent | Aquatic Life | | Drinking Water |
| Conventional Parameters | | Mineral Industry (1996) | CCME (2011) | SK MOE (2006) | Health Canada (2008) |
| Total dissolved solids | mg/L | | - | - | ≤500 (d1) |
| Chloride | mg/L | | 120 | - | ≤250 (d1) |
| Sodium | mg/L | | - | - | ≤200 (d1) |
| Sulfate | mg/L | | - | - | ≤500 (d1) |
| Ammonia as nitrogen | mg/L | | 7.0 - 48.3 (a1) | - | - |
| Un-ionized Ammonia | mg/L | 0.5 (c1) | | | |
| Nitrate | mg/L | | 2.9 (a2) | - | 45 (d3) |
| Aluminum | mg/L | | 0.005 or 0.1 (a4) | - | 0.1 (d4) |
| Antimony | mg/L | | - | - | 0.006 (d2) |
| Arsenic | mg/L | 0.5 (c1) | 0.005 | - | 0.01 (d2) |
| Barium | mg/L | | - | - | 1 (d2) |
| Boron | mg/L | | 1.5 | - | 5 (d2) |
| Cadmium | mg/L | | 0.00006 (a5) | 0.000017 to 0.0001 (b1) | 0.005 (d2) |
| Chromium | mg/L | | 0.001 (a6) | - | 0.05 (d2) |
| Cobalt | mg/L | | - | - | - |
| Copper | mg/L | 0.3 (c1) | 0.004 (a7) | - | ≤1 (d1) |
| Iron | mg/L | | 0.3 | - | ≤0.3 (d1) |
| Lead | mg/L | 0.2 (c1) | 0.007 (a8) | - | 0.01 |
| Manganese | mg/L | | - | - | ≤0.05 (d1) |
| Mercury | mg/L | | 0.00003 | 0.00003 | 0.001 |
| Molybdenum | mg/L | | 0.073 | - | - |
| Nickel | mg/L | 0.5 (c1) | 0.15 (a9) | - | - |
| Selenium | mg/L | | 0.001 | - | 0.010 (d2) |
| Silver | mg/L | | 0.0001 | - | - |
| Thallium | mg/L | | 0.0008 | - | - |
| Uranium | mg/L | 2.5 (c1) | 0.015 | 0.015 (b2) | 0.02 |
| Zinc | mg/L | 0.5 (c1) | 0.03 | - | ≤5 (d1) |

**Note:** **Canadian Environmental Quality Guidelines - CEQG (CCME 2011).**

**a1** = Guideline is dependent on temperature and pH. The value ranges between 6.98 mg/L (pH= 7.0, temperature= 15oC) and 48.3 mg/L (pH= 6.5, temperature= 5oC).

**a2** = Guideline is converted to Nitrate-N.

**a3** = Guideline is converted to Nitrite-N.

**a4** = Guideline = 5 µg/L at pH < 6.5, [Ca2+] < 4 mg/L and DOC < 2 mg/L; Guideline = 100 µg/L at pH ≥ 6.5, [Ca2+] ≥4 mg/L and DOC ≥ 2 mg/L.

**a5** = Cadmium guideline = 10[0.86 [log(hardness)] - 3.2]. Conservatively, the lowest median hardness for this site was used to calculate the guidelines.

**a6** = Guideline is for hexavalent chromium (CrVI) because its guideline is more stringent than the

trivalent chromium (CrIII) guideline of 8.9 µg/L.
**a7** = Copper guideline is dependent on [CaCO3] with a minimum of 2 µg/L. Guideline = e0.8545[ln(hardness)]-1.465*0.2. Conservatively, the lowest median hardness for this site was used to calculate the guidelines.
**a8** = Lead guideline is dependent on [CaCO3]. Guideline = e1.273[ln(hardness)]-4.705. Conservatively, the lowest median hardness for this site was used to calculate the guideline.
**a9** = Nickel guideline is dependent on [CaCO3]. Nickel guideline is dependent on [CaCO3]. Guideline = e0.76[ln(hardness)]+1.06. Conservatively, the lowest median hardness for this site was used to calculate the guideline.
**Saskatchewan Surface Water Quality Objectives (MOE 2006).**
**b1** = Cadmium Objective: 0.017 ug/L where hardness is 0 - 48.5 mg/L; 0.032 ug/L where hardness is 48.5 - 97;
0.058 where hardness is 97 - 194; 0.10 ug/L where hardness is >194.
**b2** = The objective was developed by the Industrial, Uranium and Hardrock Mining Unit of Saskatchewan Environment.
**The Mineral Industry Environmental protection Regulations, 1996**
**c1** = Maximum monthly arithmetic mean concentration.
**Guideline for Canadian Drinking Water Quality - GCDWQ (Health Canada 2008).**
**d1** = Aesthetic objective.
**d2** = Maximum allowable concentration (MAC).
**d3** = Equivalent to 10 mg/L as nitrate-nitrogen. Where nitrate and nitrite are determined separately, levels of nitrite should not exceed 3.2 mg/L.
**d4** = A health-based guideline for aluminum in drinking water has not been established. Operational guidance values of less than 100 µg/L total aluminum for conventional treatment plants and less, than 200 µg/L total aluminum for other types of treatment systems are recommended.

### *Diffuser Discharge Predictions*

A two-dimensional flow and transport model (AQUASEA) was used to model water effluent dispersion in the Saskatchewan River (see Appendix 6.2.6-A for details).

For the multi-port diffuser, the far field concentration of chloride was modelled to provide an estimate of mitigation available using the diffuser. The far field location, where the turbulent flow from the diffuser ports drops to the Saskatchewan River flow velocities, was calculated to be 40 m downstream of the ports. The modeling indicates that the multi-port diffuser increases dispersion and substantially reduces concentrations of parameters in the river as compared to the end of pipe discharge.

The total discharge from the diffuser varies from 100,000 m$^3$/d to 120,000 m$^3$/d. The larger volume was used in the modeling, The Mannville water discharge has a chloride concentration of 1700 mg/l, which was modelled across the 60 m width of the river. Transport model runs showed that chloride concentrations in the river reduced to values varying between 21 to 26 mg/l above background at a point 40 m downstream of the source, which reduces concentrations by a factor of 80 to 65. The variability in concentrations in the lateral direction is a function of river water depth and the rate of discharge through the port. The transport model results and the summary of chloride concentrations along a lateral line at 40 m downstream of the source are presented in the *Memo: Saskatchewan River Dispersion Modeling – Diffuser Plume Estimate, dated 20 July 2011* (see Appendix 6.2.6-A).

Other water quality parameters were estimated based on these results and presented in Table 6.2.7-4. The lowest concentration reduction factor (65) was used in the values in Table 6.2.7-4. The applicable guidelines are provided for comparison (Saskatchewan Protection of Freshwater Aquatic Biota guidelines; federal CCME protection of freshwater aquatic life; and Health Canada drinking water guidelines). Federal guidelines may be applicable where provincial guidelines are not available.

*Table 6.2.7-4: Water Quality Parameters*

| Parameter | Units | Saskatchewan River | Diffuser Inflow | | | | Diffuser Outflow (incremental concentration increase in the Saskatchewan River within 40 m from the Diffuser) | | | | Resultant Concentration within the Saskatchewan River | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Mean | Median | 95th Percentile | Maximum | Mean | Median | 95th Percentile | Maximum | Mean | Median | 95th Percentile | Maximum |
| **Conventional Parameters** | | | | | | | | | | | | | | |
| Specific conductivity | µS/cm | 443 | 4618 | 5430 | 5808 | 5916 | 71 | 84 | 89 | 91 | 514 | 527 | 533 | 534 |
| Total alkalinity | mg/L | 159 | 337 | 360 | 379 | 384 | 5 | 6 | 6 | 6 | 164 | 164 | 165 | 165 |
| Total dissolved solids | mg/L | 262 | **2865** | **3398** | **3702** | **3781** | 44 | 52 | 57 | 58 | 306 | 314 | 319 | 320 |
| Total hardness | mg/L | 188 | 421 | 464 | 500 | 506 | 6 | 7 | 8 | 8 | 195 | 196 | 196 | 196 |
| **Major Ions** | | | | | | | | | | | | | | |
| Bicarbonate | mg/L | 187 | 390 | 425 | 458 | 464 | 6 | 7 | 7 | 7 | 193 | 193 | 194 | 194 |
| Calcium | mg/L | 48 | 108 | 120 | 129 | 131 | 1.7 | 1.8 | 2 | 2 | 49 | 49 | 49 | 50 |
| Carbonate | mg/L | 4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.007 | 0.007 | 0.008 | 0.008 | 4 | 4 | 4 | 4 |
| Chloride | mg/L | 7 | **1212** | **1454** | **1588** | **1623** | 19 | 22 | 24 | 25 | 26 | 30 | 32 | 32 |
| Fluoride | mg/L | 0.1 | 2 | 2 | 2 | 2 | 0.03 | 0.03 | 0.04 | 0.04 | 0.2 | 0.2 | 0.2 | 0.2 |
| Hydroxide | mg/L | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.007 | 0.007 | 0.008 | 0.008 | 1.0 | 1.0 | 1.0 | 1.0 |
| Magnesium | mg/L | 17 | 35 | 40 | 43 | 44 | 0.5 | 0.6 | 0.7 | 0.7 | 18 | 18 | 18 | 18 |
| Potassium | mg/L | 3 | 40 | 48 | 52 | 53 | 0.6 | 0.7 | 0.8 | 0.8 | 4 | 4 | 4 | 4 |
| Sodium | mg/L | 20 | **876** | **1050** | **1140** | **1165** | 13 | 16 | 18 | 18 | 33 | 36 | 37 | 38 |
| Sulfate | mg/L | 67 | **537** | **641** | **692** | **707** | 8 | 10 | 11 | 11 | 75 | 77 | 78 | 78 |
| **Nutrients** | | | | | | | | | | | | | | |
| Ammonia as nitrogen | mg/L | 0.05 | 1.4 | 1.7 | 1.8 | 1.9 | 0.02 | 0.03 | 0.03 | 0.03 | 0.07 | 0.07 | 0.07 | 0.07 |
| Nitrate | mg/L | 0.4 | 0.02 | 0.02 | 0.04 | 0.04 | 0.0004 | 0.0003 | 0.0006 | 0.0006 | 0.4 | 0.4 | 0.4 | 0.4 |
| Total Phosphorus | mg/L | 0.1 | 0.04 | 0.04 | **0.05** | **0.05** | 0.0006 | 0.0007 | 0.0007 | 0.0007 | **0.1** | **0.1** | **0.1** | **0.1** |
| **Metals** | | | | | | | | | | | | | | |
| Aluminum | mg/L | **0.4** | 0.003 | 0.002 | 0.005 | 0.006 | 0.00004 | 0.00004 | 0.00007 | 0.00009 | **0.4** | **0.4** | **0.4** | **0.4** |
| Antimony | mg/L | 0.0004 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | 0.000002 | 0.000002 | 0.000002 | 0.000003 | 0.0004 | 0.0004 | 0.0004 | 0.0004 |
| Arsenic | mg/L | 0.0007 | 0.0003 | 0.0002 | 0.0005 | 0.0007 | 0.000005 | 0.000004 | 0.000008 | 0.00001 | 0.0007 | 0.0007 | 0.0007 | 0.0007 |
| Barium | mg/L | 0.1 | 0.08 | 0.04 | 0.3 | 0.3 | 0.001 | 0.0006 | 0.005 | 0.005 | 0.1 | 0.1 | 0.1 | 0.1 |
| Beryllium | mg/L | 0.0002 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.0000007 | 0.0000007 | 0.0000008 | 0.0000008 | 0.0002 | 0.0002 | 0.0002 | 0.0002 |
| Boron | mg/L | 0.03 | 1.4 | **1.7** | **1.8** | **1.8** | 0.02 | 0.03 | 0.03 | 0.03 | 0.06 | 0.06 | 0.06 | 0.06 |
| Cadmium | mg/L | **0.00008** | 0.00006 | 0.00003 | **0.0003** | **0.0003** | 0.000001 | 0.0000005 | **0.000004** | **0.000004** | **0.00008** | **0.00008** | **0.00009** | **0.00009** |
| Chromium | mg/L | **0.002** | 0.0008 | 0.0006 | **0.003** | **0.003** | 0.00001 | 0.000008 | 0.00004 | 0.00004 | **0.002** | **0.002** | **0.002** | **0.002** |
| Cobalt | mg/L | 0.0005 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.000002 | 0.000002 | 0.000002 | 0.000002 | 0.0005 | 0.0005 | 0.0005 | 0.0005 |
| Copper | mg/L | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.00003 | 0.00003 | 0.00003 | 0.00004 | 0.002 | 0.002 | 0.002 | 0.002 |
| Iron | mg/L | **0.6** | 0.2 | 0.2 | 0.2 | 0.2 | 0.003 | 0.003 | 0.003 | 0.003 | **0.7** | **0.7** | **0.7** | **0.7** |
| Lead | mg/L | 0.0006 | 0.0002 | 0.0003 | 0.0003 | 0.0003 | 0.000004 | 0.000004 | 0.000004 | 0.000005 | 0.0006 | 0.0006 | 0.0006 | 0.0006 |
| Manganese | mg/L | **0.05** | **0.06** | **0.07** | **0.08** | **0.08** | 0.001 | 0.001 | 0.001 | 0.001 | **0.05** | **0.05** | **0.05** | **0.05** |
| Molybdenum | mg/L | 0.001 | 0.001 | 0.001 | 0.004 | 0.01 | 0.00002 | 0.00002 | 0.00006 | 0.0002 | 0.001 | 0.001 | 0.001 | 0.001 |
| Nickel | mg/L | 0.002 | 0.0005 | 0.0005 | 0.0007 | 0.001 | 0.000008 | 0.000008 | 0.00001 | 0.00002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Selenium | mg/L | 0.0004 | 0.0002 | 0.0002 | 0.0004 | 0.0007 | 0.000004 | 0.000004 | 0.000006 | 0.00001 | 0.0004 | 0.0004 | 0.0004 | 0.0004 |

| Parameter | Units | Saskatchewan River | Diffuser Inflow | | | | Diffuser Outflow (incremental concentration increase in the Saskatchewan River within 40 m from the Diffuser) | | | | Resultant Concentration within the Saskatchewan River | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | Mean | Median | 95th Percentile | Maximum | Mean | Median | 95th Percentile | Maximum | Mean | Median | 95th Percentile | Maximum |
| Silver | mg/L | **0.0002** | 0.00002 | 0.000009 | 0.00005 | 0.00005 | 0.0000002 | 0.0000001 | 0.0000008 | 0.0000008 | **0.0002** | **0.0002** | **0.0002** | **0.0002** |
| Strontium | mg/L | 0.4 | 1.8 | 2 | 2 | 2 | 0.03 | 0.03 | 0.04 | 0.04 | 0.4 | 0.4 | 0.4 | 0.4 |
| Thallium | mg/L | 0.00009 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.000002 | 0.000002 | 0.000002 | 0.000002 | 0.00009 | 0.00009 | 0.00009 | 0.00009 |
| Tin | mg/L | 0.0002 | 0.003 | 0.002 | 0.005 | 0.006 | 0.00004 | 0.00004 | 0.00007 | 0.00009 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| Titanium | mg/L | 0.008 | 0.0002 | 0.0002 | 0.0003 | 0.0005 | 0.000003 | 0.000003 | 0.000005 | 0.000008 | 0.008 | 0.008 | 0.008 | 0.008 |
| Uranium | mg/L | 0.0008 | 0.00008 | 0.00006 | 0.0002 | 0.0003 | 0.000001 | 0.000001 | 0.000003 | 0.000004 | 0.0008 | 0.0008 | 0.0008 | 0.0008 |
| Vanadium | mg/L | 0.002 | 0.001 | 0.0006 | 0.003 | 0.005 | 0.00002 | 0.00001 | 0.00005 | 0.00008 | 0.002 | 0.002 | 0.002 | 0.002 |
| Zinc | mg/L | 0.01 | 0.02 | 0.02 | **0.07** | **0.07** | 0.0004 | 0.0002 | 0.001 | 0.001 | 0.01 | 0.01 | 0.01 | 0.01 |

**Note:** Shaded and bolded cells indicate a CCME guidelines exceedance.

*Site Tributaries*

The water quality in each stream within the study area was predicted with monthly time steps during mine construction and operation. The results were compared to applicable guidelines (CCME aquatics guideline, Saskatchewan water quality objectives, Health Canada drinking water quality guidelines), and peak baseline water quality in the study area in the level of 95th percentile of all baseline water quality data are presented. The contribution of all stream loadings and the diffuser to the Saskatchewan River was assessed as well.

Site tributaries downstream of facilities and below control berms/ditches will drain naturally to the Saskatchewan River. Above the facilities, water will be diverted from the runoff pond to supplement low flows in the 101 Ravine, Duke Ravine and English Creek, if needed, or to the Duke Ravine to avoid spill to Star pit.

The 101 Ravine Creek will be downslope of the Overburden and Rock Storage Pile and will change the natural catchment areas of the 101 Ravine and Caution Creek. Runoff and seepage from the pile will report to Ravine 101 Creek. The overburden pile will consist of mostly till (85%), with lesser quantities of sand and shale. Runoff and seepage from the till can reasonably be expected to be similar in quality to that existing in tributaries prior to mining. The shale, is expected to have somewhat elevated chloride and sulphate levels, but will be isolated from the pile surface. Background water quality of 101 Ravine is discussed in Section 5.2.8.

The PKCF facility will occupy portions of four watersheds - Duke Ravine, FaLC Ravine, Wapiti Ravine, and English Creek. The facility will have a projected seepage of 1,000 $m^3$/day and 90% of the seepage will be captured by drainage ditches or interception wells and pumped back to the PKCF. The rest will be collected in the surrounding PKCF ditch and discharged through adjacent wetlands to creeks. This passive water treatment will improve water quality in these four streams. The water quality variations in the streams are presented in Appendix 6.2.7-A. The median values of water quality parameters were estimated based on these results and presented in Table 6.2.7-5.

Most of the water quality parameters were within the pre-mining background range of variability. Parameters that had exceedances in the baseline conditions remained above applicable guidelines. In most cases, the changes were found to be non-measurable (incremental increase in concentrations was very small). In a few instances, metal concentrations dropped, but insignificantly, caused by changes in the proportions of surface runoff vs. groundwater discharge into the water courses. Overall, seasonal concentration did not experience a substantial fluctuation between years during mine life.

Water quality in streams was usually within the range of natural variability and continued to exceed guidelines where they were previously exceeded in the baseline; no new elevated concentrations were forecasted in streams.

As shown in Table 6.2.7-5 some parameters exceed CCME guidelines in the background Saskatchewan River data, and in the model, however the increases in these parameters fall within the natural variability of the river. The absolute values of exceedances in some creeks in the study area under baseline conditions slightly decreased due to decreased groundwater discharge into streams. This effect represents typical surface/groundwater interaction effects.

***Table 6.2.7-5: Water Quality in Local Streams during Operations - Median Values***

| Parameter | Units | Saskatchewan River | Caution Creek | Caution Creek East | Caution Creek South | Unnamed Tributary 1 | Unnamed Tributary 2 | Unnamed Tributary 3 | 101 Ravine | West Perimeter Ravine | West Ravine | Central-East Ravine | Duke Ravine West | Duke Ravine (1) | Falc Ravine | Wapiti Ravine | English Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Conventional Parameters** | | | | | | | | | | | | | | | | | |
| Chemical oxygen demand | mg/L | - | 11 | 9 | 11 | 12 | 9 | 11 | 8 | 7 | 6 | 6 | 6 | 5 | 6 | 6 | 9 |
| Total alkalinity | mg/L | 158 | 246 | 262 | 255 | 246 | 232 | 237 | 261 | 236 | 237 | 237 | 237 | 181 | 236 | 214 | 224 |
| Total dissolved solids | mg/L | 279 | 261 | 279 | 272 | 262 | 240 | 247 | 275 | 241 | 242 | 242 | 242 | 330 | 242 | 283 | 249 |
| Total hardness | mg/L | 190 | 230 | 239 | 235 | 230 | 223 | 225 | 240 | 225 | 226 | 226 | 226 | 231 | 225 | 228 | 223 |
| Total suspended solids | mg/L | - | 1.3 | 0.9 | 1.4 | 1.4 | 0.7 | 1.2 | 0.5 | 0.2 | 0.05 | 0.03 | 0.02 | 0.4 | 0.1 | 0.07 | 0.7 |
| Turbidity | NTU | - | 1.9 | 1.3 | 2 | 2 | 1.0 | 1.7 | 0.7 | 0.2 | 0.07 | 0.04 | 0.04 | 0.4 | 0.1 | 0.1 | 1.1 |
| **Major Ions** | | | | | | | | | | | | | | | | | |
| Bicarbonate | mg/L | 187 | 270 | 291 | 285 | 272 | 241 | 252 | 283 | 240 | 240 | 240 | 240 | 183 | 240 | 216 | 233 |
| Calcium | mg/L | 48 | 62 | 65 | 64 | 63 | 59 | 60 | 64 | 59 | 59 | 59 | 59 | 49 | 59 | 54 | 57 |
| Carbonate | mg/L | 3 | 3 | 4 | 4 | 3 | 0.8 | 1.7 | 4 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.8 |
| Chloride | mg/L | 11 | 4 | 4 | 4 | 4 | 6 | 5 | 5 | 7 | 7 | 7 | 7 | **169** | 7 | 79 | 27 |
| Fluoride | mg/L | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.1 | 0.2 | 0.2 |
| Hydroxide | mg/L | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Magnesium | mg/L | 17 | 15 | 16 | 16 | 15 | 13 | 14 | 16 | 13 | 13 | 13 | 13 | 16 | 13 | 14 | 13 |
| Potassium | mg/L | 3 | 1.9 | 2 | 2 | 1.9 | 1.1 | 1.4 | 2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.9 | 1.0 | 1.4 | 1.2 |
| Sodium | mg/L | 21 | 9 | 13 | 12 | 10 | 4 | 6 | 12 | 4 | 4 | 4 | 4 | 80 | 4 | 38 | 14 |
| Sulfate | mg/L | 68 | 10 | 13 | 12 | 10 | 5 | 7 | 12 | 5 | 5 | 5 | 5 | 39 | 5 | 21 | 10 |
| **Nutrients** | | | | | | | | | | | | | | | | | |
| Ammonia as nitrogen | mg/L | 0.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 |
| Dissolved organic carbon | mg/L | - | 3 | 2 | 3 | 3 | 2 | 3 | 1.9 | 1.4 | 1.3 | 1.2 | 1.2 | 1.3 | 1.3 | 1.2 | 2 |
| Nitrate | mg/L | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 |
| Nitrite | mg/L | - | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 |
| Total Organic Carbon | mg/L | - | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 1.7 | 1.6 | 1.5 | 1.5 | 1.5 | 1.6 | 1.4 | 2 |
| Total Phosphorus | mg/L | 0.07 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.008 | 0.005 | 0.003 | 0.003 | 0.003 | 0.01 | 0.004 | 0.006 | 0.01 |
| **Metals** | | | | | | | | | | | | | | | | | |
| Aluminum | mg/L | **0.5** | **0.2** | **0.3** | **0.3** | **0.2** | 0.005 | 0.08 | **0.3** | 0.001 | 0.0006 | 0.0004 | 0.0004 | 0.002 | 0.001 | 0.001 | 0.005 |
| Antimony | mg/L | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.00009 | 0.0001 | 0.0001 | 0.0001 |
| Arsenic | mg/L | 0.0008 | 0.002 | 0.003 | 0.003 | 0.003 | 0.0006 | 0.001 | 0.003 | 0.0003 | 0.0002 | 0.0002 | 0.0002 | 0.0003 | 0.0003 | 0.0002 | 0.0006 |
| Barium | mg/L | 0.1 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 |
| Beryllium | mg/L | 0.0001 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00004 | 0.00005 | 0.00005 | 0.00005 |
| Bismuth | mg/L | - | 0.00003 | 0.00002 | 0.00003 | 0.00003 | 0.00001 | 0.00002 | 0.000009 | 0.000003 | 0.0000009 | 0.0000005 | 0.0000005 | 0.000006 | 0.000002 | 0.000001 | 0.00001 |
| Boron | mg/L | 0.04 | 0.04 | 0.06 | 0.06 | 0.04 | 0.007 | 0.02 | 0.05 | 0.005 | 0.005 | 0.005 | 0.005 | 0.4 | 0.005 | 0.2 | 0.06 |
| Cadmium | mg/L | **0.00007** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** | **0.0002** |
| Cesium | mg/L | - | 0.00001 | 0.000008 | 0.00001 | 0.00001 | 0.000006 | 0.00001 | 0.000005 | 0.000002 | 0.0000004 | 0.0000003 | 0.0000002 | 0.000003 | 0.000001 | 0.0000007 | 0.000007 |
| Chromium | mg/L | **0.002** | **0.003** | **0.003** | **0.003** | **0.003** | **0.002** | **0.002** | **0.003** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** |
| Cobalt | mg/L | 0.0006 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Copper | mg/L | 0.003 | 0.001 | 0.002 | 0.002 | 0.001 | 0.0002 | 0.0006 | 0.002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0002 |
| Iron | mg/L | **0.9** | **1.1** | **1.6** | **1.5** | **1.2** | 0.1 | **0.5** | **1.4** | 0.03 | 0.008 | 0.006 | 0.005 | 0.05 | 0.02 | 0.01 | 0.1 |
| Lead | mg/L | 0.0009 | 0.001 | 0.002 | 0.002 | 0.001 | 0.00008 | 0.0005 | 0.002 | 0.00006 | 0.00005 | 0.00005 | 0.00005 | 0.00009 | 0.00005 | 0.00006 | 0.00009 |

| Parameter | Units | Saskatchewan River | Caution Creek | Caution Creek East | Caution Creek South | Unnamed Tributary 1 | Unnamed Tributary 2 | Unnamed Tributary 3 | 101 Ravine | West Perimeter Ravine | West Ravine | Central-East Ravine | Duke Ravine West | Duke Ravine (1) | Falc Ravine | Wapiti Ravine | English Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manganese | mg/L | **2** | **0.06** | **0.08** | **0.08** | **0.07** | 0.02 | 0.04 | **0.06** | 0.007 | 0.005 | 0.004 | 0.004 | 0.01 | 0.006 | 0.005 | 0.02 |
| Mercury | mg/L | - | **0.00009** | **0.00008** | **0.00009** | **0.00009** | **0.00007** | **0.00008** | **0.00006** | **0.00005** | **0.00005** | **0.00005** | **0.00005** | **0.0006** | **0.00005** | **0.0003** | **0.0002** |
| Molybdenum | mg/L | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 |
| Nickel | mg/L | 0.003 | 0.0003 | 0.0002 | 0.0003 | 0.0003 | 0.0002 | 0.0002 | 0.0001 | 0.00008 | 0.00006 | 0.00005 | 0.00005 | 0.0007 | 0.00007 | 0.0002 | 0.0002 |
| Rubidium | mg/L | - | 0.0007 | 0.0004 | 0.0007 | 0.0007 | 0.0003 | 0.0006 | 0.0002 | 0.00008 | 0.00002 | 0.00001 | 0.00001 | 0.0002 | 0.00005 | 0.00004 | 0.0004 |
| Selenium | mg/L | 0.0004 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.00008 | 0.0001 | 0.00009 | 0.0001 |
| Silicon | mg/L | - | 1.3 | 0.8 | 1.3 | 1.3 | 0.6 | 1.1 | 0.4 | 0.2 | 0.04 | 0.03 | 0.02 | 0.4 | 0.1 | 0.1 | 0.7 |
| Silver | mg/L | **0.0001** | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00004 | 0.00005 | 0.00004 | 0.00005 |
| Strontium | mg/L | 0.4 | 0.1 | 0.09 | 0.1 | 0.1 | 0.09 | 0.1 | 0.09 | 0.08 | 0.08 | 0.08 | 0.08 | 0.5 | 0.08 | 0.2 | 0.2 |
| Tellurium | mg/L | - | 0.0001 | 0.00008 | 0.0001 | 0.0001 | 0.00006 | 0.0001 | 0.00005 | 0.00002 | 0.000004 | 0.000003 | 0.000002 | 0.00003 | 0.00001 | 0.000007 | 0.00007 |
| Thallium | mg/L | 0.00009 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Tin | mg/L | 0.5 | 0.2 | 0.3 | 0.3 | 0.2 | 0.005 | 0.08 | 0.3 | 0.001 | 0.0006 | 0.0004 | 0.0004 | 0.002 | 0.001 | 0.0007 | 0.005 |
| Titanium | mg/L | 0.01 | 0.0006 | 0.0005 | 0.0006 | 0.0006 | 0.0004 | 0.0006 | 0.0003 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0005 | 0.0002 | 0.0003 | 0.0004 |
| Tungsten | mg/L | - | 0.00003 | 0.00002 | 0.00003 | 0.00003 | 0.00001 | 0.00002 | 0.000009 | 0.000003 | 0.0000009 | 0.0000005 | 0.0000005 | 0.000006 | 0.000002 | 0.000001 | 0.00001 |
| Uranium | mg/L | 0.0008 | 0.0009 | 0.001 | 0.001 | 0.0009 | 0.00003 | 0.0003 | 0.001 | 0.000007 | 0.000002 | 0.000001 | 0.000001 | 0.00002 | 0.000004 | 0.000006 | 0.00003 |
| Vanadium | mg/L | 0.002 | 0.0002 | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0002 | 0.00009 | 0.00006 | 0.00005 | 0.00005 | 0.00005 | 0.0003 | 0.00006 | 0.0001 | 0.0001 |
| Zinc | mg/L | 0.009 | **0.1** | **0.2** | **0.2** | **0.1** | **0.06** | **0.09** | **0.2** | **0.07** | **0.07** | **0.07** | **0.07** | **0.04** | **0.07** | **0.06** | **0.06** |
| Zirconium | mg/L | - | 0.00005 | 0.00003 | 0.00005 | 0.00005 | 0.00003 | 0.00004 | 0.00002 | 0.000006 | 0.000002 | 0.000001 | 0.0000009 | 0.00005 | 0.000004 | 0.00002 | 0.00003 |

**Note:** [1] Includes water from the East Ravine during Operations.
Shaded and bolded cells indicate a guideline exceedance.

*Effects on the Codette Reservoir*

An issue raised during engagement activities was a concern that high chloride concentrations in the discharge to the Saskatchewan River would result in layering in the Codette Reservoir due to a density discontinuity being built up by higher density Saskatchewan River water layering under fresher water in the reservoir. As can be seen from the results discussed above, the discharge from the Project will be completely incorporated with existing flow before water reaches the Codette Reservoir and thus layering could not occur.

*Potable Water Supply*

Potable water will be drawn from shallow groundwater and treated to meet Saskatchewan drinking water guidelines. Waste water from potable use will be routed to the sewage lagoon and from there, to the Duke Ravine.

*Closure Water Quality – streams*

The water quality in site tributaries will be restored to pre-mining conditions. Table 6.2.7-6 presents median water quality in all creeks after closure and reclamation. By the time mining has ceased, the PKCF will be dry and contain no process water as it will not be operational during Orion South mining phase. The interior surface of the PKCF will be consolidated fine kimberlite material covered with overburden and sand. The coarse PK pile will also be capped with overburden and/or sand during reclamation..

After reclamation the water quality in all tributary watersheds will be within the pre-mining range of variability as there will be no active sources of process water seepages or affected runoffs.

***Table 6.2.7-6: Water Quality in Local Streams after Mine Closure - Median Values***

| Parameter | Units | Saskatchewan River | Caution Creek | Caution Creek East | Caution Creek South | Unnamed Tributary 1 | Unnamed Tributary 2 | Unnamed Tributary 3 | 101 Ravine | West Perimeter Ravine | West Ravine | Central-East Ravine | East Ravine | Duke Ravine West | Duke Ravine | FalC Ravine | Wapiti Ravine | English Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Conventional Parameters** | | | | | | | | | | | | | | | | | | |
| Chemical oxygen demand | mg/L | 24 | 118 | 173 | 138 | 138 | 190 | 151 | 138 | 217 | 235 | 237 | 242 | 238 | 162 | 226 | 242 | 152 |
| Specific conductivity | µS/cm | 437 | 383 | 404 | 393 | 385 | 376 | 373 | 404 | 379 | 381 | 381 | 382 | 382 | 404 | 381 | 406 | 372 |
| Total alkalinity | mg/L | 157 | 222 | 235 | 227 | 225 | 229 | 223 | 228 | 233 | 236 | 236 | 237 | 236 | 231 | 235 | 250 | 222 |
| Total dissolved solids | mg/L | 270 | 239 | 251 | 245 | 241 | 238 | 236 | 255 | 240 | 241 | 242 | 242 | 242 | 254 | 241 | 257 | 235 |
| Total hardness | mg/L | 189 | 214 | 223 | 218 | 217 | 220 | 216 | 221 | 223 | 225 | 225 | 226 | 226 | 223 | 224 | 239 | 216 |
| Total suspended solids | mg/L | 39 | 3 | 2 | 3 | 3 | 1.2 | 3 | 11 | 0.6 | 0.2 | 0.1 | - | 0.09 | 9 | 0.4 | 0.8 | 2 |
| Turbidity | NTU | 40 | 4 | 3 | 4 | 4 | 1.8 | 3 | 6 | 0.8 | 0.2 | 0.2 | - | 0.1 | 5 | 0.6 | 0.7 | 3 |
| **Major Ions** | | | | | | | | | | | | | | | | | | |
| Calcium | mg/L | 48 | 60 | 61 | 61 | 60 | 59 | 59 | 61 | 59 | 59 | 59 | 59 | 59 | 61 | 59 | 63 | 59 |
| Carbonate | mg/L | 3 | 2 | 3 | 3 | 2 | 1.0 | 1.4 | 2 | 0.7 | 0.6 | 0.5 | 0.5 | 0.5 | 1.8 | 0.7 | 0.7 | 1.3 |
| Chloride | mg/L | 7 | 3 | 4 | 3 | 4 | 6 | 5 | 11 | 6 | 7 | 7 | 7 | 7 | 11 | 7 | 7 | 5 |
| Fluoride | mg/L | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Hydroxide | mg/L | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Magnesium | mg/L | 17 | 14 | 14 | 14 | 14 | 13 | 13 | 14 | 13 | 13 | 13 | 13 | 13 | 14 | 13 | 14 | 13 |
| Potassium | mg/L | 3 | 1.5 | 1.7 | 1.6 | 1.5 | 1.1 | 1.2 | 1.3 | 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.2 | 1.0 | 1.1 | 1.2 |
| Sodium | mg/L | 19 | 6 | 7 | 7 | 6 | 4 | 4 | 8 | 4 | 4 | 4 | 4 | 4 | 8 | 4 | 5 | 4 |
| Sulfate | mg/L | 67 | 6 | 8 | 7 | 6 | 5 | 5 | 7 | 5 | 5 | 5 | 5 | 5 | 7 | 5 | 6 | 5 |
| **Nutrients** | | | | | | | | | | | | | | | | | | |
| Ammonia as nitrogen | mg/L | 0.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 |
| Dissolved organic carbon | mg/L | 5 | 6 | 4 | 5 | 5 | 3 | 4 | 5 | 2 | 1.4 | 1.4 | 1.2 | 1.3 | 4 | 1.7 | 1.8 | 4 |
| Nitrate | mg/L | 0.4 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.2 |
| Nitrite | mg/L | - | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Total Organic Carbon | mg/L | 6 | 6 | 4 | 5 | 5 | 3 | 4 | 5 | 2 | 1.7 | 1.6 | 1.5 | 1.6 | 4 | 2 | 2 | 4 |
| Total Phosphorus | mg/L | 0.07 | 0.04 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.009 | 0.005 | 0.004 | 0.003 | 0.004 | 0.03 | 0.007 | 0.007 | 0.03 |
| **Metals** | | | | | | | | | | | | | | | | | | |
| Aluminum | mg/L | **0.5** | 0.09 | **0.1** | **0.1** | 0.08 | 0.009 | 0.02 | 0.04 | 0.004 | 0.001 | 0.001 | 0.0003 | 0.0009 | 0.04 | 0.003 | 0.004 | 0.02 |
| Antimony | mg/L | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Arsenic | mg/L | 0.0008 | 0.0025 | 0.0024 | 0.0026 | 0.0022 | 0.0009 | 0.0015 | 0.0015 | 0.0005 | 0.0003 | 0.0003 | 0.0002 | 0.0003 | 0.0011 | 0.0004 | 0.0004 | 0.0015 |
| Bismuth | mg/L | - | 0.00006 | 0.00004 | 0.00005 | 0.00005 | 0.00002 | 0.00004 | 0.00007 | 0.00001 | 0.000003 | 0.000002 | - | 0.000002 | 0.00006 | 0.000008 | 0.000008 | 0.00004 |
| Boron | mg/L | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.009 | 0.01 | 0.02 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.02 | 0.006 | 0.007 | 0.01 |
| Cadmium | mg/L | 0.00007 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0003 | 0.0002 | 0.0002 | 0.0002 | 0.0003 | 0.0002 |
| Cesium | mg/L | - | 0.00003 | 0.00002 | 0.00003 | 0.00003 | 0.00001 | 0.00002 | 0.00005 | 0.000006 | 0.000002 | 0.000001 | - | 0.0000009 | 0.00004 | 0.000004 | 0.000005 | 0.00002 |
| Chromium | mg/L | **0.002** | **0.001** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.002** | **0.003** | **0.002** | **0.002** | **0.002** | **0.003** | **0.002** |
| Cobalt | mg/L | 0.0006 | 0.0002 | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| Copper | mg/L | 0.003 | 0.0008 | 0.001 | 0.001 | 0.0008 | 0.0002 | 0.0004 | 0.0005 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0004 | 0.0001 | 0.0002 | 0.0004 |
| Iron | mg/L | **0.9** | **0.8** | **0.9** | **0.9** | **0.7** | 0.2 | **0.4** | **0.4** | 0.1 | 0.03 | 0.02 | 0.001 | 0.02 | **0.3** | 0.06 | 0.06 | **0.4** |
| Lead | mg/L | 0.0009 | 0.0006 | 0.0009 | 0.0008 | 0.0006 | 0.0001 | 0.0002 | 0.0003 | 0.00008 | 0.00006 | 0.00006 | 0.00005 | 0.00005 | 0.0002 | 0.00007 | 0.00008 | 0.0002 |
| Manganese | mg/L | **2** | **0.07** | **0.06** | **0.07** | **0.06** | 0.03 | 0.05 | **0.2** | 0.01 | 0.007 | 0.006 | 0.004 | 0.005 | **0.1** | 0.01 | 0.02 | 0.04 |
| Mercury | mg/L | **0.0002** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0002** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0001** | **0.0002** | **0.0001** | **0.0001** | **0.0001** |

| Parameter | Units | Saskatchewan River | Caution Creek | Caution Creek East | Caution Creek South | Unnamed Tributary 1 | Unnamed Tributary 2 | Unnamed Tributary 3 | 101 Ravine | West Perimeter Ravine | West Ravine | Central-East Ravine | East Ravine | Duke Ravine West | Duke Ravine | FalC Ravine | Wapiti Ravine | English Creek |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Molybdenum | mg/L | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Nickel | mg/L | 0.003 | 0.0006 | 0.0004 | 0.0005 | 0.0005 | 0.0003 | 0.0004 | 0.0006 | 0.0001 | 0.00008 | 0.00007 | 0.00005 | 0.00007 | 0.0005 | 0.0001 | 0.0001 | 0.0004 |
| Selenium | mg/L | 0.0004 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 |
| Silver | mg/L | **0.0001** | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00006 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00006 | 0.00005 | 0.00005 | 0.00005 |
| Strontium | mg/L | 0.4 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.09 | 0.08 | 0.08 | 0.08 | 0.08 | 0.1 | 0.09 | 0.09 | 0.1 |
| Tellurium | mg/L | - | 0.0003 | 0.0002 | 0.0003 | 0.0003 | 0.0001 | 0.0002 | 0.0002 | 0.00006 | 0.00002 | 0.00001 | - | 0.000009 | 0.0002 | 0.00004 | 0.00004 | 0.0002 |
| Thallium | mg/L | 0.00009 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Tin | mg/L | 0.0002 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.0001 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.00005 | 0.0001 | 0.00005 | 0.00006 | 0.00005 |
| Titanium | mg/L | 0.01 | 0.001 | 0.0009 | 0.001 | 0.001 | 0.0006 | 0.001 | 0.002 | 0.0004 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.002 | 0.0003 | 0.0003 | 0.0009 |
| Tungsten | mg/L | - | 0.00006 | 0.00004 | 0.00005 | 0.00005 | 0.00002 | 0.00004 | 0.00007 | 0.00001 | 0.000003 | 0.000002 | - | 0.000002 | 0.00006 | 0.000008 | 0.000008 | 0.00004 |
| Uranium | mg/L | 0.00076 | 0.00039 | 0.00061 | 0.00051 | 0.00037 | 0.00005 | 0.00009 | 0.00015 | 0.00002 | 0.00001 | 0.000005 | 0.0000004 | 0.000004 | 0.00012 | 0.00002 | 0.00002 | 0.00008 |
| Vanadium | mg/L | 0.002 | 0.0003 | 0.0002 | 0.0003 | 0.0003 | 0.0002 | 0.0002 | 0.0004 | 0.0001 | 0.00007 | 0.00006 | 0.00005 | 0.00006 | 0.0004 | 0.00008 | 0.00009 | 0.0002 |
| Zinc | mg/L | 0.009 | **0.06** | **0.1** | **0.08** | **0.07** | **0.05** | **0.04** | **0.04** | **0.06** | **0.07** | **0.07** | **0.07** | **0.07** | **0.05** | **0.06** | **0.07** | **0.04** |
| Zirconium | mg/L | - | 0.0001 | 0.00008 | 0.0001 | 0.0001 | 0.00005 | 0.00009 | 0.0002 | 0.00002 | 0.000007 | 0.000004 | - | 0.000004 | 0.0002 | 0.00002 | 0.00002 | 0.00008 |

**Note:** Shaded and bolded cells indicate a guideline exceedance.

*Closure Water Quality – end pit lakes*

Star and Orion South pits will naturally fill with water to create lakes. At the end of mining Star pit will be partially filled with overburden, processed kimberlite and water from mining Orion South, while the Orion South pit will be empty. Both pits will continue to fill, over time, with a combination of deep and shallow groundwater, as well as precipitation and surface runoff until equilibrium is reached.

After reaching steady state conditions, the shallow groundwater inflow to Star pit will be low relative to the upstream runoff from East Ravine. Conversely, the Orion South pit at the beginning will receive more deep groundwater inflow during pit infilling and proportionally very little surficial groundwater and surface runoff. The deep groundwater inflow will slow down when the water level approaches steady state conditions.

These sources of water will have different concentrations of constituents and different inflow rates during pit infilling. A detailed water balance was created and assessed in the hydrology section (Section 6.2.6). The water balance affects water quality in both pits that includes inflow and outflow from and to groundwater formations and evaporation.

At the beginning of closure it is assumed that Star pit will have about 3 m of process water on top of saturated processed kimbelite and this water will be available to mix with other water sources during pit infilling.

The Star pit at the end of infilling will be approximately 40-50 m deep and the Orion South pit lake will be approximately 230 m deep. The Star pit infilling process will take about 350 years. At the end of infilling, the Star pit will spill over towards the Saskatchewan River through the East Ravine Channel. The Orion South pit lake will reach a steady state in about 2,500 years based on the modeling results and will not spill over (see hydrology Section 6.2.6).

The Star pit during infilling and after spill over is assumed by the model to be a fully mixed basin. This is the most simplistic assumption and is the most conservative from a water quality perspective. A more likely scenario is that the lake will stratify and create meromictic conditions where the upper active layer of the lake is sitting on a stagnant dynamically passive lower layer. The morphology of pit lakes supports this scenario as pit lakes tend to be deeper with a smaller surface area in comparison to natural lakes. In addition the surface of pit lakes is usually surrounded by high pit walls that shelter the surface area from wind action and thereby reduce the likelihood of mixing.

The scenario of modelling a fully mixed lake was also applied to Orion South pit as well as a stratified option with a top layer that is fed by mostly surface runoff, surficial groundwater, and precipitation once the lake reaches a depth of 80 m.

The water quality in Star Pit Lake, at the time of spill over, is presented in Table 6.2.7-7. During Star pit infilling the water quality improves but some of the parameters are above the CCME guidelines for aquatic life. The water quality in the Orion South pit lake for both non-stratified and stratified cases is presented in Table 6.2.7-8. The annual changes of water quality in Star pit and Orion South pit are presented as mass balance model output during and post infilling period in Appendix 6.2.7-A.

***Table 6.2.7-7: Star Pit Release Water Quality***

| | | | **Guidelines** | | |
|---|---|---|---|---|---|
| | | | **Aquatic Life** | | **Drinking Water** |
| **Parameter** | **Units** | **Star Pit Release Concentration (year 320)** | **CCME (2011)** | **SK MOE (2006)** | **Health Canada (2008)** |
| **Conventional Parameters** | | | | | |
| Total alkalinity | mg/L | 120 | - | - | - |
| Total dissolved solids | mg/L | 460 | - | - | ≤500 (d1) |
| Total hardness | mg/L | 93.7 | - | - | - |
| Turbidity | NTU | 57 | - | - | - |
| **Major Ions** | | | | | |
| Calcium | mg/L | 30 | - | - | - |
| Carbonate | mg/L | 3 | - | - | - |
| Chloride | mg/L | **152** | 120 | - | ≤250 (d1) |
| Fluoride | mg/L | 0.23 | - | - | - |
| Hydroxide | mg/L | 1.8 | - | - | - |
| Magnesium | mg/L | 8.1 | - | - | - |
| Potassium | mg/L | 5.5 | - | - | - |
| Sodium | mg/L | 123 | - | - | ≤200 (d1) |
| Sulfate | mg/L | 65 | - | - | ≤500 (d1) |
| **Nutrients** | | | | | |
| Ammonia as nitrogen | mg/L | 0.2 | 7.0 - 48.3 (a1) | - | - |
| Dissolved organic carbon | mg/L | 1.6 | - | - | - |
| Nitrate | mg/L | 1.63 | 2.9 (a2) | - | 45 (d3) |
| Total Phosphorus | mg/L | 0.03 | - | - | - |
| **Metals** | | | | | |
| Aluminum | mg/L | 0.023 | 0.1 (a4) | - | 0.1 (d4) |
| Antimony | mg/L | 0.00009 | - | - | 0.006 (d2) |
| Arsenic | mg/L | 0.00083 | 0.005 | - | 0.01 (d2) |
| Boron | mg/L | 0.29 | 1.5 | - | 5 (d2) |
| Cadmium | mg/L | 0.00005 | 0.00006 (a5) | 0.000058 (b1) | 0.005 (d2) |
| Chromium | mg/L | **0.0035** | 0.001 (a6) | - | 0.05 (d2) |
| Cobalt | mg/L | 0.0005 | - | - | - |
| Copper | mg/L | 0.0006 | 0.004 (a7) | - | ≤1 (d1) |
| Iron | mg/L | 0.19 | 0.3 | - | ≤0.3 (d1) |

| Parameter | Units | Star Pit Release Concentration (year 320) | Guidelines | | |
|---|---|---|---|---|---|
| | | | Aquatic Life | | Drinking Water |
| | | | CCME (2011) | SK MOE | Health |
| Lead | mg/L | 0.00024 | 0.007 (a8) | - | 0.01 |
| Manganese | mg/L | 0.045 | - | - | ≤0.05 (d1) |
| Molybdenum | mg/L | 0.0007 | 0.073 | - | - |
| Nickel | mg/L | 0.007 | 0.15 (a9) | - | - |
| Selenium | mg/L | 0.00009 | 0.001 | - | 0.010 (d2) |
| Silver | mg/L | 0.000026 | 0.0001 | - | - |
| Strontium | mg/L | 0.22 | - | - | - |
| Thallium | mg/L | 0.00006 | 0.0008 | - | - |
| Tin | mg/L | 0.000033 | - | - | - |
| Titanium | mg/L | 0.004 | - | - | - |
| Uranium | mg/L | 0.0002 | 0.015 | 0.015 (b2) | 0.02 |
| Vanadium | mg/L | 0.0011 | - | - | - |
| Zinc | mg/L | 0.012 | 0.03 | - | ≤5 (d1) |

**Note:** Bolded and shaded cells indicate a guideline exceedance.
**Saskatchewan Surface Water Quality Objectives (MOE 2006).**
**Guideline for Canadian Drinking Water Quality - GCDWQ (Health Canada 2008).**
**d1** = Aesthetic objective.
**d2** = Maximum allowable concentration (MAC).

*Table 6.2.7-8: Orion South Pit Water Quality*

| | | Unstratified Conditions | | Stratified Conditions | | Guidelines | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Aquatic Life | | Drinking Water |
| Parameter | Units | Orion South Pit Concentration (Year 1000) | Orion South Pit Concentration (Year 2500) | Orion South Pit Concentration (Year 1000) | Orion South Pit Concentration (Year 2500) | CCME (2011) | SK MOE (2006) | Health Canada (2008) |
| **Conventional Parameters** | | | | | | | | |
| Total alkalinity | mg/L | 187 | 150 | 111 | 123 | - | - | - |
| Total dissolved solids | mg/L | **1149** | 443 | 115 | 127 | - | - | ≤500 (d1) |
| Total hardness | mg/L | 119 | 125 | 106 | 118 | - | - | - |
| Turbidity | NTU | 208 | 63 | 0.2 | 0.2 | - | - | - |
| **Major Ions** | | | | | | | | |
| Calcium | mg/L | 57 | 41 | 28 | 31 | - | - | - |
| Carbonate | mg/L | 0.4 | 0.4 | 0.3 | 0.3 | - | - | - |
| Chloride | mg/L | **520** | **272** | 3 | 4 | 120 | - | ≤250 (d1) |
| Fluoride | mg/L | 0.7 | 0.3 | 0.06 | 0.07 | - | - | - |
| Hydroxide | mg/L | 0.3 | 0.3 | 0.2 | 0.3 | - | - | - |
| Magnesium | mg/L | 17 | 10 | 6 | 7 | - | - | - |
| Potassium | mg/L | 15 | 5 | 0.5 | 0.5 | - | - | - |
| Sodium | mg/L | **330** | 101 | 2 | 2 | - | - | ≤200 (d1) |
| Sulfate | mg/L | 201 | 63 | 3 | 3 | - | - | ≤500 (d1) |
| **Nutrients** | | | | | | | | |
| Ammonia as nitrogen | mg/L | 0.5 | 0.2 | 0.01 | 0.01 | 7.0 - 48.3 (a1) | - | - |
| Dissolved organic carbon | mg/L | 2 | 1.3 | 0.7 | 0.8 | - | - | - |
| Nitrate | mg/L | 0.1 | 0.2 | 0.2 | 0.2 | 2.9 (a2) | - | 45 (d3) |
| Total Phosphorus | mg/L | 0.02 | 0.007 | 0.003 | 0.003 | - | - | - |
| **Metals** | | | | | | | | |
| Aluminum | mg/L | 0.002 | 0.003 | 0.002 | 0.003 | 0.005 or 0.1 (a4) | - | 0.1 (d4) |
| Antimony | mg/L | 0.00006 | 0.00006 | 0.00005 | 0.00005 | - | - | 0.006 (d2) |
| Arsenic | mg/L | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.005 | - | 0.01 (d2) |
| Boron | mg/L | 0.5 | 0.2 | 0.004 | 0.004 | 1.5 | - | 5 (d2) |
| Cadmium | mg/L | **0.00008** | **0.00012** | **0.00011** | **0.00012** | 0.00004 (a5) | 0.000058 (b1) | 0.005 (d2) |
| Chromium | mg/L | 0.0009 | 0.001 | 0.001 | 0.001 | 0.001 (a6) | - | 0.05 (d2) |
| Cobalt | mg/L | 0.00006 | 0.00006 | 0.00005 | 0.00006 | - | - | - |
| Copper | mg/L | 0.0007 | 0.0003 | 0.00007 | 0.00008 | 0.004 (a7) | - | ≤1 (d1) |
| Iron | mg/L | 0.08 | 0.04 | 0.02 | 0.02 | 0.3 | - | ≤0.3 (d1) |
| Lead | mg/L | 0.0001 | 0.00005 | 0.00003 | 0.00003 | 0.007 (a8) | - | 0.01 |
| Manganese | mg/L | 0.03 | 0.02 | 0.008 | 0.009 | - | - | ≤0.05 (d1) |
| Molybdenum | mg/L | 0.0004 | 0.0005 | 0.0005 | 0.0005 | 0.073 | - | - |
| Nickel | mg/L | 0.0002 | 0.0001 | 0.00006 | 0.00006 | 0.15 (a9) | - | - |
| Selenium | mg/L | 0.00009 | 0.00007 | 0.00005 | 0.00005 | 0.001 | - | 0.010 (d2) |
| Silver | mg/L | 0.00002 | 0.00003 | 0.00002 | 0.00003 | 0.0001 | - | - |
| Strontium | mg/L | 0.7 | 0.2 | 0.04 | 0.05 | - | - | - |

| | | Unstratified Conditions | | Stratified Conditions | | Guidelines | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Aquatic Life | | Drinking Water |
| **Parameter** | **Units** | **Orion South Pit Concentration (Year 1000)** | **Orion South Pit Concentration (Year 2500)** | **Orion South Pit Concentration (Year 1000)** | **Orion South Pit Concentration (Year 2500)** | **CCME (2011)** | **SK MOE (2006)** | **Health Canada (2008)** |
| Thallium | mg/L | 0.00006 | 0.00006 | 0.00005 | 0.00005 | 0.0008 | - | - |
| Tin | mg/L | 0.00003 | 0.00003 | 0.00002 | 0.00003 | - | - | - |
| Titanium | mg/L | 0.0002 | 0.0002 | 0.0002 | 0.0002 | - | - | - |
| Uranium | mg/L | 0.00003 | 0.00002 | 0.00002 | 0.00002 | 0.015 | 0.015 $^{(b2)}$ | 0.02 |
| Vanadium | mg/L | 0.00008 | 0.00006 | 0.00004 | 0.00005 | - | - | - |
| Zinc | mg/L | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | - | ≤5 $^{(d1)}$ |

**Note:** Bolded and shaded cells indicate a guideline exceedance.

**Canadian Environmental Quality Guidelines - CEQG (CCME 2007).**

**a1** = Guideline is dependent on temperature and pH. The value ranges between 6.98 mg/L (pH= 7.0, temperature= 15oC) and 48.3 mg/L (pH= 6.5, temperature= 5oC).

**a2** = Guideline is converted to Nitrate-N.

**a3** = Guideline is converted to Nitrite-N.

**a4** = Guideline = 5 µg/L at pH < 6.5, [Ca2+] < 4 mg/L and DOC < 2 mg/L; Guideline = 100 µg/L at pH ≥ 6.5, [Ca2+] ≥4 mg/L and DOC ≥ 2 mg/L.

**a5** = Cadmium guideline = 10[0.86 [log(hardness)] - 3.2].

**a6** = Guideline is for hexavalent chromium (CrVI) because its guideline is more stringent than the trivalent chromium (CrIII) guideline of 8.9 µg/L.

**a7** = Copper guideline is dependent on [CaCO3] with a minimum of 2 µg/L. Guideline = e0.8545[ln(hardness)]-1.465*0.2. Conservatively, the lowest median hardness for this site was used to calculate the guidelines.

**a8** = Lead guideline is dependent on [CaCO3]. Guideline = e1.273[ln(hardness)]-4.705. Conservatively, the lowest median hardness for this site was used to calculate the guideline.

**a9** = Nickel guideline is dependent on [CaCO3]. Nickel guideline is dependent on [CaCO3]. Guideline = e0.76[ln(hardness)]+1.06. Conservatively, the lowest median hardness for this site was used to calculate the guideline.

**Saskatchewan Surface Water Quality Objectives (MOE 2006).**

**b1** = Cadmium Objective: 0.017 ug/L where hardness is 0 - 48.5 mg/L; 0.032 ug/L where hardness is 48.5 - 97; 0.058 where hardness is 97 - 194; 0.10 ug/L where hardness is >194.

**b2** = The objective was developed by the Industrial, Uranium and Hardrock Mining Unit of Saskatchewan Environment.

**Guideline for Canadian Drinking Water Quality - GCDWQ (Health Canada 2008).**

**d1** = Aesthetic objective.

**d2** = Maximum allowable concentration (MAC).

**d3** = Equivalent to 10 mg/L as nitrate-nitrogen. Where nitrate and nitrite are determined separately, levels of nitrite should not exceed 3.2 mg/L.

**d4** = A health-based guideline for aluminum in drinking water has not been established. Operational guidance values of less than 100 µg/L total aluminum for conventional treatment plants and less than 200 µg/L total aluminum for other types of treatment systems are recommended.

### 6.2.7.6 Sediment Quality

*Existing Sediment Quality*

Baseline sediment quality is discussed in Section 5.2.8.

*Potential Effects*

Sediments can act as a sink for water quality parameters by absorption and adsorption onto sediment particles. The rate and amount of change in sediment quality is affected by absorption and adsorption rates, which are a complex combination of physical and chemical processes. As well, the changes in sediment quality parameters will be a non-linear function of the exposure time of the sediment. In fast moving streams, sediment is typically abraded from the stream bed, whereas in slow moving streams sediment may accumulate. There is no universally applicable method to predict resultant sediment quality changes from changes in water quality. Based on water management at the Project site (see Section 2), sediment export will be prevented through routing water to sedimentation ponds (or routing PKCF runoff through natural wetalnds). Runoff and seepage from the overburden pile will flow to the 101 Ravine but sedimentation into 101 Ravine will be prevented, if required, through construction of suitable sediment control structures, such as a sedimentation pond. Discharge to the Saskatchewan River will consist entirely of Mannville groundwater, and will not contain suspended solids.

The overburden pile will consist mostly of till from excavation of the Star pit, with smaller quantities of sand and shale. Site tributaries already flow over till and thus any runoff or seepage from the till fraction of the overburden pile would be expected to be the same as current tributary water quality. The shale has higher conductivity, somewhat elevated chloride and sulphate, and a high sodium adsorption ratio (SAR). To manage these shales, all shales will be buried within the overburden pile by a minimum of 2 m.

Changes in sediment quality from diffuse changes in water quality are complex and not easily predicted. Therefore, to address this scientific uncertainty, Shore commits to monitor sediment quality in the receiving environment during construction and operations (see Section 7.4). If an increasing trend in sediment concentrations is observed that can reasonably be ascribed to mine operations, appropriate management actions will be developed and implemented.

### 6.2.7.7 Potential Effects of Road Transportation

The main mine access road will, for the most part, follow an existing road to minimize new disturbance caused by the Project (see Section 2.0). New construction and upgrades will employ standard practices to minimize sediment transport into water bodies such as silt fences and temporary sedimentation ponds where required; construction during extreme weather conditions will be avoided. The crossing of the White Fox River will follow Fisheries and Oceans Operational Statements for Saskatchewan, which should result in no significant impacts to these water bodies. A list of applicable statements follows:

- Bridge Maintenance;
- Clear-Span Bridges;
- Culvert Maintenance; and
- Isolated or Dry Open-cut Stream Crossings.

Barring accidental spills on the access road, water and sediment quality will not be affected by construction or operation of the mine access road. An approved spill and emergency response plan exists for Shore exploration activities at the Project site and the plan was amended as required for the conceptual plan provided in this EIS (see Section 7).

#### 6.2.7.8 Mitigation and Management

***Mine Site***

Water management for the Project is discussed in Section 2.0. The objectives of the plan are to minimize the use of fresh surface water, to route non-contact water to the extent practical around the Project facilities, to recycle process water to the plant, and direct PKCF seepage to natural wetlands for treatment. Table 6.2.7-9 provides a summary of the key control measures proposed that mitigate water quality potential effects. Discharge of Mannville groundwater through the multi-port diffuser will mitigate changes in water quality in the Saskatchewan River and is therefore the preferred option, as described in Section 3.

*Table 6.2.7-9: Waste and Water Potential Impact Mitigation Measures*

| Mining Phase | Potential Effect | Mitigation and Management | Success Rating | Residual Effects | Significance |
|---|---|---|---|---|---|
| Construction | Sediment export | Clean water ditches will divert non-contact water around site construction or temporary sedimentation ponds will be constructed and water released in the nearby watercources. | High | Low | Not Significant |
| Construction | Sediment export | For construction of the Star pit and Orion South pit the water will be diverted around pits. Water from East Ravine will be intercepted and collected upstream from Star pit in the runoff pond. | High | Low (some minor export of sediment downstream is possible a sedimentation pond will be constructed in the diversion if site investigations indicate significant loss of sediment from the diversion) | Not Significant |
| Operation | Proximity to mining operations may cause reduction in water quality of tributaries due to dust fall | Fugitive dust will be minimized by watering or other controls | High | Low | Not Significant |
| Operation | Runoff and seepage from PKCF and Coarse Pile may cause reduction in water quality of tributaries | Seepage will be collected in perimeter ditches and pumped to the PKCF or treated in wetlands and released if acceptable. Wetland treatment can be applied for coarse kimberlite pile if necessary | High | Low (some potential effects from seepage) | Not Significant |
| Operation | Effluent | A diffuser will be | High | Low (some | Not |

| Mining Phase | Potential Effect | Mitigation and Management | Success Rating | Residual Effects | Significance |
|---|---|---|---|---|---|
| | discharge may cause reduction in Saskatchewan River water quality | employed which will result in acceptable water quality being reached a short distance downstream from the diffuser | | reduction in water quality is likely to occur in an immediate proximity to the diffuser) | Significant |
| Operation | Treated sewage may cause reduction in water quality | Treated sewage will be discharged through leachfield | High | Negligible | Not Significant |
| Closure | Sediment export | During decommissioning the PKCF will be reclaimed and become a part of Duke Ravine watershed. | High | Negligible | Not Significant |
| Closure | Metals, sediment export | Site runoff will be directed to the Star pit forming a pit lake | High | Low | Not Significant |
| Post Closure | Star pit Lake water quality and reduction of Saskatchewan River water quality | Star pit lake overflow water will be discharged directly to the Saskatchewan River as the water quality is predicted to be acceptable or contained behind a water retention structure if required. | High | Low (water quality would be maintained at levels equivalent to those maintained during operations) | Not Significant |
| Post Closure | Orion South pit lake water quality | Orion South pit Lake will be a closed lake and no water released to the environment | High | Low | Not Significant |

### *Access Road*

#### *Construction*

The mitigation for potential impacts from construction will be to use best management practices per DFO Operational Statements and standard construction practices for the general areas of the road improvements. All road areas will be ditched. Ditches on gradients greater than 10% (5º) will be rip-rapped if required to prevent erosion, and on a case-by-case basis on lower grades. Where new right-of-ways are required, sedimentation ponds will be used if required to prevent sediment export into water bodies. During heavy rains, construction will cease near water bodies and sediment control structures will be checked for adequate functioning through such periods.

*Operation*

During operation, ditches, culverts and bridge abutments will be maintained in good working order. Any sediment, debris or plant accumulations in ditches and culverts will be removed on a timely basis to prevent failures causing erosion and sedimentation into water bodies. Accidental spills will be cleaned up immediately, per the spill and emergency response plan (see Section 7.0). Use of de-icing salt will follow Saskatchewan government guidelines.

*Closure*

Most of the access road will be along a public right-of-way. The access road is expected to remain at closure, however decommissioning may be considered based on public engagement in the future.

#### 6.2.7.9 Residual Effects Assessment

Residual effects on water quality after mitigation forecasted to be not significant (see Table 6.2.7-8, above). All federal and provincial guidelines forecasted to be met or are expected to fall within the natural variability of the Saskatchewan River and streams potentially affected by the project.

### 6.2.8 Environmental Health

During mining operations, process water will be managed within the PKCF and recycled to the plant as needed. Make up water will be taken from the pit dewatering system. Excess dewatering water (consisting of primarily Mannville aquifer water) is proposed to be discharged to the Saskatchewan River via a diffuser. Shallow aquifer water will be used for site purposes, to supplement low flows in LSA ravines, or discharged to the environment. The water management strategy is described in detail in Section 2, based on an analysis of alternatives presented in Section 3.

Using a general screening level risk assessment framework, the following provides an evaluation of potential discharge water quality in relation to criteria considered relevant to environmental health.

#### 6.2.8.1 Screening and Identification of Chemicals of Potential Concern in Surface Water

Chemicals of Potential Concern (COPC) in surface water were identified by screening maximum concentrations in the Mannville aquifer ground water against the Saskatchewan Environment interim Surface Water Quality Objectives SWQOs (Saskatchewan Environment

2006). The data considered most representative of operational discharges were obtained from the pump testing of the prototype dewatering well constructed between Star and Orion South in late 2010 Additional information was considered from the exploration phase (Appendix 6.2.8-A). Other water quality information was taken from the surface water model described in Section 6.2.7. For parameters where a SWQO was not available, toxicity-based guidelines for the protection of aquatic life in surface water were obtained from the following sources, in order of preference:

- Canadian Council of Ministers (CCME) Water Quality Guidelines for the Protection of Aquatic Life (CWQG) (CCME1999, update 2007);
- Alberta Environment Surface Water Quality Guidelines for use in Alberta(1999);
- British Columbia Ministry of Environment Approved Water Quality Guidelines (2006);
- Ontario Ministry of the Environment MOE (2009), Aquatic Protection Values;
- US EPA National Recommended Water Quality Criteria (2006); and
- Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota (Suter and Tsao 1996).

For metals, the total concentrations in surface water were used in the chemical screening as aquatic receptors are likely to be exposed to metals in both the dissolved state and suspended solid. While dissolved metals concentrations are most relevant to aquatic organism exposure, regulatory authorities usually require comparisons to the more conservative total metals concentrations as being representative of the maximum possible exposure concentration.

Any chemical for which the maximum concentration exceeded the relevant guideline, or the detection limit exceeded the guideline, was carried forward and discussed further unless otherwise indicated (Table 6.2.8-1). It also should be noted that, in general, the undiluted final discharge must be non-acutely toxic based on 96-hour LD50 tests for rainbow trout and EC48 tests for *Daphnia* prior to being considered suitable for release to the environment.

***Table 6.2.8-1: Identification of COPCs in Surface Water Discharge***

| Parameter | Units | Mean | Maximum | SWQO | CWQG | Other Guidelines | COPC? |
|---|---|---|---|---|---|---|---|
| **Inorganic Ions** | | | | | | | |
| Bicarbonate | mg/L | 390 | 464 | - | - | - | YES |
| Calcium | mg/L | 108 | 131 | - | - | 116[f] | **YES** |
| Carbonate | mg/L | 0.5 | 0.5 | - | - | - | **YES** |
| Chloride | mg/L | **1212** | **1623** | - | 128** | - | **YES** |
| Fluoride | mg/L | 2 | 2 | - | 0.12 | - | **YES** |
| Hydroxide | mg/L | 0.5 | 0.5 | - | - | - | **YES** |

| Parameter | Units | Mean | Maximum | SWQO | CWQG | Other Guidelines | COPC? |
|---|---|---|---|---|---|---|---|
| Magnesium | mg/L | 35 | 44 | - | - | 82[f] | No |
| Potassium | mg/L | 40 | 53 | - | - | 53[f] | **YES** |
| Sodium | mg/L | **876** | **1165** | - | - | 680[f] | **YES** |
| Sulfate | mg/L | **537** | **707** | - | - | 100[g] (Based on dissolved) | **YES** |
| **Metals** | | | | | | | |
| Aluminum | mg/L | 0.003 | 0.006 | 0.1[a] | 0.1[d] | - | **No** |
| Antimony | mg/L | 0.0001 | 0.0002 | - | - | 1.6[h] | No |
| Arsenic | ug/L | 0.0003 | 0.0007 | 5 | 5 | - | No |
| Barium | mg/L | 0.08 | 0.3 | - | - | 2.3[h] | No |
| Beryllium | mg/L | 0.00005 | 0.00005 | - | - | 0.0053[h] | No |
| Boron | mg/L | 1.4 | **1.8** | - | - | 1.2[g] | **YES** |
| Cadmium | mg/L | 0.00006 | **0.0003** | 0.00006[b] | 0.00006[b] | - | **YES** |
| Chromium | mg/L | 0.0008 | **0.003** | 0.001[c] | 0.001[c] | - | **YES** |
| Cobalt | mg/L | 0.0001 | 0.0001 | | | 0.11[g] | **No** |
| Copper | mg/L | 0.002 | 0.002 | 0.003[b] | 0.003[b] | - | **YES** |
| Iron | mg/L | 0.2 | 0.2 | 0.3 | 0.3 | - | **YES** |
| Lead | mg/L | 0.0002 | 0.0003 | 0.004[b] | 0.004[b] | - | **No** |
| Manganese | mg/L | **0.06** | **0.08** | - | - | <1.1[f] | **No** |
| Molybdenum | mg/L | 0.001 | 0.01 | - | 0.073 | - | No |
| Nickel | mg/L | 0.0005 | 0.001 | 0.10[b] | 0.10[b] | - | **No** |
| Selenium | mg/L | 0.0002 | 0.0007 | 0.001 | 0.001 | - | **No** |
| Silver | mg/L | 0.00002 | 0.00005 | 0.0001 | 0.0001 | - | **No** |
| Strontium | mg/L | 1.8 | 2 | - | - | 42[f] | No |
| Thallium | mg/L | 0.0001 | 0.0001 | - | 0.0008 | - | No |
| Tin | mg/L | 0.003 | 0.006 | - | - | 0.35[f] | No |
| Titanium | mg/L | 0.0002 | 0.0005 | - | - | - | **YES** |
| Uranium | ug/L | 0.00008 | 0.0003 | 15 | - | - | No |
| Vanadium | mg/L | 0.001 | 0.005 | - | - | 0.02[h] | **No** |
| Zinc | mg/L | 0.02 | **0.07** | 0.03 | 0.03 | - | **YES** |

*Table 6.2.8-2: Identification of COPCs in Surface Water Discharge (cont'd)*

| Parameter | Units | Mean | Maximum | SWQO | CWQG | Other Guidelines | COPC? |
|---|---|---|---|---|---|---|---|
| **VOCs** | | | | | | | |
| Benzene | ug/L | Below MDL | Below MDL | - | 370 | - | No |
| Ethylbenzene | ug/L | Below MDL | Below MDL | - | 90 | - | No |
| HydrocarbonsF1(C6-C10) | ug/L | Below MDL | Below MDL | - | - | 190 | No |
| HydrocarbonsF2(C10-C16) | ug/L | Below MDL | Below MDL | - | - | 152 | No |
| HydrocarbonsF3(C16-C34) | ug/L | Below MDL | Below MDL | - | - | - | **No** |
| HydrocarbonsF4(C34-C50) | ug/L | Below MDL | Below MDL | - | - | - | **No** |
| Toluene | ug/L | Below MDL | Below MDL | - | 2 | - | No |
| Xylene | ug/L | Below MDL | Below MDL | - | - | 330 | No |
| Oil & Grease | mg/L | Below MDL | Below MDL | - | - | - | **No** |
| **Nutrients** | | | | | | | |
| Ammonia as nitrogen | mg/L | 1.4 | 1.9 | 0.502[d] | 0.502[d] | - | **YES** |
| Nitrate | mg/L | 0.02 | 0.04 | - | 13 | - | No |
| Total phosphorus | mg/L | 0.04 | **0.05** | - | Framework | 0.05[i] | **YES** |
| **Physical Properties** | | | | | | | |
| Specific conductivity | uS/cm | 4618 | 5916 | NA | NA | NA | NA |
| Total alkalinity | mg/L | 337 | 384 | - | - | >20[j] | No |
| Total dissolved solids | mg/L | **2865** | **3781** | - | - | - | **YES** |
| Total hardness | mg/L | 421 | 506 | - | - | - | **YES** |

**Notes:** [1]

[a] Based on a pH ≥6.5; Ca ≥ 4 mg/L and DOC ≥ 2 mg/L

[b] Based on a water hardness of 150 mg/L

[c] Assumed to be chromium (VI)

[d] Assuming a pH of 8.5 and Temperature of 5°C

**Currently in Draft, based on long-terms effects

[e] Based on a pH ≥6.5

[f] Suter and Tsao (1996)

[g] British Columbia Ministry of the Environment (2006)

[h] Ontario Ministry of the Environment, Aquatic Protection Values (2009)

[I] Alberta Environment (1999)

[j] US EPA National Recommended Water Quality Criteria (2006)

Bolded values are greater than SSWQO (SE 2006) and/or CWQG (CCME 2007).

Note: 1) Data from water quality modeling (Section 6.2.7).

NA-Not applicable.

There is no guideline for bicarbonate, but it was not considered a COPC since maximum concentrations in the discharge (464 mg/L) are greater than the maximum bicarbonate concentrations in the Saskatchewan River (Appendix 6.2.8-B).

Parameters in surface water identified as COPCs, as presented in Table 6.2.8-2, were addressed further.

### 6.2.8.2 Ecological Conceptual Site Exposure Model and Potential Receptors at the Site

Site runoff will be managed as described in Section 2. Based on the hydrology modeling presented in Section 6.2.4 and water quality modeling in Section 6.2.7, site runoff will most affect flows and water quality in the Duke Ravine. Water not needed in the plant will be discharged into the Saskatchewan River, where COPCs will mix with surface water and may deposit in sediments. Generic ecological receptors that reside in the Saskatchewan River and be exposed to the COPCs include aquatic plants, aquatic and benthic invertebrates, fish, and semi-aquatic birds (e.g. waterfowl) and mammals (e.g. muskrat) via direct contact with affected media, ingestion of affected prey, and incidental ingestion of affected media. Terrestrial receptors (e.g. soil invertebrates such as earthworms, songbirds, and mammals such as hares) have minimal contact with aquatic habitats and thus the exposure pathway for these receptors is considered incomplete.

#### *Exposure Estimates for Aquatic Receptors*

Concentrations identified in water samples collected from the Mannville formation in 2010 and modeling of operational flows were used to estimate maximum exposure to aquatic receptors in the Saskatchewan River, and maximum modelled concentrations in the Duke Ravine were used to estimate exposure to aquatic receptors in the Duke Ravine. The use of the maximum concentration is likely to be conservative as the modelled concentrations in Section 6.2.7 are generally lower. Considering that concentrations of most COPCs in the Saskatchewan River are below the SWQO, the Saskatchewan River will have an assimilative capacity.

#### *Risk Characterization*

Characterization of risk to ecological receptors in a screening level ecological risk assessment can employ qualitative or quantitative methods. Hazard Quotients (HQ) are a simple approach that provide a quantitative estimate of potential risk. The HQ is a unitless value defined as the ratio of the magnitude of exposure to magnitude of a standard effect:

$$Hazard\ \ Quotient\ = \frac{Exposure\ \ Estimate}{TRV}$$

TRV: toxicity reference value.

Exposure ratios are interpreted as follows: if the HQ is less than 1, no unacceptable risks to ecological receptors would be expected, because concentrations are below levels known to cause adverse effects. Conversely, if the HQ exceeds 1, it may be inferred that adverse effects to individuals are possible. It is important to note that exceeding an HQ of 1 does not necessarily mean adverse effects will occur; rather, it suggests that we have less confidence that adverse effects will not occur. For a variety of reasons, adverse effects demonstrated in laboratory studies often fail to manifest in the field as a measurable or meaningful impact. It is also important to recognize that the magnitude of HQs are not directly associated with the magnitude of potential effects. That is, a large HQ (>10) should not be interpreted as a 10-fold greater risk than an HQ of one.

For those COPCs with HQs greater than 1, potential risks at a population level cannot be ruled out and should be evaluated further.

Risks to aquatic receptors were estimated by comparing the exposure concentration (i.e., maximum concentration of the COPCs in the effluent discharge) to a surface water guideline or toxicity value protective of aquatic life (as identified in the chemical screening). Risks using the mean exposure concentration were also provided for comparison (Table 6.2.8-3).

***Table 6.2.8-3: Risk Estimates for Aquatic Receptors in the Saskatchewan River during Operations***

| Parameter | Units | Maximum | Mean | SWQO (SE, 2006) | CWQG (CCME, 2007) | Other Guidelines | HQ (max) | HQ (mean) |
|---|---|---|---|---|---|---|---|---|
| Calcium | mg/L | 50 | 49 | | | 116 | 0.4 | 0.4 |
| Carbonate | mg/L | 4 | 4 | - | - | - | NV | NV |
| Chloride | mg/L | 32 | 26 | - | 128** | - | 0.2 | 0.3 |
| Fluoride | mg/L | 0.2 | 0.2 | - | - | - | NV | NV |
| Hydroxide | mg/L | 1 | 1 | - | - | - | NV | NV |
| Potassium | mg/L | 4 | 4 | - | - | 53[f] | 0.1 | 0.1 |
| Sodium | mg/L | 38 | 33 | - | - | 680[f] | 0.05 | 0.1 |
| Sulfate | mg/L | 78 | 75 | - | - | 100[g] (Based on dissolved) | 0.8 | 0.8 |
| Boron | mg/L | 0.06 | 0.06 | - | - | 1.2[g] | 0.1 | 0.1 |
| Cadmium | mg/L | **0.00009** | **0.00008** | 0.00006[b] | 0.00006[b] | - | **1.5** | **1.3** |
| Chromium | mg/L | **0.002** | **0.002** | 0.001[c] | 0.001[c] | - | **2.0** | **2.0** |
| Copper | mg/L | 0.002 | 0.002 | 0.003[b] | 0.003[b] | - | 0.7 | 0.7 |
| Iron | mg/L | 0.07 | 0.7 | 0.3 | 0.3 | - | 2.3 | 2.3 |
| Titanium | mg/L | 0.008 | 0.008 | - | - | - | NV | NV |
| Zinc | mg/L | 0.01 | 0.01 | 0.03 | 0.03 | - | 0.3 | 0.3 |
| Ammonia as nitrogen | mg/L | 0.07 | 0.07 | 0.502[d] | 0.502[d] | - | 0.1 | 0.1 |
| Total phosphorus | mg/L | 0.1 | 0.1 | - | - | - | NV | NV |
| Total dissolved solids | mg/L | 320 | 306 | - | - | - | NV | NV |
| Total hardness | mg/L | 196 | 195 | - | - | - | NV | NV |

**Notes:** [1]N = number of samples analyzed.

[a]Based on a pH ≥6.5; Ca ≥ 4 mg/L and DOC ≥ 2 mg/L

[b]Based on a water hardness of 150 mg/L

[c]Assumed to be chromium (VI)

[d]Assuming a pH of 8.5 and Temperature of 5°C

**Currently in Draft, based on long-terms effects

[e] Based on a pH ≥6.5

[f] Suter and Tsao (1996)

[g] British Columbia Ministry of the Environment (2006)

[h] Ontario Ministry of the Environment, Aquatic Protection Values (2009)

[I] Alberta Environment (1999)

[j] US EPA National Recommended Water Quality Criteria (2006)

Bolded values indicate the HQ >1

Note: 1) Data from the prototype dewatering well testing.

NA-Not applicable.

Risks due to carbonate, fluoride, hydroxide, titanium, total phosphorus, total dissolved solids (TDS), and total hardness in the estimated surface water of the Saskatchewan River are not calculated since no TRVs are available.

Hazard Quotients based on maximum concentrations are near or below 1 for COPCs listed in Table 6.2.8-3. HQs for cadmium (1.5) and chromium (2) are marginally above 1, indicating that adverse ecological effects are very unlikely. HQs above 1 represent the order of magnitude by which the concentration of each COPC exceeds the guideline. As such, for a HQ greater than one, they also represent how much the concentration of each COPC would need to be reduced to in order to meet guidelines ( i.e., be assumed not to have any significant effects).

For the most part, the HQs generated in the risk characterization phase of the SLRA should be considered to be quite conservative (i.e., HQs greater than one do not necessarily mean toxicity is occurring at the Site). There is greater inherent uncertainty associated with results of screening level assessments than higher-tier assessments. Areas of conservatism and uncertainty include the exposure values and guidelines employed, as discussed further below.

The maximum concentration was used to assess exposure, which is conservative. The exposure estimates of the discharge do not take into consideration the dilution/attenuation in the Saskatchewan River. In addition, the HQs do not account for conditions in the receiving environment (e.g., baseline water quality in the Saskatchewan River naturally exceeds the TRV for chromium and cadmium). However, the exposure estimates do provide an indication of the degree of attenuation/dilution required prior to the point of compliance to meet protection of freshwater aquatic life guidelines.

In 2010, AMEC conducted a modeling study to evaluate mixing of discharge water in the Saskatchewan River for chloride from a proposed outfall near the mouth of the FalC Ravine, under a variety of flow conditions. A comprehensive field program, including assessments of bathymetry, water levels, flow velocities and discharge, was conducted in a study reach extending 1 km upstream of the proposed outfall and 6.5 km downstream. Using data collected during the survey, a two-dimensional hydrodynamic model was created to model various flow scenarios for consideration during design of the outfall structure and dispersion modeling. Hydrological analysis was also carried out using historical data from the North and South Saskatchewan River to conduct 7Q10 (1:10 year seven-day open water low flow) low flow analysis. Using data collected during the surveys, the mixing of discharge water into the Saskatchewan River was modeled under 7Q10 and for annual average flow conditions. Mixing ratios were calculated based on average (439 $m^3/s$) and 7Q10 (188 $m^3/s$) flows in the Saskatchewan River. Dispersion of chloride in average and 7Q10 flows was modeled for predicted chloride concentrations of 1775 mg/L (which is higher than the revised maximum concentration) in the discharge water at a rate of 2.3 $m^3/s$. Background chloride concentrations in the river used for dispersion modelling were 10 mg/L during 7Q10 flows and 7 mg/L for average flows.

Quantitative mass balance modelling was conducted for all water quality parameters measured in background studies (Section 6.2.7). The model predicted water quality in the Saskatchewan River based on diffuser discharge and provided results for a range of scenarios include dry, normal and wet years for various mining stages. The conclusions from modelling were that, at 40 m downstream from the discharge, all provincial and federal guidelines for the protection of freshwater aquatic life would be met with the exception of those parameters which nautrally exceeded guidelines in the baseline scenario. (see Section 6.2.7 for a discussion).

Evaluation of modeled water quality in Duke Ravine under possible post-closure scenarios (Table 6.2.8-4) indicate that concentrations of cadmium, chromium and zinc, may be above selected water quality guidelines. However, concentrations are within a factor of 3 of benchmarks (*i.e.* HQs < 3) indicating that risk of adverse effects is low.

***Table 6.2.8-4: Risk to Aquatic Receptors in Duke Ravine Post-Closure.***

| Parameter | Units | Selected Guidelines | Result | HQ |
|---|---|---|---|---|
| **Conventional Parameters** | | | | |
| Chemical oxygen demand | mg/L | | 162 | NC |
| Specific conductivity | µS/cm | | 404 | NC |
| Total dissolved solids | mg/L | | 254 | NC |
| **Major Ions** | | | | |
| Carbonate | mg/L | | 1.8 | NC |
| Chloride | mg/L | 128 | 11 | 0.09 |
| Fluoride | mg/L | 0.12 | 0.1 | 0.8 |
| Hydroxide | mg/L | | 0.5 | NC |
| Potassium | mg/L | 53 | 1.2 | 0.02 |
| Sodium | mg/L | 680 | 8 | 0.01 |
| Sulfate | mg/L | 100 | 7 | 0.07 |
| **Nutrients** | | | | |
| Ammonia as nitrogen | mg/L | 0.502 | 0.03 | 0.06 |
| Dissolved organic carbon | mg/L | | 4 | NC |
| Total Organic Carbon | mg/L | | 4 | NC |
| Total Phosphorus | mg/L | 0.05 | 0.03 | 0.6 |
| **Metals** | | | | |
| Aluminum | mg/L | 0.1 | 0.04 | 0.4 |
| Bismuth | mg/L | | 0.00006 | NC |
| Boron | mg/L | 1.2 | 0.02 | 0.02 |
| Cadmium | mg/L | 0.00006 | 0.0002 | 3 |
| Cesium | mg/L | | 0.00004 | NC |

| Parameter | Units | Selected Guidelines | Result | HQ |
|---|---|---|---|---|
| Chromium | mg/L | 0.001 | 0.002 | 2 |
| Cobalt | mg/L | 0.11 | 0.0002 | 0.002 |
| Copper | mg/L | 0.003 | 0.0004 | 0.1 |
| Iron | mg/L | 0.3 | 0.3 | 1 |
| Lead | mg/L | 0.004 | 0.0002 | 0.05 |
| Manganese | mg/L | 1.1 | 0.1 | 0.09 |
| Mercury | mg/L |  | 0.0002 | NC |
| Nickel | mg/L | 0.1 | 0.0005 | 0.005 |
| Selenium | mg/L | 0.001 | 0.0002 | 0.2 |
| Silver | mg/L | 0.0001 | 0.00006 | 0.6 |
| Tellurium | mg/L |  | 0.0002 | NC |
| Titanium | mg/L |  | 0.002 | NC |
| Tungsten | mg/L |  | 0.00006 | NC |
| Vanadium | mg/L | 0.02 | 0.0004 | 0.02 |
| Zinc | mg/L | 0.03 | 0.05 | 2 |
| Zirconium | mg/L |  | 0.0002 | NC |

### 6.2.8.3 Toxicity Testing of Discharge Water

Due to the inherent uncertainty in predicting toxicological responses from literature studies, there is some uncertainty associated with toxicity reference values. In most cases, toxicity-based guidelines are assumed to be conservative. This is because most reference values are based on the most sensitive species tested or a similar low effect level (e.g., 10th or 25th percentile of species sensitivity distribution), and toxicity tests upon which they are based are typically conducted under conditions that maximize toxicity (i.e., the use of soluble metal salts). The use of laboratory toxicity tests can reduce the uncertainty associated with the use of guidelines in assessing risks. Acute toxicity testing is required under the Metal Mining Effluent Regulations, and is also required for permitted operating diamond mines in Canada. Further discussion can be found in Section 3.5.1. Additionally, any discharge must meet the requirements of the *Fisheries Act.* A detailed discussion of the applicability of the toxicity within the context if the Act is also presented in Appendix 6.2.8-E.

Two separate toxicological studies have been carried out for the Project. The first was conducted in 2007 based on testing of process water coming from the exploration plant, and can be considered representative of process water in the PKCF (Appendix 6.2.8-D). A second round of testing was initiated as a result of review comments and changes to the water management strategy in 2011. The 2011 testing focused on establishing the toxicity of the Mannville formation water (Appendix 6.2.8-E).

In 2007, toxicity testing of water discharged from the exploration shafts (MWS-01) was conducted by CanNorth Environmental Services (CanNorth, 2008). Toxicity tests were conducted using protocols specified in the Canadian *Metal Mine Effluent Regulations*. Toxicity testing involved two acute and four sublethal exposure tests. Acute toxicity tests included a 96hr LC50 using rainbow trout (*Oncorhynchus mykiss*) and a 48hr LC50 with *Daphnia magna.* While these species do not necessarily inhabit a receiving body, the MMER assume that they are appropriate surrogates for species that actually do inhabit a receiving body.

Sublethal toxicity tests included a 7 day IC25 (inhibition concentration) (survival and reproduction) using *Ceriodaphnia dubia*, a 7 day IC25 (survival and growth) of fathead minnow (*Pimephales promelas*), a 72 hour IC25 (growth) using green algae (*Selenastrum capricornutum*) and a 7 day IC25 (growth) using lesser duckweed (*Lemna minor*). Various concentrations of discharge water were used during acute (i.e. dilution factor of 0.5) and sublethal tests (i.e. dilution factor 0.3); concentrations were selected to be representative of actual concentrations upon dilution in the Saskatchewan River under various flow conditions. Water samples were analyzed for various water quality parameters and indicated that aluminum, total ammonia, cadmium, chloride, chromium, fluoride and selenium exceeded the SWQO and CWQGs (Appendix 6.2.8-A). The toxicity test report is provided in Appendix 6.2.8-D.

No mortality was observed at 100% concentration in rainbow trout or *Daphnia magna* during the 96hr LC50 tests, while no adverse effects in terms of fathead minnow survival or growth and on green algae growth were evident in the sublethal tests.

Lesser duckweed growth was not affected at 97% concentrations of the MWS-01 water, but did show decreased frond growth at 53.7% in sublethal exposure tests, while, *C. dubia* showed a reduced survival at an LC50 at 16.4% and reduced reproduction (IC25) at 4.1% effluent concentration.

The *Metal Mining Effluent Regulations* (*MMER*), promulgated under the federal *Fisheries Act*, prohibits the discharge of effluent that is acutely lethal to fish (rainbow trout). The above toxicity tests indicate that the undiluted effluent from the process plant to the PKCF does not appear to be acutely toxic to rainbow trout or *D. magna*.

With the changes to the water management system, a second round of toxicity testing was requested by Environment Canada on the Mannville water. Since process water is no longer being proposed for direct discharge, water quality will no longer be influenced by processing or interactions with kimberlite. Testing included acute testing of *Daphnia magna* and rainbow trout and chronic testing of fathead minnows and *Ceriodaphnia dubia.* Additional testing was conducted to further explore the relationship between hardness effects and toxicity in *Ceriodaphnia dubia.* A detailed discussion of the toxicity testing is presented in Appendix 6.2.8-E. Conclusions of the detailed analysis are summarized below.

Acute toxicity tests conducted with *Daphnia magna* and rainbow trout indicate that Mannville Formation water is non-deleterious. Chronic toxicity tests conducted with fathead minnow indicated that Manville Formation water is non-toxic. While *Ceriodaphnia dubia* did exhibit some chronic effects, results were given a low weight due to numerous site-specific uncertainties. The use of chronic toxicity tests to determine whether mining effluent is ‘deleterious’ has heretofore been unprecedented in Canada, and should be given low weight based on the evidence presented in Appendix 6.2.8-E.

Furthermore, most environmental effects may be reduced, even eliminated, by incorporating a diffuser for discharge to the receiving body and allowing for consideration of a mixing zone within the river (as is standard practice with other mines) combined with monitoring and field studies to confirm effects on field-based early-warning indicators and prior to effluent management.

Lake sturgeon, which inhabit the Saskatchewan River, were given additional consideration because of their protected status. A review of the scientific literature and the results of the acute and chronic fish toxicity tests suggest that Mannville Formation water would not be deleterious to lake sturgeon even absent the ameliorating effects of dilution through the proposed diffuser. Further effects on fish are described in Section 6.3.1.

Considering the results of the SWQO concentration comparisons, toxicity tests, and lake sturgeon evaluation, the weight of evidence indicates that Mannville Formation water should be considered non-deleterious.

#### 6.2.8.4 Summary

This assessment, through use of hazard quotients, has provided a measure of the dilution required for the water to meet receiving environment guidelines. Effluent discharged from mines in Canada must be non-acutely toxic to rainbow trout and the water flea *Daphnia*. Based on toxicity tests conducted as part of this environmental assessment, neither water from the process plant to the PKCF, nor the Mannville water discharged to the Saskatchewan River through the diffuser, are acutely toxic and would be able to be discharged undiluted based on that criterion. Detailed discussion about the applicability of chronic testing is provided in Appendix 6.2.8-E. Mine discharge water is typically regulated at a point downstream of the discharge. . With use of a multi-port diffuser in the Saskatchewan River, all parameters which do not naturally exceed guidelines in the baseline conditions are forecast to be below guidelines within 40 m of the diffuser.