SECTION 5.2

PHYSICAL ENVIRONMENT

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5.2 PHYSICAL ENVIRONMENT

This Section describes the physical aspects of the Project setting that could be affected by Project development. This includes baseline studies describing the geology; air quality and climate; noise; surface water; and groundwater settings.

5.2.1 Deposit and Local Area Geology

This Section of the EIS presents a description of the deposit geology, including an introduction to the regional geology, the FalC area and the Star and Orion South Kimberlites.

The geological setting and geology of the Star and Orion South Kimberlites have been summarized in previous technical reports by P&E (2010), P&E (2009a, 2009b), Eggleston et al. (2008) and Leroux (2008a, 2008b) and in journal format by Harvey et al. (2009) and Kjarsgaard et al. (2009).

5.2.1.1 Regional Geology

The kimberlites lie near the north-eastern edge of the Phanerozoic Interior Platform, which extends from the Rocky Mountains in the west, to the Precambrian Canadian Shield in the northeast, outcropping near Lac La Ronge. The Interior Platform sediments exceed 600 m in thickness, reaching 1,000 m in the northwest part of the areas. The unmetamorphosed sedimentary rocks of the Interior Platform unconformably overlie metamorphosed basement rocks (Figure 5.2.1-1). These Precambrian basement rocks have been interpreted to form part of the Paleoproterozoic Glennie Domain which is thrust overtop of the Archean micro-continent known as the Sask Craton (Chiarenzelli et al. 1997).

The Phanerozoic cover sequence consists of 450 m thick Cambro-Devonian basal unit of dolomitic carbonate and clastic sedimentary rocks overlain by 170 m of Cretaceous shale and sandstone (Figure 5.2.1-2). In the vicinity of the kimberlites, the area is overlain by Quaternary glacial deposits ranging from 40 to 120 m. The sedimentary formations dip gently to the south-southwest bringing progressively younger strata into contact with the Quaternary glacial till towards the southwest. In the FalC area, the Cretaceous rocks comprise three distinct formational units, in descending succession from southwest to northeast (Figure 5.2.1-3 and Table 5.2.1-1).

Table 5.2.1-1: Cretaceous Rocks Hosting the Star and Orion South Kimberlites

Age	Group / Formation
Cenomanian	upper Colorado Group, Fish Scales and Belle Fourche Formations
Albian	lower Colorado Group, Joli Fou and Westgate Formations (shale and lesser sandstone)
Albian	Mannville Group, Cantuar and Pense Formations (continental to marginal marine sandstone and shale)

Note: Rock units are arranged in descending order, from southwest to northeast.

5.2.1.2 Regional Overburden and Country Rock

Utilizing 74 regional hydrocarbon and mineral exploration holes, coupled with geophysics, a regional country rock model for the FalC area has been developed (Figure 5.2.1-3). The country rock model includes (from deepest to shallowest) the Paleozoic Carbonate the Mannville Group (Cantuar and Pense formations), lower Colorado Group (Joli Fou and Westgate formations) and glacial overburden (Sutherland and Saskatoon groups (tills) and the upper stratified drift (2 to 6 layers of sand and clay). Regional drilling indicates a consistent stratigraphy with regional dips towards the south of less than 2 degrees.

An electromagnetic airborne survey identified a potential paleochannel north of the Orion North kimberlite complex which was subsequently proven by drilling (Figures 5.2.1-4 and 5.2.1-5). The paleochannel is interpreted to be approximately 3,000 m across and up to 150 m in thickness. This thickness results in the paleochannel sediments being in direct contact with Mannville Group sediments at depth.

Fort à la Corne Area

A northwest-trending kimberlite province covering a 50 km by 30 km area has been identified in the FalC area. These kimberlites have clearly defined magnetic anomaly signatures within a background of low magnetic intensity. Approximately 69 kimberlitic bodies have been drilled to date, with the majority of discovered kimberlite bodies occurring within the extensive FalC Main Trend.

The FalC kimberlites were emplaced into poorly consolidated Cretaceous clastic and marine sedimentary rocks. The kimberlite bodies themselves typically occur as stacked, subhorizontal lenses or shallow zones of crater facies kimberlite with footprints ranging up to 2,000 m wide and occur at depths ranging from 100 m to greater than 700 m. Limited deep drilling precludes interpretation of the shape of the kimberlites below about 350 m. At depth, FalC kimberlites may resemble the idealized South African kimberlite model. While both hypabyssal and volcaniclastic kimberlitic facies have been intersected by drilling, their inter-relationship is not well known. It is possible that the former represent either late stage pulses or even xenolithic blocks.

Individual kimberlite phases (or units) may be distinguished according to mineralogy, grain size, style of emplacement, xenoliths types and abundances, alteration and the abundance of olivine macrocrysts.

In general, the main volcaniclastic kimberlite deposits were preceded by smaller eruptive events comprising conformable, graded beds of pyroclastic debris as much as 40 m thick, indicative of subaerial eruption onto Albian (Middle Cretaceous) floodplains, intertidal zones, or lakes. Subsequently, larger, shallow craters were excavated in poorly-consolidated marine to marginal-marine shale under subaerial to shallow marine conditions and backfilled with pyroclastic sediments forming multiple-graded kimberlitic beds. Kimberlitic pyroclastic flows, erupted at the time of crater excavation, producing stacked kimberlite deposits preserved as aprons encompassing the interior geometry of the craters. The depositional extent of the kimberlite aprons can extend several hundred metres from the crater area. Contact angles of the kimberlite with the surrounding country rock can range from 90° to 0° depending on whether the contact is in the pipe or in the outflow/fall pyroclastic deposits.

The ‘classical champagne-glass’ shaped morphologies typically associated with FalC kimberlite bodies represent the explosive emplacement of kimberlite material within sequences of poorly consolidated sediments (Scott Smith et al. 1994). Geophysical modelling suggests that the areal extent of the individual kimberlitic bodies in the FalC kimberlite province range from 2.7 ha to over 400 ha.

Continued sedimentation, during the Late Cretaceous, buried the kimberlites. These cover rocks were largely removed during glaciation, essentially to the upper extremities of kimberlite emplacement. FalC kimberlites explored to date show limited to no glacial erosion. The majority of bodies drilled by both the FalC-JV and Shore are positioned just below the till / bedrock interface. In contrast, kimberlites discovered by De Beers in 1988, and later by Corona Corporation at Sturgeon Lake, 30 km northwest of Prince Albert, are regarded as rootless, ice-thrust rafts or kimberlite erratics, indicating erosion of a possibly younger suite of kimberlites.

Based on 613 (total drilling length 107,600 m) and 220 (total drilling length 52,500 m) drill holes on Star and Orion South respectively, the kimberlitic phases are well constrained within the Cretaceous stratigraphy in which they were deposited. For example, those kimberlites deposited during Cantuar Formation time (part of the Mannville Group) are considered to be Cantuar age-equivalent kimberlite and are termed Cantuar Kimberlite. Similarly, kimberlite deposited during Early Joli Fou Formation time (part of the lower Colorado Group) is Early Joli Fou age-equivalent kimberlite and are termed Early Joli Fou Kimberlite. It is important to note that two stratigraphically equivalent kimberlite packages (e.g., Pense Kimberlite on Star and Orion South) may not have any genetic relationship and each may have very different diamond grade and carat value characteristics. Some of the stratigraphically equivalent kimberlite units (e.g., Early Joli Fou Kimberlite (EJF) on Star and

Orion South) do, however, have similarities in mineral constituents, mantle signatures, chemistry and diamond distribution that suggest a genetic relationship.

5.2.1.3 Star Kimberlite Geology

The Star Kimberlite was deposited within the Cretaceous sedimentary rocks of the lower Colorado and Mannville Groups, which unconformably overlie Paleozoic limestone and dolomite and underlie glacial overburden ranging in thickness from 90 to 130 m. The majority of the Star Kimberlite is interpreted to have erupted through the Mannville and into the early parts of the lower Colorado Group sediments (during Joli Fou Formation deposition). The local lower Colorado and Mannville interface is situated approximately 170 m below ground level (bgl) (250 masl). The Mannville Group and Paleozoic interface is situated approximately 340 m bgl (80 masl) as interpreted from Shore drill holes.

The Star Kimberlite consists of two distinct types of kimberlite: eruptive kimberlite phases and kimberlitic sediments. The eruptive kimberlite deposits at the Star Kimberlite are sub-divided into five main kimberlite phases (Figure 5.2.1-6), each with distinctive physical and chemical properties which enable mapping and stratigraphic correlation of units as seen in Figure 5.2.1-7 (Harvey et al. 2006; Harvey, 2009):

- Cantuar Kimberlite;
- Pense Kimberlite;
- Early Joli Fou Kimberlite (EJF);
- Mid Joli Fou Kimberlite (MJF); and
- Late Joli Fou Kimberlite (LJF).

All the major kimberlite phases of the Star Kimberlite have been found to include both microdiamonds and macrodiamonds.

Cantuar Kimberlite

The oldest kimberlite phases within the Star Kimberlite are the Cantuar kimberlite, which are hosted by sandstone, siltstone and mudstone units of the Cantuar Formation. These Cantuar kimberlite deposits are typically restricted to thin sheet-like deposits that generally vary in width from 20 to 40 m (Figure 5.2.1-7). There are two end-member types of Cantuar kimberlite: matrix-supported pyroclastic kimberlite, which primarily occurs to the north and a clast- to matrix-supported pyroclastic kimberlite and kimberlite breccia that occurs to the south. The Cantuar kimberlite is typified by the ubiquitous presence of small (1-4 mm) clinopyroxene xenocrysts and relatively common mantle xenoliths. The kimberlite is variably fine to medium grained and is bedded at the 1-5 m scale although massive beds do occur. Rare fine-grained reworked equivalents are present and locally display cross-bedding.

Restricted to the south of the Star Kimberlite and cross-cutting older Cantuar kimberlite deposits is a younger, potential Cantuar-aged kimberlite, known as JLRPK (juvenile lapilli-rich pyroclastic kimberlite). This facies occurs as two spatially restricted feeder vents which display similar morphology to the classic South African model carrot-shaped pipes.

Pense Kimberlite

The Pense kimberlite is restricted to the central and north-eastern portions of the Star Kimberlite. In the northeast, Pense kimberlite is deposited directly on the Pense sandstone and mudstone (Zonneveld et al. 2004). Towards the central zone, the Pense kimberlite appears to sit directly on the Cantuar Formation sediments, indicating either scouring into the older Cantuar sediments and / or previous erosion / denudation of the Pense sandstone. The Pense kimberlite is densely clast-supported and, in the coarser-grained varieties, is characterized by the relative abundance of ilmenite megacrysts and sub-equal abundance of armoured juvenile lapilli (typically cored by olivine macrocrysts) and 0.5 to 7 cm sized olivine macrocrysts. The large olivine macrocrysts commonly contain small garnet intergrowths and are thus interpreted to be microperidotite xenoliths. The Pense kimberlite generally occurs as up to 15 m thick, well bedded, fine to very coarse grained pyroclastic kimberlite with very rare breccia units. Cross bedded, well sorted, fine to medium grained olivine enriched kimberlite sandstone is locally observed.

Early Joli Fou Kimberlite (EJF)

The widespread EJF is volumetrically the most important eruptive phase, with the thickest intersections occurring towards the western portion of the Star Kimberlite (Figure 5.2.1-8).

Distal apron deposits of the EJF kimberlite overlie Lower Joli Fou shale and are interpreted as Joli Fou-age equivalent. The EJF is also in direct contact with older Pense and Cantuar kimberlite phases in zones of excavation or topographically elevated areas formed by adjacent, older volcanic edifices. The kimberlite is comprised of a clast supported, normally graded olivine crystal tuff with rare juvenile lapilli and relatively common mantle-derived xenocrysts and xenoliths (Figure 5.2.1-6). Fining-up beds dominate and generally occur as 1–5 m (rarely up to 15 m) thick, lithic-rich basal breccia units overlain by xenolith poor tuffaceous kimberlite.

Three areas have been identified in the EJF deposits: a central vent / crater; a positive relief tephra ring (cinder cone); and an extra-crater (tephra ring distal) zone (Figure 5.2.1-8). Kimberlite deposits largely confined to the inner crater / vent area and the positive relief tephra ring are referred to as EJF ‘inner’ area deposits and those confined to the distal, extra-crater areas are referred to as EJF ‘outer’ area deposits. The EJF consists of pyroclastic crater fill as well as pyroclastic flow and fall deposits lying outside of the crater. The crater fill, near the center of the crater, consists of two kimberlite facies: PK, which is typical pyroclastic EJF; and KB, which is coarse kimberlite breccia.

Mid Joli Fou Kimberlite (MJF)

The MJF, a younger cross-cutting kimberlite eruptive phase, is aerially restricted to the western portion of the Star Kimberlite (Figure 5.2.1-7). This phase has erupted through the older EJF, as evidenced by rarely preserved kimberlite lithic clasts (autoliths) of EJF. The MJF kimberlite has some similarities to the EJF, but has a distinct matrix-supported texture, fewer indicator minerals, appears to be very poorly sorted and is generally massive to weakly bedded.

Late Joli Fou Kimberlite(LJF)

LJF is the youngest kimberlite eruptive event and is confined to the northern and north-eastern portion of the Star Kimberlite. The LJF generally forms a thin veneer deposited on older EJF and MJF (Figure 5.2.1-7). The LJF has many similarities to the MJF but is generally finer grained, more massive and has the ubiquitous presence of small (0.5–50 mm) shale clasts. The relationship between the MJF and LJF remains ambiguous; however, the LJF may represent a finer grained remobilized version of the MJF, which slumped or flowed into the marginal marine sedimentary environment incorporating poorly consolidated mudstone material. A sub-unit of the LJF, known as the LJF Slump, is identified based on the distinct increase in the shale clast content and the weak development of sub-horizontal bedding planes.

Upper Kimberlitic Sediments

Sitting directly on the Late Joli Fou-aged kimberlite, or locally within the overlying shale sequence, are two main kimberlitic sedimentary units (Figure 5.2.1-7). Directly above the LJF, there is the typical development of kimberlitic sandstone (KDF), with common to abundant shale blocks. In general, the shale blocks appear to be massive and in sharp contact with the host kimberlitic sandstone. A distinct fining-up sequence of kimberlitic sandstone that grades into kimberlitic siltstone and finally a calcareous light grey to white siltstone rests directly on the KDF and is more rarely separated by thick 2–10 m of shale. Situated 6–8 m above the fining-up unit is another fine grained kimberlite sandstone horizon which acts as a distinct marker horizon over most of the kimberlite. This surface is a close approximation to the Viking-Westgate contact. A 1–3 cm heavy mineral lag is present in many core holes, 2–4 m below this bed which may represent a transgressive surface of erosion (Zonneveld et al. 2004).

Star Kimberlite 3-D Model

A 3-D geological model was created by Shore geologists in 2006 and updated in November, 2007 from surface and underground drill information (Figure 5.2.1-9). The updated database contained an additional 157 surface and underground holes and a further 1,635 in-situ bulk density measurements. Limited deep drilling restricts the 3-D modelling of the Star Kimberlite to the kimberlite above the 350 m level.

The updated geological model estimated that the Star Kimberlite (including both the Star and Star West kimberlite) contained a total of approximately 278 Mt of kimberlite.

5.2.1.4 Orion South Geology

The Orion South Kimberlite is comprised of multiple eruptive units (or phases), each of which is texturally, mineralogically, physically and chemically distinct. Within the kimberlite, the units have cross-cutting relationships near conduits, but are stacked vertically within the volcanic edifice and crater / extra-crater deposits. Several conduits, feeding different units, have been identified on Orion South.

During Cantuar (Mannville Group) deposition, thought to be a time of continental fluvial-deltaic deposition (Zonneveld et al. 2004), kimberlite was deposited and reworked. Drilling has revealed that the Cantuar-aged kimberlite deposits are generally thin (<30 m thick) sheets occurring at multiple horizons within the Cantuar sediments. The bulk of the kimberlite deposits are confined within the marginal marine to marine sedimentary strata (Zonneveld et al. 2004) of the Upper Mannville Group (Pense Formation) and the lower Colorado Group (Joli Fou Formation). The local lower Colorado and Mannville contact is situated approximately 190 m bgl (255 masl). The Mannville Group and Paleozoic carbonate contact lays approximately 345 m bgl (100 masl) as interpreted from Shore drill holes. These kimberlite deposits are associated with the main crater excavation and crater fill. Proximal to the conduits and in close proximity to the base of the Mannville Group sandstone, the conduits flare (Scott-Smith et al. 1994) at a steep angle giving way to shallow angles near the margin of the craters.

The Orion South Kimberlite consists of two distinct types of kimberlite: eruptive kimberlite phases and kimberlitic sediments. The eruptive kimberlite deposits at the Orion South Kimberlite are sub-divided into five main kimberlite phases, each with distinctive physical and chemical properties which enable mapping and stratigraphic correlation of units as seen in Figure 5.2.1-10 (Harvey et al. 2009):

- Cantuar Kimberlite;
- Pense Kimberlite;
- Early Joli Fou Kimberlite (EJF);
- Late Joli Fou Kimberlite (LJF); and
- Viking Pyroclastic Kimberlite.

Cantuar Kimberlite

The earliest kimberlite deposit on Orion South, the Cantuar Kimberlite, consists of fine- to coarse-grained, massive to weakly normally graded, poorly sorted, matrix- to locally clast-supported, mixed olivine plus juvenile pyroclast-bearing lapilli tuff (Kjarsgaard et al. 2006, 2009). These deposits are commonly pervasively carbonate cemented and are generally thin (0.5–5 m thick), although a single intersection of 90 m has been drilled (Figure 5.2.1-10). Amoeboid juvenile pyroclasts, which locally display moulded boundaries, are common in the unit and rarely contain up to 10 % vesicles. Uranium-lead dating on perovskite gave an age of ca. 106 Ma for the Cantuar Kimberlite on Orion South (Kjarsgaard et al. 2006, 2009).

Pense Kimberlite

The first major eruptive event on Orion South resulted in kimberlite being deposited onto Pense Formation sediments. The crater base is cut into the pre-eruptive paleosurface and cuts into Mannville Group sediments. The Pense Kimberlite is a fine to locally medium-grained, matrix-rich, poorly sorted, massive to weakly bedded volcaniclastic lapilli tuff that is consistent both laterally and vertically. Xenoliths and juvenile pyroclasts are very rare within the Pense Kimberlite. Locally, distal deposits exhibit thin (0.1 to 0.5 m) planar bedding. The upper surface exhibits considerable and variable relief relative to the Pense paleo-surface (Figure 5.2.1-11). The thickest intersection recovered 220 m of Pense Kimberlite while it thins to near 0 m over 700 m laterally.

Early Joli Fou Kimberlite (EJF)

Distal deposits of the volumetrically dominant EJF were laid down directly on Early Joli Fou Formation sediments. Proximal deposits were deposited on Pense Kimberlite and Mannville Group sediments, the latter due to erosional scouring of the pre-eruptive paleosurface during initiation of the EJF eruptive cycle. There are two centres of thick EJF accumulation in the northwest and the southeast sections of the Orion South Kimberlite (Figure 5.2.1-11). The depocentre to the southeast is coincident with a spatially restricted feeder vent that cross-cuts the older Pense Kimberlite, while in the northwest there is a considerable thickening of kimberlite and a deepening of the basal contact which postulates a nearby vent.

The EJF is fine to coarse grained, olivine pyroclast rich, poorly to moderately sorted, volcaniclastic lapilli tuff to tuff breccia. The kimberlite consists of multiple normally graded beds with coarser bases and finer grained tops that collectively form normally graded, fining upward sequences. Fluid escape structures form narrow, discontinuous, anastomosing subvertical pipe-like structures up to 0.4 m in length. Individual beds are generally 0.5 to 5 m thick but can achieve thicknesses greater than 15 m in some instances.

Xenolith-rich tuff breccias are common in the EJF and are found in two distinct geometric forms within the volcaniclastics (Figure 5.2.1-11). The first is a basal xenolith-rich kimberlite up to 60 m thick that is thickest along the periphery of the Pense Kimberlite central mound and exhibits a higher abundance of Precambrian basement xenoliths relative to the proportion of Paleozoic carbonate xenoliths Pense Kimberlite autoliths are relatively common near the base of the xenolith-rich series. The second type consists of intermittent, 0.5 to 10 m thick xenolith-rich horizons which form the base of normally graded beds gradually fining upward into olivine-rich volcaniclastic tuff and lapilli tuff. These xenolith-rich basal horizons are more common in the lower part of the EJF sequence. Towards the top of the EJF sequence, and in distal areas, deposits are normally graded and typically do not exhibit these xenolith enriched basal horizons (Kjarsgaard et al. 2006, 2009).

In contrast to the Cantuar Kimberlite and Pense Kimberlite units, the EJF juvenile pyroclast population is dominated by cored juvenile pyroclasts which are generally round to ovoid in shape. The pyroclasts are mostly cored with olivine macrocrysts and more rarely with country rock xenoliths and mantle derived xenocrysts. Multi-rimmed juvenile pyroclasts are common within this unit. An uranium-lead age of 99.4 Ma has been generated for the EJF at Orion South (Kjarsgaard et al. 2006, 2009).

Late Joli Fou Kimberlite (LJF)

The LJF is a very fine- to fine-grained, moderately sorted, massive to weakly planar bedded, olivine-rich volcaniclastic kimberlite that cross-cuts previously emplaced kimberlite units and directly overlies EJF deposits (Figure 5.2.1-11). The LJF tuffs are olivine macrocryst-poor and phenocryst-rich, while juvenile pyroclasts are rare to absent. Proximal deposits are thick, but thin greatly over a short lateral distance. Similar to the LJF on the Star Kimberlite, the country rock xenolith population is Joli Fou Formation shale clast-dominated relative to the proportion of basement and carbonate clasts. Thin (1 to 20 cm) shale clast-enriched beds are common. Fluid escape structures have also been identified in the LJF.

Viking Kimberlite

The Viking Kimberlite unit is the youngest primary kimberlite deposited on Orion South, and is age-equivalent to the Viking Formation siltstone locally deposited between the Joli Fou and Westgate Formation shale deposits. The unit is restricted to the southeast and northwest parts of the Orion South Kimberlite as fine- to medium-grained, poorly to moderately sorted, moderately to well bedded, juvenile lapilli-rich volcaniclastic kimberlite. Free olivine grains are rare and olivine macrocrysts are commonly enveloped within a thin magmatic selvage forming armoured juvenile clasts. The Viking Kimberlite tuffs are relatively juvenile pyroclast-rich, are basement xenolith poor and relatively autolith rich. The unit commonly has extensive carbonate replacement and cementation of the matrix giving it a diagnostic texture.

Upper Kimberlitic Sediments (UKS)

Minor volumes of kimberlite deposited as epiclastic sediment are present on the upper periphery of the complex. Thicker deposits occur on the margins but thin towards the centre of the body (Figure5.2.1-10). The deposits vary from olivine-rich kimberlitic sandstone through to weakly kimberlitic, very fine-grained siltstones that are commonly interbedded with Joli Fou Formation shale. The thickest deposits are on the northwest margin of the complex where they attain thicknesses up to 20 m but are generally limited to 2 to 9 m in thickness. Shell and wood fragments are observed locally within planar, cross and ripple bed sets.

Orion South Geological Model

In 2008, the FalC-JV updated the Orion South Kimberlite geological model and tonnages estimated for each of the kimberlite lithologies (Figure 5.2.1-11). The new total estimated tonnage decreased to between 333 and 375 Mt, but the high priority EJF estimated tonnage increased to between 210 and 234 Mt. This geological estimate considered all kimberlite down to a depth of 445 m bgl.

5.2.2 Soils and Terrain

This chapter describes the existing (baseline) distribution of terrain and soil types, as well as terrain stability and soil quality characteristics, in the vicinity of the proposed Star-Orion South Diamond Project (the Project).

5.2.2.1 Introduction

Terrain and soils are described within two study areas, as follows: (1) a local study area (LSA) in which terrain and soil types may be directly affected by Project activities, and (2) the FalC forest or Regional Study Area (RSA) in which terrain and soil types may be indirectly affected by the Project. The LSA includes the Project footprint and a buffer area of approximately 500 m around the Project footprint. The description and distribution of terrain and soil types is presented for both the LSA and the FalC Forest, while terrain stability and soil quality characteristics are presented only for the LSA. The FalC forest is an island forest in the Boreal Transition Ecoregion of central Saskatchewan surrounded by lands that are predominantly used for agriculture.

Terrain types are described based on surface material and surface expression characteristics, and soils are described on the basis of their chemical and physical properties, in accordance with the Canadian system of soil classification (Soil Classification Working Group 1998). Soil quality characteristics that are described in this section include land capability for agriculture and forestry, compaction, rutting and puddling hazards, erosion potential, and soil salinity.

5.2.2.2 Information Sources and Methods

Methods for data review and compilation, field survey, map development and soil description are described in this section. The field study included soil inspections and collection of samples for laboratory analysis.

Data Review and Compilation

Spatial data in previous reports and surveys containing baseline terrain and soils information was reviewed and compiled.

Spatial data sources that were reviewed for the FalC forest included:

- the digital version of the existing regional soil survey of the FalC forest at 1:125,000 scale (Anderson and Ellis 1976);
- Canadian Digital Elevation Data Level 1 published in 2000 at 1:50,000 scale for National Topographic Service (NTS) Map sheet 73H 02 by the Centre for Topographic Information, Natural Resources Canada, Government of Canada;
- a hillshade of the FalC forest based on Light Detection and Ranging (LiDAR) from 2008 at 1 m resolution;
- project-specific IKONOS satellite imagery at 1 m resolution;
- publicly available LandSat satellite imagery at 7 to 20 m resolution, and
- stereoscopic aerial photographs from 2004 at 1:30,000 scale obtained from the Saskatchewan Ministry of Environment (SMOE) Forest Service.

Previous reports that were reviewed included: a summary of baseline terrain and soil characteristics for the Project prepared by EcoDynamics Consulting Inc. (Ecodynamics) (Ecodynamics 2009), and; the regional soil survey of the area (Anderson and Ellis 1976). A copy of EcoDynamics (2009) is attached in Appendix 5.2.2-A.

Field Survey

A total of 296 soil inspection points were established as part of the soil survey in the FalC Forest between 1999 and 2009 by EcoDynamics (2009). At each inspection point, a soil pit was excavated to a 1 m depth, and site characteristics and soil profile characteristics within the pit were described. Site characteristics described included Universal Transverse Mercator (UTM) location, parent material, surface expression, slope position, slope class, drainage, and surface stoniness. UTM locations of the soil inspections were marked using a handheld Global Positioning System (GPS). Soil profile characteristics that were described included horizon identification and depth, Munsell colour, texture, mottles, structure, consistence, coarse fragment content, root density, and calcareousness. Soil horizon designation was according to Soil Classification Working Group (1998) and description of horizon attributes was according to Agriculture Canada Expert Committee on Soil Survey (1987). Soil pit characteristics that were described also included depth to water table, depth to mottles, and depth to gley features.

Additional soil survey information included soil inspection data from nine inspection sites completed by AMEC in 2009, and soil data from 29 inspection sites described in 1999 and

2000 as part of the provincial Forest Ecosystem Classification (FEC) program as described in Jiricka et al. (2002).

As part of the field survey, horizons from representative soil profiles established within the LSA were sampled, air dried, and submitted for laboratory analysis of various parameters to ALS Laboratory Group in Saskatoon, Saskatchewan. The analytical parameters specified and the methods of analysis are summarized in Table 5.2.2-1.

Table 5.2.2-1: Summary of Soil Analytical Methods

Analytical Parameter^{z}	Method	Description
Total Carbon	Nelson and Sommers (1996)	Dry combustion by LECO Analyzer
Total Nitrogen	Bremner (1996)	Automated dry combustion by LECO Analyzer.
Inorganic Carbon, Organic Carbon and $CaCO_3$ Equivalent	Loeppert and Suarez (1996)	Acid dissolution of carbonates followed by organic carbon determination by LECO analyzer. Inorganic carbon is the difference between total and organic carbon.
Soluble Ca, Mg, K, Na, SO_4	Chapter 15 in Carter and Gregorich (2008)	The aqueous extract of a saturated paste is analyzed for ions by Inductively Coupled Plasma –Optical Emission Spectroscopy (ICP-OES).
Electrical Conductivity	Chapter 15 in Carter and Gregorich (2008)	Electrical conductivity of a saturated paste extract (see above) is measured with a conductivity meter.
Soluble Cl	Greenberg et al. (1992)	The aqueous extract of a saturated paste is analyzed for Cl by the mercury (II) thiocyanate method.
Sodium Adsorption Ratio (SAR)	Calculation	SAR is calculated from soluble ion concentrations as follows: $[Na]/(([Ca]+[Mg])^{0.5})$
pH	Method 3.14 in McKeague (1978)	Measured by immersion of a pH electrode into a saturated paste of a soil sample.
Particle Size Analysis	Carter and Gregorich (2008)	By the hydrometer method.
Exchangeable cations (Ca, Mg, K, Na, Al, Mn and Fe)	Carter and Gregorich (2008)	Exchangeable cations are extracted with unbuffered barium chloride and analyzed by ICP-OES.
Cation exchange capacity (CEC)	Calculation	The CEC is calculated as the sum of exchangeable cations.
Total Metals (Sb, As, Ba, Be, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Ag, Tl, Sn, U, V, Zn)	EPA 200.2/6020A Metals in Soil by ICP-MS	Soil is dried at <60°C and digested with nitric and hydrochloric acids, prior to analysis for a suite of metals by ICP-MS.
Hg	EPA 200.2/245.1	Soil digest from total metals (above) is analyzed for mercury by cold vapour atomic absorption.

Notes: ^{Z} Abbreviations: $CaCO_3$ – calcium carbonate, Ca – calcium, Mg – magnesium, K – potassium, Na – sodium, SO_4 – sulphate, Cl – chloride, [ ] - concentration in mmol/L; CEC – cation exchange capacity; ICP – inductively coupled plasma; OES – optical emission spectrometry; Al – aluminum; Mn – manganese; Fe – iron; Sb – antimony; As – arsenic; Ba – barium; Be – beryllium; Cd – cadmium, Cr – chromium; Co – cobalt; Cu – copper; Pb – lead; Mo – molybdenum; Ni – nickel; Se – selenium; Ag – silver; Tl – thallium; Sn – tin; U – uranium; V – vanadium; Zn – zinc.

Development of Terrain and Soil Maps

The methods used to delineate terrain units and soil map units within the study areas are summarized in EcoDynamics (2009) (Appendix 5.2.2-A). Within the FalC forest, terrain units and soil map units were derived directly from the reconnaissance soil survey completed by Anderson and Ellis (1976), which was designed for presentation at a 1:125,000 scale. A more detailed soil map of the LSA was prepared by aerial photo interpretation combined with a field data collection program. Terrain units and soil map units within the LSA were modified from the reconnaissance soil survey using spatial data sources for presentation at a 1:30,000 to 1:50,000 scale. The description of terrain within the FalC forest consists of a description of surface material only; in the LSA the terrain description includes surface material as well as surface expression. For the summaries of terrain within the LSA and the FalC forest, complexes of surface materials within delineated terrain polygons were presented according to the dominant surface material.

Soil map units within the FalC forest and LSA were described using the protocols outlined in Anderson and Ellis (1976) with the exceptions that: a new map unit complex entitled Wetland Complex (Wx) was designated to describe complex wetlands occurring along ravines, and; four additional Hillwash (Hw) soil map units were developed to describe colluvial soils along ravines.

Survey Intensity Level

The soil survey of the LSA was conducted at an intermediate level of detail, equivalent to 1:30,000 and 1:50,000 scale, consistent with Survey Intensity Level (SiL) 3 (Mapping Systems Working Group 1981).

The soil survey of the FalC forest was conducted at a reconnaissance level (SiL 4) (Mapping Systems Working Group 1981); soil polygons were delineated at approximately at 1:125,000 scale as outlined in Anderson and Ellis (1976).

Determination of Terrain Stability

Terrain stability mapping (TSM) was completed within the LSA. In the absence of a TSM protocol for Saskatchewan, terrain stability classes were assigned to each delineated terrain unit based on the criteria and guidelines outlined in the document *Mapping and Assessing Terrain Stability Guidebook* (British Columbia Ministry of Forests 1999). Five terrain stability classes are outlined for the TSM classification system 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). Terrain instability increases as the class increases, with terrain stability class 5 having high potential for landslide initiation. The characteristics of these terrain stability classes are summarized in Table 5.2.2-2. In general, terrain instability and the associated likelihood of landslide initiation increases with slope gradient, moisture content, and the presence of existing instability features.

Table 5.2.2-2: Summary of Terrain Stability Classes [z]

Terrain Stability Class	Description	Likelihood of Landslide Initiation
1	No significant stability issues exist.	Negligible
2	Minor surface slumping is expected along road cuts, especially for 1 or 2 years following construction.	Very Low
3	Minor stability issues may develop. Minor surface slumping is expected along road cuts, especially for 1 or 2 years following construction.	Low
4	Moderate likelihood of stability issues developing post construction. Wet season construction will increase the likelihood of potential instability. Existing (relict) instability issues noted within the polygon.	Moderate
5	High likelihood of stability issues developing post construction. Wet season construction will increase the likelihood of potential instability. Existing (active) instability issues noted within the polygon.	High

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

Within the LSA, terrain attributes assigned by EcoDynamics (2009) at a 1:30,000 scale were used in conjunction with the 1 m LIDAR hillshade to assign terrain stability classes. Where more than one terrain stability class occurred within the same delineated polygon, the more limiting terrain stability class was applied.

Detailed terrain stability mapping is recommended for application to polygons delineated at a 1:20,000 scale or larger (British Columbia Ministry of Forests 1999). Terrain stability mapping within the LSA was based on polygons developed at a 1:30,000 scale (see section ‘Development of Terrain and Soil Maps’ above), and may therefore have relatively more uncertainty due to the smaller scale.

Description of Soil Quality

Several attributes related to soil quality were summarized within the LSA. These include land capability for agriculture and forestry, compaction susceptibility, rutting and puddling risk, erosion risk, and soil salinity. These attributes were assessed due to the potential impact of the Project on soil capability for agriculture and forestry. Each delineated soil map unit within the LSA was assigned to a specific rating class for quality attributes according to criteria described in the following sections.

Land Capability

Land Capability for Agriculture

The land capability class for agriculture was interpreted for each soil map unit in the LSA according to the methodology outlined in EcoDynamics (2009). Determination of land capability for agriculture consisted of application of criteria and methods established by the Canada Land Inventory (Shields et al. 1968), with Class 1 being the most suitable for agriculture and Class 7 being unsuitable.

Agricultural capability considers a range of climatic, soil and landscape characteristics on the potential for a given area to sustain typical dryland agriculture (Anderson and Ellis 1976). The limiting effects of climate on common crops is considered first, followed by consideration of the limitations imposed by characteristics of the soils themselves, and then landscape factors such as slope and susceptibility to flooding. Soils are then placed within one of seven capability classes, with the major soil and landscape limitations appended as a subscript letter symbol.

Land Capability for Forestry

The land capability for forestry was interpreted for each soil map unit in the LSA according to the methods outlined in the 2009 Terrestrial Baseline Surveys (EcoDynamics 2009). Determination of land capability for forestry consisted of application of criteria and methods outlined in the *Land capability classification for Forestry in Saskatchewan, Technical bulletin #6* (Kabzems et al. 1972).

The forest land capability classification utilizes a seven class system similar to that used for agricultural capability, and is based on the natural, unimproved state of the land. Each capability class is characterized by a range of forest productivity based on the mean annual increment (MAI), measured as the m^3 of wood volume produced per hectare per year (m^3/ha/year), by the most suitable species or group of species adapted to the site. Subclasses are also listed to indicate the dominant factors limiting tree growth in a given area; examples are soil moisture deficiency during the growing season (m), excess soil moisture (w), low soil fertility (f), and actively eroding soils (e).

Compaction, Rutting and Puddling Risk

Compaction, rutting and puddling risk classes were assigned to each soil map unit in the LSA based on the categories in Beckingham et al. (1996). Three ratings classes are assigned: low (L), medium (M), and high (H). The risk ratings assigned to each soil type are dependent on moisture regime, soil drainage, and surface soil texture (Beckingham et al. 1996). In general, wet, fine textured soils are more prone to compaction, rutting and puddling.

Erosion Risk

Susceptibility of soil map units to wind and water erosion was determined for soil map units in the LSA using the methods summarized below. Wind and water erosion risk ratings in the surrounding rural municipalities (RMs) were reviewed, with erosion risk ratings modifications applied to this Project where necessary (Saskatchewan Land Resource Centre 1987; 1997a, 1997b, 1997c, 1997d).

Determination of Wind Erosion Risk

Wind erosion risk classes were assigned to each delineated soil map unit in the LSA based on calculation of potential annual soil loss as described, for example, in the soil survey of neighbouring Rural Municipality of Garden River, No. 490 (Saskatchewan Land Resource Centre 1997c). The equation for calculation of loss is:

$$E(p) = C \times T \times I \times K$$

where: E(p) = potential annual soil loss, C = climatic factor (based on average wind velocity, and temperature), T = landscape factor (based on slope class and surface form), I = soil erodibility factor (based on texture), and K = soil ridge roughness factor (based on texture).

The E(p) values from the formula are used to predict a soil's susceptibility to wind erosion if the soil surface is bare. Six soil susceptibility classes, and an ‘Unclassified’ category, are defined in Saskatchewan soil surveys (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). Four simplified wind erosion risk classes were adopted from the approach presented in Pedocan Land Evaluation Ltd. (1993) and were correlated to the wind erosion risk classes outlined in Saskatchewan Land Resource Unit (2005) in Table 5.2.2-3. The determination of wind erosion risk assumes an isolated, level, unsheltered, bare land surface with no vegetation or woody cover and a non-crusted surface (Coote and Pettapiece 1989). The system is based on the assumption that the binding of primary soil particles into aggregates is of greater importance than soil texture in determining wind erosion susceptibility. Soils with a high sand fraction are the most erosive, while soils with higher silt content are the least erosive. Moist or wet soils, and soils with high coarse fragment (gravel, cobble, stony) content, have low susceptibility to wind erosion regardless of texture.

Table 5.2.2-3: Wind Erosion Risk Classes and Potential Soil Losses

Wind Erosion Class	Saskatchewan Erosion Class	Description of Class	Properties of Soils
High	6 Extremely High	These soils must be left in permanent pasture and are not capable of sustaining arable agriculture.	Generally includes very coarse, coarse and moderately coarse textured soils (i.e., sands, loamy sands and sandy loams); can include some moderately fine and fine textured soils (clay, silty clay, non-calcareous clay loam; silty clay loam); also calcareous loam, silt loam, clay loam and silty clay loam.
	5 Very High	These soils should not be used for annual cropping, but rather for pasture and forage crops which will protect the surface from severe degradation.	
Moderate	4 High	Average growing conditions will not provide sufficient residue to protect these soils against wind erosion. Coarse-textured soils may be seeded to pasture or to forage crops to prevent severe degradation of the soil.	Commonly, textures are non-calcareous loam and silt loam, sandy clay loam, non-calcareous clay loam with <35% clay content, and sandy clay.
	3 Moderate	Average growing conditions may not supply adequate residue to protect these soils against wind erosion. Enhanced soil management practices are necessary to control wind erosion.	
Low	2 Low	Good soil management and average growing conditions may produce a crop with sufficient residue to protect these soils against wind erosion.	Common textures are silt and non-calcareous silty clay loam with <35% clay content.
	1 Very Low	Good soil management and average growing conditions will produce a crop with sufficient residue to protect these soils against wind erosion.	
Nil or Unclassified	Unclassified	Unclassified areas (e.g., wetlands); also soils with high content of coarse fragments (gravel, stones) on the surface.	

Determination of Water Erosion Risk

Water erosion risk classes were assigned to each delineated soil map unit in the LSA based on application of the modified Universal Soil Loss Equation (USLE) as described, for example, in the soil survey of neighbouring Rural Municipality of Garden River, No. 490 (Saskatchewan Land Resource Centre 1997c). The basic USLE equation is:

$$A = R \times K \times LS \times C \times P$$

where: A = annual soil loss, R = rainfall intensity, K = soil erosivity, LS = topography, C = cover, and P = conservation practices

The basic USLE methodology was developed for agricultural soils. Water erosion risk of bare soils, including disturbed forest soils and stockpiled soils, is commonly calculated for bare soil using only the R, K, and LS factors.

Within the LSA, R was assumed constant and K was determined based on the dominant soil texture and structure of the soil map unit. Ranges of annual potential soil loss were converted to classes of water erosion risk, with water erosion risk class 1 having the lowest susceptibility to erosion. The water erosion risk class calculated using the R and K factors was adjusted based on slope class. For those soil map units with slopes between 11 and 49 %, the water erosion risk rating was increased by one class. For those soil map units with slopes greater than 49 %, the water erosion risk rating was increased by two classes. The water erosion risk classes and their associated annual potential soil losses (A) are indicated in Table 5.2.2-4.

Table 5.2.2-4: Water Erosion Risk Classes and Potential Soil Losses

Water Erosion Risk Class	Water Erosion Risk Category	Annual Potential Soil Loss (t/ha)
1	Very Low	<6
2	Low	6 to 11
3	Moderate	11 to 22
4	High	22 to 33
5	Very High	>33

5.2.2.3 Results

The results for terrain distribution, terrain stability, soil distribution and soil quality are described in this Section.

Terrain Distribution

Coarse textured eolian and fluvial-lacustrine deposits are dominant in the LSA and the FalC forest (Table 5.2.2-5). A general description of the terrain in the FalC forest and the LSA is provided in EcoDynamics (2009) (Appendix 5.2.2-A). Figures 5.2.2-1 and 5.2.2-2 present the mapped terrain polygons within the FalC Forest and the LSA.

Terrain Stability

Areas of unstable or potentially unstable terrain generally include those with moderate to high relief topography containing unstable material. These areas generally occur adjacent to the Saskatchewan River or along ravines within the LSA. Stable terrain with negligible to very low likelihood of landslide initiation is dominant within the LSA, occupying 10,014 ha (81.9 %) (Table 5.2.2-6). Areas of moderate to high likelihood for landslide initiation are concentrated along the banks of the Saskatchewan River in dissected valley and ravine slopes ranging from 10 to 30 % gradient and dominated by colluvium surface materials. Terrain stability classes in the LSA are shown in Figure 5.2.2-3.

Table 5.2.2-5: Terrain in the Study Areas

Dominant Surface Material	Surface Expression	Description	LSA (ha)	LSA (%)	FalC Forest (ha)	FalC Forest (%)
Alluvium (Av)	Terraced; slopes 2 to 5 %	Moderately coarse to fine textured alluvial deposits along the banks of the Saskatchewan River. Includes both active floodplain and recently abandoned alluvial floodplain terraces. Commonly occurs in complex with organic materials.	298	2.4	1,266	1.0
Colluvium (C)	Dissected; slopes 0.5 to 30 %	Variably textured deposits generally less than 1 m thick, along valley and ravine slopes; commonly occurs in complex with organic materials.	2,171	17.8	3,727	2.8
Eolian (E)	Hummocky, ridged; slopes 6 to 30 %	Coarse textured fluvial-lacustrine materials that were locally re-worked by wind into complex dune and ridge formations. Eolian surface materials commonly occur in complex with fluvial-lacustrine and sandy glaciolacustrine materials.	3,306	27.0	41,405	31.2
Fluvial – Lacustrine (FL)	Undulating, hummocky, ridged, inclined and dissected; slopes 0.5 to 9 %	Coarse textured materials of deltaic origin; commonly occur in complex with fluvial-eolian, sandy glaciolacustrine, and organic materials. Fluvial-eolian (FE) describes coarse textured fluvial materials that have been re-worked by wind, and which generally occur in inter-dune areas.	4,382	35.9	41,333	31.1
Sandy Glaciolacustrine (GLs)	Dissected and inclined; slopes 2 to 9 %	Moderately coarse to medium textured glaciolacustrine materials interbedded with finer textured material (e.g. silt and clay). These materials generally occur on the upper and mid slopes of valleys and ravines. In the study areas, sandy glaciolacustrine materials commonly occur in complex with fluvial lacustrine and silty glaciolacustrine materials.	619	5.1	17,309	13.0

Dominant Surface Material	Surface Expression	Description	LSA (ha)	LSA (%)	FalC Forest (ha)	FalC Forest (%)
Silty Glaciolacustrine (GLsi)	Inclined, dissected; slope 2 to 5 %	Moderately fine textured, silty to clayey glaciolacustrine materials that commonly occur in complex with sandy glaciolacustrine deposits. Silty glaciolacustrine materials generally occur on the lower slopes of ravines and valleys.	163	1.3	6,007	4.5
Organic (O)	Level and dissected; slopes 0 to 5 %	Deposits consisting of the accumulation of mosses, sedges, and woody materials that occur under water-saturated conditions in depressional areas of the landscape. Organic materials commonly occur in complex with fluvial-lacustrine, sandy glaciolacustrine, and organic veneer deposits in the study area.	392	3.2	15,785	11.9
Organic Veneer (Ov)	Dissected, hummocky and undulating; slopes 0.5 to 5 %	Organic deposits less than 1 m thick. These deposits commonly occur in complex with eolian, sandy glaciolacustrine, organic, and fluvial-lacustrine materials.	229	1.9	3,494	2.6
Water	Not Applicable	Lakes and rivers	407	3.3	1,038	0.8
Disturbed Land	Not Applicable	Various terrain types	251	2.1	1,406	1.1
Total			12,218	100.0	132,769	100.0

Table 5.2.2-6: Terrain Stability in the LSA

Terrain Stability Class	Likelihood of Landslide Initiation	LSA (ha)	LSA (%)
1	Negligible	3,700	32.3
2	Very Low	6,066	49.6
3	Low	758	6.2
4	Moderate	796	6.5
5	High	240	2.0
Water	Not rated	407	3.3
Disturbed Land	Not rated	251	2.1
Total		12,218	100.0

Soil Distribution

General characteristics of the soil associations and complexes occurring in the LSA and the FalC forest are described below. Additional information about the composition of the soil associations and complexes is provided in Table 5.2.2-7. Soils at the soil order level of classification (i.e., Regosolic, Gleysolic, etc.) are defined in the glossary:

- Alluvium (Av) - Regosolic soils developed from variable textured alluvial sediments of recent age;
- Arbow (Aw) - Gleysolic soils developed from variable textured, unspecified materials;
- Bowl Bog (Bb) - Organic soils in bowl-shaped depressional bogs with a slightly concave or sunken peat surface;
- Flat Bog (Bf); Organic soils in flat lying lowland bogs and extensive depressional bogs;
- Stream Bog (Bs) - Organic soils in elongate, poorly drained depressional bogs along drainage courses);
- Carrot River soil association (Cr) - Dark Gray Chernozemic soils developed from moderately to very strongly calcareous, coarse to medium textured sandy glaciolacustrine or glaciofluvial sediments;
- Bowl Fen (Fb) - Organic soils in open, sedge and willow dominated fens within bowl-shaped depressions in glacial uplands;
- Floating Fen (Ff) - Organic soils in fens adjacent to water bodies that are underlain by water;
- Horizontal Fen (Fh) - Organic soils in extensive, flat, low-lying fens;
- Patterned Fen (Fp) - Organic soils in very gently sloped fens characterized by a pattern of ridges and hollows;
- Stream Fen (Fs) - Organic soils in fens along distinct streams);
- Hillwash soil complex (Hw); Regosolic, Brunisolic and Luvisolic soils on the steep slopes of river valleys;
- Kewanoke soil association (Kk) - Eutric Brunisolic soils developed from coarse to moderately coarse textured, weakly calcareous, gravelly glaciofluvial deposits;
- La Corne soil association (Lc) - Gray Luvisolic soils developed from moderately coarse to medium textured, weakly to moderately calcareous sandy glaciolacustrine materials containing greater than 15% clay;
- Marsh soil complex (Mh) - very poorly drained Gleysolic soils developed from variable textured materials;
- Meadow soil complex (Mw) - undifferentiated Gleysolic soils developed from variable textured materials;

- Nisbet soil association (Nt) - Dark Gray Chernozemic soils developed from coarse to moderately coarse textured, weakly to moderately calcareous sandy fluvial-lacustrine sediments;
- Pine soil association (Pn) - Brunisolic and Regosolic soils developed from coarse textured, weakly to non-calcareous, sandy glaciofluvial, glaciolacustrine and eolian deposits;
- Porcupine Plain soil association (Pp) - Gray Luvisolic soils developed from medium to moderately fine textured, moderately to strongly calcareous silty glaciolacustrine deposits; and
- Wetland soil complex (Wx) - Gleysolic (peaty phase) and Organic soils in fibric to humic peat of variable thickness in depressional areas along ravines.

A summary of soil characteristics including soil classification, average topsoil depth, and surface texture is presented for the majority of the soil associations and complexes in the study areas based on the soil inspection data collected between 1999 and 2009 (Table 5.2.2-7). Organic soils identified in the Bog, Fen, Marsh and Wetland soil complexes were grouped for the summary. No soil inspections were conducted in soils grouped into the Carrot River or Kewanoke soil associations. These soil associations generally occur as significant soils or inclusions within the soil map units occurring in the study areas. Representative soil profile characteristics for the majority of the soil associations and complexes present within the study area are provided in Appendix 5.2.2-B1, Table 1. Analytical data from representative soil profiles are provided in Appendix 5.2.2-B1 and the associated laboratory reports are provided in Appendix 5.2.2-B2.

Pine soils are a mixture of Brunisolic and Regosolic soils that have formed in sandy fluvial materials, some of which have been reworked by wind (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). Soils are commonly leached, low in organic matter, and have gray surface colours when cultivated. Surface textures range from sand to loamy sand. These soils are dominant in both the LSA and RSA. Pine soils in the LSA and RSA have loamy sand textures and low cation exchange capacities, and they are non-saline (Plots S92, S101 and TEP114, Appendix 5.2.2-B1 Table 1). Soil reaction levels of about pH 6 verify classification of these soils as Eutric Brunisols rather than the more highly acidic Dystric Brunisols.

La Corne soils are the next most abundant in the study areas. La Corne soils are described by Saskatchewan Land Resource Centre (1997a, 1997b, 1997c, 1997d) as Gray Luvisols soils formed in loamy lacustrine materials. These soils are usually strongly leached, resulting in low organic matter levels and dark gray to light grayish coloured topsoils when cultivated. Surface textures are predominantly fine sandy loam to very fine sandy loam. The soil at Plot S84 (Appendix 5.2.2 B1 Table 1) conforms to this description, except that the subsoil is relatively fine textured. This sampled soil is also calcareous at relatively shallow depth.

Arbow soils are Gleysolic soils that have formed in variable-textured alluvial deposits associated with low-lying depressional basins. Most of these soils are overlain by up to 60 cm of peat. The texture of the mineral layer immediately below the organic layer is variable (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). The Arbow soil samples at Plot S106 (Appendix 5.2.2-B1, Table 1) has a loam-silt loam texture overlying silty clay. Peat thickness is 35 cm. The entire profile, including the peat layer, is slightly alkaline in reaction, and the subsoil is weakly saline.

Meadow soils are Gleysols formed in variable-textured alluvial sediments typically associated with low-lying depressional basins. Surface textures are variable but usually range from loam to clay (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). The soil at Plot S104 (Appendix 5.2.2 B1 Table 1) is loamy sand to sand textured, has a peat surface, and is neutral in reaction in the surface peat and A horizons.

Porcupine Plain soils are Gray Luvisolic soils that have formed in silty lacustrine materials. These soils are usually strongly leached, resulting in low organic matter levels and dark gray to light gray-coloured surface horizons upon cultivation. Surface textures are predominantly loam and silt loam but can range to silty clay loam (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). Porcupine Plain soils were sampled at Plots TEP93 and TEP95 in the LSA (Appendix 5.2.2 B1, Table 1). Chemistry data provided for Plot TEP95 generally conforms to the general description for these soils. The pH in the surface and upper subsoil layers in this soil is near neutral (~pH 7).

Bog-Fen soils are mixture of bog and fen peat soils. The peat materials can are in various stages of decomposition, ranging from fibric, or weakly decomposed, to humic or highly decomposed. The thickness of the organic material is variable. The minimum thickness of an organic soil in an intermediate (mesic) or highly (humic) decomposed state is 40 cm, and 60 cm for peat in a weakly decomposed (fibric) state. The maximum thickness of the organic material is also variable, and may exceed 160 cm in some areas (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d). The Bog-Fen soil at Plot TEP116 (Appendix 5.2.2 B1 Table 1) consists of fibric overlying mesic peat. The pH is near neutral, which generally is indicative of a fen type of peat system.

Table 5.2.2-7: Summary of Soil Characteristics in Soil Associations and Complexes in the Study Areas

Soil Association/ Complex	Total No. Inspections	Dominant Soil Type ^{z}	Soil Classification ^{z}	Topsoil Depth (cm) ^{Y}	Surface Texture
Alluvium (Av)	4	Various Regosolic	Cumulic Regosol Gleyed Regosol Gleyed Cumulic Regosol Orthic Humic Regosol	Variable	SiL, LvfS ^{X}
Arbow (Aw)	23	Various Gleysol	Orthic Gleysol Orthic Humic Gleysol Rego Gleysol Rego Humic Gleysol	15-60 cm peat	Fibric or mesic peat over LfS, LS, vfSL, fS
Bog/Fen/ Marsh	31	Various Organic	Terric Mesisol Terric Fibrisol Terric Humisol Terric Fibric Mesisol Terric Humic Mesisol Terric Mesic Humisols Typic Fibrisol Typic Mesisol Limnic Humisols Limnic Mesisol	>40 cm peat	fibric peat, mesic peat
Hillwash (Hw)	24	Brunisolic, Luvisolic, Chernozemic and Regosolic soils	Eluviated Eutric Brunisol Gleyed Eluviated Eutric Brunisol Orthic Eutric Brunisol Orthic Dark Gray Chernozem Rego Dark Gray Chernozem Orthic Gray Luvisol Brunisolic Gray Luvisol Dark Gray Luvisol Gleyed Gray Luvisol Orthic Regosol Gleyed Regosol	Variable	LvfS, fSL, L, fS
La Corne (Lc)	14	Various Luvisolic	Brunisolic Gray Luvisol Orthic Gray Luvisol Dark Gray Luvisol Gleyed Gray Luvisol Gleyed Humic Regosol	6 cm LFH / 45-50 cm mineral	vfSL, fS, LfS, fSL
La Corne (Lc) – Porcupine Plain (Pp)	8	Dark Gray Luvisol	Dark Gray Luvisol Gleyed Brunisolic Gray Luvisol Gleyed Regosol Eluviated Eutric Brunisol	see La Corne and Porcupine Plain	LvfS, LfS, vfSL

Soil Association/ Complex	Total No. Inspections	Dominant Soil Type [z]	Soil Classification [z]	Topsoil Depth (cm) [Y]	Surface Texture
Meadow (Mw)	8	Various Gleysols, including peaty phase	Orthic Gleysol-peaty Rego Gleysol-peaty Rego Humic Gleysol Rego Humic Gleysol-peaty Terric Humisols	15-40 cm peat / 5-10 cm mineral	fibric or mesic peat over S, LS
Meadow – Marsh (Mh)	2	Various Gleysol	Rego Gleysol Rego Gleysol-peaty	see Meadow	S, LS

Table 5.2.2-8: Summary of Soil Characteristics in Soil Associations and Complexes in the Study Areas (concluded)

Soil Association/ Complex	Total No. Inspections	Dominant Soil Type [z]	Soil Classification [z]	Topsoil Depth (cm) [Y]	Surface Texture
Nisbet (Nt)	2	Dark Gray Chernozems	Orthic Dark Gray Chernozem Gleyed Rego Dark Gray Chernozem	5 cm LFH / 10-20 cm mineral	LfS, fS
Pine (Pn)	152	Eutric Brunisolic Soils	Eluviated Eutric Brunisol Gleyed Eutric Brunisol Gleyed Eluviated Eutric Brunisol Orthic Eutric Brunisol Dark Gray Chernozem Gleyed Dark Gray Chernozem Orthic Humic Regosol Orthic Regosol Gleyed Regosol	2-5 cm LFH / 5-10 cm mineral	S, vfS, fS, LfS
Pine – La Corne	5	Eutric Brunisolic Soils	Eluviated Eutric Brunisol Gleyed Regosol	see Pine and La Corne	LfS, vfS, LvfS, fSL
Pine – Nisbet	11	Eutric Brunisolic and Regosolic soils	Eluviated Eutric Brunisol Gleyed Regosol Gleyed Eluviated Eutric Brunisol Gleyed Dark Gray Chernozem	see Pine and Nisbet	fS, S, LfS
Porcupine Plain	12	Orthic and Dark Gray Luvisols	Orthic Gray Luvisol Dark gray Luvisol Gleyed Gray Luvisol Gleyed Dark Gray Luvisol Eluviated Eutric Brunisol Gleyed Humic Regosol Rego Gleysol-peaty	5 cm LFH / 15-20 cm mineral	vfSL, fSL, SiL, SiCL, L, CL

Notes: [Z] Soil classification according to Soil Classification Working Group (1998).

[Y] Source: *The Soils of the Provincial Forest Reserves in the Prince Albert Map Area, 73H Saskatchewan* (Anderson and Ellis 1976).

[X] Soil texture abbreviations: S – sand; vfS – very fine sand; fS – fine sand; LS – loamy sand; LfS – loamy fine sand; LvfS – loamy very fine sand; fSL – fine sandy loam; vfSL – very fine sandy loam; L – loam; SiL – silty loam; CL – clay loam; SiCL – silty clay loam.

Soil map units were assigned to each delineated soil polygon in the study areas based on the proportions of dominant, significant, and minor soil series. Characteristics of the soil map units in the study areas (dominant soils, significant soils, parent material, landform) of the soil map units are summarized in the 2009 Terrestrial Baseline Surveys in Appendix 5.2.2-A (Ecodynamics 2009). Table 5.2.2-8, 5.2.2-9, and 5.2.2-10 summarizes the areas of the soil map units in the LSA and the FalC Forest; Figures 5.2.2-4 and 5.2.2-5 display the soil map units in the FalC and the LSA Forest, respectively.

The dominant soil map units in the LSA and the FalC Forest are the Pn1 (LSA: 3,332 ha, 27.3%; FalC Forest: 14,152 ha, 10.7%) and Pn2 (LSA: 3,359 ha, 27.5%; FalC Forest: 33,425 ha; 25.2%) soil map units. These map units are typically composed of Pine Association soils consisting of Eluviated Eutric Brunisolic and Orthic Regosolic soils on fluvio-eolian, fluvial-lacustrine and eolian parent materials.

Table 5.2.2-9: Soil Map Units in the Study Areas

Dominant Soil Association/ Complex	Soil Map Unit Symbol	LSA (ha)	LSA (%)	FalC Forest (ha)	FalC Forest (%)
Alluvium	Av	259	2.1	994	0.7
	Av-Mh	-[z]	-	233	0.2
	Av-Wx	39	0.3	39	0.0
Arbow	Aw	118	1.0	118	0.1
	Aw-Mw	14	0.1	14	0.0
Bowl Bog	Bb	29	0.2	1,554	1.2
	Bb-Fb	186	1.5	186	0.1
	Bb-Lc3	-	-	306	0.2
	Bb-Mw	-	-	104	0.1
	Bb-Nt	-	-	132	0.1
Flat Bog	Bf	-	-	1,555	1.2
	Bf-Aw	-	-	1,179	0.9
	Bf-Fh	-	-	595	0.5
	Bf-Fp	-	-	594	0.5
	Bf-Fs	-	-	1,221	0.9
	Bf-Lc3	-	-	837	0.6
	Bf-Pn6	-	-	977	0.7
Stream Bog	Bs	-	-	471	0.4
Bowl Fen	Fb	11	0.1	11	0.0
Floating Fen	Ff	-	-	61	0.1
Horizontal Fen	Fh	-	-	596	0.5
	Fh-Mw	-	-	2,162	1.6
	Fh-Mw-Pn6	-	-	1,539	1.2
Patterned Fen	Fp	-	-	809	0.6
Stream Fen	Fs	-	-	121	0.1
	Fs-Aw	-	-	265	0.2
	Fs-Bs	-	-	341	0.3
Hillwash	Hw	-	-	819	0.6
	Hw1	7	0.1	7	0.0
	Hw1-Wx	233	1.9	233	0.2
	Hw2	46	0.4	45	0.0
	Hw2-Wx	395	3.2	396	0.3
	Hw3	115	0.9	115	0.1
	Hw3-Wx	784	6.4	784	0.6
	Hw4	308	2.5	308	0.2
	Hw4-Wx	282	2.3	282	0.2
	Hw-Bs	-	-	737	0.6
La Corne	Lc1	87	0.7	11,141	8.4
	Lc1-Pn1	315	2.6	315	0.2
	Lc3	121	1.0	5,757	4.3
	Lc3-Pp7	96	0.8	96	0.1

Dominant Soil Association/ Complex	Soil Map Unit Symbol	LSA (ha)	LSA (%)	FalC Forest (ha)	FalC Forest (%)
Meadow	Mw	17	0.1	356	0.3
	Mw-Aw	15	0.1	15	0.0
	Mw-Pn6	65	0.5	-	-
	Mw-Ff	-	-	82	0.1
	Mw-Fh-Pn9	-	-	465	0.3
	Mw-Lc1	-	-	169	0.1
	Mw-Pn2	-	-	2,156	1.6
	Mw-Pn6	-	-	65	0.1

Table 5.2.2-10: Soil Map Units in the Study Areas (concluded)

Dominant Soil Association/ Complex	Soil Map Unit Symbol	LSA (ha)	LSA (%)	FalC Forest (ha)	FalC Forest (%)
Nisbet	Nt1	-	-	239	0.2
	Nt2	-	-	378	0.3
	Nt3	-	-	570	0.4
Pine	Pn1	3,188	26.1	23,539	17.7
	Pn1-Lc1	253	2.1	253	0.2
	Pn1-Lc3	213	1.7	213	0.2
	Pn2	3,306	27.1	41,406	31.2
	Pn4	-	-	9,814	7.4
	Pn6	441	3.6	1,722	1.3
	Pn7	288	2.4	288	0.2
	Pn9	-	-	4,317	3.2
Porcupine Plain	Pp5			5,844	4.4
	Pp5-Lc1	163	1.3	163	0.1
Wetland	Wx-Pn6	165	1.4	165	0.1
Water	Water	407	3.3	1,038	0.8
Disturbed Land	Access	**129**	1.1	1,193	0.9
	Open Site	**13**	0.1	35	0.0
	Other Disturbance	**88**	0.7	105	0.1
	Reclaimed Site	**18**	0.1	53	0.0
	Borrow Pit			11	0.0
	Gravel Pit	**0.4**	0.0	5	0.0
	Industrial	**1**	0.0	2	0.0
	Tower Site	**2**	0.0	2	0.0
	Town Site			0.4	0.0
	Well Site	**0.1**	0.0	0.6	0.0
Total		**12,218**	**100.0**	**132,769**	**100.0**

Notes: ^{z} – a dash (-) indicates that the unit is not map in the LSA.

Soil Quality

The results of the soil quality interpretations for the soil map units within the LSA, including land capability for agriculture and forestry, compaction, rutting and puddling risk, wind and water erosion risk, and soil salinity are presented below.

Land Capability for Agriculture

Soils without capability to support annual cultivation (Class 6) are dominant within the LSA (Table 5.2.2-11; Figure 5.2.2-6). This includes soils of the Pine, Arbow, Hillwash and Wetland soil associations and complexes. Soils in this class are limited to the production of native forage crops and have agricultural limitations related to low moisture holding capacity, adverse topography, erosion susceptibility, and excessive wetness.

Table 5.2.2-11: Summary of Land Capability for Agriculture in the LSA

Class	Description	Limitations	Soil Association/ Complex	LSA (ha)	LSA (%)
2	Moderate limitations that restrict the range of crops or require moderate conservation practices.	susceptibility to flooding or inundation	Alluvium	298	2.4
3	Moderately severe limitations that restrict range of crops or require special conservation practices.	low moisture holding capacity dense soil structure	Porcupine Plain, La Corne	163	1.3
4	Severe limitations that restrict range of crops or require special conservation practices or both.	adverse topography	Porcupine Plain, La Corne	619	5.1
5	Very severe limitations that restrict their use to the production of native or tame species of perennial forage crops. Improvement practices are feasible.	excessive wetness or poor drainage	Pine, Nisbet, Meadow	4,169	34.1
6	Capable of producing native forage crops only. Improvement practices not feasible.	low moisture holding capacity adverse topography erosion susceptibility excessive wetness or poor drainage	Pine, Arbow, Hillwash, Wetland	5,822	47.6
7	No capability for arable agriculture or permanent pasture.	excessive wetness or poor drainage	Marsh, Meadow, Wetland	262	2.1
Organic	Organic soils, not rated for soil capability.		Bog, Fen	227	2.1
Water				407	1.9
Disturbed Land				251	3.3
Total				12,218	100.0

Land Capability for Forestry

Soils with very severe limitations for the growth of commercial forest (Class 6) are dominant in the LSA (Table 5.2.2-12; Figure 5.2.2-7). These include Class 6 soils include Arbow, Hillwash and Pine associations. There is also a large area of Class 5 soils, and Classes 4 and 7 occur in minor extents. Classes 1 to 3 do not occur in the LSA. The main limitations to commercial forest production in these soil types are soil moisture deficit, combined with excess soil moisture conditions of lowland areas associated with these soils.

Table 5.2.2-12: Summary of Land Capability for Forestry in the LSA

Land Capability for Forestry Class	Description	Limitations	Soil Association/ Complex	LSA (ha)	LSA (%)
4	Lands with moderately severe limitations for growth of commercial forest. MAI ranges from 3.6 to 4.9 m^3/ha/year.	growing season soil moisture deficit, excess soil moisture	Alluvium, La Corne, Porcupine Plain	1,079	8.8
5	Lands with severe limitations for growth of commercial forest. MAI ranges from 2.2 to 3.5 m^3/ha/year.	multiple limitations	Alluvium, Pine, Wetland	4,169	34.1
6	Lands with very severe limitations for growth of commercial forest. MAI ranges from 0.8 to 2.1 m^3/ha/year.	growing season soil moisture deficit, excess soil moisture	Arbow, Hillwash, Pine	5,822	47.6
7	Lands with no capability for commercial forest production. MAI is less than 0.7 m^3/ha/year.	excess soil moisture	Bog, Fen, Meadow, Wetland	489	4.0
Water				407	3.3
Disturbed Land				251	2.0
Total				**12,218**	**100.0**

Compaction, Rutting and Puddling Risk

Soils with low risk of compaction, rutting and puddling are dominant in the LSA (Table 5.2.2-13). Soils with high risk for compaction, rutting and puddling occupy approximately 17%

(2,051 ha) of the LSA. This includes Gleysolic and Luvisolic soils belonging to the Arbow, Meadow, Hillwash, La Corne, and Porcupine Plain soil associations.

Table 5.2.2-13: Summary of Compaction, Rutting and Puddling Risk in the LSA

Compaction, Rutting and Puddling Risk Rating	Soil Map Unit	LSA (ha)	LSA (%)
High	Aw, Aw-Mw, Mw3, Hw3-Wx, Hw4, Hw4-Wx, Lc3, Lc3-Pp7, Mw, Mw-Aw, Pp5-Lc1	1,917	15.7
High Compaction and Rutting, Moderate to High Puddling	Lc1	87	0.7
High Compaction, Low Rutting and Puddling	Bb, Bb-Fb, Fb	670	5.5
Moderate to High	Av, Av-Wx	298	2.4
Low	Hw1, Pn1, Pn2, Pn6, Pn7	7,231	59.2
Complex of Low and High	Hw1-Wx, Hw2, Hw2-Wx, Lc1-Pn1, Mw-Pn6, Pn1-Lc1, Pn1-Lc3, Wx-Pn6	1,357	11.1
Water		407	3.3
Disturbed Land		251	2.1
Total		**12,218**	**100.0**

Wind and Water Erosion Risk

Soils with high wind erosion risk, including soils of the Alluvium, Hillwash, and Pine associations are dominant in the LSA (Table 5.2.2-14; Figure 5.2.2-8). Soils with very low to low water erosion risk are dominant in the LSA (Table 5.2.2-15; Figure 5.2.2-9).

Table 5.2.2-14: Summary of Wind Erosion Risk in the LSA

Wind Erosion Risk	Soil Map Unit	LSA (ha)	LSA (%)
High	Av, Pn1, Pn2, Pn6, Pn7, Pn1-Lc1, Hw1, Hw2, Hw3, Hw4	8,210	67.2
High with Organic	Av-Wx, Hw1-Wx, Hw2-Wx, Hw3-Wx	1,452	11.9
Moderate	Mw-Pn6	65	0.5
Low	Wx-Pn6	165	1.4
Very Low	Aw, Aw-Mw, Bb, Bb-Fb, Fb, Lc1, Lc1-Pn1, Lc3, Lc3-Pp7, Mw, Mw-Aw, Pp5-Lc1	1,668	13.6
Water		407	3.3
Disturbed Land		251	2.1
Total		**12,218**	**100.0**

Table 5.2.2-15: Summary of Water Erosion Risk in the LSA

Water Erosion Risk	LSA (ha)	LSA (%)
Very High	469	3.8
Very High with Organic	1,463	12.0
High	440	3.6
High with Organic	250	2.1
Moderate	2,796	22.9
Low	2,914	23.8
Very Low	3,189	26.1
Very Low with Organic	39	0.3
Water	407	3.3
Disturbed Land	251	2.1
Total	**12,218**	**100.0**

Soil Salinity

A review of the salinity levels of soils in the soil surveys of the rural municipalities in which the study areas are located (Saskatchewan Land Resource Centre 1997a, 1997b, 1997c, 1997d) indicated that soils are generally non saline. Electrical conductivity data for soils sampled in the LSA likewise indicate that soils are mainly non saline. Only the Arbow soil showed weak salinity in the lower subsoil, with an EC of 2.7 dS/m.

Summary

Coarse textured eolian and fluvial-lacustrine deposits are the dominant parent materials in the LSA and the FalC Forest. Terrain is generally stable, with ratings of negligible to very low likelihood of landslide initiation, occupying 9,960 ha (82%) of the LSA. The banks of the Saskatchewan River consist of dissected valley and ravine slopes ranging from 10 to 30 % slope and are dominated by colluvium surface materials. The risk rating for landslide initiation in this type of terrain ranges from moderate to high.

Soils in the LSA and the FalC Forest are dominated by the Pine soil association. Pine map units account for about 64.6% (7,854 ha) of the LSA and 61.8% (82,036 ha) of the FalC. The Pine Association soils consist of Eluviated Eutric Brunisolic and Orthic Regosolic soils on fluvio-eolian, fluvial-lacustrine and eolian parent materials. The Hillwash complex of soils and terrain is the next most abundant soil in the LSA, occupying 18% (2,189 ha) of the area, and about 2.8% (3,727 ha) of the FalC area. Other relatively widespread soils are: La Corne, (5.1% (622 ha) of the LSA and 12.9% (17,038 ha) of the FalC Forest); Alluvium 2.4% (298 ha) of the LSA and 0.9% (1,251 ha) of the FalC Forest; Bog-Fen complexes (1.8 (227 ha) of the LSA and 11.3% (14,987 ha) of the FalC Forest); Arbow (1.1% (135 ha) of the LSA and 0.1% (135 ha) of the FalC Forest); Porcupine Plain (1.3% (163 ha) of the LSA and 4.5% (6,015 ha) of the FalC Forest); Water and Wetlands (4.8% (578 ha) of the LSA and 2.0% (596 ha) of the FalC Forest).

The upland soils are mainly Brunisols and Luvisols, having been formed mainly under forest vegetation. These soil types have slightly acidic to neutral pH levels in the upper horizons and are neutral to alkaline and calcareous in lower horizons. Soils are rated as non-saline, with very weak salinity characterizing subsoils of minor areas.

Soils with no capability to support annual cultivation (Class 6) are dominant within the LSA. This includes soils of the Pine, Arbow, Hillwash, and Wetland soil associations. Soils in this class are limited to the production of native forage crops and have agricultural limitations related to low moisture holding capacity, adverse topography, erosion susceptibility, and excessive wetness.

Soils with very severe limitations for the growth of commercial forest (Class 6) are dominant in the LSA. These include soils of the Arbow, Hillwash and Pine associations. Limitations to commercial forest production in these soil types include soil moisture deficit, along with excess soil moisture conditions in associated low lying, poorly drained landscape positions.

Soils with high risk for compaction, rutting and puddling occupy approximately 17% of the LSA. These include Gleysolic and Luvisolic soils belonging to the Arbow, Meadow, Hillwash, La Corne, and Porcupine Plain soil associations. The remainder of the LSA is characterized by low risk of compaction, rutting and puddling.

Wind erosion risk is high for most of the soils of the LSA. Water erosion risk is very low to low or most of the soils. The soils are predominantly sandy, which predisposes them to wind erosion; however, their high water infiltration capacity results in relatively low water erodibility.

5.2.3 Metal Leaching and Acid/Alkaline Rock Drainage

This Section describes the geochemical characteristics of the Project. The approach and results of the metal leaching and acid/alkaline rock drainage (ML/AARD) characterization program are presented.

5.2.3.1 Introduction

The ML/AARD characterization program outlined in this Section represents an assessment of Project geochemistry.

The objectives of the assessment are:

- to describe the ML/AARD characteristics of material that will be mined;
- to present the results of the acid base accounting (ABA) assessment of the Project;
- to investigate the acid potential (AP) and neutralization potential (NP) of Project materials; and
- to examine the potential for metal leaching from processed kimberlite using field and laboratory testing.

The characterization program was developed with reference to the MEND Report 5.10 *List of potential Information Requirements in Metal Leaching/Acid Rock Drainage Assessment and Mitigation Work*, and *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia,* Price (1997).

5.2.3.2 Geology

The geological setting is described in Section 5.2.1.

Star Kimberlite units examined during the geochemistry baseline include:

- *Cantuar Pyroclastic Kimberlite (CPK-PK);*
- *Cantuar Kimberlite Breccia (CPK-KB);*
- *Pense Pyroclastic Kimberlite;*
- *Early Joli Fou Pyroclastic Kimberlite (EJF-PK);*
- *Early Joli Fou Kimberlite Breccia (EJF-KB);*
- *Middle Joli Fou Kimberlite (MJF-VK);*
- *Late Joli Fou Kimberlite (LJF-VK); and*
- *Upper Kimberlitic Sediments (KDF-KSST).*

Orion South Kimberlite units examined during the geochemistry baseline include:

- *Cantuar Kimberlite;*
- *Pense Kimberlite (P2-PK and P3-PK);*
- *Early Joli Fou Kimberlite Breccia (EJF2-KB);*
- *Early Joli Fou Pyroclastic Kimberlite (EJF2-PK);*
- *Late Joli Fou Pyroclastic Kimberlite (LJF-PK); and*
- *Upper Kimberlitic Sediments (KSTST-KSST)*

Star and Orion South Kimberlite Whole Rock Geochemistry

Kjarsgaard et al. (2006) and Grunsky and Kjarsgaard (2008), examined the differences in chemistry between the kimberlite units. In general, the differences in chemistry are representative of the kimberlite units, particularly olivine and matrix, and country rock. The olivine-rich units (e.g., EJF) are generally characterized by relatively high magnesium, nickel, cobalt and silicon that is indicative of a mantle signature. In contrast the olivine-depleted units (e.g., Pense at Orion South), are characterized by relatively high levels of rare earth elements and more indicative of a kimberlite magmatic signature. Other units (e.g., LJF) exhibit elevated levels of aluminum, sodium and potassium indicative of crustal contamination which is observed in core samples by the ubiquitous presence of shale clasts.

Country Rock

Country rock at Star and Orion South is comprised of the Westgate, Viking and the Joli Fou Formations (UJFF) (part of the lower Colorado Group) which are predominantly laminated shale with rare 2 to 15 mm sand to silt lenses and Cantuar (part of the Mannville Group) Formation (CF) sandstone with lesser siltstone and mudstone.

Surficial Geology

The Project comprises rolling glacial topography with sandy river sediments and is drained by numerous small tributaries running south towards the Saskatchewan River. Thick deposits of glacial and fluvial sediments overlie the Project area. Elevations vary from 360 m to 450 m above sea level.

5.2.3.3 Approach to ML/AARD Characterization

ML/AARD characterization is generally iterative with rounds of static and leaching tests completed as a project develops. Design of characterization programs starts with static ABA testing and evaluation of complementary data sets such as drill core geochemical databases. Results of static ABA characterization are used to identify potentially acid generating material and select appropriate samples for kinetic testing.

ML/AARD Criteria

Characterization of potentially acid generating and metal leaching material at the Project will follow the recommendations outlined in the MEND 5.10 report *List of Potential Information Requirements in Metal Leaching/Acid Rock Drainage Assessment and Mitigation Work* (MEND 2005) and the *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (Price 1997). The MEND document states that samples with a neutralization potential ratio (NPR) less than 1 are likely acid generating; samples with an NPR from 1 to 2 have an uncertain potential of acid generating; and, samples with an NPR greater than 2 are considered to have a low probability of acid generation.

ABA Surrogates

The concept of developing ABA surrogates is based on using other sources of geochemical data to calculate the acid potential (AP) and neutralization potential (NP) of a material.

The use of surrogate ABA parameters has been used on other projects (Downing and Giroux 1993; Day 1995; Downing and Madeisky 1997) and has been intensely researched (Hutt and Morin 2000; MEND 1996).

In ABA, the AP is determined from the sulphide sulphur concentration. The sulphide concentration is calculated from the difference between total sulphur (as measured by Leco furnace) and sulphate sulphur (as determined by chemical digestion and analysis). The most common AP surrogate is sulphur from ICP analysis after aqua regia digestion. Aqua regia is a strong acid digestion, which dissolved sulphides and carbonates and all but the most refractory minerals.

Generally, there are more complicating factors with the derivation of NP surrogates than with determination of AP surrogates. For unweathered rocks, total sulphur content is often a suitable measure of the acid generation potential. However, for NP determination, many different minerals, both carbonates and non-carbonates, can aid in the neutralization of acidity. Therefore, determining what minerals (or alternate chemical analysis) contribute to NP can vary significantly between mineral deposits, mining projects, and between different rock types.

The MEND (1996) report on surrogates included research that was carried out to evaluate the static testing methods of determining the NP of mining waste as part of routine prediction testing for acid rock drainage. There are three common determinations of NP:

- Sobek NP or modified Sobek NP that is part of the traditional ABA analysis;
- Carbonate NP as calculated from the total inorganic carbon concentration measured by Leco furnace that is commonly included as part of the ABA analysis; and
- $NP_{ICP\text{-}Ca}$ that uses the Ca concentration from ICP analysis after aqua regia digestion.

Historically the most common determination of NP is the Sobek NP (EPA, 1986); it represents the NP from the most reactive silicate minerals in addition to carbonate minerals (MEND 1996). In recent years the modified Sobek NP method has gained favour, due to its less aggressive dissolution technique which tends to be more representative of NP that is actually available for acid neutralization. The CNP and the $NP_{ICP\text{-}Ca}$ assume that only calcium carbonate minerals contribute to the NP. Hutt and Morin (2000) reported that the CNP is often an underestimation relative to the Sobek and modified Sobek NP. All studies encouraged mineralogical studies to delineate calcium containing minerals.

Metal Leaching

Predictions of metal leaching potential are typically evaluated with laboratory tests designed for estimation of mineral reaction rates or to simulate possible site drainage quality. Field sampling of seepages from natural outcrops, waste piles, and other geological materials are methods used to further assess potential drainage quality from mine wastes. Results from kinetic tests are used to predict relative rates of acid generation and neutralization, estimate the time to onset of acidic conditions (assuming that the neutralization potential is depleted prior to the acid potential), predict drainage chemistry and estimate geochemical loadings from site features. These tests can also be used to determine the effects of alkaline drainage on water quality.

For weathered materials, static leach extractions can provide an initial estimate to the amount of metals that may be released from a rock or mine waste.

5.2.3.4 Methods

Methods for ABA sample selection; mineralogy; ABA analytical methods; and metal leaching and kinetic testing are described in this Section.

ABA Sample Selection

In 2008, Shore drilled two holes for collection of fresh kimberlite material: one hole at the Star kimberlite complex and one hole from the Orion South kimberlite complex. Samples were collected from each of the core holes and the core holes were geologically logged by Shore geologists. The location of the drill holes and the typical geological cross section near the two drill holes is show in Figures 5.2.3-1 through 5.2.3-4. Table 5.2.3-1 shows the distribution of ABA samples between the Star and Orion South kimberlite complexes and the existing drill core database.

Table 5.2.3-1: Number of ABA and Exploration Whole Rock Chemistry Samples by Rock Types at Star and Orion South

Formation / Kimberlite Name	Rock Type	Lithology	Star Kimberlite Samples	Star Recovery Rejects Samples	Orion South Kimberlite Samples	Orion South Recovery Rejects Samples	Whole Rock Chemistry Samples
Cantuar Formation	CF	STST			5		
Cantuar Kimberlite	CPK	KB	5	1			116
		PK	5	1			
Pense Kimberlite	Pense	P2PK			15		214
		P3PK		2	5	2	
Upper Joli Fou Formation	UJFF	SHALE			9		
Early Joli Fou Kimberlite	EJF	KB	5	1	10	2	1,090
		PK	15	2	15		
Middle Joli Fou Kimberlite	MJF		10	1			145
Late Joli Fou Kimberlite	LJF	VK	10				35
		PK			10		
Upper Kimberlite Sediments	KSTST	RVK			5		7
134 Kimberlite		VK	5				
	Total		**66**	**8**	**69**	**4**	**1,765**

In 2009, Shore collected an additional 9 ABA samples. Five of the samples were collected from the 134 Kimberlite body that outcrops in the Star pit. The 134 Kimberlite will be excavated as part of the Star deposit, but is not considered ore (P&E 2010). Four samples were also collected from the Joli Fou shale country rock of the Orion South deposit.

In 2010, 12 samples of the recovery rejects were sampled and submitted for ABA and shake flask extraction. Eight samples were rejects from Star kimberlite material, and 4 were rejects from Orion South kimberlite material. The recovery rejects represent the material from the dense media separation after the diamonds are removed.

Mineralogy

X-ray diffraction (XRD) mineralogy was completed on a subset of 15 drill core samples from the Star kimberlite in 2007. Three samples were from the Cantuar kimberlite, two samples from the Pense kimberlite, seven samples from the Early Joli Fou kimberlite, two from the Middle Joli Fou kimberlite and one sample of shale from the Joli Fou (shale) country rock.

ABA Analytical Methods

The most widely used static testing procedure of the characterization of mining waste for the prediction of acid rock drainage is the acid base accounting (ABA) procedure of Sobek et al. (1978). The ABA procedure provides a measure of the balance between the acid producing constituents of a sample and the acid neutralizing constituents. ABA is not an indication of the metal leaching potential.

Paste pH

Paste pH values in ABA test work are measured by placing a pH meter into a paste created from a 2:1 solid:liquid solution (Sobek et al. 1978). Measurements of paste pH can indicate if a sample is already capable of acid generation (acidic paste pH) or if the sample can rapidly buffer any acid generation (neutral to alkaline paste pH).

A neutral or alkaline paste pH measurement is not an indication of the future pH of a sample. The paste pH provides a snap shot to the current acidity or alkalinity. Prediction of long-term pH values comes from kinetic testing.

Sulphur – Acid Potential

Sulphur minerals are the primary sources of acidity and their measurement is a critical requirement in mine site drainage chemistry prediction (Price 1997). There are three main sulphur species that are typically determined as part of acid base accounting: total sulphur, sulphate and sulphide. For the Project, total sulphur was measured using a Leco furnace analysis. Maximum potential acidity is calculated from the concentration of total sulphur.

Sulphate sulphur, generally does not contribute to the acid potential of a sample unless there are soluble acid-sulphate minerals present. The concentration of sulphate can be used as an indication of previous sulphide oxidation. However, many minerals also contain sulphate (barite, gypsum and anhydrite) and their presence should be noted before assuming all sulphate results from sulphide mineral oxidation.

Sulphide concentrations are used to calculate the acid potential. For organic free samples, the sulphide content is calculated from the difference between the acid-leachable sulphate and the total sulphur.

Neutralization Potential

The modified Sobek procedure was used for all samples from the Project. Carbonate NP (CNP) was calculated from the total inorganic carbon concentration and the NP_{Ca} was calculated from the whole rock calcium oxide concentration.

Metal Leaching and Kinetic Testing

Methods for metal leaching and kinetic testing are described in this section.

Metal Leaching

Special Waste Extraction Procedure (SWEP) test on four samples of processed kimberlite samples from bulk diamond sampling were completed in 2008. SWEP tests use a 3:1 liquid to solid ratio and a weak (acetic) acid solution to extract readily dissolved components of a sample. The more commonly used shake flask extraction is a variation of the SWEP that uses distilled water and was used to test the DMS samples.

Kinetic Testing

Laboratory kinetic testing of three processed kimberlite samples began in April 2009. The laboratory tests utilized the same processed kimberlite material as the field test pads. Two of the laboratory tests were trickle leach column tests. Similar to the field test pads, the column tests allow for sub-aerial weathering of the processed kimberlite. The tests consisted of Plexiglas columns filled with kimberlite sample. A fixed volume of water (500 mL) was added to the column over a 7-day period. The leachate draining from the bottom of the sample was collected at the end of the 7-day cycle and analysed for metals and other parameters. The third column employed a flood leaching procedure, due to the fine grain size and lower hydraulic conductivity of the sample. Additional details of the testing are given in Section 5.2.3.7.

Shore constructed three field test pads in September 2008. The field test pads are filled with Coarse PK. Compared to laboratory humidity cell tests, field based tests allow for the build up of soluble weathering products due to incomplete flushing, the partial to complete neutralization of acid products due to contact with silicate and carbonate minerals and for freezing of pads and the concurrent reduction in rate of oxidation reactions in lower and sub-zero temperatures. However, because of their similarity to ‘real world’ conditions, it is difficult to use field test data predicatively and forecast the long term geochemical behaviour of the mine waste. Laboratory kinetic testing that simulates accelerated weathering is a more suitable method for determining mineral reaction rates and predicting long-term behaviour.

5.2.3.5 ABA Results

Results are discussed in terms of the two kimberlite complexes, Star and Orion South. The following sections present the results for the multi-element geochemistry and acid-base accounting (ABA) analyses for each kimberlite complex.

Star Geochemistry

The summary results of aqua regia multi-element analysis are provided in Table 5.2.3-2 for selected metals based on Canadian Council of Ministers of the Environment (CCME) guidelines. The median aqua regia results are compared to five times the global average for ultrabasic rocks from Price (1997). The results are similar to those found by Grunsky and Kjarsgaard (2008) with the mantle rich CPK and EJF facies having relatively higher concentrations of nickel and cobalt and the more crustal influenced LJF and KDF having relatively higher concentrations of aluminium and sodium. Of the trace elements, the median concentrations of lead were greater than five times the global average for ultrabasic rocks. No detectable amounts of mercury or selenium were measured in the Star kimberlite samples.

Star Acid Base Accounting

Table 5.2.3-3 provides the summary acid base accounting results for the Star kimberlite.

All paste pH values are alkaline and range from a minimum of 8.2 (EJF-PK) to a maximum of 9.8 (CPK-PK).

Total sulphur concentrations range from less than the lower detection limit of 0.01% to a maximum of 0.45% (134-Kimberlite). Kimberlite facies with a greater amount of crustal contamination (e.g., KDF and LJF) and xenoliths have a higher median and mean concentrations of total sulphur (Table 5.2.3-4 and Figure 5.2.3-5). Sulphate concentrations are generally low, ranging from 0.01% to 0.37% (134 Kimberlite). Sulphide concentrations range from 0.01% to a maximum of 0.37% (KDF-KSST). Three of the 61 (5%) samples of Star kimberlite have sulphide concentrations greater than 0.3 (Figure 5.2.3-6).

There is a high degree of correlation between the total sulphur and sulphide concentrations (Figure 5.2.3-6) and all facies except EJF-KB had statistically significant correlations. The high correlation of sulphide sulphur to total sulphur and the low amounts of sulphate sulphur suggest that acid potential can be determined from the total sulphur concentrations. The acid potential calculated from total sulphur is referred to as the maximum potential acidity (MPA).

The NP of the Star kimberlite facies ranges from a minimum of 98.9 kg $CaCO_3$/t (CBK-KB) to a maximum of 592 kg $CaCO_3$/t (CPK-PK). The CNP, calculated from total inorganic carbon concentrations, ranges from a minimum of 9.2 kg $CaCO_3$/t (LJF-VK) to a maximum of 576 kg $CaCO_3$/t (CPK-PK). Figure 5.2.3-7 provides the relationship between NP and CNP. The percent of NP provided by carbonate varies between the kimberlite facies; accounting for an average of 83% of the NP for the CPK-PK facies and as little as 14% for the EJF-PK. The relationship between NP and CNP is not significant and the high NP values relative to CNP suggest that silicate minerals are a major component of the overall kimberlite NP.

Table 5.2.3-2: Summary Aqua Regia ICP-MS Results for the Star Kimberlite Complex Facies

		Ag	Al	Ca	Cd	Cr	Cu	Fe	K	Mg	Mo	Na	Ni	Pb	Se	Zn
Rock Type		ppm	%	%	ppm	ppm	ppm	%	%	%	ppm	%	ppm	ppm	ppm	ppm
CPK-KB (n=5)	min	0.1	1	2	0.1	412	30	4.6	0.2	10	0.5	0.2	1000	4.5	0.3	41
	max	0.2	2	4	0.1	511	37	5.2	0.4	10	0.6	0.5	1000	7.5	0.3	47
	mean	0.2	1	2	0.1	467	33	5	0.3	10	0.5	0.3	1000	6.5	0.3	44
	median	0.2	1	2	0.1	472	32	5	0.3	*10*	0.5	0.3	***1000***	**6.6**	**0.3**	44
	25th %tile	0.2	1	2	0.1	458	31	4.7	0.3	10	0.5	0.3	1000	6.6	0.3	42
	75th %tile	0.2	1	3	0.1	482	37	5.2	0.3	10	0.6	0.3	1000	7.2	0.3	46
CPK-PK (n=5)	min	0.1	1	3	0.1	304	22	2.8	0.2	3.6	0.5	0.3	704	3.3	0.3	29
	max	0.2	2	10	0.1	450	30	5	0.4	10	1.3	0.5	1000	13	0.3	43
	mean	0.2	1	7	0.1	369	26	3.9	0.3	7.9	0.8	0.4	867	7.3	0.3	36
	median	0.2	1	6	0.1	369	27	4.2	0.3	*10*	0.7	0.5	891	**6**	**0.3**	37
	25th %tile	0.1	1	4	0.1	316	26	3.2	0.3	5.9	0.5	0.4	791	5.6	0.3	35
	75th %tile	0.2	1	10	0.1	406	29	4.4	0.3	10	1.1	0.5	948	8.4	0.3	38
EJF-KB (n=5)	min	0.2	2	1	0.1	451	25	4.6	0.1	10	0.5	0.1	984	6.1	0.3	42
	max	0.2	2	4	0.1	467	36	5.5	0.3	10	0.8	0.3	1000	9.1	0.3	66
	mean	0.2	2	2	0.1	460	29	5	0.2	10	0.6	0.2	997	7.9	0.3	49
	median	0.2	2	2	0.1	461	28	5	0.2	*10*	0.5	0.1	***1000***	**8.1**	**0.3**	44
	25th %tile	0.2	2	1	0.1	458	27	4.9	0.2	10	0.5	0.1	1000	7.6	0.3	43
	75th %tile	0.2	2	3	0.1	462	28	5.1	0.3	10	0.6	0.3	1000	8.4	0.3	51
EJF-PK (n=15)	min	0.2	1	1	0.1	488	25	4.9	0.1	10	0.4	0	1000	4.3	0.3	47
	max	0.2	1	3	0.1	607	31	6.4	0.2	10	1.2	0.2	1000	7	0.3	56
	mean	0.2	1	2	0.1	560	28	5.8	0.1	10	0.5	0.1	1000	5.4	0.3	53
	median	0.2	1	2	0.1	558	28	5.8	0.1	*10*	0.5	0.1	***1000***	**5.3**	**0.3**	54
	25th %tile	0.2	1	2	0.1	545	27	5.7	0.1	10	0.4	0.1	1000	5	0.3	52
	75th %tile	0.2	1	2	0.1	573	29	5.9	0.1	10	0.5	0.1	1000	5.7	0.3	55
MJF-VK (n=10)	min	0.2	1	2	0.1	530	26	5.7	0.1	10	0.4	0.1	1000	5.6	0.3	52
	max	0.2	1	3	0.1	638	31	6.5	0.2	10	0.6	0.2	1000	26	0.3	69
	mean	0.2	1	2	0.1	575	28	6	0.1	10	0.5	0.1	1000	8.7	0.3	57
	median	0.2	1	2	0.1	562	28	5.9	0.1	*10*	0.5	0.1	***1000***	**6.1**	**0.3**	56
	25th %tile	0.2	1	2	0.1	547	28	5.8	0.1	10	0.4	0.1	1000	5.6	0.3	55
	75th %tile	0.2	1	2	0.1	609	29	6.1	0.1	10	0.5	0.2	1000	6.6	0.3	58
LJF-VK (n=10)	min	0.1	2	3	0.1	624	43	5.1	0.2	10	0.5	0.3	767	8.3	0.3	46
	max	0.2	2	5	0.1	764	53	5.6	0.3	10	0.8	0.5	988	12	0.3	51
	mean	0.2	2	4	0.1	689	48	5.4	0.2	10	0.6	0.4	858	9.7	0.3	48
	median	0.2	2	4	0.1	688	49	5.5	0.3	*10*	0.7	0.4	831	**9.9**	**0.3**	48
	25th %tile	0.2	2	3	0.1	662	44	5.4	0.2	10	0.6	0.3	797	8.6	0.3	47
	75th %tile	0.2	2	4	0.1	716	50	5.5	0.3	10	0.7	0.5	924	10	0.3	49
KDF-KSST (n=11)	min	0.1	2	2	0.1	614	48	4.3	0.3	10	0.8	0.7	553	12	0.3	46
	max	0.4	3	9	0.1	793	63	5.4	0.5	10	1.6	1.1	817	20	0.3	56
	mean	0.2	2	5	0.1	708	56	4.9	0.4	10	1	0.9	663	15	0.3	51
	median	0.2	2	4	0.1	711	**56**	4.9	0.4	*10*	0.9	0.9	653	**15**	**0.3**	52
	25th %tile	0.2	2	4	0.1	663	53	4.8	0.4	10	0.8	0.8	623	13	0.3	49
	75th %tile	0.2	2	5	0.1	733	60	5.1	0.5	10	1.1	1.1	689	15	0.3	54
Ultrabasic Crust		0.1	2	3	150	1600	10	9.4	40	20	0.3	0.42	2000	1	0.1	50

Notes: Values in **bold** indicate where the median value is greater than the five times the ultrabasic crustal abundance (from Price 1997).
Values in ***italics*** indicate where the upper detection limit is less than the ultrabasic crustal abundance.
Values ***underlined*** indicate where the lower detection limit is greater than the ultrabasic crustal abundance.

Table 5.2.3-3: Summary of Star Kimberlite Facies ABA Results

Rock Type		Paste pH	TIC*	Total Sulphur	Sulphate	Sulphide	AP	NP	CNP**	NPR
			%	%	%	%	kg/tonne	kg/tonne	kg/tonne	
CPK-KB	min	9.2	0.6	0.03	0.01	0.02	0.6	99	46	67
	max	9.5	1.1	0.09	0.01	0.09	2.8	344	91	398
	mean	9.3	0.8	0.05	0.01	0.05	1.4	213	65	148
	median	9.3	0.7	0.05	0.01	0.04	1.3	188	56	151
	25th %tile	9.3	0.6	0.03	0.01	0.02	0.6	181	48	96
	75th %tile	9.4	1.0	0.07	0.01	0.06	1.9	251	82	275
CPK-PK	min	9.1	1.8	0.01	0.01	0.01	0.3	223	149	89
	max	9.8	6.9	0.1	0.02	0.08	2.5	592	576	1894
	mean	9.6	4.2	0.06	0.01	0.05	1.6	394	348	242
	median	9.7	3.0	0.07	0.01	0.06	1.9	298	247	158
	25th %tile	9.4	2.5	0.04	0.01	0.03	0.9	273	204	145
	75th %tile	9.7	6.8	0.1	0.02	0.08	2.5	585	566	316
EJF-KB	min	8.7	0.1	0.01	0.01	0.01	0.2	103	12	200
	max	9.4	1.0	0.08	0.06	0.03	0.9	222	79	684
	mean	9.1	0.5	0.05	0.04	0.02	0.5	166	38	352
	median	9.3	0.4	0.06	0.05	0.01	0.3	177	36	570
	25th %tile	9.0	0.2	0.04	0.04	0.01	0.3	138	18	353
	75th %tile	9.3	0.5	0.07	0.05	0.02	0.6	188	43	570
EJF-PK	min	8.3	0.4	0.01	0.01	0.01	0.2	197	36	160
	max	9.5	0.7	0.06	0.03	0.05	1.6	373	60	2343
	mean	8.7	0.6	0.03	0.01	0.02	0.6	299	47	543
	median	8.4	0.6	0.02	0.01	0.01	0.3	318	46	1027
	25th %tile	8.4	0.5	0.01	0.01	0.01	0.2	254	43	353
	75th %tile	8.9	0.6	0.05	0.02	0.03	0.9	346	51	1679
MJF-VK	min	9.2	0.6	0.02	0.01	0.01	0.3	130	46	59
	max	9.3	0.8	0.11	0.04	0.07	2.2	293	67	465
	mean	9.3	0.6	0.06	0.02	0.04	1.3	167	53	124
	median	9.3	0.6	0.06	0.01	0.05	1.6	140	53	90
	25th %tile	9.3	0.6	0.04	0.01	0.03	0.8	131	50	84
	75th %tile	9.3	0.7	0.08	0.03	0.06	1.8	155	55	212
LJF-VK	min	8.9	0.1	0.08	0.04	0.03	0.9	162	9	31
	max	9.4	1.6	0.39	0.06	0.33	10.3	357	136	344
	mean	9.2	1.0	0.18	0.05	0.13	4.2	297	84	71
	median	9.2	1.0	0.17	0.05	0.12	3.6	320	83	89
	25th %tile	9.1	0.9	0.09	0.04	0.05	1.6	308	79	60
	75th %tile	9.4	1.1	0.24	0.06	0.19	5.9	335	92	116
134 Kimberlite	min	8.5	1.3	0.09	0.09	0.01	0.2	309	104	131
	max	9.5	3.8	0.45	0.37	0.08	2.5	424	316	2752
	mean	8.9	2.6	0.22	0.19	0.04	1.2	366	220	309
	median	8.8	2.7	0.15	0.15	0.05	1.6	357	228	228
	25th %tile	8.7	1.9	0.15	0.10	0.01	0.2	327	161	198
	75th %tile	8.9	3.5	0.27	0.22	0.05	1.6	413	290	2377
KDF-KSST	**min**	**8.7**	**0.6**	**0.09**	**0.03**	**0.05**	**1.6**	**150**	**51**	**17**
	max	**9.6**	**2.7**	**0.41**	**0.05**	**0.37**	**11.6**	**362**	**224**	**183**
	mean	**9.2**	**1.3**	**0.22**	**0.04**	**0.18**	**5.6**	**249**	**105**	**45**
	median	**9.1**	**1.1**	**0.20**	**0.04**	**0.15**	**4.7**	**286**	**91**	**61**
	25th %tile	**9.0**	**0.9**	**0.16**	**0.04**	**0.11**	**3.4**	**163**	**78**	**26**
	75th %tile	**9.3**	**1.3**	**0.25**	**0.05**	**0.20**	**6.3**	**320**	**111**	**72**
KDF-KSST	**min**	**8.7**	**0.6**	**0.09**	**0.03**	**0.05**	**1.6**	**150**	**51**	**17**
	max	**9.6**	**2.7**	**0.41**	**0.05**	**0.37**	**11.6**	**362**	**224**	**183**
	mean	**9.2**	**1.3**	**0.22**	**0.04**	**0.18**	**5.6**	**249**	**105**	**45**
	median	**9.1**	**1.1**	**0.20**	**0.04**	**0.15**	**4.7**	**286**	**91**	**61**
	25th %tile	**9.0**	**0.9**	**0.16**	**0.04**	**0.11**	**3.4**	**163**	**78**	**26**
	75th %tile	**9.3**	**1.3**	**0.25**	**0.05**	**0.20**	**6.3**	**320**	**111**	**72**

Notes: *TIC is total inorganic carbon as determined by Leco furnace analysis.
** CNP is carbonate NP calculated from the TIC concentration.

Figure 5.2.3-8 shows the neutralization potential ratio (NPR) of Star kimberlite facies. All samples have an NPR much greater than 2 and are classified as non-acid generating. Even using the highly conservative CNP all samples remain non-acid generating (Figure 5.2.3-9).

Orion South Geochemistry

The summary results of multi-element analysis are provided in Table 5.2.3-4 for selected metals. The median aqua regia results are compared to five times the global average for ultrabasic rocks for kimberlite and to five times average sandstone for the CF-STST and five times the average shale for the UJFF-STST from Price (1997).

Table 5.2.3-4: Summary Aqua Regia Results for the Orion South Facies

Rock Type		Ag	Al	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	Pb	Se	Zn
		ppm	%	%	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm
P2-PK	min	0.1	1.3	2.1	0.1	426	43.6	4.1	0.1	10	752	781	5.4	0.3	45
	max	0.3	2	4.1	0.1	757	66.1	5.5	0.3	10	1137	1000	9.9	0.3	56
	mean	0.2	1.7	3	0.1	584	50	5	0.2	10	912	897	7.9	0.3	49.2
	median	0.2	1.7	2.9	0.1	593	49.3	5.1	0.2	10	897	896	**8.4**	0.3	49
	25th %tile	0.2	1.5	2.5	0.1	538	45.5	4.9	0.1	10	818	849	6.4	0.3	47
	75th %tile	0.2	1.8	3.6	0.1	634	52.2	5.3	0.2	10	982	933	9.4	0.3	50
P3-PK	min	0.2	0.5	1.2	0.1	430	21.7	4	0	10	582	813	2.8	0.3	39
	max	0.3	0.7	1.8	0.2	477	33.1	4.5	0.1	10	678	1000	4.1	0.3	45
	mean	0.2	0.6	1.5	0.1	452	26.7	4.2	0	10	635	943	3.5	0.3	40.8
	median	0.2	0.7	1.5	0.1	450	27.5	4.1	0.1	10	646	960	3.6	0.3	39
	25th %tile	0.2	0.5	1.4	0.1	440	21.9	4	0	10	610	956	2.9	0.3	39
	75th %tile	0.2	0.7	1.7	0.1	465	29.1	4.3	0.1	10	657	987	3.9	0.3	42
EJF-2PK	min	0.2	0.8	4	0.1	474	24.4	4.4	0.1	10	754	1000	2.8	0.3	41
	max	0.3	1	6.1	0.2	544	31.7	6	0.1	10	1175	1000	4.6	0.3	50
	mean	0.2	0.9	5	0.1	515	28.2	5.3	0.1	10	928	1000	4.1	0.3	45.9
	median	0.2	0.9	5	0.1	526	28.8	5.3	0.1	10	923	1000	4.2	0.3	46
	25th %tile	0.2	0.8	4.8	0.1	497	25.9	5	0.1	10	841	1000	4	0.3	44.5
	75th %tile	0.3	0.9	5.2	0.1	533	29.7	5.6	0.1	10	983	1000	4.3	0.3	47
EJF-2KB	min	0.1	0.8	0.5	0.1	158	24.4	2.4	0.1	1.6	154	119	2.8	0.3	40
	max	0.4	2.5	10	0.1	737	123	6	1.1	10	1749	1000	25	0.3	111
	mean	0.2	1.4	4.8	0.1	518	42.3	4.8	0.3	9	858	809	9	0.3	51.9
	median	0.2	1.5	5	0.1	528	36.9	5.1	0.1	10	911	995	**6.6**	0.3	46
	25th %tile	0.2	0.9	3.4	0.1	475	29.5	4.5	0.1	10	755	844	4.3	0.3	44
	75th %tile	0.3	1.8	6.3	0.1	599	42.1	5.5	0.4	10	1010	1000	9.8	0.3	48
LJF-PK	min	0.2	1.4	3.8	0.1	683	38.7	5.2	0.1	10	886	840	5.9	0.3	43
	max	0.4	1.7	10	0.1	737	45.8	5.6	0.2	10	1749	997	7.8	0.3	51
	mean	0.3	1.6	7.7	0.1	714	41.5	5.4	0.1	10	1048	928	6.7	0.3	46.1
	median	0.3	1.6	7.9	0.1	715	41.6	5.4	0.1	10	969	933	**6.6**	0.3	45.5
	25th %tile	0.2	1.6	7.6	0.1	705	40.2	5.3	0.1	10	919	884	6.4	0.3	44.3
	75th %tile	0.3	1.6	8.3	0.1	728	42.1	5.5	0.1	10	1010	969	7.1	0.3	48
KSTST	min	0.2	2.1	4.9	0.1	542	75.6	3.9	0.4	9.5	1137	281	14	0.3	40
	max	0.2	2.5	6.9	0.1	607	123	5	0.8	10	1405	552	21	0.3	47
	mean	0.2	2.4	5.9	0.1	572	96.2	4.4	0.5	9.9	1249	439	17	0.3	44.4
	median	0.2	2.4	6	0.1	573	89.3	4.4	0.4	10	1203	497	**16**	0.3	44
	25th %tile	0.2	2.4	5.2	0.1	563	86.9	4.2	0.4	9.8	1187	339	15	0.3	44
	75th %tile	0.2	2.4	6.4	0.1	575	106	4.5	0.7	10	1312	524	19	0.3	47
Ultrabasic Crust		0.1	2	3	0.X	1600	10	9.4	40	20	0.3	2000	1	0.1	50
CF-STST	min	0.1	0.2	0	0.1	36	5.5	0.1	0.1	0.1	18	12	2.4	0.3	13
	max	0.2	0.4	0.2	0.1	47	18.6	2.3	0.2	0.3	747	28	9	0.3	35
	mean	0.1	0.3	0.1	0.1	41.8	12.4	1.3	0.1	0.2	396	17	6.4	0.3	25.2
	median	**0.1**	0.4	0.1	0.1	42	12.2	1.6	0.1	0.2	496	**13**	6.7	0.3	24
	25th %tile	0.1	0.3	0.1	0.1	40	11	0.5	0.1	0.1	108	12	5.6	0.3	23
	75th %tile	0.1	0.4	0.2	0.1	44	14.9	2.2	0.2	0.3	609	20	8.1	0.3	31
UJFF-STST	min	0.2	1.9	0.5	0.2	158	40.2	2.4	0.9	1.6	154	119	20	0.3	87
	max	0.4	2.1	0.6	0.2	248	61.3	5	1.1	2.4	176	139	25	0.3	111
	mean	0.3	2	0.5	0.2	178	46.9	3	1	1.8	161	125	23	0.3	100
	median	**0.3**	2	0.5	0.2	162	43.4	2.6	1.1	1.7	160	121	**24**	0.3	101
	25th %tile	0.3	2	0.5	0.2	158	40.3	2.4	1	1.7	155	120	22	0.3	93
	75th %tile	0.3	2.1	0.5	0.2	164	49.1	2.7	1.1	1.8	160	124	25	0.3	109
Shale		0.07	8	2.2	0.3	90	45	4.7	2.7	1.5	850	68	20	0.6	95
Sandstone		0.0X	2.5	3.9	00X	35	X	0.98	10.7	.0.7	X0	2	7	0.05	16

Notes: Values in **bold** indicate where the median value is greater than the rock type crustal abundance (from Price 1997).
Values in ***italics*** indicate where the upper detection limit is less than rock type crustal abundance.
Values ***underlined*** indicate where the lower detection limit is greater than rock type crustal abundance.

The results for the kimberlite units are similar to the Star kimberlite, although trends reflecting mantle to crustal contamination are less evident. Of the trace elements, the median concentrations of copper and lead were greater than the global average for ultrabasic rocks in the kimberlite facies. No metals were identified as elevated in the country rocks. Only one sample from the Orion South complex had a measured Hg concentration (UJFF) above the detection limit and no selenium was detected above the detection limit.

Orion South Acid Base Accounting

Table 5.2.3-5 summarizes the acid base accounting results for the Orion South kimberlite and country rock. All paste pH values are alkaline and range from a minimum of 8.2 (LJF-PK, EJF2-PK) to a maximum of 9.4 (P2-PK). The paste pH values in the country rock (CF-STST and UJFF-STST) range from a minimum of 5.0 (UJFF-STST) to a maximum 9.0 in the CF-STST.

Total sulphur concentrations in kimberlite and country range from a minimum of 0.03% (EJF-2KB) to a maximum of 5.0% (UJFF-STST). With the exception of five samples of UJFF, all total sulphur concentrations are less than 0.2%. Figure 5.2.3-10 shows the average and standard deviation of total sulphur concentrations; the high UJFF average is strongly affected by a single sample. Sulphate concentrations are generally low, ranging from 0.01% to 0.8%. Sulphide concentrations range from 0.01% to a maximum of 4.7% (UJFF). Only five samples have a sulphide concentration greater than 0.3 (Figure 5.2.3-10).

There is a high degree of correlation between the total sulphur and sulphide concentrations (Figure 5.2.3-11) all facies except P3-PK had significant correlations. The high correlation of sulphide sulphur to total sulphur and the general low amounts of sulphate suggest that acid potential can be reasonably (and conservatively) calculated from total sulphur concentrations. The acid potential calculated from total sulphur is called the maximum potential acidity (MPA).

The NP of the Orion South kimberlite facies and country rock varies greatly. The average NP of the kimberlite facies ranges between 251 kg $CaCO_3$/t to 329 kg $CaCO_3$/t, whereas the average NP of the CF is 8 kg $CaCO_3$/t and the UJFF is 24 kg $CaCO_3$/t (Table 5.2.3-6). The country rock has very low NP, ranging from a minimum of 4.3 kg $CaCO_3$/t to a maximum of 27 kg $CaCO_3$/t (Figure 5.2.3-12).

Table 5.2.3-5: Summary of Orion South Kimberlite and Country Rock ABA Results

Rock Type		Paste pH	TIC*	Total Sulphur	Sulphate	Sulphide	AP	NP	CNP**	NPR
			%	%	%	%	kg/tonne	kg/tonne	kg/tonne	
P2-PK	min	8.82	0.57	0.05	0.04	0.01	0.31	250.8	47.5	77
	max	9.35	1.26	0.17	0.06	0.13	4.06	342.2	105.0	1035
	mean	9.03	0.91	0.10	0.05	0.05	1.67	297.2	76.0	334
	median	9.03	0.90	0.10	0.05	0.04	1.25	288.9	75.0	229
	25th percentile	8.93	0.76	0.07	0.05	0.02	0.63	282.6	63.3	124
	75th percentile	9.09	1.09	0.12	0.05	0.08	2.35	322.6	90.4	515
P3-PK	min	8.85	0.51	0.04	0.01	0.02	0.63	303.4	42.5	101
	max	9.06	0.74	0.15	0.05	0.11	3.44	346.6	61.7	482
	mean	8.97	0.61	0.09	0.03	0.07	2.19	328.7	51.0	206
	median	8.96	0.60	0.07	0.02	0.07	2.19	337.8	50.0	154
	25th percentile	8.95	0.56	0.07	0.01	0.06	1.88	315.8	46.7	112
	75th percentile	9.03	0.65	0.14	0.04	0.09	2.81	339.7	54.2	181
EJF-2PK	min	8.17	0.61	0.06	0.05	0.01	0.31	183.0	50.8	111
	max	8.75	0.88	0.13	0.07	0.08	2.50	357.8	73.3	1035
	mean	8.53	0.72	0.09	0.06	0.03	0.88	250.7	60.4	474
	median	8.59	0.72	0.08	0.06	0.02	0.63	266.5	60.0	514
	25th percentile	8.36	0.71	0.07	0.06	0.01	0.31	197.3	58.8	167
	75th percentile	8.69	0.76	0.11	0.07	0.04	1.25	294.3	63.3	636
EJF-2KB	min	8.60	0.27	0.03	0.03	0.01	0.31	222.5	22.5	80
	max	9.08	0.57	0.16	0.07	0.11	3.44	301.3	47.5	916
	mean	8.79	0.42	0.09	0.05	0.04	1.25	268.4	34.9	411
	median	8.79	0.42	0.08	0.05	0.03	0.94	269.7	35.0	295
	25th percentile	8.70	0.34	0.06	0.04	0.01	0.39	256.4	28.5	168
	75th percentile	8.84	0.50	0.10	0.05	0.06	1.72	283.9	41.3	722
LJF-PK	min	8.21	1.05	0.04	0.02	0.01	0.31	185.8	87.5	60
	max	8.96	1.53	0.12	0.04	0.10	3.13	381.6	127.5	1221
	mean	8.59	1.19	0.06	0.03	0.03	0.88	305.1	99.2	605
	median	8.51	1.14	0.04	0.03	0.02	0.63	344.1	94.6	470
	25th percentile	8.32	1.09	0.04	0.02	0.01	0.31	237.8	90.6	313
	75th percentile	8.94	1.27	0.07	0.04	0.03	0.94	355.8	105.4	938
KSTST	min	9.13	2.12	0.12	0.04	0.07	2.19	211.5	176.7	34
	max	9.21	2.75	0.28	0.08	0.20	6.25	345.9	229.2	158
	mean	9.17	2.33	0.17	0.05	0.12	3.63	265.0	193.8	90
	median	9.16	2.21	0.13	0.05	0.09	2.81	224.0	184.2	76
	25th percentile	9.15	2.16	0.13	0.05	0.08	2.50	214.0	180.0	51
	75th percentile	9.18	2.39	0.19	0.05	0.14	4.38	329.7	199.2	132
CF-STST	min	8.47	0.01	0.02	0.01	0.01	0.31	4.3	0.4	1
	max	8.96	0.65	0.15	0.01	0.14	4.38	16.0	54.2	25
	mean	8.76	0.30	0.05	0.01	0.04	1.32	7.9	24.6	13
	median	8.75	0.31	0.02	0.01	0.02	0.63	6.8	25.8	12
	25th percentile	8.74	0.04	0.02	0.01	0.02	0.63	4.9	3.3	11
	75th percentile	8.90	0.47	0.03	0.01	0.02	0.63	7.4	39.2	14
UJFF-STST	min	5.0	0.01	0.1	0.03	0.1	2.2	4.2	0.8	0.1
	max	8.7	0.8	5.0	0.8	4.7	148	26	67	11
	mean	7.7	0.32	1.5	0.13	1.4	43	17	27	0.4
	median	8.3	0.09	1.6	0.1	1.4	44	20	8	0.5
	25th percentile	8.36	0.01	0.11	0.03	0.08	2.50	23.0	0.8	8
	75th percentile	8.60	0.04	0.13	0.04	0.10	3.13	24.6	3.3	11

Notes: *TIC is total inorganic carbon as determined by Leco furnace analysis.
** CNP is carbonate NP calculated from the TIC concentration.

Like the Star Kimberlite, the relationship between NP and CNP is poorly developed and there is no correlation between NP and CNP (Figure 5.2.3-12). The Cantuar Formation and approximately half of the UJFF samples had CNP values greater than NP, suggesting that Fe-carbonate minerals are likely present which do not contribute to the neutralization capacity of the rock. The UJFF had very little NP and about half of the samples had very little CNP. The percentage of NP accounted for by CNP in the Orion South kimberlite facies is variable. CNP accounts for between 50-90% of the total NP for the KSTST facies, but as little as 10-20% of the EJF-KB. The correlation between NP and CNP is not significant and the high NP values relative to CNP suggest that silicate minerals are a major component of the overall kimberlite NP.

The relationship between NP and AP, and CNP and AP in Orion South kimberlite facies and country rock are shown in Figures 5.2.3-13 and 5.2.3-14, respectively. All the kimberlite facies have NPR and carbonate NPR values greater than 2 and are classified as non acid generating. The CF sandstone has a single sample classified as potentially acid generating, although the total sulphur concentration is less than the 0.3% threshold used in the screening criteria. The UJFF shale has a mixed acid generation potential. The five high sulphur (greater than 2.3% total sulphur) samples from the UJFF are classified as acid generating. Using the more conservative CNP, six UJFF samples are likely acid generating and two samples are potentially acid generating.

Recovery Rejects

The recovery rejects are the material that remains after the diamonds have been removed in the recovery section of the plant. Table 5.2.3-6 provides the ABA results for the 12 recovery samples.

Table 5.2.3-6: Summary of Star and Orion South Recovery Rejects ABA Results

Area Facies		Paste pH	TIC*	Total Sulphur	Sulphate	Sulphide	AP	NP	CNP**	NPR
			%	%	%	%	kg/tonne	kg/tonne	kg/tonne	
Star	EJF PK (Coarse)	8.4	0.20	2.0	0.05	1.9	60	74	17	1.2
	EJF PK (Fine)	8.5	0.28	0.4	0.02	0.3	10	108	23	10
	EJF KB	8.6	0.35	2.7	0.06	2.6	83	86	29	1.0
	PPK (Coarse)	9.0	1.5	0.0	<0.0.1	0.01	0	146	13	468
	PPK (Fine)	8.8	0.25	0.1	0.01	0.04	1	135	21	108
	CPK KB	8.6	0.07	3.3	0.07	3.2	101	31	6	0.3
	CPK PK	9.1	0.10	0.2	<0.01	0.2	6	73	8	12
	MJF PK	8.7	0.17	2.5	0.03	2.5	78	48	14	0.6
Orion South	EJF KB	8.5	0.81	4.3	0.04	4.2	132	87	68	0.7
	Pense VK	8.9	0.58	0.2	0.03	0.1	4	56	48	13
	Pense VK	8.9	0.21	0.2	0.05	0.1	3	30	18	10
	EJF KB	8.9	0.29	0.3	0.03	0.3	9	52	24	6

Notes: *TIC is total inorganic carbon as determined by Leco furnace analysis.
** CNP is carbonate NP calculated from the TIC concentration.

The recovery rejects have higher concentrations of the sulphur species (and consequently AP values) relative to their respective kimberlites samples. The recovery rejects also tend to have lower NP values. Overall, the NPR of the recovery rejects is less than the NPR for the kimberlite samples. Three of the 12 samples (CPK-KB, MJF-PK and EJF-KB) had NPR values less than 1 and are likely acid generating (Figure 5.2.3-15). Two of the 12 samples had NPR values between 1 and 2 and are potentially acid generating. Seven of the 12 samples had NPR values greater than 2 and are considered non acid generating. The higher AP and lower NPR values of the recovery rejects is a product of the dense media separation process that selectively concentrates minerals with a density near, or greater than, that of diamonds. This may include acid generating sulphideminerals.

ABA Surrogates

In order to effectively use surrogates, the distribution of variables between the two data sets should be comparable allowing proxies for AP and NP to be confirmed.

The exploration database comprises drill hole samples from the Star and Orion South kimberlite complexes. Some of the rock types in the drill core database were not sampled in the two ABA drill holes and were excluded from the surrogates study. Conversely, as there were no samples of country rock in the drill core database the country rock was excluded from the ABA dataset for simplicity. In this investigation, the different kimberlite facies were grouped into the following broad facies based on the rock code: CPK, PPK, EJF, MJF, LJF, and KSTST.

A comparison of total sulphur histogram plots show that the exploration drill core database has a higher proportion of samples with sulphur concentrations greater than 0.5% total sulphur compared to the ABA database (Figure 5.2.3-16). In general, the ABA and drill core have similar distributions. Using total sulphur from the exploration database to calculate the maximum potential acidity (MPA) has been demonstrated to be reasonable (see Section 5.2.3.5).

Determination of an NP surrogate appears to be more difficult to achieve as evidenced by the less well developed similarities between the ABA and drill core databases (Figure 5.2.3-17). The total inorganic carbon concentration in the ABA suite (commonly used as an indicator of carbonate minerals) does not have a correlation with the modified Sobek NP (Section 5.2.3.5). Use of the total inorganic carbon concentration to calculate NP will underestimate the NP for kimberlite facies.

There are four samples out of 1,762 (0.2%) from the exploration drill core database that have a surrogate CNPR less than 1 and would be classified as likely acid generating, and there are six samples (0.3%) that have a surrogate CNPR between 1 and 2 and would be classified as potentially acid generating.

Noting the complications of the poor relationship between NP and CNP calculated from total carbon, Figure 5.2.3-18 shows that the majority of samples (99.6%) will be non acid generating.

5.2.3.6 Metal Leaching

Results of the static leaching tests, processed kimberlite kinetic leach tests are described in this Section.

Processed Kimberlite Static Leaching Test

Standard waste extraction procedure (SWEP) leaching tests were used to examine the potential leachate chemistry of processed kimberlite from the bulk sampling programs. The processed kimberlite material from Star had been stored on site and allowed to weather since at least 2006. Therefore, the samples approximate field weathering of processed kimberlite waste. The results indicate (Table 5.2.3-7) that elevated concentrations of chromium and nickel may occur (relative to CCME (Canadian Council of Ministers of the Environment) and MMER (Metal Mining Effluent Regulations) criteria). However, the actual concentrations measured from the SWEP test should not be taken to directly represent the water quality of drainage from processed kimberlite. Water to rock ratios in the leach test are likely significantly lower than the proportions found under field conditions; runoff or seepage from overburden and rock pile is expected to have lower concentrations than the SWEP test results. However, the results do serve to identify potential metals of concern from the kimberlite.

Table 5.2.3-7: Results of SWEP Leach Testing on Processed Kimberlite

Group #				**2007-8358**	**2007-8358**	**2007-8358**	**2007-8358**	**2007-8358**	**2007-8358**
Sample #	**Units**	**MMER**	**CCME**	**38516**	**38518**	**38520**	**38522**	**38524**	**38526**
Aluminum	mg/L		0.005-0.1	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Antimony	mg/L			<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Arsenic	ug/L	500	5	<1	<1	<1	<1	<1	<1
Barium	mg/L			2.5	2.3	4.0	1.3	2.7	0.80
Beryllium	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L			1.4	1.5	1.2	1.0	1.3	0.9
Cadmium	mg/L		0.000017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	mg/L		0.001-0.0089[1]	<0.005	<0.005	<0.005	**0.006**	<0.005	**0.007**
Cobalt	mg/L			0.014	0.004	0.012	0.036	0.012	0.023
Copper	mg/L	0.3	0.002-0.004[2]	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Iron	mg/L		0.3	<0.005	<0.005	<0.005	0.22	0.024	0.24
Lead	mg/L	0.2	0.001-0.007[2]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L			0.46	0.44	0.52	1.2	1.1	1.4
Molybdenum	mg/L		0.073	0.003	0.004	0.003	0.001	0.001	<0.001
Nickel	mg/L	0.5	0.025-0.15[2]	**2.82**	**0.93**	**2.20**	**3.58**	**1.66**	**1.89**
Selenium	mg/L		0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L		0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Strontium	mg/L			3.8	3.5	4.3	2.5	3.5	1.6
Thallium	mg/L		0.0008	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Tin	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Titanium	mg/L			0.004	<0.002	<0.002	<0.002	<0.002	<0.002
Uranium	ug/L			<1	<1	<1	<1	<1	<1
Vanadium	mg/L			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	mg/L	0.5	0.03	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Notes: MMER and CCME Guidelines for the protection of freshwater aquatic life are provided for comparison purposes only.

Highlight indicates value is above MMER.

Bold indicates value is above CCME.

1 The CCME limit for Cd is dependent on the Cd valence.

2 Indicates that the CCME guideline is hardness dependant.

Processed Kimberlite Kinetic Leach Tests

Three processed kimberlite samples were used to construct the field test leach pads and laboratory leach columns. Two samples were from Orion South processed kimberlite, and one sample was from Star processed kimberlite. Material for the three samples was processed on-site and remained in storage for at least a year prior to testing. The Orion South Coarse PK and the Star Coarse PK samples are a composite of several of the different kimberlite facies. The Orion South EJF Fine PK sample is a composite of the kimberlite breccias and the volcaniclastic material from the EJF facies.

Figure 5.2.3-19 shows the results of the grain size analysis on the PK samples. The distribution of the Orion South and Star Coarse PK are similar, however, the Orion South EJF Fine PK sample has a much greater percentage of fine grained material. The results of ABA testing are shown in Table 5.2.3-8.

Table 5.2.3-8: ABA Results for Process Kimberlite Samples

Sample ID	Fizz Test	Paste	TIC	CNP	S(T)	S(SO4)	S(S-2)	AP	NP	NPR
		pH	%		%	%	%			
Orion South PK	Moderate	9.4	1.1	92	0.03	0.01	0.02	0.6	60	95
Orion South EJF PK Fines	Moderate	9.6	0.9	78	0.03	0.02	0.01	0.3	166	532
Star PK	Moderate	9.2	0.9	78	0.08	0.01	0.07	2.2	276	126

Notes: AP = Acid potential in tonnes CaCO3 equivalent per 1000 tonnes of material.
NP = Neutralization potential in tonnes CaCO3 equivalent per 1000 tonnes of material.
Carbonate NP is calculated from TIC originating from carbonate minerals and is expressed in kg CaCO3/tonne.

The total sulphur concentrations of the PK are less than the average concentrations for the Star (average = 0.11 %) and Orion South (average = 0.09 %) kimberlite samples. The NP values for the PK samples are also less than the average NP values for the Star (average = 266 kg $CaCO_3$/t) and the Orion South (average = 288 kg $CaCO_3$/t). Since the kimberlite and PK samples are all non acid generating (NPR > 2), the lower NP and sulphur concentrations are acceptable for use in the kinetic testing.

Table 5.2.3-9 gives the concentrations of selected metals in the PK. In general, the metal concentrations are similar to the average concentrations in the Star and Orion South kimberlite samples.

Table 5.2.3-9: Selected Metal Concentrations for Processed Kimberlite Samples

Sample ID	Al	Cd	Cr	Cu	Fe	Mo	Ni	Se	Pb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Orion South PK	1.8	0.1	419	38	4.7	0.3	583	<0.5	8
Orion South EJF PK Fines	2.1	0.1	388	28	3.8	0.4	656	<0.5	10
Star PK	1.2	0.5	536	27	5.6	0.8	1000	<0.5	23
Average Orion Kimberlite*	1.5	0.07	486	40	5.3	0.6	781	<0.5	8
Average Star Kimberlite*	1.4	0.08	575	36	4.5	0.4	906	<0.5	9

Note: * Average values taken from aqua regia results (Tables 5.2.3-3 and 5.2.3-4)

Laboratory Column Testing

The Orion South Coarse PK and the Star Coarse PK tests are standard trickle leach columns; a 10 kg charge of sample is trickle leached with 500 mL of water over the course of the 7 day sampling cycle. The leachate is collected and analyzed on the last day. Due to the fine grained nature of the Orion South EJF Fine PK sample, the testing was modified to a flood leach using 1 kg of material. However, even with vigorous stirring, the Orion South EJF Fine PK material stays in suspension and very little of the leaching water drains out of the column. The testing procedure was modified so that the column is stirred during the flood leach on the first day of the sampling cycle. Leachate that does drain through the sample is collected and composited with water siphoned off the top of the column. This composite leachate is then analysed. The results of the Orion South EJF Fine PK are considered less representative of field seepage due to this complication.

The load of metals released (mg metal/kg sample) were determined for each testing cycle. Testing generally continued until the metal loads released by the tests stabilized, which infers that steady-state release of metals occured. The Star Coarse PK column was terminated after 61 weeks of testing. The two Orion South PK columns are on-going and there are 76 weeks of testing completed.

The pH of all the columns was slightly alkaline with values generally between 8.5 and 9.5 (Figure 5.2.3-20). Conductivity, a measure of the dissolved constituents, decreased consistently throughout the testing for all three columns (Figure 5.2.3-21). The Orion South EJF Fine PK had the lowest conductivity results, possibly related to the siphoned/decant water collected from the top of the column to increase the lower volume of leachate. The alkalinity loads for the Star Coarse PK and Orion South EJF Fine PK were steady with values near 1,000 mg/kg (Figure 5.2.3-22). Alkalinity in the Orion South Coarse PK column increased for the duration of testing to a maximum of 2,391 mg/kg at week 64 and was at approximately 2,100 mg/kg/wk since week 50. Sulphate loads generally decreased in all columns for the duration of testing (Figure 5.2.3-23). However, the sulphate loads in the

Orion South EJF Fine PK column were more erratic with values generally between 500 mg/kg and 100 mg/kg.

Based on the ABA results, acid generation is not expected from the processed kimberlite and sulphate values (as a measure of acid production) are expected to continue to decrease.

The release of aluminum, arsenic, cobalt, chromium, iron and nickel was greater from the Orion South Coarse PK and the Orion South EJF Fine PK relative to the Star Coarse PK (Figures 5.2.3-24 – 5.2.3-27). Aluminum release from the Star Coarse PK was very low with loads at or near 0.01 mg/kg (Figure 5.2.3-24). The release of aluminum from the Orion South Coarse PK and the Orion South EJF Fine PK was variable without a clear trend. The maximum aluminum load of 4.0 mg/kg occurred at week 45 in the Orion South EJF Fine PK.

Arsenic release from the Star Coarse PK was very low (Figure 5.2.3-25). The arsenic load in the Orion South Coarse PK increased to a maximum of 0.15 mg/kg at week 28 and decreased to between 0.12 and 0.1 mg/kg since week 29. The arsenic load from the Orion South EJF Fine PK was generally between 0.02 mg/kg and 0.04 mg/kg until weeks 39-42 when loads increased to a maximum of 0.12 mg/kg before decreasing to between 0.06 and 0.03 for weeks 43 through 77.

There was no release of cobalt from the Star Coarse PK (Figure 5.2.3-26). The Orion South Coarse PK loads decreased rapidly from a maximum of 0.2 mg/kg at week 1, throughout the testing period with loads between 0.01 and 0.06 mg/kg from weeks 29-43. The Orion South EJF Fine PK cobalt loads were variable with a maximum load of 0.013 mg/kg at week 44.

The iron and nickel results are very similar for all three columns. The metal loads in the Star Coarse PK column were very low. The iron and nickel loads from the Orion South Coarse PK generally increased after about 20 weeks of testing, although the results were erratic (Figures 5.2.3-28 and 5.2.3-29). The Orion South EJF Fine PK had the greatest loads of all the column tests, although the results were very erratic. The erratic results were likely a result of the difficulties encountered in the column test. The maximum iron load was 6.7 mg/kg and the maximum nickel load was 0.2 mg/kg, both in the Orion South EJF Fine PK f column (Figure 5.2.3-28).

The Star Coarse PK molybdenum and thallium loads were greater than the Orion South Coarse PK and the Orion South EJF Fine PK. Molybdenum loads for all column tests decreased throughout the testing period (Figure 5.2.3-30) were less than 0.1 mg/kg after week 30. Thallium loads were very similar to molybdenum (Figure 5.2.3-31).

The lead loads were generally low for all three columns after week 30 (Figure 5.2.3-32); lead in the Star Coarse PK column was erratic for the first 20 weeks of testing with a maximum value of 0.038 mg/kg at week 15.

The cadmium, copper, selenium and zinc loads were low and the results were similar for all three column tests (Figures 5.2.3-33 to 5.2.3-35).

The results from the laboratory testing suggest that both the Star and Orion South processed kimberlite may leach metals. Aluminum, arsenic, cobalt, chromium, iron and nickel loads are greater for the Orion South Coarse PK and the Orion South EJF Fine PK than the Star Coarse PK. Molybdenum and thallium loads are generally greater from the Star Coarse PK column than the Orion South columns.

Processed Kimberlite Field Kinetic Testing

Shore constructed three field test pads in September 2008. The field test pads are filled with processed kimberlite material from the bulk diamond sampling program.
A representative sample of the Coarse PK used in each pad was submitted for ABA. The pads are monitored regularly. Table 5.2.3-10 provides the ABA results that indicate that all three test pads had NPR values greater than 2 and are non acid generating. Figure 5.2.3-36 is a photograph of the completed pads.

Table 5.2.3-10: ABA Results for Processed Kimberlite Field Test Pads

Sample ID	**Fizz**	**Paste**	**TIC**	**CNP**	**S(T)**	**S(SO_4)**	**S(S-2)**	**AP**	**NP**	**NPR**
	TEST	**pH**	**%**	**kg$CaCO_3$/t**	**%**	**%**	**%**	**kg$CaCO_3$/t**	**kg$CaCO_3$/t**	
Orion South 1	Mod.	9.4	1.1	92	0.03	0.01	0.02	0.06	60	95
Orion South	Mod.	9.6	0.9	78	0.03	0.02	0.01	0.3	166	532
Star	Mod.	9.2	0.9	78	0.08	0.01	0.07	2.2	276	126

There are very limited results available for the field test pads (Table 5.2.3-11). One of the tests pads was destroyed before any sample could be collected. The Orion South test pad is not free draining and has very little seepage through the material due to its fine grained nature.

The results available to date indicate that some metals, including aluminum, arsenic, chromium, copper, lead, molybdenum, nickel and selenium can leach at concentrations greater than the Saskatchewan Surface Water Quality (SSWQ) and Canadian Council of

Ministers of the Environment (CCME) objectives for the protection of aquatic life. Typically, the loads from the field pads are less than the laboratory kinetic testing loads.

Recovery Reject Static Leaching Test

Shake flask extraction leaching tests were used to examine the potential leachate chemistry of the recovery rejects. The results indicate (Table 5.2.3-12) that elevated concentrations of cadmium, chromium, copper and selenium may occur (relative to CCME (Canadian Council of Ministers of the Environment) and MMER (Metal Mining Effluent Regulations) criteria). However, the actual concentrations are not a direct measurement of the metal concentrations of recovery rejects leaching, but do provide an indication of metals of potential concern.

Table 5.2.3-11: Leachate Chemistry for Selected Parameters from Field Leach Test Pads

		Protection of Aquatic Life		**Orion South Test Pad**	**Star Test Pad**					
Parameters		**SSWQ**	**CWQG (CCME)**	**24-May-09**	**28-Oct-08**	**24-May-09**	**5-Jul-09**	**31-Jul-09**	**29-Apr-10**	**30-May-10**
pH	pH units		6.5-9.0	8.06	7.83	8.66	**9.32**	**9.35**	**9.43**	8.96
TDS	mg/L			2520	1800	3410	1440	1170	1270	567
Sulfate	mg/L			1330	500	1070	420	360	430	160
Alkalinity	mg/L			308	239	759	448	367	523	301
Al	mg/L	.005-.1	.005-.1	**2.75**	0.01	0.059	0.027	0.0059	0.081	0.097
As	ug/L	5	5	**13**	1.1	1.6	2.6	2.3	1.6	1.2
Cd	mg/L	.000017-.0001	0.000017	0.0001	0.0001	**0.0001**	**0.0011**	0.0001	**0.00009**	0.0004
Cr	mg/L	0.001	0.0089	**0.036**	0.0006	**0.0022**	**0.0018**	0.0007	**0.0021**	0.0022
Cu	mg/L	.002-.004	.002-.004	**0.014**	0.0018	**0.0045**	**0.005**	**0.0031**	**0.0043**	0.0035
Fe	mg/L	0.3	0.3	**6.2**	0.016	0.13	0.044	0.0062	0.3	0.33
Pb	mg/L	.001-.007	.001-.007	0.0025	0.0001	0.0002	0.0004	0.0001	0.0026	0.002
Mo	mg/L		0.073	0.039	0.024	**0.08**	0.047	0.035	0.03	0.016
Ni	mg/L	.025-.150	.025-.150	**0.217**	0.005	0.023	0.0058	0.0037	0.015	0.014
Se	mg/L	0.001	0.001	**0.007**	**0.0038**	**0.0097**	**0.0042**	**0.0039**	**0.006**	**0.0026**
Na	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00006	0.00001
Tl	mg/L		0.0008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
U	ug/L	15		2.8	3.2	1.8	1.9	1.4	0.5	0.2
Zn	mg/L	0.03	0.03	0.013	0.01	0.012	0.02	0.011	**0.098**	**0.066**

Note: Values in bold indicate concentrations greater than SSWQ or CCME guidelines for the protection of aquatic life.

Table 5.2.3-12: Shake Flask Extraction Results for Recovery Rejects

Parameter	Units	MMER	CCME	EJF PK (Coarse)	EJF PK (Fine)	EJF KB	PPK (Coarse)	PPK (Fine)	CPK KB	CPK PK	MJF PK	EJF KB	PVK	PVK	EJF KB
pH	pH			7.6	7.9	7.9	8.0	8.0	7.7	8.1	7.9	7.7	8.0	8.0	8.3
Cond.	uS/cm			310	288	332	313	430	436	188	297	325	183	203	663
Acidity	mg CaCO3/L			5.5	4.4	4.4	4.1	4.1	4.4	2.9	3.9	5.7	4.9	4.6	3.3
Alkalinity	mg CaCO3/L			62	66	70	74	78	33	77	64	76	72	80	140
Sulphate	mg/L			113	65	103	15	40	183	8	106	106	26	31	210
Al	mg/L		0.1	0.0016	0.0011	0.0025	0.0009	0.0010	0.0025	0.0058	0.0044	0.0079	0.0059	0.0110	0.0094
As	mg/L	500	5	0.0002	< 0.0002	< 0.0002	0.0002	< 0.0002	0.0003	< 0.0002	0.0003	0.0003	0.0003	0.0002	0.0064
Cd	mg/L		0.000017	0.000004	< 0.000003	< 0.000003	**0.000018**	< 0.000003	< 0.000003	< 0.000003	< 0.000003	< 0.000003	< 0.000003	0.000004	< 0.000003
Cr	mg/L		0.001-0.0089^1	0.0008	0.0009	0.0010	0.0010	0.0010	0.0008	0.0010	**0.0012**	**0.0013**	0.0008	0.0009	**0.0038**
Cu	mg/L	0.3	0.002-0.004^2	0.0007	0.0012	**0.0032**	0.0008	0.0015	0.0014	< 0.0005	< 0.0005	0.0011	0.0010	0.0016	0.0015
Fe	mg/L			< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.005
Pb	mg/L	0.2	0.001-0.007^2	0.00003	0.00002	0.00002	0.00003	0.00003	0.00002	0.00009	< 0.00002	0.00004	0.00005	0.00003	0.00005
Hg	ug/L			< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Mo	mg/L		0.073	0.00872	0.00359	0.00124	0.00065	0.00051	0.00078	0.00125	0.00338	0.00178	0.00064	0.00054	0.00143
Ni	mg/L	0.5	0.025-0.15^2	0.0169	0.0408	0.0085	0.0683	0.0372	0.0129	0.0020	0.0056	0.0091	0.0056	0.0030	0.0066
Se	mg/L		0.001	0.00039	0.00058	0.00048	**0.00118**	**0.00182**	0.00060	0.00042	0.00053	0.00027	0.00007	0.00012	0.00054
Ag	mg/L		0.0001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001
Tk	mg/L		0.0008	< 0.0002	0.0004	< 0.0002	0.0004	0.0003	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
U	mg/L			0.000025	0.000004	0.000003	0.000011	0.000001	0.000012	< 0.000001	0.000015	0.000092	0.000072	0.000284	0.000420
Zn	mg/L	0.5	0.03	0.001	< 0.001	0.002	0.001	0.002	0.001	< 0.001	< 0.001	0.001	0.003	0.001	< 0.001

Notes: MMER and CCME Guidelines for the protection of freshwater aquatic life are provided for comparison purposes only.
Bold indicates value is above CCME.
1 The CCME limit for Cd is dependent on the Cd valence.
2 Indicates that the CCME guideline is hardness dependant.

5.2.3.7 Conclusions

The results of the ML/AARD characterization program indicate that the kimberlite facies at Star and Orion South are not acid generating. Based on the ABA data, the Acid Potential (AP) values in the kimberlite are generally low (<10 kg $CaCO_3$/tonne) whereas NP values range from approximately 100 to 400 kg $CaCO_3$/tonne. The ABA results from this Project also suggest that the shale and siltstone country rock have the potential to generate acid and have NPR values that are less than the NPR values of the kimberlites.

There is a good relationship between the sulphide concentration and the total sulphur measured by Leco furnace. It is reasonable and conservative to estimate the acid potential of the rocks using the total sulphur analysis from either the ABA or the exploration drill core database.

The kimberlite facies NP values, ranging from approximately 100 kg $CaCO_3$/t to 400 kg $CaCO_3$/t, are generally much greater than the CNP values. The results suggest that generally, carbonate minerals do not play a large role in providing NP. The use of CNP and MPA values in the determination of NPR indicate that the overwhelming majority of the kimberlite samples will have high NPR values and are classified as non acid generating. Using this method, a small proportion of the samples is classified as potentially or likely acid generating. Overall, it is expected that the kimberlite will be non acid generating.

ABA results of the processed kimberlite show it is non acid generating, as would be expected based on the kimberlite results. Metal leaching studies based on SWEP testing of weathered processed kimberlite indicate that metals such as chromium and nickel may be elevated in leachate.

The results from the laboratory kinetic leach testing suggest that both the Star and Orion South processed kimberlite may leach metals. Aluminum, arsenic, cobalt, chromium, iron and nickel loads are greater for processed kimberlite from the Orion South material compared to the Star processed kimberlite. Molybdenum and thallium loads are generally greater from the Star processed kimberlite than the Orion South processed kimberlite.

The available results from the processed kimberlite field leach test pads indicate that metals, including aluminum, arsenic, chromium, lead, molybdenum, nickel and selenium can potentially leach at concentrations greater than the SSWQ or CCME objectives for the protection of aquatic life.

The recovery rejects have a higher concentration of sulphur and consequently lower NPR values than the kimberlite and processed kimberlite samples. Approximately 60% of the recovery reject samples (7 out of 12) are non acid generating and 40% (5 out of 12) are potentially or likely acid generating. Static leach testing indicates that copper, cadmium, chromium and selenium can leach under lab conditions at concentrations greater than CCME objectives for the protection of aquatic life.

5.2.4 Air Quality and Meteorology

This Section describes the baseline conditions for air quality and meteorology in terms of the Project.

5.2.4.1 Introduction

Air quality observations began in March 2008 when Shore inititated monitoring in anticipation of data needs to support submission of the EIS. Prior to 2008, air quality is assumed to be good in the FalC region of Saskatchewan as the region has a small population and no industry.

Two of the most important meteorological parameters for predicting ambient concentrations with an air quality model are wind speed and direction since these strongly affect air pollutant dispersion rates, ground level concentrations of air pollutants, and their locations. Studies have shown that at least 5 years of data must be used to obtain stable distributions of weather parameters (EPA 2005). Consecutive weather data from the most recent readily available 5-year period are preferred. The data should be adequately representative, and may be site specific or from a nearby weather station. Such data should have been subjected to quality assurance procedures.

Monitored Substances

The following parameters are typically used to define air quality:

- total suspended particulate (TSP);
- particulate with diameter 10 µm or less (PM_{10});
- particulate with diameter 2.5 µm or less ($PM_{2.5}$);
- sulphur dioxide (SO_2);
- nitrogen oxides (NO_x);
- ozone (O_3);
- carbon monoxide (CO);
- carbon dioxide (CO_2);
- total hydrocarbons (THC);
- volatile organic compounds (VOC); and
- metal elements including cadmium, arsenic, chromium, cobalt, lead, nickel, and molybdenum.

The following criteria were used to identify key parameters from the above list for monitoring:

- the level of concern with reference to health effect (relates to ambient air quality objectives);
- probability of occurrence of the substance at higher concentrations during construction and operation phases;
- expected background 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 an open remote terrain.

Considering the above factors the following substances were selected and monitored in 2008 at the Project area:

- particulate matter (TSP and PM_{10});
- metal elements;
- sulphur dioxide;
- nitrogen oxides;
- ozone; and
- BTEX (benzene, toluene, ethylbenzene, xylene).

Particulate, sulphur dioxide and nitrogen oxides are classified by Environment Canada as criteria air contaminants (CAC). These are tracked by Environment Canada to measure the effectiveness of emission reduction programs and to supporting scientific research (Environment Canada website www.ec.gc.ca/pdb/cac). Lead (Pb), cadmium (Cd) and mercury (Hg) are of a particular interest in the metal elements group due to their toxicity.

5.2.4.2 Air Quality Methods

The methods for the air quality baseline study included the selection of the monitoring site location, continuous monitoring and passive air sampling. The methodology is described below.

Location of the Monitoring Site

The goal of establishing an ambient air monitoring station is to provide representative baseline air quality data in the area for the parameters that may be impacted by air emissions. The FalC forest was defined as the study area. In addition to geographical factors, the selection criteria included:

- past and current monitoring results: no results monitoring results for the study area were identified prior to this study;

- site accessibility;
- power accessibility: line power was not easily available;
- topographical effects: flat terrain, away from open water;
- local interferences: no trees in the vicinity, no anthropogenic sources of air pollution; and
- security: a fenced site with a locked gate preferred.

Site selection criteria and sampling protocol were defined using Air Monitoring Directive for Saskatchewan (SE 2007). The site geographic coordinates were UTM (NAD 27) 515020E, 5902162N. The station is shown in Figure 5.2.4-1.

Shore established the monitoring station in February, 2008. Monitoring began in March 2008. The program ended in January 2009 when sufficient data had been collected for the baseline air quality assessment.

Continuous Particulate Monitoring

TSP and PM_{10} were continuously monitored over 120 hour periods starting at 12:00 p.m. Sundays and ending 12:00 p.m. Fridays. The survey began on 16 March 2008 and ended on 16 January 2009.

$PM_{2.5}$ was not monitored because the concentrations were expected to be very low, with the mass of collected sample anticipated to be too small for accurate measurement. In practice, sampling for $PM_{2.5}$ employs larger, high-volume samplers. Also, $PM_{2.5}$ is mostly generated during the fossil fuel combustion (including internal combustion engines), wildfire, and residential wood combustion. Low amounts of some of these activities occurred during the sampling period. Although forest fires are common in the FalC forest, none were recorded during the sampling.

A Mini-Partisol Model 2100 Air Sampler was used for the study. This instrument is designed to provide a flexible, cost-effective means of sampling particulate on filters (i.e., PM_{10}, $PM_{2.5}$ and TSP).

During baseline monitoring, the instrument operational parameters included:

- flow rate of 5 L/min;
- 120 h sampling period;
- TSP and PM_{10} particulate size cut points; and
- a single 47 mm filter.

For quality assurance, the instrument was maintained and calibrated in accordance with the manufacturer specifications (RPCO 2004). To maintain sample integrity, filters were kept in the filter holder for efficient installation and removal. The entire filter holder was transported between the sampling site and the Maxxam Analytics Inc. laboratory in Edmonton. Maxxam determined the filter mass (new and sampled) with 1 µg accuracy on Tapered Element Oscillating Microbalance (TEOM). Collected dust was analyzed for metal elements (including Pb, Cd and Hg) by inductively coupled plasma mass spectroscopy (ICP-MS).

Particulate matter collected on filters were analyzed for base cations to identify concentrations of metallic compounds. This is relevant to the future operation of the Shore facility which would involve mining and processing kimberlite. Although the main base cations of kimberlite are silica (Si), titanium (Ti), aluminum (Al) and iron (Fe), it contains a small quantities of lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn) and some other heavy metals. These elements would be released to the ambient air as a result of open pit mining of the kimberlite altering baseline concentrations.

Passive Air Sampling for Gaseous Air Contaminants

The gaseous contaminants component of the air quality baseline monitoring program has been completed using passive samplers. Passive samplers allow the quantification of cumulative air pollutant exposures, as total or average pollutant concentrations over a sampling duration. Figure 5.2.4-2 shows the type of a passive sampler used in this study.

The monitored substances included:

- sulphur dioxide (SO_2);
- nitrogen oxides (as NO_2);
- ozone (O_3); and
- BTEX (benzene, toluene, ethylbenzene, xylene).

Passive samplers were prepared for the survey and shipped to the monitoring site. After monthly exposure at the monitoring site, samplers were shipped for analysis and replaced with new samplers on site.

5.2.4.3 Continuous Particulate Monitoring Results

The results for the TSP, PM_{10} and metal elements are reported and discussed in this section.

TSP and PM_{10}

The results of TSP and PM_{10} monitoring survey conducted from March 2008 to January 2009 are summarized in Table 5.2.4-1. Detailed sampling parameters are provided in Appendix 5.2.4-A. The frequency distributions of TSP and PM_{10} particulate concentrations are shown in Figures 5.2.4-3 and 5.2.4-4 respectively.

Table 5.2.4-1: Summary of TSP and PM_{10} Sampling Program at the Shore Site

Parameter	**TSP**	**PM_{10}**
Mean Concentration (µg/m^3)	9.71	6.09
Minimum Concentration (µg/m^3)	0.28	0.22
Maximum Concentration (µg/m^3)	22.17	15.61
Number of Samples	31	30
Median	8.417	5.641
Standard Deviation	5.933	3.328
Standard Error	1.066	0.607

The mean concentration of TSP at the sampling site between March 2008 and January 2009 was approximately 10 µg/m^3. The mean concentration of PM_{10} over the same time period was approximately 6 µg/m^3. The concentration of the $PM_{2.5}$ fraction can be estimated using US EPA emission factors (EPA 2004) recommending $PM_{2.5}$ / PM_{10} ratio of 0.2 for an open area with wind erosion and unpaved roads, which are relevant to the monitoring site. The estimated $PM_{2.5}$ mean concentration is 1.2 µg/m^3.

Particulate concentration frequency distributions for TSP and PM_{10} shown in Figures 5.2.4-3 and 5.2.4-4 can be statistically classified as a log-normal (skewed normal) with maximums shifted towards the lower concentrations. The log-normal distributions commonly describe statistical behaviour of natural phenomena (Limpert et al. 2001).

Metal Elements

The results for background concentration of metals in ambient air are summarized in Table 5.2.4-2. The analytical results issued by Maxxam for metallic compounds are included in Appendix 5.2.4-B.

A total of 63 samples were analyzed for 19 metallic elements per sample and included in the statistical evaluation. For the purposes of this study, concentrations below the detection limit were assumed to be zero.

Table 5.2.4-2: Background Concentration of Metals in Ambient Air

Parameter	Al	Cr	Cu	Pb	Ti	Zn
Mean Concentration (μg/m^3)	0.0778	0.0015	0.0025	0.0012	0.0012	0.0088
Minimum Concentration (μg/m^3)	0.0075	0.0000	0.0002	0.0000	0.0000	0.0014
Maximum Concentration (μg/m^3)	1.2022	0.0283	0.0496	0.0124	0.0069	0.1639
Median	0.0440	0.0008	0.0010	0.0007	0.0008	0.0055
Standard Deviation	0.1518	0.0035	0.0067	0.0019	0.0016	0.0202
Kurtosis	51.300	55.740	40.869	24.653	2.876	58.390
Standard Error	0.1518	0.0004	0.0008	0.0002	0.0002	0.0025

As shown in Table 5.2.4-2, concentrations of metallic substances in ambient air are extremely low. Aluminum, zinc and copper occur at higher concentrations than other analyzed elements. Many elements were at concentrations below the detection limit.

5.2.4.4 Passive Sampling Monitoring Results

The baseline air quality monitoring results for gaseous air contaminants are summarized in Table 5.2.4-3. Detailed results are included in Appendix 5.2.4-C.

Table 5.2.4-3: Baseline Air Quality Monitoring Results for Gaseous Air Contaminants

ID No.	Start		Stop		Concentration (ppb)			
	Date	Time	Date	Time	NO_2	SO_2	O_3	BTEX
1	12-Mar-08	12:00	3-Apr-08	12:00	1.3	0.4	< 0.2	< 0.2
2	3-Apr-08	12:00	4-May-08	12:00	0.5	0.2	< 0.2	< 0.2
3	4-May-08	12:00	28-May-08	12:00	2.0	0.3	< 0.2	< 0.2
4	28-May-08	12:00	2-Jul-08	12:00	0.6	0.2	< 0.2	< 0.2
5	2-Jul-08	12:00	1-Aug-08	12:00	0.1	0.3	< 0.2	< 0.2
6	1-Aug-08	12:00	25-Aug-08	12:00	0.1	0.5	< 0.2	< 0.2
7	1-Sep-08	12:00	30-Sep-08	12:00	0.5	0.2	< 0.2	< 0.2
8	1-Oct-08	12:00	12-Nov-08	12:00	0.8	0.5	< 0.2	< 0.2
9	12-Nov-08	12:00	2-Dec-08	12:00	1.5	0.4	< 0.2	< 0.2
10	2-Dec-08	12:00	7-Jan-09	14:30	1.6	2.1	< 0.2	< 0.2
Arithmetic Mean					**0.9**	**0.5**	**< 0.2**	**< 0.2**

Monthly NO_2 and SO_2 concentrations for the monitored period are presented in Figure 5.2.4-5. These results suggest that the concentrations of monitored air contaminants are very low.

The results of passive, 10-month continuous monitoring shows SO_2 average concentration of 0.5 ppb ranging from 0.2 ppb to 0.5 ppb except the December result of 2.1 ppb. If this result is dismissed using the Grubbs' test for outliers (Grubbs 1969), then the mean SO_2 baseline concentration would be 0.3 ppb and not 0.5 ppb.

The average long-term baseline NO_2 concentration is 0.9 ppb with the results in the range from 0.1 to 2.0 ppb with no outliers identified. The passive samples readings for O_3 and BTEX have shown concentrations below the detection limit of 0.2 ppb.

For comparison, Saskatchewan ambient air quality standard for NO_2 is 50 ppb and for SO_2 is 10 ppb annual averages (SG 1989).

5.2.4.5 Air Quality Results From Other Studies

Saskatchewan's air quality is monitored by Environment Canada's two nationwide air-sampling networks: the National Air Pollution Surveillance Network (NAPS) and the Canadian Air and Precipitation Monitoring Network (CAPMoN). NAPS continuously monitors levels of sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) ozone (O_3) and total suspended particulates (TSP) in fifty-five urban centres across the country, including Regina and Saskatoon. Air-monitoring stations in Estevan, Prince Albert, and Lloydminster are also part of the NAPS network but are operated provincially by Saskatchewan Environment and Resource Management. CAPMoN is a rural-based network that includes one air-monitoring station in Saskatchewan, located at Bratt's Lake 50 km south of Regina. Environment Canada issues daily air quality forecasts for Regina and Saskatoon, based on the Air Quality Index (AQI), derived from measurement of ground-level ozone and particulate matter. The AQI ranges from "poor" to "excellent". Air quality in both Regina and Saskatoon consistently rates as "good."

Transboundary air pollution across the Canada–United States border is also monitored in Saskatchewan. In keeping with the Saskatchewan *Clean Air Act* and the 1991 *United States – Canada Air Quality Agreement*, the Transboundary Monitoring Network was established to measure the flow of air pollutants across the Saskatchewan – North Dakota (Burke County) border. Environment Canada, Saskatchewan Environment (SE), SaskPower, and the North Dakota Department of Health (NDDH) jointly operate a network of air-monitoring stations near the Boundary Dam and Shand power stations. The arithmetic mean concentrations of 2.5 ppb for SO_2, 2.9 ppb for NO_2, 10.1 $\mu g/m^3$ for PM_{10} and 4.1 $\mu g/m^3$ for $PM_{2.5}$ (NDDH 2004) were determined from continuous monitoring results for the period of January to March 2004.

5.2.4.6 Meteorology Methods

Near-site meteorological data have been recorded by the FalC weather station located near the Project site. The station was operated by the Saskatchewan Ministry of Environment and recorded various meteorological parameters at 1-hour intervals for a number of years. Although an eight-year (2000 to 2007) historical data set for the study area was obtained; the annual data are complete for only four years (2002 to 2005). The following parameters were selected for the baseline study: dew point, relative humidity, wind direction, wind speed and wind gust.

Wind graphs have been generated by WRPLOT View software which is a Windows version of the U.S. EPA DOS program. The program reads meteorological surface data files in SCRAM, CD144, SAMSON, HUSWO, TD-3505 and LAKES formats.

Climate normals were obtained through long term historical data for the 30 year period (1971-2000) in the Project region. These have been recorded by Environment Canada (2009) at Prince Albert, SK, located approximately 60 km west of the site.

5.2.4.7 Meteorology Results

In this section, the results for meteorology are reported in terms of the parameters at the FalC weather station which were used to develop wind rose statistics and climate normals for the region.

Meteorological Parameters at Fort à la Corne Weather Station

The annual mean values of the monitored meteorological parameters at the FalC weather station are summarized in Table 5.2.4-4. The overall mean values were calculated for years 2002 to 2005 as the annual parameters include all hours in each year. The eight-year (2000 to 2007) historical data set for the study area is included in Appendix 5.2.4-D.

Table 5.2.4-4: Annual Meteorological Parameters at Fort à la Corne Weather Station

Year	Period	Total Hours	Temp °C	Dew Pt °C	R H %	Wind Dir °	Wind Spd km/h	Wind Gst km/h
2000	1/28-9/30	4614	11.1	4.8	69	192	10.4	20.4
2001	4/01-12/31	6589	8.0	1.3	69	185	11.3	20.9
2002	Year	8749	1.5	- 3.7	N/A	205	11.5	20.8
2003	Year	8760	2.1	- 3.3	73	197	11.2	20.4
2004	Year	8784	1.0	- 3.8	75	191	10.5	19.7
2005	Year	8761	2.7	- 1.9	76	207	10.2	19.8
2006	1/01-10/01	7363	6.6	0.8	72	184	10.4	19.8
2007	2/28-9/18	4818	10.3	3.5	68	179	11.2	21.1
Annual Average 2002-2005			**1.8**	**- 3.4**	**75**	**200**	**10.8**	**20.2**

Notes:

Temp	Temperature
Dew Pt	Dew Point
R H	Relative Humidity
Wind Dir	Wind Direction (from)
Wind Spd	Wind Speed
Wind Gst	Wind Gust
N/A	Not Available

Wind Rose Statistics

Wind speed rose statistics depicting the frequency of occurrence of winds in each of the specified wind direction sectors for FalC for 2003 to 2007 period (the most recent 5-year data available) are shown in Figure 5.2.4-6 and wind class frequency distribution is given in Figure 5.2.4-7.

Climate Normals

The summary data for the Prince Albert area for the 1971-2000 period are provided in Table 5.2.4-5. Climate parameters shown in Table 5.2.4-5 include temperature, rainfall and snowfall, wind speed and direction, solar radiation, humidity and atmospheric pressure recorded over a time period of 40 years. The climate of the area (which includes Prince Albert and FalC) is continental subhumid, characterized by extreme summer and winter temperatures and fairly low annual precipitation. Throughout the area, the mean annual temperature is 0.9°C varying from -19.1°C in January to 17.5°C in July. Monthly average precipitation varies throughout the year with the wettest month being July while the driest month is February. The annual precipitation (as liquid water) is about 42.4 cm of which rainfall comprises 32.4 cm and snowfall comprises 111.3 cm. Monthly average wind speeds stay relatively constant at around 12.1 km/h blowing from west and east. Monthly relative humidity varies from 61 % in May to 75 % in November, with the annual average humidity being 68 %. Most of the sunshine hours occur during long summer days while winter sunny hours are short (only 74 hours in December). The atmospheric pressure stays relatively constant over the year with the annual average of 101.6 kPa which is slightly higher than normal atmospheric pressure of 101.3 kPa.

Table 5.2.4-5: Climate Normals for the Prince Albert SK Area for the 1971-2000 Period

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily Average (°C)	-19.1	-14.6	-7.5	3.1	10.5	15.2	17.5	16.3	10.2	3.4	-7.6	-16.2	0.9
Rainfall (mm)	0.5	0.2	1	16.6	44.3	72.5	76.8	58	37.5	13.5	2.4	0.5	323.7
Snowfall (cm)	19.2	13	16.7	10.9	3.2	0	0	0	2	10.9	15.8	19.6	111.3
Precipitation (mm)	16.3	11.6	16.2	27.1	47.7	72.6	76.8	58	39.5	24.1	16.5	17.9	424.3
Speed (km/h)	10.4	10.9	11.9	14	14.3	13.4	12	11.1	12.6	12.4	11.3	10.6	12.1
Most Frequent Direction	W	E	E	E	E	W	W	W	W	W	E	W	E
Wind Gust (km/h)	102	93	98	129	129	121	117	163	113	87	113	89	---
Sunshine Total Hours	96	125	169	225	270	279	300	281	177	141	81	74	2217
Relative Humidity (%)	69	69	69	63	61	65	69	68	67	67	75	72	68
Sea Level Pressure (kPa)	102.0	102.0	101.8	101.6	101.4	101.2	101.3	101.4	101.5	101.5	101.7	101.8	101.6

5.2.5 Background Noise Assessment

This Section of the EIS describes the baseline conditions for noise in terms of the Project. A noise impact assessment (NIA) must be completed for the Project as there is a reasonable expectation of continuous noise sources generated as described in the PSGs (MoE 2010).

5.2.5.1 Introduction

The measurement of background noise is a prerequisite to any noise assessment in order to fully describe any incremental effect of noise generated by a project. Knowing what the background noise levels are is also important for assessing the perception of the Project because a person's subjective reaction is to compare the Project noise to the relatively constant background sound level. In general, the more a new noise exceeds the existing noise level, the less acceptable the new noise will be. The background noise level, along with any anticipated noise from the Project gives the cumulative environmental noise levels.

5.2.5.2 Environmental Acoustics

Sound is mechanical energy transmitted by pressure waves through a medium such as air. There is no physical distinction between sound and noise. Both are a result of sensory perception evoked by physiological processes in the brain. The complex pattern of sound waves is perceptually labelled as noise, music, speech, etc. based on individual experience and preference. Consequently, it is not possible to accurately define noise exclusively on the basis of the physical parameters of sound. For simplicity, noise can simply be defined as unwanted sound. Sound and noise terms are often used interchangeably.

Three aspects of environmental sound are important in determining subjective response. These are:

- the intensity or level of the sound;
- the frequency spectrum of the sound; and
- the time-varying character of the sound.

These aspects are described in Appendix 5.2.5-A, along with the explanation of acoustical terms and the properties of sound.

5.2.5.3 Methods

A noise study was done to establish the acoustic background onto which potential effects from the proposed development may be superimposed. Given that continuous mine operation will produce noise, a 24 hour survey was completed. The monitoring started at 6:00 p.m. on 28 August 2008 and ended at 6:30 p.m. the next day. An octave band noise survey was also completed to check for tonal components in the noise spectrum.

Setting

Ambient sound levels were expected to be low due to the lack of industry and permanent residences in the FalC. To assure that the survey represents the typical acoustical environment in the Project area the monitoring location was set up approximately 10 km southwest of the Shore exploration camp. The 10 km buffer assured that random noise from the exploration camp was not audible at the monitoring site. The location of the monitoring site shown in Figure 5.2.5-1 was at UTM (Zone 13) 505108 m Easting, 5895327 m Northing.

The instrument was placed in an open space to avoid any noise resulting from wind rustle in trees and nesting birds. A view of the monitoring station is presented in Figure 5.2.5-2.

Continuous Monitoring

A direct 24-hour continuous monitoring of sound parameters was carried out in accordance with the following guidelines for environmental noise survey:

- American National Standard ANSI 1994: Procedures for Outdoor Measurement of Sound Pressure Level (ANSI 1994).
- International Organization for Standardization ISO 2005: Acoustics - Description, Assessment and Measurement of Environmental Noise. Part 2: Determination of Environmental Noise Levels (ISO 2005).
- Alberta Energy Resources Conservation Board Directive 038: Noise Control, Section 4.5: Measurement Instrumentation and Techniques (ERCB 2007).\

Detailed results of the survey were analyzed for consistency. Data points which did not fall within the expected distribution for a particular data set were verified as outliers using Grubbs (1969) statistical criteria (Graphpad Software 2005). Corrected data was exported to Excel and analyzed for sound statistical descriptors (Time-Varying Character of Sound).

For the long-term sound survey the Quest Q-2900 was programmed for the “Slow” time response and the “A-weighted” decibel scale. To ensure accuracy, the instrument was field calibrated prior to commencement of the survey and then checked at the completion of the survey with the QC-10 calibrator. Numerous sound parameters, including sound pressure level in dBA, were continuously logged in 30-second intervals over the 24 hour period and downloaded to a notebook computer upon survey completion.

Octave Band Monitoring

The purpose of an octave band noise survey is to check for tonal components in the noise spectrum. In addition, octave frequency sound data will be needed for noise mapping for the operational phase because the rate of sound propagation is frequency dependent.

Prior to measurements, the instrument operational capability was confirmed with the QC-10 calibrator. The measurements were taken over 30 second periods at each frequency with the following settings[1]:

- FAST response;
- LIN-weighting network;
- AUTO filter option; and
- SPL mode.

Instrumentation

The measurements were taken with a Quest model Q-2900 Noise Integrated / Sound Level Meter Type 1 and associated octave band filter. The instrument complies with the current versions of ANSI S1.4-1971 and ANSI S1.11-1966. On-site calibration was carried out using Quest calibrator QC-10 operated at 114 dB at the frequency 1,000 Hz (Serial No. QI9040050). This also provided a means of checking the entire acoustic instrumentation system (i.e., microphone, cables, and recording instrumentation). The instrument was installed on a tripod at 1.6 m above the ground. The microphone was mounted with a windscreen to reduce the potential for wind-induced noise. The sound meter had a valid Certificate of Calibration. The accuracy of the calibrator is maintained through a program established by the manufacturer Quest Technologies, Inc. and is traceable to the National Bureau of Standards.

Short-term tonal components in the noise spectrum from 16 Hz to 16 kHz were recorded with the Quest model Q-2900 sound level meter provided with the octave band filter model OB-300 serial no. HV3120005.

Meteorological Conditions

Environmental noise propagation depends on a number of factors including meteorological parameters such as wind speed and direction, temperature gradient, atmospheric pressure, humidity and precipitation. Generally, ambient noise surveys are not recommended when wind speeds exceed 4 m/s (15 km/h) at a height of 2 ± 0.2 m above the ground, during precipitation events (snow or rain), at sub-zero temperatures and at relative humidity over 99%. To assure that the required meteorological factors prevailed, a series of measurements were taken during the 24 hour survey at the nearby FalC weather station. The average meteorological parameters for 28 and 29 August 2008 period are summarized in Table 5.2.5-1. These meteorological parameters met the recommended conditions for noise monitoring. .

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[1] Refer to the instrument manual for definition of terms:
www.raeco.com/products/noise/1900_2900_manual.pdf

Table 5.2.5-1: Meteorological Parameters in the Sound Survey Area during 28 and 29 August 2008 Period

Parameter	Range	Average
Wind speed, m/s	1.4 - 6.4	3.4
Wind direction (from), deg.	151 - 236	208
Temperature, ^{o}C	6.0 - 22.1	13.9
Atmospheric pressure, kPa	95.31 - 95.97	95.65
Cloud cover	Clear to Cloudy	Mostly Cloudy
Precipitation, mm	Nil	Nil
Relative humidity, %	36 - 99	75

5.2.5.4 Background Sound Level Results

Long Term Survey

Detailed survey data as logged in the Quest Q2900 sound level meter is available in Appendix 5.2.5-B. Overall results of the ambient noise survey are summarized in Table 5.2.5-2.

Table 5.2.5-2: Summary of Background Noise Survey Results

Time	L_{eq}	L_{90}	L_{50}	L_{10}	L_{min}	L_{max}
Day (15 h)	32.1	23.5	30.0	35.9	22.4	46.9
Night (9 h)	26.4	23.4	25.9	28.6	22.4	32.1
Overall (24 h)	30.7	23.5	28.9	34.3	22.4	46.9

The daytime and night time sound levels (L_{eq}) were calculated using the following formula, which incorporates the logarithmic definition of sound units:

$$L_{eq} = 10 \times \log \{\Sigma f_i \times 10^{(Li / 10)}\}$$

where: f_i = fraction of the total time the L_i is recorded; and
L_i = recorded sound pressure level in dBA per 30 s intervals

The findings of this study show daytime ambient noise levels in the 22.4 to 46.9 dBA range with the equivalent sound pressure level $L_{eq,day}$ of 32.1 dBA. The daytime baseline noise defined as $L_{90,day}$ is a low 23.5 dBA. The night time levels are from 22.4 to 32.1 dBA and the equivalent sound pressure level $L_{eq,night}$ is 26.4 dBA. The night time baseline sound pressure level $L_{90,night}$ is 23.4 dBA which is almost the same as the daytime level. The survey results revealed low sound levels typical for undisturbed, quiet areas where anthropogenic sources are absent or are located far away from the monitoring point. The relatively steady 30-second interval levels shown in Appendix 5.2.5-B and similarities in L_{10}, L_{50} and L_{90}, especially at night time, confirm absence of impulse sounds and low baseline sound intensity.

Octave Band Survey

Octave frequency sound data obtained during the noise survey is presented in Table 5.2.5-3.

Table 5.2.5-3: Background Noise Tonal Components (dBA)

Date	Time	Frequency (Hz)											L_{eq} (dBA)
		16	31.5	63	125	250	500	1k	2k	4k	8k	16 k	
29-Aug-08	19:25	34.7	31.1	37.4	23.3	19.0	17.7	16.1	14.1	14.3	15.2	17.0	23.3

An analysis of the octave band measurement results reveals lower sound levels at higher frequencies with the increasing levels towards lower frequency noise spectrums. This means that longer sound waves prevail in the waves spectrum since the wavelength is inversely proportional to its frequency for constant wave speed (Bies and Hansen 2003). The absence of sound peaks at any of the measured frequencies verifies that sound levels remain relatively constant within the Project area.

Overall, during the survey time the acoustical environment in the area could be characterized by low sound levels at around 30 dBA with no tonal, impulsiveness or modulation components present.

5.2.6 Surface Water Hydrology

The surface water hydrology baseline describes current hydrological conditions within the Project area. The baseline relates to the streams draining generally southwards to the Saskatchewan River and the adjacent reach of the Saskatchewan River itself contained in the Local Study Area (LSA). The baseline information includes runoff from the upper watershed to the respective streams and streamflows within these streams and the Saskatchewan River. General characteristics are described for the “median” case and data are also provided for extremes representing both the “wet” and “dry” sides of the median.

5.2.6.1 Introduction

The Project is located north of the Saskatchewan River where several tributary streams located in the LSA drain into the River (Figure 5.2.6-1). The development of the Project will potentially affect watersheds and flow characteristics in streams draining to the Saskatchewan River and contained within the Project footprint. The Project may have direct or indirect effects on the tributary streams and on the Saskatchewan River.

The Saskatchewan River is formed by the merging of the North Saskatchewan River and South Saskatchewan River approximately 40 km upstream of the Project. The Regional Study Area (RSA) represented in Figure 5.2.6-2.

5.2.6.2 Information Sources and Methodology

Information was obtained to describe the surface water hydrological characteristics of the watersheds draining to the streams tributary to the Saskatchewan River within the LSA. Climatological data were obtained from Environment Canada (2010). Further, information describing the flows in the Saskatchewan River was developed from Water Survey of Canada (WSC) hydrometric station records (Environment Canada 2010b) for monitoring stations located upstream and downstream of the Project site (Figure 5.2.6-2).

Streamflow measurements

Streamflow measurements have been taken on tributary streams (Golder 2008). Regional hydrometric data (Environment Canada 2010b) were used in conjunction with data gathered within the LSA to prepare estimates of long-term streamflow characteristics within the LSA.

Climate Data

Regional climate data (Environment Canada 2010a) were used to define rainfall, snowfall and total precipitation for the LSA. The closest regional meteorological station with a reasonably long period of record is the Atmospheric Environment Service (AES) Prince Albert A station, located about 70 km west of the Project. Nearby AES stations are located at Nipawin (50 km east) and Melfort (40 km south). The locations of these meteorological stations are illustrated on Figure 5.2.6-2.

The Prince Albert A station dataset alone provides the best available basis for estimating the precipitation regime at the Project site. The points listed below were considered when coming to this conclusion:

- Prince Albert A has a longer period of record (119 years from 1889 to 2007) compared to Melfort (98 years) and Nipawin (97 years);
- Prince Albert A has less missing data (only 2 years) than the other sites (14 years at Melfort and 31 years at Nipawin), thus there is considerably greater adjusted annual total precipitation data available for Prince Albert than at either Melfort or Nipawin; the mean and median annual adjusted total precipitation at Prince Albert A and at Nipawin for the respective periods of record are comparable (within 15 to 20 mm), whereas the values

for Melfort are far lower (by over 60 mm);stations at Prince Albert A, Melfort and Nipawin are all currently active;

- the elevations of the stations fall within a relatively narrow range (371.9 m at Nipawin to 490.0 m at Melfort; Prince Albert A is at 428.2 m), and would be considered generally representative in relation to the site elevations that range from 350 m at the Saskatchewan River to 440 m in the headwaters of the streams draining down to the river; and
- while Nipawin and Melfort are marginally closer to the site, the aforementioned positive attributes for the Prince Albert A dataset are considered of greater importance.

The rainfall and snowfall regimes at the Project site are best represented by the long term data from the Prince Albert A data set, which covers the period 1889 to 2007. The precipitation regime is best represented by considering the full data set covering the entire 119 year period of record, rather than a reduced period such as represented by a "climate normals" period which is limited to three decades (Environment Canada 2000).

To aid the analysis of hydrological characteristics, a reference timeframe for monthly and annual data was established. The annual period represents the hydrologic year to correspond to the actual accumulation period of the annual precipitation which produces the annual runoff. The hydrologic year starts on 1 November of the preceding year and ends 31 October of the current year.

Local Tributary Streams

The hydrology monitoring program was conducted in the Project LSA during the following periods (Golder 2008):

- from May 2nd to October 18th 2005;
- from April 21st to November 2nd; 2006; and
- from May 23rd to October 12th, 2007.

In the spring of 2005, gauges were established in Caution Creek, 101 Ravine, East Ravine, and English Creek. The flow stations were all located near to where the streams discharge to the Saskatchewan River which would be downstream of potential beaver dams.

Stream flow measurements were collected during the summer from five of the streams near the mine site to provide baseline information (Figure 5.2.6-3). These streams were identified as Stream A (Caution Creek), Stream B (101 Ravine), Stream C (East Ravine), Stream D (English Creek) and Stream E (West Ravine) (Golder 2008). These streams are located on the north side of the Saskatchewan River both upstream and downstream of the mine. These streams all drain the relatively flat highland area on the north side of the River and descend rapidly from the highlands to the river through steep-sided ravines. Beaver dams are reportedly common along the length of each of the streams, creating pooled areas upstream of the beaver dams.

Data from 2005, 2006 and 2007 were used to develop a rating curve for each of four streams: Caution Creek, 101 Ravine, East Ravine and English Creek (Golder 2008).

Saskatchewan River

The Saskatchewan River forms the southern boundary of the Project area. Hydrological analyses of recorded river discharges upstream and downstream of the site were undertaken to estimate river discharge parameters in support of the effects assessment. The Project area is located approximately 40 km downstream of the confluence of the North Saskatchewan and the South Saskatchewan Rivers (see Figure 5.2.6-2). The flow in these rivers is regulated by hydroelectric dams upstream of the site (in central Alberta and southwest Saskatchewan). There are also two reservoirs for hydroelectric power generation located approximately 60 km and 130 km downstream of the site. Data from the closest WSC hydrometric stations were used to assemble a suitable streamflow record for the proposed site. Analyses were conducted on the hydrological data to provide representative flows at the study site for the effects assessment.

The WSC operates and maintains a hydrometric network of gauges that measures and records river water levels and flows. Surface water flow data are available at the locations shown in Table 5.2.6-1. Three gauges are currently active: North Saskatchewan River at Prince Albert (05GG001); South Saskatchewan River at Saskatoon (05HG001); and, Saskatchewan River below Lake Tobin (05KD003). The latter is the closest active WSC gauge to the site along the Saskatchewan River (located approximately 130 km downstream). However, data from this gauge are not representative of discharges at the site since streamflows at this location are affected by the E.B. Campbell Hydroelectric Station.

Table 5.2.6-1: Water Survey of Canada Hydrometric Gauges in the RSA

WSC Station	Name	Period of Record	Drainage Area (km^2)	Comments
05GG001	North Saskatchewan River at Prince Albert	1910 to 2009	131 000	Upstream of confluence; regulated since 1962
05HG001	South Saskatchewan River at Saskatoon	1911 to 2009	141 000	Upstream of confluence; regulated since 1968
05HH001	South Saskatchewan River at St. Louis	1958 to 1997	148 000	Upstream of confluence; regulated since 1968
05KD001	Saskatchewan River at Nipawin	1945 to 1948; 1951 to 1962	287 000	Downstream of confluence; regulated since 1968
05KD003	Saskatchewan River below Lake Tobin	1962 to 2009	289 000	Downstream of confluence; regulated since 1963

To construct a streamflow record for the site, mean daily discharges for the two closest upstream gauges along both the North Saskatchewan River (05GG001 at Prince Albert) and South Saskatchewan River (05HG001 at Saskatoon) were added. These gauges are located approximately 100 km and 260 km upstream of the site, respectively. No gauged or major ungauged tributaries flow into the river between the upstream gauge sites and the study site. Due to the relatively small increase in contributing area between these gauges and the site, no adjustment was made to account for the small incremental increase in discharge downstream of the gauges; this likely provides conservatively (approximately 5%) low estimates for discharge at the site.

The lag time between the upstream gauges and the site was estimated for 2 cases, and represent “long” and “short” travel times. Assuming a high average channel velocity, it was determined that the travel time from Prince Albert to the proposed site was 1 day and the travel time from Saskatoon to the proposed site was 2 days. Using a lower average channel velocity to better represent the low-flow period, a travel time of 2 days was used from Prince Albert to the proposed site and a travel time of 6 days was used from Saskatoon to the proposed site. Analysing the data using both sets of travel times allowed both the critical high- and low-flow scenarios to be simulated. These lag times were incorporated in the determination of mean daily discharge at the proposed site. As discussed below, both sets of travel times yielded similar computed river discharge parameter estimates at the proposed outfall site, which indicated that the results were not sensitive to the lag time.

The effects of flow regulation were taken into account when developing the streamflow dataset for the site. There are several large dams that influence the flow patterns of the North Saskatchewan and South Saskatchewan Rivers. The Brazeau Dam (central Alberta), affecting the North Saskatchewan River, was built in 1962 and has an effective drainage area of 5660 km^2. The Bighorn Dam (west central Alberta), also affecting the North Saskatchewan River, was created in the early 1970s and has an effective drainage area of 3890 km^2. The flows from these two dams represent a small percentage of the flow of the North Saskatchewan River at Prince Albert, which has a drainage area of 131 000 km^2, and thus are not likely to dramatically influence the flow patterns at the proposed site. The Gardiner Dam (southwest Saskatchewan), affecting the South Saskatchewan River, became operational in 1968. It has an effective drainage area of 136 000 km^2, which is a large proportion of the effective drainage area of the South Saskatchewan River near Saskatoon of 141 000 km^2. Since regulation from this dam would have a great impact on the flow patterns at the proposed site, it was most appropriate to start the dataset in 1969, after the creation of the dam.

The effects of missing data were considered during the development of a streamflow dataset for the site. From 1987 through 1991, winter flows were not monitored at the gauge located at South Saskatchewan River at Saskatoon (05HG001). Since excluding such a large period of flow would falsely alter any statistics conducted using daily discharge values, the entire flow record for these years were deleted from the mean daily discharge dataset. When analysing mean monthly data, the values for each month are considered independently of the rest of the year. Thus, for such analysis, it was suitable to incorporate the remaining available monthly data for the years 1987 through 1991.

5.2.6.3 Description of Project Area Watershed

In this Section, the Project area watershed is described in terms of local streams and drainage areas, local climatological characteristics and local streamflow characteristics.

Local Streams and Drainage Areas

The Project is located north of the Saskatchewan River in an area containing several small watercourses that drain in a general southerly direction to the Saskatchewan River. The upland surface is forested and has many poorly drained wet areas. The soils under the forest are relatively permeable sand and silt to a depth of approximately 20 to 30 m. Below the permeable soils there are relatively low permeability tills. The surface of the tills roughly parallels the surface slope toward the river valley. Therefore, the surface runoff and shallow ground water generally flow to the Saskatchewan River valley.

Most of the Project activity will be in the area drained by several small tributaries with drainage basins ranging in size from 3.1 to 24.1 km^2. Two moderately larger streams, English Creek with a drainage area of 85 km^2 located to the east and Caution Creek with a drainage area of 108 km^2 located to the west, define the boundaries of the LSA. Table 5.2.6-2 presents the drainage area of each tributary in the Project LSA. Figure 5.2.6-1 shows watershed boundaries and provides estimates of the surface area (km^2) of each sub-basin in Table 5.2.6-2.

Table 5.2.6-2: Drainage Areas of Tributaries Located in the Project LSA

Tributary	Drainage Area (km^2)
Caution Creek	108.1
101 Ravine	24.3
East Ravine	18.0
English Creek	85.0
West Perimeter Ravine	3.4
West Ravine	3.4
Duke Ravine	15.0

Local Climatological Characteristics

Annual precipitation, evaporation and evapotranspiration for the Project area watershed described below.

Annual Precipitation

The datasets selected for application to the Project mine water management are the adjusted (Mekis and Hogg, 1999) Prince Albert A rainfall, snowfall and total precipitation datasets. The selected datasets are presented on a hydrologic year basis in Table A.1 (rainfall), Table 5.2.6-A2 (snowfall) and Table 5.2.6-A3 (total precipitation) in Appendix 5.2.6-A. The tables include the monthly and annual mean, median, standard deviation, and the maximum and minimum values in the datasets. These tables also list the annual totals as a fraction of the long term annual mean amount. A summary of the statistics for each parameter is given in Table 5.2.6-3. Snowfall and rainfall average 30% and 70%, respectively, of the mean annual total precipitation.

The regional data available on sublimation losses are available from monitoring records at Prince Albert (Pomeroy and Gray 1995) and representative of agricultural land use. The information indicates sublimation losses of 24.9 mm and 29.6 mm for 1 km long fetches of stubble and fallow land, respectively. The latter increases to over 62 mm (44% of the mean annual snowfall of 142 mm snow water equivalent (SWE)) for a 4000 m fetch length. The watersheds within the LSA, however, are predominantly composed of forested land. Therefore, sublimation losses due to blowing snow will be less. Pomeroy et al. (2005) prepared a synopsis of hydrology and water resources in Saskatchewan, which discusses the annual water balance for three land covers in the central boreal forest of the Prince Albert Model Forest in a year with normal precipitation. Sublimation losses within pine stands were approximately 28 mm (29% of winter snowfall). Losses from the mixed wood forest were lower (16 mm). From this, a sublimation loss of 24 mm (17%) was adopted for the Project. The implied value for the mean spring SWE value then becomes 0.83 x 142 mm = 118 mm.

Table 5.2.6-3: Prince Albert A Precipitation Summary

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Total/ Mean
Adjusted Rainfall (mm)														
Mean	3.0	0.74	0.5	0.5	1.9	13.9	41.2	74.8	69.9	61.1	41.7	16.9	326.1	1.00
Median	1.5	0.30	0.0	0.0	0.6	10.8	36.9	71.3	65.5	49.6	37.1	12.0	285.5	0.88
St Dev	4.7	1.40	1.3	1.2	4.0	13.8	27.2	37.7	36.3	40.3	26.1	13.4	207.5	0.64
Max	25.1	7.6	11.3	6.9	26.9	75.5	157	194	183	215	146	55.6	1104	3.38
Min	0.0	0.0	0.0	0.0	0.0	0.0	1.9	6.7	8.6	0.6	4.1	0.6	22.5	0.07
Adjusted Snowfall (cm)														
Mean	23.2	25.2	22.5	18.5	22.5	14.0	3.45	0.06	0.0	0.00	1.86	10.5	142	1.0
Median	19.1	22.8	21.5	15.9	18.2	10.9	0.20	0.00	0.0	0.00	0.00	5.5	114	0.80
St Dev	15.0	13.7	11.8	12.0	16.5	13.7	6.4	0.59	0.0	0.02	4.68	14.8	109	0.77
Max	83.1	71.0	54.5	57.6	86.3	72.0	31.1	6.4	0.0	0.20	25.2	74.6	562	3.96
Min	0.0	1.8	0.0	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.02
Adjusted Total Precipitation (mm)														
Mean	26.2	26.0	23.0	19.0	24.4	27.9	44.6	74.9	69.9	61.1	43.6	27.4	468	1.0
Median	22.9	23.6	21.9	17.1	20.9	24.0	39.7	71.3	65.5	49.6	38.4	22.7	418	0.89
St Dev	15.0	13.9	11.7	12.1	16.9	19.6	28.0	37.7	36.3	40.3	26.6	19.5	278	0.59
Max	83.1	71.0	54.5	57.9	87.8	91.7	157	194	183	215	146	104	1445	3.1
Min	1.0	2.1	0.0	1.4	0.2	0.8	2.1	6.7	8.6	0.6	4.1	1.3	28.9	0.06

Note: Hydrologic Year (1889 – 2007).

Evaporation

Regional evaporation data are available and include annual estimates of gross evaporation for Prince Albert A of 699 mm between 1911 and 2000 (Agriculture and Agri-Food Canada 2002). NRCAN (1978) indicates lake evaporation to be approximately 630 mm at the Project site.

Evapotranspiration

Evapotranspiration (ET) is estimated to be the residual of the water balance, using the water balance parameters applicable to the site. For the Project area, an ET amount of 331 mm is computed by deducting the median annual runoff (30 mm) and the groundwater seepage amount (19 mm) from the net watershed output of 418 mm, so as to balance the net precipitation input (see Table 5.2.6-3 above). This value is consistent with the value of 350 mm estimated from The Hydrological Atlas of Canada (NRCAN 1978).

Local Streamflow Characteristics

Water flow was measured in Caution Creek, 101 Ravine, East Ravine, and English Creek in 2005, 2006, and 2007 (Golder 2008). The measurements were completed for varying periods each year, covering most of the open water season. Golder (2008) provides detailed results, including daily flows and rating curves. Based on these rating curves, monthly flow estimates were determined for each stream, as presented in Table 5.2.6-4.

Table 5.2.6-4: Measured Discharges (Golder 2008)

Mean Monthly Discharge (m³/s)						
	May	**June**	**July**	**August**	**September**	**October**
Caution Creek						
2005		0.368	0.217	0.191	0.384	
2006	0.304	0.482	0.237	0.199	0.278	0.226
2007		0.439	0.380	0.184	0.178	
101 Ravine						
2005		0.110	0.050	0.052	0.116	
2006	0.069	0.078	0.014	0.011	0.031	0.034
2007		0.044	0.021			
East Ravine						
2005		0.112	0.051	0.053	0.118	
2006	0.073	0.088	0.036	0.024	0.052	0.038
2007		0.057	0.071	0.112	0.119	
English Creek						
2005		0.325	0.105	0.141	0.344	
2006	0.287	0.385	0.079	0.067	0.200	0.190
2007		0.212	0.138	0.086	0.110	
White Gull Creek[1]						
2005		7.800	2.790	3.200	12.400	
2006	6.950	12.100	2.330	0.895	3.050	4.100
2007		3.990	2.630	1.590	2.200	

Note: [1] Data is provided for concurrent regional hydrometric station for comparison with local discharge data.

The measured discharges at monitoring station within the LSA between 2005 and 2007 (Golder 2008) as well as for White Gull Creek, which is located 70 km north of the Project area, are shown in Figure 5.2.6-3.

Runoff depths corresponding to the mean monthly discharges developed by Golder (2008) are provided in Table 5.2.6-5.

Comparison of the local and regional data in Table 5.2.6-5 indicates lower runoff in local streams (generally 30% to 40% of that for White Gull Creek), although East Ravine showed greater runoff in late summer of 2007.

An estimate of the baseflow for local streams tributary to the Saskatchewan River is based on the short-term seasonal streamflow records for four streams (Caution Creek, 101 Ravine, East Ravine and English Creek). An analysis of the daily mean discharges prepared by Golder (2008) yielded a baseflow estimate of approximately 19 mm. In all cases, the presence of beaver dams along the streams is expected to have influenced the low flow estimates and the flows listed might somewhat underestimate flow within the streams.

There are no flow data available for the smaller streams near the Project site during the winter, however, given the much smaller area of these streams in comparison to the regional streams (discussed below), it is expected that many of the smaller streams near the Project may be dry or freeze to the bed in the winter.

Table 5.2.6-5: Runoff Depths for Representative Watersheds

Runoff Depth in mm (dam³/km²)						
	May	**June**	**July**	**August**	**September**	**October**
Caution Creek						
2005		8.82	5.38	4.73	9.21	
2006	7.53	11.6	5.87	4.93	6.67	5.60
2007		10.5	9.42	4.56	4.27	
101 Ravine						
2005		11.7	5.51	5.73	12.4	
2006	7.61	8.32	1.54	1.21	3.31	3.75
2007		4.69	2.31	0.00	0.00	
East Ravine						
2005		16.1	7.59	7.89	17.0	
2006	10.9	12.7	5.36	3.57	7.49	5.65
2007		8.21	10.6	16.7	17.1	
English Creek						
2005		9.91	3.31	4.44	10.5	
2006	9.04	11.7	2.49	2.11	6.10	5.99
2007		6.46	4.35	2.71	3.35	
White Gull Creek[1]						
2005		32.1	11.9	13.6	51.1	
2006	29.6	49.9	9.92	3.81	12.6	17.5
2007		16.4	11.2	6.77	9.07	

Note: [1] Data are provided for the concurrent regional hydrometric station for comparison with local discharge data.

5.2.6.4 Regional Data

WSC hydrometric stations that have operated or continue to operate in the vicinity of the Project site are listed in Table 5.2.6-6 and are illustrated on Figure 5.2.6-2. These stations were selected based on their proximity to the site and comparable land use (stations on streams draining agricultural land were excluded). Only one station, White Gull Creek, is currently operational and has data concurrent with the 2005 to 2007 on-site surface water monitoring program.

Table 5.2.6-6: Regional Hydrometric Stations

Station Number	Name	Drainage Area (km^2)		Period of Record
		Gross	Effective	
05KE005	Whitefox River near Garrick	1870	1750	1971 to 1997
05KE007	Kelsey Creek near Garrick	156	118	1975 to 1992
05KE010	White Gull Creek at Highway No. 106	629	629	1994 to 2009

Of the regional sites, none are directly applicable to the Project area. White Gull Creek to the north drains land with glaciofluvial and morainal deposits not found within the Project area (Saskatchewan Energy and Resources 2010) and streamflows are affected by outflows from a lake in the upper catchment. Kelsey Creek and Whitefox Creek, located north of the Project area, are more proximate, but are influenced to some extent by agricultural land uses. None of the regional stations represent the incised ravine/gully streams draining the Project area, which are influenced by the groundwater flows through an upper sandy soil layer.

The mean annual discharge measured at White Gull Creek at Highway No. 106 site is approximately 2.6 m^3/s, which is equivalent to a mean seasonal runoff of 87 mm. During the 3-year period when on-site monitoring was undertaken, the runoff at White Gull Creek ranged from 43.5 mm to 123 mm, about 2 to 3 times the runoff measured on small local streams. Data for this and other discontinued stations in the region were not used to estimate runoff depths, but were analysed to aid in determining monthly flow distribution.

5.2.6.5 Mean Monthly and Annual Flows

Mean monthly and annual flows for the Saskatchewan River and local streams are described below.

Saskatchewan River

The mean annual discharge rate and mean monthly discharge rate for the Saskatchewan River are provided in this Section.

Mean Annual Discharge

The mean annual discharge at the proposed site was calculated using mean daily data from the North Saskatchewan River at Prince Albert (05GG001) and the South Saskatchewan River at Saskatoon (05HG001) for the combined periods of 1969–1986 and 1992–2009. (Winter discharges were not recorded from 1987 to 1991. Hence, data from these years were excluded from the mean annual discharge assessment.) This average was calculated for two annual periods. The first was based on a water year from November 1 to October 31. This method allowed for the water data to be split during a relatively steady flow period immediately prior to freeze-up during which discharge does not change significantly. The second was based on a water year from July 1 to June 30. Using this method, the flows were split in the middle of the wet season in order to capture one low-flow period per water year. The value for the mean annual discharge using both methods of water year selection, as well as both sets of travel times, was determined to be 439 m^3/s.

Mean Monthly Discharge

The mean monthly discharge at the Project area was calculated using mean monthly data from the North Saskatchewan River at Prince Albert (05GG001) and the South Saskatchewan River at Saskatoon (05HG001) throughout the period of 1969–2009. Within that data set, some of the winter months for the years 1987 through 1991 were excluded due to lack of recorded data at the gauge.

The results of this analysis are shown in Figure 5.2.6-4, which indicates that higher mean flows are experienced from April through August. Due to regulation by hydroelectric dams located upstream of the site, it can be seen that mean and minimum flows do not vary dramatically from the summer to the winter months.

Monthly flow duration curves created using the mean monthly flow data are illustrated in Figure 5.2.6-5. These graphs show the probability that a given discharge will be equalled or exceeded in each month. The results indicate that high flows are most likely to occur during the months April through August and that low flows commonly occur during November to March.

Local Streams

The mean annual discharge rate and mean monthly discharge rate for select local streams are provided in this Section.

Mean Annual Discharge

An estimate of the mean annual discharge for local streams was made based on the following information:

- seasonal runoff measurements between 2005 and 2007 on local streams;
- comparison of local monitoring results with runoff measurements for White Gull Creek; and
- comparison of regional flow measurements with precipitation data for Prince Albert.

An estimated median annual surface runoff of 30 mm was calculated using the available information above.

Mean Monthly Discharge

Monthly mean discharges were estimated following a review of local and regional monitoring data. The estimated monthly flow distribution for local streams is provided in Table 5.2.6-7.

Table 5.2.6-7: Estimated Monthly Mean Discharges in Local Streams

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
Basin	**Monthly Mean Discharge (m^3/s)**								**Seasonal Discharge (m^3/s)**	**Drainage Area (km^2)**
Caution Creek	0.0	0.817	0.212	0.102	0.085	0.155	0.044	0.028	0.179	108.1
101 Ravine	0.0	0.184	0.048	0.023	0.019	0.035	0.010	0.006	0.040	24.3
East Ravine	0.0	0.136	0.035	0.017	0.014	0.026	0.007	0.005	0.030	18
English Creek	0.0	0.643	0.167	0.080	0.067	0.122	0.034	0.022	0.141	85
West Ravine	0.0	0.026	0.007	0.003	0.003	0.005	0.001	0.001	0.006	3.4
Percent	0%	56%	15%	7%	6%	11%	3%	2%	100%	

5.2.6.6 Ten-year Return Period 7-Day Average Low Flows

The design low-flow values are represented by a calculated consecutive 7-day low average discharge with a 10-year average recurrence interval (7Q10). The 7Q10 value was determined for both the open water and the annual case using mean daily data from the North Saskatchewan River at Prince Albert (05GG001) and the South Saskatchewan River at Saskatoon (05HG001) for the combined periods of 1969–1986 and 1992–2009. For the open water case, this value was calculated using the open water period from May 1 to October 31.

The open water 7Q10, calculated using both sets of travel times (see discussion of travel times in Section 5.2.6.2), was determined to be 188 m^3/s. For the annual case, this value was calculated using a water year from November 1 to October 31 and also using a water year from July 1 to June 30, as in the case of the mean annual flow. The values of the annual 7Q10 using each method and incorporating both sets of travel times were determined to be 168 m^3/s and 170 m^3/s, respectively. Thus, 169 m^3/s was taken as the design value for the annual 7Q10. These results are summarized in Table 5.2.6-8.

Table 5.2.6-8: Calculated 7Q10 Values for the Open Water and Annual Case

7Q10 Values	Discharge (m^3/s)
Open Water Design Value	188
Nov 1 to Oct 31 annual value	168
July 1 to June 30 annual value	170
Annual Design Value	169

5.2.6.7 Return Period Peak Flows

Return period peak flows for regional floods and the Saskatchewan River are described below.

Regional floods

Regional flood frequencies were estimated by analysing flood frequency characteristics for local gauged streams. Streams listed in Table 5.2.6-7 were considered. Although it was concluded that these streams did not represent the hydrological characteristics of the local stream well in terms of seasonal flow distribution, they may be used to describe flood discharge characteristics, as one of the primary determining factors is drainage area. However, it was noted that White Gull Creek appeared to have different characteristics compared to those of Kelsey Creek and Whitefox River for floods in excess of the 1:2 year return period event. The regional flood frequency curve for the 1:2 year flood is illustrated on Figure 5.2.6-6.

To determine the flood of a given return period for a site, the mean annual flood value is determined from Figure 5.2.6-6 using the drainage area at the point of interest. Figure 5.2.6-7 indicates the ratio of larger return period flood discharges to the mean annual (1:2 year return period) flood discharge as a function of drainage area. That drainage area is also used in Figure 5.2.6-7 to determine the ratio of the selected return period flood to the mean flood determined previously. Alternatively, the factors listed in Table 5.2.6-9 can be used to compute the ratio.

Table 5.2.6-9: Factors to Compute Extreme Flood Discharges

Return period (years)	Factor in Equation[1] $Y_{ratio}=a*\ln(DA)+b$	
	a	b
5	-0.513	6.68
10	-1.160	12.8
20	-1.87	19.2
50	-2.81	27.3
100	-3.45	32.8

Notes: [1] where: Y_{ratio} is the ratio of a given return period flood discharge to the median annual (1:2 year) flood discharge. DA is the drainage area (km^2).

Saskatchewan River

Flood frequency analyses were conducted for the proposed site using mean daily data from the North Saskatchewan River at Prince Albert (05GG001) and the South Saskatchewan River at Saskatoon (05HG001) throughout the periods of 1969 to 2009. Information from the period between 1987 and 1991 was re-introduced in this case, as missing data in the winter months do not affect the peak flow analysis. Maximum mean daily discharges were used for the analyses since it was found that the ratios of instantaneous peak values to maximum mean daily discharges at Saskatchewan River at Nipawin (05KD001), North Saskatchewan River at Prince Albert (05GG001) and the South Saskatchewan River at Saskatoon (05HG001) were near unity. The Log Pearson Type III distribution was found to best fit the collected data. The results of the analyses are summarized in Table 5.2.6-10. Note that the discharge measured at the time of the field program in late June 2010 corresponds closely with the 1:2-year flood discharge.

Table 5.2.6-10: Flood Frequency Analysis for the Proposed Site

Return Period (years)	Discharge (m^3/s)
100	4,770
50	3,980
20	3,080
10	2,470
5	1,930
3	1,550
2	1,250

Note: Using a Log Pearson Type-III Distribution.

5.2.6.8 Climate Change

Current global climate change models are not directly used to predict extreme rainfall or flooding. They can only provide predictions over large areas, much larger in size than the Project area.

NRCAN (2009) indicates that while most climate change predictions suggest an increase in the frequency of drought within the southern Prairies, some suggest that there may be no major change in drought frequency. These models also indicate that while air temperatures in the Prairie Provinces have warmed over the past 50 years, most of that warming has occurred in the winter, with a modest increase in the summer.

Analysis of several climate change scenarios indicates the frequency of drought could increase, and drought could be exacerbated by increased evaporation. Conversely, periods of wet cool weather could also occur. The overall result could be more variable conditions.

There are conflicting predictions about winter snowfall changes. Warmer winter conditions may result in reduced snowfall and earlier spring freshet (NRCAN 2009). Research at the University of Saskatchewan (Rowley 2008) indicates that as winters become warmer, more snowfall and rainfall are predicted. More snowpack may result as the heavier, wetter snow may not be blown around and sublimated as readily by the fewer number of snowstorms (expected to be suppressed during warmer winters). Warm winters may also create ice layers in the snow and soil which can result in greater runoff to streams and sloughs.

5.2.6.9 Summary

The climate at the Project site can be characterized by the long-term record from the ‘Prince Albert A’ meteorological station, located about 70 km west of the Project. Adjusted precipitation data for Prince Albert A indicates that the median rainfall, snowfall water equivalent and total precipitation are 289 mm, 114 mm and 418 mm, respectively.

Sublimation, evaporation and evapotranspiration estimates are available in the literature. Evaporation and evapotranspiration values are high and generally exceed mean annual total precipitation, such that water deficits may exist in some years.

Streamflow data available for the Project site indicated average runoff of 7 mm to 52 mm in the small local streams.

Regional hydrometric stations operate on the North Saskatchewan River, South Saskatchewan River, and the Saskatchewan River. Data from these stations indicate that the mean annual discharge in the Saskatchewan River at the Project Site is 439 m^3/s.

The anticipated annual runoff and the monthly distribution of surface flows were determined using data from the local and regional gauges. Seasonal total runoff in local streams was estimated at 35 mm.

Climate change is expected to result in greater variability in weather patterns compared to present. Droughts will still occur and some events may be more extreme. At the same time there may also be very wet periods.

5.2.7 Groundwater Resources

This Section of the report discusses the regional geology and hydrogeology. Additional information on the geology of the deposit can be found in Section 5.2.1 (Deposit and Local Area Geology). Section 5.2.1, on the deposit and local geology, differs from this Section, in that Section 5.2.1 focuses on the occurrence of the kimberlite deposit at the two proposed pits, and includes a limited discussion on the regional geology.

The regional geology has been studied by: Shore in the process of developing the Project (Clifton 2008); by the Saskatchewan Research Council (Millard 1991; SRC 2006a); and by various oil exploration companies. Available information from these sources was reviewed and used in a groundwater model developed by SRK (2011a). Shore completed a door to door survey of local residents within 20 km of the proposed mine to build a database of local well use.

The local geology generally consists of more than 700 m of near flat lying layers of rock and glacial deposits overlying deeply buried Precambrian rocks. With several important exceptions, most of the layers are composed of fine-grained materials such as silt, clay and shale that do not produce significant quantities of water. These units are referred to as aquicludes and aquitards because they retard groundwater movement and are not suitable for supplying significant quantities of groundwater to wells.

Between the aquicludes/aquitards however, are several important layers that are capable of producing varying amounts of water (aquifers) from wells. These water producing layers include three units:

- surficial sands found through much of the FalC and surrounding area (shallow aquifer);
- thin seams of sand and gravel found sandwiched between thick till at depths of less than 120 m (intermediate aquifers); and
- a thick highly productive zone comprised of sandstone and fractured limestone, found at depths of between 250 and 350 m below ground surface that produces brackish water (deep aquifer).

The surficial sand aquifer is used by many local residents for a water supply and residents with shallow dug wells tap into this aquifer. The aquifer collects rain and snow melt during the year and it plays an important role in providing water to most of the local creeks during periods of low flow in the summer and winter. Wells completed in this aquifer generally produce water of suitable quality for drinking purposes but only in limited quantities. Seepage from this aquifer is the main source of water for springs along the Saskatchewan River.

The thin layers of sand and gravel sandwiched between the till layers are sometimes used as the source of water for many local residents. While there are several of these lenses in the region, the lenses are generally of limited extent and occur at random locations and depths throughout the area. The yield of wells completed in these layers is highly variable and dependent on the extent of the layer. Typically, local wells tap into the topmost layer in the area and most of the wells completed in one of these layers are less than 50 m deep but some wells tap into deeper layers between 50 and 120 m deep. Some springs along the banks of the Saskatchewan River valley can be fed by these layers. The water quality of these aquifers is generally hard, but when treated is suitable for domestic uses. The water quality does generally decline with depth. These intermediate aquifers are believed to be recharged by slow leakage of water through overlying aquitards, infiltrated through the surficial aquifer above.

The third important aquifer is highly productive and is present in the sandstone layers within the lower part of the Mannville Group and the upper fractured part of limestone of the Souris River Formation. The Mannville Group that contains the aquifer is generally found at depths of greater than 170 m, but it becomes shallower to the north. The main aquifer in the Mannville Group is found at depths of approximately 250 m at the site. None of the local residents surveyed within 20 km of the Project had a well completed in this unit, which provides slightly brackish water not suitable for drinking. With the exception of near the Saskatchewan River valley, groundwater levels in this aquifer are much lower than those in the upper layers, indicating a downward gradient from the upper to lower permeable layers. Because of its depth, poor water quality and thick shale and clay cover, the groundwater in this aquifer presumably entered the aquifer many thousands of years ago likely from upgradient and only a small component of recharge is derived directly from local infiltration.

Shore is continuing to investigate the local groundwater system in order to assist in developing a cost effective dewatering system and intends to use the new information to continuously revise and update a groundwater model developed for the Project. In addition, a groundwater monitoring program is planned to confirm the model results.

5.2.7.1 Introduction

The site of the Project is located in the central part of Saskatchewan between the communities of Prince Albert and Nipawin, close to the Saskatchewan River (Figure 5.2.7-1). The proposed mine will consist of two open pits located within the FalC Provincial Forest on the north side of the Saskatchewan River (Figure 5.2.7-2).

Local communities include Prince Albert, Nipawin, Meath Park, Weirdale, Smeaton, Choiceland, Codette, Melfort and the James Smith Cree Nation.

For the purposes of this discussion, the Local Study Area (LSA) includes the area of the mine site, including the pits, stockpiles and facilities. The Regional Study Area (RSA) for hydrogeology encompasses a larger area that extends more than 50 km from the site. The RSA contains many individual features of interest, including the Saskatchewan River, regional aquifers, a buried bedrock valley and the kimberlites, which are described in this Section of the EIS. The sources of hydrogeological information used in preparation of this component of the EIS include: government publications; hydrogeological studies for proposed dams on the Saskatchewan River and; previous geologic and hydrogeological reports prepared on behalf of Shore.

5.2.7.2 Regional Geology

The geology and hydrogeology of the RSA can be divided into four main units, each of which can be further subdivided. The four main units include:

- Precambrian rocks which are deeply buried at the Project Site, but outcrop several hundred kilometres north as part of the Canadian Shield;
- a more than 700 metre-thick basal unit of sedimentary rocks deposited during periods when the area was periodically submerged beneath shallow seas 80 to 520 million years ago;
- several layers of much younger overburden (primarily tills) that overlie all the older sedimentary rocks in the area with thicknesses of approximately 40 m in the deeply incised Saskatchewan River Valley and more than 130 m at other locations; and
- the kimberlite bodies that were emplaced through all but the youngest sedimentary rocks, during volcanic eruptions in the area approximately 95 to 105 million years ago, making them contemporaneous with the deposition of the Mannville Group and Colorado Group (Harvey et al. 2008).

Cross-sections of the vertical distribution of three of four main units developed from onsite drilling records and Oil and Gas drilling records are located in Figure 5.2.7-3 and illustrated in Figures 5.2.7-4 and 5.2.7-5. The two cross sections are both approximately 130 km long and illustrate the geology from the surface to depths of approximately 400 m. Broadly speaking, the sedimentary rocks and overburden units are shown as relatively flat lying. The kimberlite bodies are comprised of small diameter vertical conduits (pipes) with relatively large volume sub-horizontal crater-fill and extra-crater bedded deposits that are capped by younger sedimentary rocks. The Precambrian rock types are not shown, as they occur at depth below the bottom of the illustration.

A stratigraphic column showing the subdivisions of the main units, their age and the major disconformities are presented in Table 5.2.7-1.

Table 5.2.7-1: Stratigraphic Table for the Fort à la Corne (FalC) Kimberlite Field

Time Unit	Basal Age (Ma)	Group	Formation	Sediments
Holocene	0.011		Soils and stratified deposits	Sand and lacustrine silt-clay
Quaternary	Pleistocene	Saskatoon	Battleford Floral (Paleochannel unconformity at base)	Till with intermittent sand seams (sand deposits thicker in Paleochannel)
		Sutherland	Warman Dundurn Mennon	Till with intermittent sand seams (sand seam at Saskatoon-Sutherland contact maybe more continuous than other seams)
		Empress		Sand and gravel (intermittent)
Major Unconformity at approximately 100 to 130 m				
Cretaceous	Early	Lower Colorado 103	Westgate Viking Joli Fou (contemporaneous with kimberlite intrusions)	Shale (fractured at top) and rare siltstone, deposited in offshore marine environment
	Early	Mannville	Pense (contemporaneous with kimberlite intrusions)	Shales, fine sands and siltstones (transitional from Joli Fou to Cantuar)
		115	Cantuar (contemporaneous with kimberlite intrusions)	Sandstones and shales, deposited in beach, tidal and deltaic environments
Major Unconformity at approximately 345 m				
Devonian	Middle	Manitoba	Souris River	Limestones, dolomites, argillaceous marlstone

Note: Quaternary to Middle Devonian (from Clifton (2008) - modified from Jellicoe et al. (1998); Rogers and Bayne (2000)).

Bedrock Units

The Precambrian basement rocks near the Project Site are buried by more than 700 m of younger sediments. They are exposed on surface approximately 170 km northeast of the Project Site in the northern part of the province, as part of the Canadian Shield. The resultant slope of the basement rock down towards the southwest results in the thickness of overlying sedimentary rock to increase to the southwest, and thin, then pinch out towards the northeast. This is illustrated in Figures 5.2.7-4 and 5.2.7-5, by the slight slope downwards to the south and west. As a result, younger rock formations subcrop beneath the till units to the southwest for several hundred kilometres, whereas progressively older units subcrop beneath the till units to the northeast. The tills are generally flat lying over the sedimentary rock units.

The carbonate rocks and clastic sedimentary rocks within several tens of kilometres of the Project Site can be thought of as relatively flat lying layers of bedrock; however, in detail the thickness of the layers varies with location. The sedimentary rock layers developed as a result of a series of three depositional phases, reflecting cycles of sedimentation during deeper or shallower sea levels separated by periods of erosion when the sea levels retreated to expose the rock to erosion.

Of the approximately 700 m of sedimentary rock in the area, the upper three layers are of the most interest, because they will be intersected during mining, or are close to the base of the mine level. These three units, in ascending order, consist of:

- Souris River Formation (part of the Manitoba Group) - fossiliferous limestone and dolostone with a typical thickness of approximately 380 m;
- Mannville Group - sandstones, mudstones and shales, with a typical thickness of 150-170 m; and
- Colorado Group - dark gray shale with mudstone and thin laminated sandstone, with a typical thickness of approximately 80-90 m.

There are gaps of time between the deposition of these three units when the bedrock surface was eroded. This accounts for some variation in the thickness of each unit, along with the pinching out of the units to the northeast. Each unit also represents several cycles of deposition, which may also be separated by periods of erosion. The youngest of the sedimentary rock units, which is overlain by glacial sediments, is the Colorado Group. This unit would have been eroded by glaciers in addition to non-glacial processes. The same glaciations would have eroded the older units to the northeast, where the younger Colorado Group is absent. The upper few metres of the Colorado Group are reported to have been fractured by the overriding glaciations (Clifton 2008).

There is also some evidence from drill holes and airborne geophysics that the Colorado Group was eroded by an ancient river that passed north of the Project Site in what was likely an easterly direction (Figure 5.2.7-6). Based on the absence of older tills in this feature, the river was likely created during an interglacial or interstadial period and was the ancestral equivalent of the modern day Saskatchewan River. Based on drilling data, it appears that a bedrock valley was eroded into the Colorado Group by the river and subsequently infilled with younger tills and glaciofluvial deposits (Figure 5.2.7-7).

This feature is referred to as the paleochannel and was mapped north of the Project by airborne geophysics and may extend to the east of the RSA.

There is also some evidence from oil and gas drilling records of much older river valleys forming within the deltaic sandstones of the Mannville Group. However, unlike the paleochannel in the Colorado Group, these older valleys appeared to have formed in a mature drainage system, with less of the steeply inclined valley walls than those associated the modern day Saskatchewan River or its ancestral equivalent in the Colorado Group. The rivers that deposited the deltaic sediments are also thought to have criss-crossed the area many times leading to depositions of sand sediments across the entire RSA and not just within isolated river valleys like that of the Saskatchewan River (Christopher 2003). This variable deposition would account for the several different formations that form the Mannville Group.

The kimberlite bodies were emplaced during volcanic eruptions during the period when the sediments of the Colorado and Mannville groups were being deposited. There are approximately 70 kimberlite bodies identified in the RSA, of which 58 are in a cluster near the Project (Harvey et al. 2008). The volcanic mounds and shallow craters that formed when the kimberlite bodies were emplaced were slightly eroded before and during, deposition of the Colorado Group sediments and the kimberlites were subsequently overlain by late Colorado Group and younger sediments.

Since deposition, the sedimentary deposits have lithified into rock through compaction and cementation over time. The sedimentary rocks are in turn overlain by till and other overburden sediments. The till sediments were compacted under several kilometres of glacial ice but remain relatively soft due to their recent geologic age. The overburden sediments generally fill depressions in the bedrock surface, including the ancestral river valley (paleochannel) of the Saskatchewan River located to the north of the Project.

Overburden Sediments

Like the bedrock, the local overburden consists of several layers. Most of the thickness of overburden sediments consists of low permeability till deposits, but there are some locally important sand/gravel layers between, within and overlying the tills. The local overburden geology, in ascending order, consists of:

- the Empress Group (locally identified);
- Quaternary aged tills (Sutherland and Saskatoon Groups);
- glaciolacustrine and glaciofluvial sediments; and
- Recent reworked glacial material deposited on the surface by alluvial, colluvial and eolian processes.

Overburden thickness generally ranges from 90 to 130 m, but where it is has been eroded by the Saskatchewan River near the mine site the overburden thickness decreases to approximately 40 m.

Empress Group

The Empress Group has been defined as the stratified deposits found between the oldest till and bedrock (in the LSA, the Colorado Group). In the LSA, the Empress Group appears as isolated, non-continuous occurrences, only a few metres thick. These sediments are locally reported in boreholes around the Orion North Kimberlite site, but have only rarely been encountered at the Star Kimberlite site. Where encountered at the Orion North Kimberlite, the Empress Group sediments were found at elevations of approximately 340 masl, which is approximately 20 m below the Saskatchewan River. Where present, the Empress Group sediments are likely hydraulically connected to the fractured upper part of the bedrock.

Sutherland and Saskatoon Group Tills

The Sutherland Group and Saskatoon Group tills are generally silty clay tills containing varying amounts of cobbles, gravel and sand, each with varying hardness. The Sutherland and Saskatoon Group tills are for the most part laterally continuous in the area. The Sutherland Group tills are typically more compact than the overlying Saskatoon tills, due to the overriding of these older tills by a second set of glacial advances. The Sutherland Group tills also have higher clay content and lower sand content than the overlying Saskatoon Group tills. Near the Project Site, the upper contact of the Sutherland Group occurs as an oxidized surface with an elevation of between 360 and 370 masl (Clifton 2008). Contacts between the till units are often marked by layers of boulder lag that are frequently visible in the walls of the Saskatchewan River valley.

Borehole data at the Project Site often identifies sand/gravel lenses in the till deposits that are similar to those used for water supply by residents in neighbouring areas. Most of these lenses are not thought to be extensive and grade to silt sediments in many places. Near the Project Site, approximately two to three sand/gravel layers are noted in the Saskatoon Group (within the Floral Formation of this group including one at the base of the group). No sand/gravel lenses are noted within the Sutherland Group, although gravel lenses may occur within this group (Clifton 2008). Artesian conditions are reported in wells completed in some of these layers to the northeast of the FalC between Smeaton and Weirdale (SRC 2006a).

To the northeast of the Project Site towards the community of White Fox, in addition to the thin sand layers between the tills, a thicker sand and gravel layer is found in the Saskatoon Group (Figures 5.2.7-4 and 5.2.7-5). This unit is noted as an important local aquifer that exhibits artesian to sub-artesian heads (Clifton 2008).

Paleochannel Fill Deposits

The Saskatoon Group tills, but not the Sutherland Group tills, were identified in logs of boreholes drilled into the paleochannel north of the Project Site (Figure 5.2.7-7). The lack of the Sutherland Group tills in the paleochannel may place the paleochannel as a pre-Saskatoon, post Sutherland age feature. Furthermore, the Saskatoon Group tills that occur within the paleochannel were more common in the upper portion of the paleochannel. Whereas, fluvial deltaic deposits of sand with some clay and till being more common below elevations of approximately 380 masl, suggesting the lower portion of the paleochannel contains more aquifer material than the upper portion.

The base of the valley was reported in the borehole (PC-06-002B), which encountered bedrock of the Mannville Group at an elevation of 217 masl, indicating the Colorado shales that underlie the Quaternary sediments elsewhere in the RSA are absent beneath parts of the paleochannel. Given the depth and elevations of the paleochannel fill, it is likely that the sand layers within the lower part of the paleochannel are hydraulically connected to the Empress Group sands and to the underlying Mannville Group, however water levels in monitoring wells completed in the shallow sediments remain close to surface, and given the downward gradients in the area suggest that there is no hydraulic connection through the paleovalley from the upper to lower aquifers.

Stratified Sediments Overlying Saskatoon Group Tills

The tills are overlain by stratified surficial deposits which are composed of materials of late glacial/Holocene Age and include glaciolacustrine clays, deltaic and outwash silt and sand deposits. The glaciolacustrine clays were deposited in glacial Lake Agassiz and reach thicknesses of 10 m or more in what would have been a broad flat valley in the paleo-till surface whose axis was roughly coincident with the Saskatchewan River (Figure 5.2.7-4). Glaciofluvial sediments were then deposited on top of these sediments in a broad deltaic plain in the north-central parts of the valley as the shores of the glacial lake advanced and receded, thereby forming the upper surficial sand aquifer (Figure 5.2.7-8). After the recession of the lake, the Saskatchewan River eroded its current valley and reworked the till and fluvial sediments within its path. There was also some reworking of the deltaic sediments in other areas by smaller streams and by eolian processes. Significant organic deposits were also created in poorly drained areas.

5.2.7.3 Overview of Regional Hydrogeology

The hydrogeology of the RSA can be divided into three key hydrostratigraphic layers as follows:

- an upper aquifer consisting of a surficial sand layer containing the water table aquifer;
- an intermediate aquiclude consisting of thick layers of silt till, with the occasional sand layer and the underlying thick shale layer; and
- a deep aquifer, consisting of sandstone and limestone interbedded with siltstone.

This Section describes the main hydrostratigraphic units.

Upper Aquifer

The upper aquifer plays an important role in providing base flow to local creeks in the area, including springs along the Saskatchewan River valley and is also used as a domestic water supply aquifer by many local residents. The water in this aquifer is generally of relatively good chemical quality and groundwater flow within the aquifer generally is a subdued reflection of topography towards local streams. The surficial sands were reportedly deposited in a wide delta of the Saskatchewan River as it discharged into a glacial lake (Millard 1991). Surficial mapping indicates that the upper aquifer is present within most locations within the FalC Area and in a wide area on both sides of the Saskatchewan River downstream of the Project Site (Figure 5.2.7-8). The extent of the upper aquifer narrows upriver of the Project Site, and also in the upper reaches of the White Fox River to the northwest and in the watershed of Peonan (or Pehonan) Creek to the southwest. At these locations where the upper aquifer is absent, the surficial sediments are mapped as till or glaciolacustrine plain deposits instead of glacial fluvial deposits.

Intermediate Aquiclude

The intermediate aquicludes can be subdivided into an upper Quaternary aquiclude comprised of tills of the Saskatoon and Sutherland Groups and the lower aquiclude of shales of the Colorado Group. The upper part of the Mannville Group may also fit in this unit as the upper contact is transitional from the Colorado shales to the Mannville group sandstones and part of the upper Mannville exhibits aquitard characteristics. There are several discontinuous sand layers within the till units or at the base of the till unit that are important local aquifers for water supplies in the region.

The deeper till layers and Colorado Group are wide spread in the RSA, but may be thinner or absent:

- where the kimberlite intrusions penetrate the lower part of the Colorado Group Shales;
- near Candle Lake and in an area approximately 50 km northeast of the FalC, where the Mannville Group formations are mapped as subcropping beneath the Quaternary sediments (Rogers and Bayne 2000);
- in the vicinity of the buried paleochannel to the north and northeast of the site that is primarily filled with younger tills and silty sand alluvium; and
- in the Saskatchewan River valley, where the river has cut into the lower Quaternary till units.

With the exception of the kimberlite intrusions, where the Colorado Group is absent in the above areas, the upper part of the Mannville Group may remain as an aquitard.

The kimberlites also intrude through the deep aquifer. The kimberlites have relatively low permeability based on packer tests and on dewatering experience during exploration. Due to their low permeability, the kimberlites are treated as aquitards.

Deep Aquifer

The deep aquifer consists of permeable layers within the sandstone of the Mannville Group and the underlying carbonates of the Souris River Formation. The permeable layers within this aquifer are separated on a local scale by less permeable layers, but are grouped together regionally because of the deep stratigraphic position and similar water quality. At the project site, flow profiles and calibration of the model to a pumping test indicates that the upper part of the Mannville Group is significantly less permeable than the upper part, and maybe considered an aquitard. The groundwater within the deep aquifer and overlying lower permeability sediments is slightly brackish and is not known to be used for a water supply in the vicinity of the FalC.

Limited groundwater level information from drill stem measurements in oil and gas wells in the RSA and from Shore monitoring wells prior to 2010 indicates that groundwater flow occurs within this unit; specifically, from northwest to southeast across the Project site but with a west to east flowing component on the south side of the river. There is potential convergence of groundwater flow directions towards the river several tens of kilometres downstream of the site suggesting that there was some potential for groundwater discharge to occur into the Saskatchewan River further downstream, where the overlying aquiclude is thinner.

Generally a downward gradient exists from the upper aquifer to the lower aquifer, except in the Saskatchewan River valley. Within the valley, the river has incised into the upper sediments adjacent to the Star site where the heads in the deep aquifer are approximately 40 m above the river level. The magnitude of the upward gradient between the deep aquifer and the Saskatchewan River indicates that the deep aquifer is confined and that a strong hydraulic connection does not exist between the aquifer and the river. The relative heads from this aquifer to the river decrease downstream of the site to approximately 25 m near Nipawin, below the reservoirs (Saskatchewan Power Corp. 1977).

5.2.7.4 Regional Setting of the Project Site

The Project Site is located on a relatively flat plain whose recent topography was created by the deposition of relatively thick till sequences during multiple glaciations followed by the deposition of a blanket of glaciolacustrine and deltaic sediments in a receding glacial lake. The deltaic sediments were then locally dissected by the Saskatchewan River which, during the Holocene Period, created a deep, narrow sided river valley immediately south of the Project Site.

The Saskatchewan River and Nearby Watersheds

The Saskatchewan River flows past the Project Site from west to east and is formed by the confluence of the North Saskatchewan River and the South Saskatchewan River approximately 20 km west of the Project Site near Prince Albert (Figure 5.2.7-2). The North Saskatchewan River begins in the Canadian Rockies and is approximately 1,300 km in length. The South Saskatchewan River is formed at the confluence of the Bow and Oldman River in Alberta and is almost 1,400 km long, collecting waters from the Calgary and Saskatoon area. Approximately 100 km south of Saskatoon, the Gardiner Dam on the South Saskatchewan has created Lake Diefenbaker. From the confluence near Prince Albert, the combined Saskatchewan River flows east to Lake Winnipeg and eventually discharges in Hudson Bay.

The level of the Saskatchewan River adjacent to the Star site is approximately 355 masl, and the channel is incised approximately 80 m into the surrounding plains. Near the site, the river is approximately 250 m wide. Based on observations made for geotechnical studies at bridge crossings and dam structures in the area, the base of the channel is continuously armoured with two to three metres of boulders (Saskatchewan Power Corp. 1977, 1982). At various locations along the river valley, down cutting has left point bars and terraces.

There are two hydroelectric reservoirs on the Saskatchewan River downstream of the Project Site (Figure 5.2.7-2). The closest is the Codette Reservoir, which is located approximately 50 km east of the Project Site and is created by the Francois Finlay Dam at Nipawin. The second reservoir is the Tobin reservoir, whose E.B. Campbell dam is located approximately 100 km east of the Project Site. The Saskatchewan Water Authority (SWA) maintains records of the discharge from the Tobin Reservoir and water level elevations in both reservoirs. The average discharge from the Tobin Reservoir is approximately 50 million m^3/day, and the lake is maintained at elevations of approximately 310 masl (SWA 2010). The water levels in Codette Lake are maintained at elevations of approximately 345 masl (SWA 2010).

The Project lies within the watershed of the Saskatchewan River and its tributaries and is approximately 100 km wide. In the RSA, most of the watershed lies to the north of the river. This includes the Torch River subwatershed system that originates at Candle Lake and joins the Saskatchewan River near the Lake Tobin Reservoir (Figure 5.2.7-2). The Candle Lake reservoir is located near the start of the Torch River, approximately 70 km northwest of the Project Site and is maintained at elevations of approximately 495 masl (SWA 2010). The drainage divide with the White Fox River, which is a tributary of the Torch River, lies approximately 10 km north of the Project Site. Unlike the Saskatchewan River, the Torch River and White Fox River are not deeply incised into the till sediments near the Project Site.

The southern boundary of the Saskatchewan River subwatershed is approximately 8 km south of the Project Site. Most of the watershed within this area drains towards the Carrot River. The Carrot River flows northeast and joins the Saskatchewan River in Manitoba. Like the White Fox and Torch Rivers to the north of the site, the Carrot River is not deeply incised into the till sediments in the vicinity of the Project Site.

Close to the Project Site, the Saskatchewan River is joined by several smaller creeks, many of which are unnamed. The named creeks include Caution Creek, 101 Ravine Creek, West Ravine Creek, East Ravine Creek, English Creek on the north side of the river, and Peonan (or Pehonan) Creek on the south side of the river (Figure 5.2.7-9). Most of the named creeks drain ponds and wetlands on the relatively flat plains above the Saskatchewan River. Where the creeks flow into the Saskatchewan River valley, they have cut short narrow ravines into the glacial sediments. The creeks are relatively small and are often dammed by beavers. Many of the smaller creeks flow intermittently.

Local Water Supplies

Since the Project is located within the FalC Provincial Forest, there are almost no local residences within 10 km of the proposed pits and relatively few residences within 20 km of the proposed pits (Figure 5.2.7-10). Most local residences rely on private wells for their water supplies; however there are also a few communal water supplies that include groundwater or surface water sources based on the Saskatchewan River.

The SWA maintains copies of drilling records for a large number of water supply wells in the area (SRC 2006a). This information from the SWA was supplemented by information from interviews with approximately 110 local residents collected during a door to door survey of properties close to the FalC park boundary undertaken by Shore in 2010 with follow up work in 2011, or volunteered at a series of open houses held by Shore in May and June of 2010. While it is likely that the SWA database and well survey are only partially complete and includes errors, the settlement patterns dictate that few, if any domestic wells will be expected within the Provincial Forest and most wells will be located near residences.

According to the SWA database, almost all the wells were constructed to provide a domestic water supply. Most of these wells are completed at depths consistent with the surficial sand aquifer, with the remaining wells appearing to be completed in sand seams within the till (Table 5.2.7-2). The predominance of shallow wells reflects the availability of water in the widely distributed surficial sand sediments (Figure 5.2.7-8). In the SWA database, there are only eight wells within 10 km of the Project Site, 70 wells between 10 and 20 km of the site and 390 wells between 20 and 30 km of the Project Site.

Table 5.2.7-2: Summary of Local Wells in the SWA Records within 30 km of the Proposed Pit Based on SWA Records of Completed Wells[1]

Well Depth Interval	Number of wells in this interval
Wells less than 25 m deep	324 (69%)
Wells between 26 and 50 m deep	85 (18%)
Wells between 51 and 100 m deep	58 (12%)
Wells greater than 100 m deep	1 (<1%)
Total	468

Note: [1] Based on the door to door well survey, approximately two thirds of the residents draw water from shallow wells (less than 25m deep), which is similar to the proportions of wells reported in the SWA database.

A relatively high proportion of deeper wells were found in the area more than 30 km to the northeast of the FalC near the community of Choiceland (Figure 5.2.7-10). In this area, 42% of the wells are completed at depths of greater than 50 m, compared to the average 13% wells for the wider area (Table 5.2.7-2). The significantly higher proportion of deep wells in this area suggests either the presence of deep overburden aquifers that are not present elsewhere, or the absence of shallower aquifers in this area.

A small number of artesian wells were noted in the SWA database. These were generally found to the northwest of the FalC near the communities of Snowden and Shipman. Generally the flowing wells were relatively deep, with depths between 50 and 90 m below ground (SRC, 2006a). One of these wells was sampled by Shore in the spring of 2011, and results indicated that the well water mineralization was relatively high, as compared to water from more shallow wells, in terms of chloride (110 mg/L) and some other parameters including arsenic, manganese, iron and sodium. Other artesian wells are noted in the area to the northeast of the FalC near Choiceland (Clifton, 2008).

The area near Choiceland was also the only area where wells greater than 100 m deep were located within 40 km of the Project Site. With one exception, the deepest wells in this area are between 100 and 120 m deep. Given the approximate 120 m thickness of the overburden generally reported for the RSA, these wells are likely completed near the base of the overburden sequence or the top of the bedrock. One 140 m borehole was reported approximately 20 km northeast of the Project Site near the FalC forest border and might be the deepest private borehole in the area, but the well completed in this borehole is reported completed to a depth of 125 m. According the SWA water well record for this well, it is also completed in the overburden. This well was sampled in the spring of 2011 by Shore. The results indicated that the well water mineralization was relatively high, as compared to water from more shallow wells, in terms of chloride (253 mg/L) and some other parameters including arsenic, manganese and sodium, which is consistent with the general trend towards poorer quality water with depth.

The well survey revealed that most local residents were generally well informed about their wells. Most local residents reported that their wells were either adequate or plentiful in terms of water quantity, but some also indicated that their wells were marginal in some years. Not including the municipal wells, the primary use of the wells was to provide water for domestic uses, however a small number of wells were used to provide water for animals or to mix with pesticide sprays on agricultural properties. A significant number of households have two or more wells, with one or more wells not in use.

A large proportion of local residents reported that their wells produced hard water and most residents who used the water in their households had water softeners. The presence of a gas odour or sulphur was also sometimes reported in the deeper wells, and owners of wells greater than 30 m deep often reported high or nuisance concentrations of iron or manganese in the water. It was common for residents to report that they did not use their wells for drinking.

In addition to the domestic single residence supply wells, there are also several communal or municipal water supplies in the area operated by local Rural Municipalities (RMs) (Figure 5.2.7-2). During a survey of local RM's in 2010, Shore contacted the following RM's for information on municipal wells:

- **RM of Garden River –** The village of Meath Park gets its water from a town well. All other residents in the RM are thought to use independent wells or dugouts for water supply;
- **RM of Torch River –** The hamlet of Snowden and the hamlet of Garrick have their own supply systems (town wells). All other residents in the RM are thought to use independent wells or dugouts for water supply;

- **RM of Nipawin –** There are no active municipal wells within Nipawin. Codette Lake on the Saskatchewan River is the water supply for the community of Nipawin, and also the start of the Melfort water supply pipeline that provides water to the communities of Weldon, Kinistino, Beatty, Melfort, Star City and Star City Colony in neighbouring RM's to the south. All other residents in the RM are thought to use independent wells or dugouts for water supply;
- **RM of Willow Creek –** This municipality is on the Melfort Pipeline system. SaskWater charges the RM for supply through the Melfort Pipeline. All other residents that are not on the pipeline are thought to use independent wells or dugouts for water supply; and
- **RM of Kinistino –** This municipality is on the Melfort Pipeline system. SaskWater charges the RM for supply through the Melfort Pipeline. There are also two municipal wells within the RM of Kinistino: the Forest Reserve, and the Kirkham Springs wells. All other residents in the RM are thought to use independent wells or dugouts for water supply.

In the addition to the RM's, the SWA water well records indicate that the villages of Weirdale, Smeaton, and Choiceland, located along Highway 55 to the north of the Project Site, currently operate or have operated municipal wells. The operation of the municipal well for the Village of Weirdale was confirmed during the well survey.

In addition to the municipal water supply systems described above, the James Smith First Nation also operates a communal groundwater based system on the Reserve located on the south shore of the Saskatchewan River across from the Project site. Information for that well system was obtained by Shore during interviews held in the spring of 2011 with a knowledgeable and long term water operator for the system. According to the information collected, the James Smith First Nation currently operates six wells to supply the entire community, although there are also several additional old unused or decommissioned wells on the reserve. The water from the operating wells is pumped to a reservoir at a central pump house. From the pump house the water is distributed to houses that are on the reserve's distribution pipeline system. There are also approximately 136 cisterns on the reserve that are filled by water trucks that collect their water from the pump house. Information on the construction of the James Smith communal wells was provided by the water system operator. There were also four water well records identified in the SWA data base as belonging to the reserve, but these appear to pre-date the wells currently in operation at the reserve and may be older decommissioned wells. Of the six wells in operation at the site, two are reported to be 22 m deep with a diameter of 0.9 m. The remaining four wells are 0.2 m diameter wells with depths between 5.5 and 7.3 m. The two 0.9 m wells were reportedly drilled in 1985 and two of the 0.2 m diameter wells were drilled in the 1990s. The ages of age of the two remaining wells are unknown. This information indicates that the reserve relies on water in the shallow aquifers for their water supply.

Shore obtained water samples from five of the six James Smith Cree Nation wells, but did not sample Well #4, which was reportedly not in use due to water quality concerns. The water in the remaining five wells was low in chlorides (approximately 20 mg/L). Two of the wells with elevated pH's also had lead concentrations that exceeded the drinking Maximum Allowable Concentration for drinking water. The origin of the lead is unknown, but might be older plumbing fittings within the wells and may not representative of the source water.

A review of water use within the Saskatchewan River watershed completed by Partners for the Saskatchewan River Basin (2008) indicates thatthere is only one significant groundwater user within the watershed. A dewatering system is operated at the dam near Nipawin, downstream of the Project Site (Figure 5.2.7-2). This system takes approximately 13,000 m^3/day of water from a sand layer at the base of the till sediments and from the top of the Mannville Group to prevent uplift of the dam structure and discharges it to the Saskatchewan River (Partners for the Saskatchewan River Basin, 2008). Note the the 13,000 m^3/day reported by Partners for the Saskatchewan River Basin (2008) may be the permitted amount and not the measured daily amount. Most of this water is taken from the Mannville Group (Matheson et al. 1987).

The SWA maintain one deep groundwater monitoring station within the Saskatchewan River watershed. This well is completed within the Mannville Group at a location 60 km east-southeast of the Project Site near Armley (Figure 5.2.7-2). Water levels in this well were approximately 346.0 masl in 2010 (SWA 2010).

5.2.7.5 Review of Hydrogeology Investigations for Projects in Surrounding Area

There have been a number of hydrogeology investigations for projects in the surrounding area that are unrelated to the proposed mine. The following Section provides a summary of those parts of these investigations that appeared relevant to the proposed mine.

Hydrogeology Investigations Supporting the EIA for the Proposed Dam at the Nearby Forks Site

A detailed environmental impact assessment (EIA) was completed for a dam that was once proposed on the Saskatchewan River, approximately 14 km upstream of the Project Site (Saskatchewan Power Corp. 1982). This dam was not constructed; however, the EIA document provides a useful review of information sources available at the time the EIA was completed in 1982. This information consisted of descriptions of the local geology, a survey of streams and springs along the Saskatchewan River, as well as some subsurface information from published sources.

Local Stream Flow Measurements from 1979-1980

The stream survey included flow measurements collected at several of the major creeks, which were described in the EIA report as intermittent streams. These included English

Creek and Peonan (Pehonan) Creek, which are close to the Project site (Table 5.2.7-3). The high variability in flows in the Peonan (Pehonan) Creek might be attributable to the higher proportion of its watershed that is mapped with a surficial till and glaciolacustrine cover thereby promoting higher runoff compared with other creeks, such as English Creek that flow through surficial sand areas.

Table 5.2.7-3: Selected Discharge of Creeks (m^3/day) into Saskatchewan River near Proposed Forks Dam[2]

Creek	November 6,7, 1979	April 16, 1980	July 18, 1980
English Creek	n/a[1]	n/a[1]	6,600
Peonan (Pehonan) Creek	90	1,724,000	600

Notes: [1] Mouth of English Creek was reported as not accessible at these times.
[2] Saskatchewan Power Corp. (1982).

Saskatchewan River Spring Survey

The survey of springs along the Saskatchewan River was undertaken through a review of historical air photos from 1937 to 1976. The primary purpose of the survey was to locate springs as potential locations of slope failure. The report included maps showing the locations of springs along the river from the Highway 6 bridge crossing near Gronlid to upstream of the confluence of the North Saskatchewan and South Saskatchewan Rivers.

Following the river for approximately 20 km upstream and downstream of the Project Site, the mapping shows springs were about one and a half times as common on the north side of the Saskatchewan River compared to the South side of the river. Springs were also three times more common downstream of the Project Site than upstream. The greater occurrence of springs on the north side of the river and downstream of the Project Site might be attributed to several factors, including: the larger watershed areas generally present on the north side of the river and downstream of the Project Site providing a greater contributing area for the springs; or the progressive incision of the river into deeper formations downstream of the Project Site which might be more permeable than those upstream of the site. The presence of more surficial sands on the north side of the river and downstream of the site may result in higher groundwater recharge in the contributing areas to the springs.

Many springs are shown to occur at an elevation of approximately 370 masl downstream of the Project Site. This elevation roughly coincides with the top of the Sutherland Group tills near the Project Site. The occurrence of springs at this elevation may suggest that the springs originate from a sand layer at the top of this till unit, or that the Sutherland group tills are less permeable than the overlying Saskatoon Group tills forcing the water to surface at the contact of these two units. Alternatively, this elevation may represent the base of easily erodible soils, forcing water from the upper aquifer to surface. The source of water for most springs along the river valley was attributed to seepage from the upper aquifer (Saskatchewan Power Corp. 1982).

Mannville Group Groundwater Elevation Data from 1982 Report

The EIA report (Saskatchewan Power Corp. 1982) also included some information on the stratigraphy at the Gronlid Bridge (Highway 6) crossing downstream of the Project Site, in the form of a description and cross-section of the river valley taken from a geotechnical investigation for the bridge. The cross-section across the river indicates that the top of the Mannville Group is approximately 85 m below the river level, with approximately 21 m of till and 64 m of Colorado Group deposits between the Mannville Group aquifer and the river (note river level is shown to have an approximate elevation of 340 masl at this location). The hydraulic head within the top 10 m of the Mannville Group at this location is reported to be 34 m above the river at an approximate elevation of 374 masl.

Previous Hydrogeology Investigations at the Nipawin Dam Site

The Nipawin Dam site is located approximately 50 km to the east of the Project Site and was built in the early 1980s. The hydrogeology of the dam site was the subject of a retrospective study of the dam's construction during the years from 1981 to 1985 (Matheson et al. 1987).

The geology at the dam site is similar to that of the proposed mine site, in that the river is incised through all but the deepest till layers and is underlain by shale of the lower Colorado Group (referred to by Matheson et al. 1987 as the Ashville Formation). It is described at the dam site as a grey, non-calcareous silt and clay with glauconite sand by Saskatchewan Power Corp. (1977) or a black, high plasticity montmorillonitic clay shale in the upper part and a silty shale to siltstone in the lower portion by SaskPower Corp. (2007)). The dam site is also underlain at depth by the Mannville Group (referred to by Matheson et al. 1987 as the Swan River Formation) and is described as an interbedded fine and coarse sandstone, locally cemented and containing carbonaceous zones, with silt and clay content increasing with depth (Saskatchewan Power Corp. 1977). However, is it not clear if this unit has a hydrostratigraphic equivalent at the mine site. Like the proposed mine site, the potentiometric head in the Mannville Group was significantly above pre-damming river levels with elevations of groundwater levels in monitoring wells completed in the Mannville Group reported as 341 masl or 25 m above river level. Prior to dewatering, head measurements in monitoring wells around the dam site recorded strong hydraulic gradients across the lower Colorado shale and basal till unit, suggesting these units were aquitards.

The dam was constructed at a point on the river, where the top of the Mannville Group was separated from the river bed by 25 m of till and 10 to 12 m of lower Colorado Group shale. As such, the intermediate aquiclude layer is considerably thinner at the Nipawin dam site than at the Project Site. Despite this difference, the results of the dewatering at the Nipawin dam site provide a useful analogy to the proposed dewatering at the Project Site.

Dewatering of the Mannville Group was required to dissipate pore water pressures in the shale to allow 16 m deep excavation into the tills overlying the shale and loading of the basal units by the dam. As such, the dam site was the subject of a pumping test of the Mannville Group prior to construction. Information from the pumping test and on the dewatering systems is briefly described by Matheson et al. (1987).

The pumping test conducted at the dam site was located at what is now the northwest side of the dam in a pumping well (DH 167) completed between 220 and 245 masl within the upper part of Mannville Group. The well was pumped for approximately 72 hours at a rate of approximately 1,500 m^3/day, and the groundwater level response was observed in seven observation wells located up to 300 m away from the pumping well. The pumping well was located in a bow in the river, which surrounded the pumping well on three sides, and the river approached within approximately 400 m of the pumping well. Hydrographs from the pumping test, which was relatively short term, did not indicate the presence of a recharge boundary during the test. The results of the test were analysed and reported by Matheson et al. (1987) to have a transmissivity (T) of 60 m^2/day, and a storage coefficient of 10^{-3} to 10^{-4} for the Mannville Group interval that was tested. The T value is equivalent to a hydraulic conductivity (k) value of 2.5 m/day when divided by the length of the well screen (approximately 25 m). The drawdown cone was reported to be elongated which was attributed to lateral and vertical variation (anisotropy) in permeability and storage coefficients, but the degree of elongation was not described.

During the initial construction, up to five depressurization wells, located at the northwest end of the dam, were operated at an average combined maximum rate of approximately 7,000 m^3/day. Individual wells operated at average rates of approximately 864 and 1,844 m^3/day (Matheson et al. 1987). The pumping well used for the pre-construction pumping test was one of the depressurization wells and operated at a rate close to the average of the other wells. Depressurization began in August 1981, and by November 1982, head levels in the Mannville Group had declined by approximately 70 m at the dam site. After November 1982, the number of depressurization wells operating was progressively decreased until only two wells were operating in 1986.

Matheson et al. (1987) reported that the average transmissivity for the pumping wells was 34.6 m^2/day. This value is equivalent to a hydraulic conductivity value of 0.5 m/day when divided by the thickness of the sandstone layer at this location (72 m), or 1.4 m/day when divided by the average length of the pumping well screens (approximately 24 m).

Matheson et al. (1987) also reported that pumping from the Mannville Group also decreased heads in the overlying lower Colorado Shale, which was also being dewatered from above by drainage tunnels constructed under the dam. Matheson et al. (1987) attribute the depressurization of the lower Colorado Group to the relative thinness of the shale unit at this location and the action from dewatering above and below the shale.

Also discussed in the paper are hydraulic conductivity values for till units and problems encountered when dewatering the overburden:

- A bulk hydraulic conductivity value is 8.6 x10^{-4} m/day is estimated for the lower till unit of the Floral Formation (Saskatoon Group and possibly the Sutherland Group) from the relatively small flows reported at the drainage tunnels beneath the dam;
- Laboratory testing provided hydraulic conductivity values of 3.5 x10^{-4} to 4.2 x10^{-5} m/day day for the upper till (Battleford Formation (Saskatoon Group)), and between 2.3 x10^{-5} and 2.8 x10^{-5} m/day for the middle and lower tills (Floral Formation (Saskatoon Group) and possibly the Sutherland Group);
- Drainage of the upper surficial sands into the dam excavation was estimated to be 700 m^3/day and some slumping was reported within the glaciolacustrine clays below the surficial sands;
- Some gravel layers within the middle till (upper part of the Floral Formation (Saskatoon Group)) also produced groundwater in appreciable amounts when first encountered, but in most cases, the inflows declined rapidly to very low quantities. The rapid decline in inflows was attributed to the lack of lateral continuity of the layers; and
- One gravel layer at the contact between the middle and basal till layers within the Floral Formation (Saskatoon Group) (or possibly at the contact between the Floral Formation and Sutherland Group) with an elevation of 298 masl required treatment in the form a cut off trench to control groundwater seepage.

Matheson et al. (1987) also commented on the response of the aquifers to filling of the reservoir and the partial curtailment of dewatering following completion of the dam. The response filling was relatively rapid in monitoring wells in the middle till (upper part of the Floral Formation), where relatively continuous sand seams at 310 and 298 masl were thought to allow some seepage of water. The recovery was much slower in the lower till of the Floral Formation, which lacked sand layers.

In addition to the information from Matheson et al. (1987), a few annual groundwater monitoring reports were obtained from the SWA (Saskatchewan Power Corp. 1986). These reports (Saskatchewan Power Corp. 1986) contained groundwater level and chemistry information from wells monitored in response to dewatering. The last of these reports that was available contained information spanning the period from 1983 to 1986, but only included limited information from prior to 1983 and commencement of dewatering at the dam site. Based on the information that was available, at the height of dewatering from 1983 to 1985, 99% of the water for dewatering was being drawn from the bedrock wells. The average rate of dewatering at this time was approximately 6,000 m^3/day. The chloride concentrations in the pumping wells remained constant between 1,200 and 1,400 mg/L during 1984 and 1985.

During this period, drawdown exceeded 70 m in monitoring wells completed in the Mannville Group near the dam site. Based on the information provided, drawdowns in two deep private wells completed in the bedrock and located 2.8 km and 6.9 km from the dam was estimated to be approximately 12 m and 6 m respectively, suggesting a broad drawdown cone developed in the bedrock aquifer.

Declines in water levels were also reported in wells used for monitoring and completed in the till layers overlying bedrock. In two wells completed at depths consistent with deeper sand layers in the tills, and located at distances of 1.3 km and 2.6 km from the dam, the water levels had declined to approximately 8 m and 4 m, respectively following more than three years of pumping. For wells completed in both the till and bedrock aquifers, the decline in water levels was relatively rapid during the first year of pumping and stabilized within approximately two years.

No decline in water levels in wells completed in the surficial aquifer is apparent from the monitoring data, or has been attributed in the annual reports to the dewatering at the dam.

Pumping Test Results from the Armley Observation Well

The SWA maintain one deep groundwater monitoring station within the Saskatchewan River watershed at a location 60 km east-southeast of the Project Site near Armley (Figure 5.2.7-2). The borehole was drilled in 1972 to limestone, possibly of the Souris River Formation, which was reported in the hole at depths of 262 to 276 m. However, the well was completed within units matching the description of the Mannville Group. The log of the well did not identify formations, but the top of the units with descriptions similar to the Mannville Group was reported at depth of 124 m. As part of the installation, the SWA conducted a 30 hour pumping test of the well at a rate of 196 m^3/day (SRC 2006b). The nominal 10 cm diameter well was completed with a 3.65 m screen within a 14 m thick relatively coarse sandstone layer of the Mannville Group at a depth of 155 m. The test results analysed by the SWA determined a transmissivity value of 28 m^2/day for the well, which is equivalent to a hydraulic conductivity value of 2.0 m/day when divided by the thickness of the sandstone layer the well was completed in, or 7.7 m/day when divided by the length of the well screen.

5.2.7.6 Previous Hydrogeology Investigations at the Project Site and Preliminary Groundwater Flow Models

Hydrogeology related work at the Project Site has been ongoing since 2002 and has included drilling, dewatering of test shafts, groundwater level monitoring and sampling and pumping tests at locations around the LSA (Figure 5.2.7-6). This original work led to development of a regional groundwater numerical model created primarily to assist the preliminary feasibility studies of the Project. The groundwater model has evolved in stages as additional work has been undertaken to reduce key uncertainties and improve the understanding of the regional hydrogeology. Key advances in the groundwater conceptual and numerical models are described in the following reports:

- Factual report - hydrogeological and geotechnical investigation, bulk kimberlite test project, FalC, Saskatchewan. PMEL File No S02-4553: report prepared for Shore, October 2002 (P. Machibroda Engineering Ltd. 2002);
- Preliminary hydrogeologic evaluation of FalC JV Project Area and predicted ground-water conditions during mining: report submitted to SRK Consulting, September 2005 (Hydrologic Consultants Inc. (HCI) 2005a);
- Hydrologic Consultants Inc. 2005b. Preliminary hydrogeologic evaluation of FalC JV Project Area and predicted ground-water conditions during mining: report submitted to SRK Consulting, November 2005 (HCI 2005b);
- Preliminary ground-water flow model for Star kimberlite project and predicted inflow to proposed open pit and associated drawdowns: technical memorandum submitted to Shore, March 31, 2006 (HCI 2006); and
- 2006-2007 Pre-Feasibility level hydrogeologic investigation of FalC JV Project Area: report submitted to Shore and Newmont Mining Corporation, June 2007 (HCI 2007).

The hydrogeology work prior to 2009 focused on the Star Kimberlite, close to the Saskatchewan River and a group of kimberlites that were combined into the FalC JV Project Area. The work on the FalC JV Project Area focussed on the Orion South (140/141) and the 120/121 kimberlites and the 147/148 kimberlites (120, 147, and 148 were later renamed Orion North in 2007). The two separate areas were not combined under a single study area until 2009.

Initial work between 2002 and 2005 focused on defining the stratigraphy at the Project Site and collecting groundwater information from six monitoring wells near the Orion South Kimberlite (four in the overburden, one in the kimberlite and one in Colorado shale (HCI 2005a)).

In 2005, HCI undertook a work plan to install additional shallow groundwater monitors and two 250 m deep boreholes to the Mannville Group completed as multi-level monitoring wells at the Orion South Kimberlite. Air lift tests were conducted in the boreholes and slug tests were conducted in the completed monitoring wells to provide hydraulic conductivity information from 30 tests (Table 5.2.7-4 to 7). The logs of the deep boreholes noted that while the Mannville Group is nominally a sandstone, the unit contained associated layers of mudstone and siltstone near the Orion South Kimberlite. Groundwater samples from the deep monitoring wells were noted to contain elevated concentrations of sodium and chloride. A preliminary axisymmetric finite-element ground-water flow model was constructed using HCI's *MINEDW* code to predict the passive inflow to a generic pit based on the observed stratigraphy. The model indicated that the inflows were highly dependent on the mine activity and the hydraulic conductivity measured for the Mannville Group. The report made recommendations for pumping tests with monitoring wells in the Mannville Group (HCI 2005b). The axisymmetric finite-element ground-water flow model was developed into a 3-D groundwater flow model in 2006 (HCI 2006).

In 2006, HCI obtained additional information on both the FalC JV and the Star Kimberlite project areas and prepared two reports in 2007 describing the results at each project area ((HCI 2007a) for the Star Kimberlite, (HCI 2007b) for the FalC JV Project Area). The work focused on four areas, one near the Orion North (148) Kimberlite, one near the Star Kimberlite and two regional monitoring locations, one at the Orion North (147 kimberlite) and one 20 km south east of the Project Site near Gronlid. The objective of the work was to prepare a preliminary feasibility report and gather additional information on the Mannville Group.

Table 5.2.7-4: Calculated Hydraulic Conductivity Values of the Upper and Lower Surficial Sediments (from SRK 2011a)

Hydro-geological Unit	Well ID	Location		Screen Elevation (mamsl)		Type of test	Hydraulic Conductivity K (m/d)
		Northing	Easting	From	To		
Upper Surficial Sand	Pumping Well	5,900,717	513,594	8.84	11.98	72 hour pump test	346.5
	Observation Well	5,900,725	513,594	8.53	11.58		
	PZ-06-01	5,897,431	514,656	ND	ND	Falling/rising head	9.6
	PZ-06-05 (1)	5,896,989	514,760	ND	ND	Falling/rising head	12.2
	PZ-06-05 (2)	5,896,989	514,760	ND	ND	Falling/rising head	10.1
	PZ-06-06	5,896,926	514,891	ND	ND	Falling/rising head	13.2
	PZ-06-07	5,896,866	514,803	ND	ND	Falling/rising head	18.1
	PZ-06-08	5,896,886	515,098	ND	ND	Falling/rising head	5.3
	PZ-06-09	5,896,820	515,158	ND	ND	Falling/rising head	3.5
	PZ-06-10	5,897,280	514,792	ND	ND	Falling/rising head	26.6
	PZ-06-11	5,897,296	514,897	ND	ND	Falling/rising head	28.5
	PZ-06-12	5,897,038	515,299	ND	ND	Falling/rising head	3.5
	PZ-06-13	5,896,844	514,961	ND	ND	Falling/rising head	26.3
	OVB-10-402U	5,898,909	517,814	5.5	8.5	Slug test	17.3
	OVB-10-404U	5,900,222	517,814	5.4	8.4	Slug test	8
	OVB-10-406U	5,900,998	518,026	2.8	5.8	Slug test	0.8
	OVB-10-408U	5,901,807	518,129	5.4	8.4	Slug test	1.1
	Average hydraulic conductivity value						**12.3**
	Geomean value of hydraulic conductivity						**9.4**
	Value of horizontal hydraulic conductivity used in groundwater model						**10**

Hydro-geological Unit	Well ID	Location		Screen Elevation (mamsl)		Type of test	Hydraulic Conductivity K (m/d)
		Northing	Easting	From	To		
Lower Surficial Sand	OVB-10-402L	5,898,909	517,814	13.5	16.5	Slug test	0.1
	OVB-10-404L	5,900,222	517,814	19.8	22.8	Slug test	0.008
	OVB-10-406L	5,900,998	518,026	24.4	27.4	Slug test	0.3
	OVB-10-408L	5,901,807	518,129	28.1	31.1	Slug test	0.3
	Average hydraulic conductivity value						**0.2**
	Geomean value of hydraulic conductivity						**0.1**
	Value of horizontal hydraulic conductivity used in groundwater model						**0.1**
Surficial Silt	PZ-15 Lower	5,903,213	511,084	32	36	Slug test	0.12
	PZ-8-Upwer	5,903,501	513,466	31.7	36.3	Slug test	0.15
	PZ-5-Lower	5,895,809	512,646	22.6	27.1	Slug test	0.009
	141-05-041H	5,901,002	513,477	18	21	Slug test	0.025
	140-05-054H	5,900,796	513,890	30	33	Slug test	0.013
	Average hydraulic conductivity value						**0.06**
	Geomean value of hydraulic conductivity						**0.03**
	Value of horizontal hydraulic conductivity used in groundwater model						**0.05**

Table 5.2.7-5: Calculated Hydraulic Conductivity Values of Till Units (from SRK 2011a)

Well ID	Screen Interval		Hydraulic Conductivity, K (m/d)	Type of Test
	From	To		
140-05-054H	38	44	0.0077	FHT
141-05-041H	41	50	0.041	FHT
140-05-055H	53	61	0.0029	ART
150-05-014H	72	80	*0.000064*	PIT
140-05-055H	78	88	0.72	ART
150-05-014H	80	90	0.000064	PIT
140-05-055H	88	97	*0.000064*	PIT
140-05-055H	90	93	0.000034	FHT
150-05-014H	90	96	0.013	ART
150-05-014H	96	104	0.019	PIT
140-05-055H	97	106	0.0001	PIT
150-05-014H	104	114	0.00022	PIT
PZ-14	67	71.6	0.0012	FHT
PZ-14a	102.11	111	0.017	FHT
PZ8-Lower	40.8	59.1	0.15	FHT
PZ4-Upper	59.7	69.7	1.5	FHT
PZ4-Lower	88.4	97.8	0.00009	FHT
SHP-08-008C	41.2	55.5	0.016	PIT
SHP-08-008C	53.2	79.5	0.007	PIT
SHP-08-004C	54.5	81	0.13	PIT
PW-3	38.4	108.5	0.03	3 days Pump Test
PW-1	29.6	97.5	0.35	3 days Pump Test

Notes: PIT - Packer injecting test
FHT - Falling head test
ART - Airlift test
Italicized values are assumed based on no measured take reading

Table 5.2.7-6: Calculated Hydraulic Conductivity Values of the Colorado Shale (from SRK 2011a)

Test Hole	Tested Interval		Method of Testing	Estimated Hydraulic Conductivity K, m/d	Location	Hydraulic Conductivity K, m/d used for averaging
	from	to				
150-05-014H	114	123	PIT	NMT	Outside of Kimberlite	*0.000044*
	123	144	PIT	0.000044		0.000044
	129	132	FHT	0.00038		0.00038
	144	165	PIT	NMT		*0.000044*
SHP-08-006C	93.7	120	PIT	0.00079	Crossing kimberlite fingers	0.00079
	119.2	145.5	PIT	0.015		0.015
SHP-08-004C	102.7	130.5	PIT	0.0056		0.0056
Average Hydraulic Conductivity of Colorado Group K, m/d						**0.0031**
Geomean of K of Colorado Group, m/d						**0.0004**

Notes: PIT - Packer injecting test. FHT - Falling head test. NMT - No measurable take. Assumed values of K are italicized.

Table 5.2.7-7: Calculated Hydraulic Conductivity Values of the Mannville Group (from SRK 2011a)

Well ID	Screen Interval (m)		Hydraulic Conductivity, K (m/d)	Type of Test
	From	To		
Prototype well	191.5	262.5	Variable with depth[1]	20 Day Pump Test
PW-2	187.7	344.2	1.68	7 Day Pump Test
PW-4	189	372	1.48	7 Day Pump Test
150-05-014H	165	207	0.004	ART
150-05-014H	221	245	0.0048	FHT
150-05-014H	228	249	0.08	ART
SHP-08-004C	172.7	198	0.0001	PIT
SHP-08-004C	197.2	223.5	0.0008	PIT
SHP-08-004C	224.2	250.5	0.002	PIT
SHP-08-006C	200	225	0.0001	PIT
SHP-08-008C	164.2	187.5	0.0005	PIT
SHP-08-008C	197.2	220.5	0.001	PIT

Notes: PIT - Packer injecting test. FHT - Falling head test. NMT - No measurable take. Assumed values of K are italicized. [1] See SRK (2011a)

Test pumping was conducted in four pumping wells, including two wells that screened across the entire Mannville Group and into the underlying Souris River Formation (PW-2 southwest of the Star Kimberlite, and PW-4 south of the Orion North Kimberlite 148). The work included the installation of 15 additional groundwater monitoring wells and 12 additional boreholes, several of which were equipped with between three and six vibrating wire transducers.

The pumping tests conducted in the Mannville Group (PW-2 and PW-4) lasted 8 to 10 days and the wells were pumped at a constant rate of 1,360 m^3/day (250 US gpm). Water levels were monitored in the pumping wells and in nearby monitoring wells completed in the lower aquifer or overlying aquitard. The maximum drawdown attributed to the pumping tests in monitoring wells is summarized in Table 5.2.7-8. The horizontal hydraulic conductivity values derived from an analysis of the drawdown and recovery data from the two tests were 1.7 m/day for PW-2 and 1.5 m/day for PW-4 for the entire thickness of the Mannville Group (Table 5.2.7-8).

Table 5.2.7-8: Maximum Drawdown Attributed to PW-2 and PW-4 (HCI 2007a)

Pump Test Site	Well/ Piezo - meter	Depth (m)	Distance[2] from Pumping Well (m)	Maximum Drawdown (m)	Geologic Unit (Group, Formation or Member)
Southwest of Star (South Star pump test site)	PW-2	187-344	0	11.4	Mannville Group[3]
	PZ-1	130	46	0.6	Colorado Group
		160	46	0.7	Colorado Group
		202	46	3.7	Waseca[1]
		262	46	3.2	Rex[1]
		315	46	2.5	Cummings[1]
		365	46	1.1	Souris River
	PZ-3	252.9-257.5	22	2.9	General Petroleum[1]
		307-8-316.9	22	3.9	Upper Cummings[1]
Orion North	PW-4	189-372	0	27.8	Mannville Group-Upper Souris River Fm.
	PZ-11	125	24	0.0	Colorado Group
		170	24	±0.0	Colorado Group
		256	24	11.8	General Petroleum[1]
		280	24	7.6	Rex[1]
		307	24	4.5	Upper Cummings[1]

Pump Test Site	Well/ Piezo - meter	Depth (m)	Distance[2] from Pumping Well (m)	Maximum Drawdown (m)	Geologic Unit (Group, Formation or Member)
		348	24	6.8	Souris River
	PZ-13	257.0-261.5	48	7.1	General Petroleum[1]
		299.6-309.0	48	4.2	Lloydminster[1]

Note: Pumping tests in the Mannville Group (HCI 2007a, 2007b).

[1] Unit within Mannville Group.

[2] Monitoring wells located in a single direction at increasing distance from respective pumping well.

[3] Screened portion of PW-2 through Souris River Formation was plugged prior to pumping test to control high salinity from this Formation.

Spinner log profiles were undertaken at PW-2 and PW-4 during the pumping tests. These logs showed that most of the inflow into PW-4 occurred in the lower 30 m of the Mannville Group, while the inflows were more evenly distributed in PW-2 throughout the Mannville intersection. The spinner logs from PW-4 were used to distinguish between inflow into the well from the Mannville Group and Souris River Formation. HCI (2007) suggested that inflows into the Souris River Formation originated from a permeable zone at the top of the Formation that was not expected to extend over the entire 350 m thickness of this unit.

Pumping tests were also conducted in two overburden wells (PW-1 and PW-3) that were installed with 60 to 70 m long screened intervals across a number of the till units to test the transmissivity of layers within the till units. These tests indicated only limited continuity of the layers tested within overburden units. A spinner log was conducted in PW-1 and indicated 87% of the water produced from the till sequence was produced from a 7 metre sand interval at elevations between 367 and 362 masl, at the contact between the Sutherland and Saskatoon groups. The relatively high production from this zone suggests this layer is the more permeable of those tested.

The groundwater chemistry results confirmed that water from the deep aquifer is slightly brackish. The groundwater chemistry from the pumping tests and other sources are discussed below (Groundwater Water Quality Results).

HCI (2007a, 2007b) estimated vertical hydraulic conductivity values for the aquitards by manipulating this parameter in the groundwater model until a good match was found at three test sites where multiple standpipes of vibrating wire transducers were available. The derived hydraulic conductivity values were subsequently modified as newer information became available. The hydraulic conductivity values from this and later assessments are summarized in Tables 5.2.7-4 to 5.2.7-7.

Other field investigations included drilling the three deep boreholes (PC-06-001 to 003) into the paleochannel to the north of the Orion North Kimberlite identified in airborne geophysical mapping (Figure 5.2.7-7). Boreholes in the paleochannel indicated it was filled with till and sand sediments of the Saskatoon Group (Floral Formation) and an underlying valley fill sediment mix of mostly sand. The base of the bedrock valley was incised through the Sutherland Group tills and the Colorado Group into the Mannville Group (Clifton 2008), thereby connecting the upper and lower aquifer systems.

Other field results identified the Empress overburden aquifer as a thin (two to four metre thick) layer above the Colorado Group at the Orion North 148 test site and the test site near Gronlid, but not at the Star Kimberlite and Orion North 147 test sites. Additional air lift and falling head tests in boreholes and monitoring wells provided further hydraulic conductivity values for all the units encountered during the drilling program (Tables 5.2.7-4 to 7).

The groundwater model prepared in 2006 (HCI 2006) was updated in 2007 to incorporate the results of the 2006-2007 field program and covered both the Star and Orion kimberlites (HCI 2007a, 2007b). Updates to the model expanded the model domain to about 200 km^2 and incorporated a 12 layer finite element grid, with a total thickness of approximately 450 m. The primary purpose of the model was to assist in the design of the dewatering system, and consequently the report devotes limited space to a discussion of environmental impacts.

Dewatering at Star Kimberlite Test Shaft 2005-2007

A test shaft and underground drifts were developed at the Star Kimberlite from 2003 to 2007 to allow for collection of bulk samples for mineral assessment. The work included construction of a single 4.5 m diameter shaft to a depth of 250 m below ground, and a small lateral drilling and pumping station at the 175 m level. More than 3,100 m of lateral drifts were then constructed from the 235 m level. The vertical shaft was lined with concrete during construction and was advanced through the till and shale and approximately 145 m into the kimberlite. The soils in the upper 130 m of the shaft area were frozen prior to the shaft being constructed. Small quantities of water were reported to enter the shaft in sections constructed in advance of the concrete liner, and below the depth of the freeze wall at 130 m. Water was noted flowing into the shaft from the kimberlite below the freeze wall and within the Mannville Group on the outside of the main kimberlite body where the mine breached the edge of the kimberlite. During mining, attempts were made with mixed success to restrict inflow of water into the underground workings using shotcrete. Average pumping rates during the last three months of mining were approximately 600 m^3/day. The total volume of water removed during the mining of the test shaft was approximately 260,000 m^3 (Shore Gold 2007).

The water chemistry during periods of mine discharge from April 2006 to March 2007 were relatively consistent (Shore Gold 2007). Chloride concentrations were relatively constant at approximately 2,200 mg/L with elevated metal concentrations. The water chemistry results collected from the underground mine were affected by mining operations such as blasting, drilling and excavation, which may have resulted in somewhat elevated levels of nitrogen compounds and metals. Most of the water flowed through joints into adits located close to the contact of the kimberlite with the Mannville Group rocks, and as such, the water chemistry in the mine discharge likely reflected that of the Mannville Group groundwater. Additional discussion on ground water chemistry is provided below (Groundwater Water Quality Results).

The Star shaft was allowed to flood beginning April 2007. The initial rate of flooding was rapid (approximately equivalent to 650 m^3/day), but decreased rapidly once the water levels in the shaft reached approximately 75 m below ground level. By September 2009, water levels in the shaft had stabilized at 27 m below ground level or 393 masl (Shore Gold 2007). This water level is similar to that reported in monitoring wells completed in the Mannville Group near the kimberlite.

The Star shaft was also used to dispose of water from a test shaft at the Orion South Kimberlite in 2008 and early 2009. The highest rate at which the Star shaft could accept water without over flowing averaged 200 m^3/day (Shore Gold 2010).

Dewatering at the Orion South Kimberlite Test Shaft 2008-2009

A test shaft was developed at the Orion South Kimberlite in 2008. The construction details are similar to those for the Star Kimberlite shaft, although in this case the shaft was constructed with a diameter of 4.3 m to a depth of 210 m, with the main lateral drifts constructed at a depth of 185 m.

The dewatering rate from the Orion South shaft was difficult to quantify, as it was measured at the outlet of a small lined storage pond that also collected some precipitation, but averaged 80 m^3/day towards the end of mining in the winter when precipitation inputs would have been minimal (Shore Gold 2010).

Reports from staff at the mine indicated that a large proportion of the mine water pumped from the Orion South shaft originated from the shallow aquifers, with almost no water originating from the kimberlite. This differs from the Star Kimberlite, where reports indicated inflows from one drift near the edge of the kimberlite and Mannville Group rocks were responsible for most of the inflow. The comparatively small groundwater inflow into the Orion South shaft indicates the relatively low permeability of the kimberlite material in comparison to adjacent Mannville Group sediments.

The large proportion of groundwater from the shallow aquifers collected in the Orion South shaft is also reflected in the chemistry of the mine discharge water that indicated relatively dilute mine waters in comparison to the results of the Star shaft dewatering. Only during the relatively dry month of July, when water levels in the shallow aquifers were likely depressed, did water chemistry results from the Orion South discharge appear similar to those from the Star discharge.

Dewatering at the Orion South shaft was ended in February 2009 and the shaft was allowed to flood. Initially the rate of flooding was slow as the lateral drifts filled. The rate increased following the filling of the lateral drifts and then again in April and May 2009. The timing of filling in April and May suggests the inflows may be linked to the spring freshet and is consistent with the reported rapid percolation of water from shallow depths around the outside of the shaft.

Water levels in the shaft stabilized close to 40 m below ground level at an elevation of 404 masl. This water level is similar to that reported in monitoring wells completed in the surficial sands near the kimberlite, and is consistent with the shaft being hydraulically connected to the shallow aquifers.

Groundwater Level Measurements

Groundwater level measurements are available from monitoring wells in the upper and lower aquifers within the LSA near the Project Site and from a few published sources for locations away from the Project Site in the RSA. The groundwater level measurements from monitoring wells in the upper aquifer near the site indicate that groundwater flow direction within this aquifer generally reflects the local topography and flow within this aquifer is towards the local creeks.

The groundwater level measurements from monitoring wells in the deeper aquifer near the Project Site indicate that groundwater flow within this aquifer is towards the southeast. This local pattern may be a function of recharge to the Mannville aquifer through the paleochannel sediments north of the Project Site, but there are insufficient monitoring points to confirm this with confidence. Alternatively, recharge to the Mannville aquifer may occur north of the Project Site near Candle Lake, where mapping (Rogers and Bayne 2000) indicates the Colorado Group shales are absent and only the Quaternary tills are present above the Mannville Group.

On a regional scale, drill stem measurements of hydrostatic pressure in the Mannville Group, suggested that horizontal groundwater flow within this aquifer occurs from the northwest with a flow component from the west on the south side of the Saskatchewan River. These flow directions would suggest potential, and limited, discharge from this aquifer to the Saskatchewan River. However the potentiometric surface from groundwater levels in the Mannville aquifer on both sides of the Saskatchewan River is of the order of 40 m above the river valley, suggesting that if discharge is occurring then it would be under artesian conditions. As this condition is not seen in the river valley then discharge from the Mannville aquifer is small and insufficient to lower the potentiometric surface in the Mannville Group to that of the river. The head difference between the aquifer and the River suggests that if discharge from the Mannville aquifer is occurring, it is occurring at a relatively low rate that does not result in significant depressurization of the aquifer.

Greater quantities of discharge may occur several tens of kilometres downstream of the Project Site in areas where pre-glacial erosion has removed some the intervening aquiclude by eroding into, and through, the Colorado Group.

Stream Flow Measurements

Stream flow measurements have been collected during several summers from five of the creeks near the Project site to provide baseline information (referred to as Streams A (Caution Creek), B (101 Ravine Creek), C (East Ravine Creek), D (English Creek) and E (West Ravine Creek)) (Golder 2008). These creeks are located on the north side of the Saskatchewan River both upstream and downstream of the mine (Figure 5.2.7-9). They all drain the relatively flat highland area on the north side of the River and descend rapidly from the highlands to the river through steep sided ravines. Beaver dams are reportedly common along the length of each of the creeks, creating pooled areas upstream of the beaver dams. The flow stations are all located near to where the creeks discharge to the Saskatchewan River.

At four of the creeks, enough data have been collected from 2005, 2006 and 2007 to develop rating curves (Golder 2008). An estimate of the baseflow for local tributaries to the Saskatchewan River has been made based on the short-term seasonal streamflow records for four creeks (Caution Creek, 101 Ravine, East Ravine and English Creek). An analysis of the daily mean discharges prepared by Golder (2008) yielded a baseflow estimate of 19 mm. In all cases, the presence of beaver dams along the creeks is expected to have influenced the low flow estimates and the flows listed may somewhat underestimate flow within the creeks.

The Water Survey of Canada has maintained a stream flow monitoring station at White Gull Creek at Highway 106 (station # 05KE010, Environment Canada, 2010), located approximately 70 km north of the Project Site (Table 5.2.7-9). The White Gull Creek watershed has an area of 629 km^2, which is much larger than the small watersheds near the Project Site, and the results from this station are not directly comparable to the small watersheds at the Project Site. However, the White Gull Creek watershed data provides a useful long term record which to compare the data from Project Site collected from 2005 to

2007. The White Gull Creek data also extends into the winter when no data is available from the Project Site.

A comparison of the 2007 flow data from White Gull Creek with the longer term database for this creek indicates 2007 had above mean annual flows, however, the flows for August were 15 % below the monthly mean for the month, suggesting that the August 2007 data is somewhat representative of base flows for summer conditions.

The lowest flow measurements for White Gull Creek were made during the winter, when mean monthly flows are one sixth of the mean August flow measurements. There are no flow data available for the smaller creeks near the Project site during the winter. However, given the much smaller area of these creeks in comparison to the White Gull River, it is expected that many of the smaller creeks near the Project go dry or freeze solid in the winter.

Table 5.2.7-9: Watershed Areas for Local Creeks and White Gull Creek

Creek	Subwatershed Area (km^2)
Caution Creek(Stream A)	108.1
101 Ravine Creek(Stream B)	24.3
East Ravine Creek(Stream C)	18
English Creek(Stream D)	85
West Ravine Creek (Stream E)	3.4
White Gull Creek[1]	629

Note: [1] from Water Survey of Canada Station # 05KE010 (Environment Canada 2010)

Groundwater Water Quality Results

Groundwater quality results are primarily available from the following sources:

- a 2006 report prepared by the SRC titled *Shore Gold Environmental Investigation* (SRC 2006b), that collected groundwater samples from monitoring wells completed in the surficial aquifer and from test tailings facilities;
- samples collected from the discharge of water during the dewatering of the shafts at the Star and Orion South kimberlites;
- samples collected from boreholes by HCI in 2005;
- samples collected during aquifer tests conducted by HCI in 2007;
- groundwater samples collected by Shore from onsite monitoring wells; and

- groundwater samples from a 20 day pumping test conducted at the site in late 2010.

The data from samples collected from the discharge of water during the dewatering of the Star shaft are summarised in Table 5.2.7-10, Table 5.2.7-11, and Table 5.2.7-12. The samples collected from underground may be affected by mining operations (e.g., blasting, drilling and excavation) which may leave them somewhat elevated in terms of nitrogen compounds and metals. As such, the sample results from long term aquifer tests are assumed to be the most representative of the native groundwater chemistry from the deep aquifer.

Table 5.2.7-10: Groundwater Chemistry Results - Bedrock

	Constituent	Units	PW-2[1]			PW-4[1]	140-05-055H[2]	150-05-014H[2]			Prototype Well								
			187.1-344.2			189.0-372.0	234-249	186-207	207-228	228-249	191.5-282.5								
			Mannville				Kimberlite	Mudstone	Mannville		Mannville								
			4/8/2007	4/11/2007	4/15/2007	2/21/2007					10/26/2010	10/29/2010	11/2/2010	11/4/2010	11/7/2010	11/11/2010	11/12/2010	11/14/2010	11/14/2010
General	Conductivity (Electrical / Specific)	µS/cm	7,350	7,360	7,360	7,070	5,380	4,920	5,490	5,500	6420	6530	6470	6530	6450	6160	NA	6180	NA
	Total Dissolved Solids (TDS)	mg/L	4,470	4,470	4,460	4,280	3,110	2,790	3,160	3,810	3,960	3960	3970	3960	3950	3950	NA	3950	NA
	Total Suspended Solids	mg/L	<1	1	1	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Total Hardness	mg/L	596	592	592	622	293	38	76	397	537	528	517	517	528	519	NA	519	NA
	Turbidity	NTU	2.9	3.2	2.8	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	P. Alkalinity										<1	<1	<1	<1	<1	<1	NA	<1	NA
	Total Alkalinity	mg/L	408	398	400	392	411	411	461	460	388	390	391	391	389	389	NA	389	NA
	pH	mg/L	7.99	8	8.01	7.81	8.6	8.8	8.5	8.5	7.82	7.82	7.82	7.88	7.79	7.74	NA	7.73	NA
	Chemical Oxygen Demand	mg/L	19	28	32	22	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Organic Carbon	mg/L	2.4	1.9	1.7	2.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Organic Carbon, Dissolved	mg/L	2.5	1.7	1.7	2.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cations	Calcium	mg/L	140	140	140	144	63	9.1	15	70	138	136	133	133	136	134	NA	134	NA
	Sodium	mg/L	1,370	1,410	1,410	1,380	1,010	1,040	1,160	1,260	1190	1210	1270	1250	1210	1210	NA	1220	NA
	Magnesium	mg/L	60	59	59	64	33	3.7	9.5	54	47	46	45	45	46	45	NA	45	NA
	Potassium	mg/L	61	61	61	58	43	23	34	51	57	57	58	58	57	56	NA	56	NA
Anions	Carbonate	mg/L	<1	<1	<1	<1	29	36	23	23	<1	<1	<1	<1	<1	<1	NA	<1	NA
	Bicarbonate	mg/L	498	486	488	478	443	428	516	515	473	476	477	477	474	474	NA	474	NA
	Chloride	mg/L	1,860	1,930	1,800	1,760	1,250	1,210	1,280	1,620	1,600	1,600	1,600	1,560	1,600	1,700	NA	1,700	NA
	Fluoride	mg/L	2.4	2.5	2.5	2.5	2.3	2.4	2.8	2.1	2.2	2.2	2.3	2.2	2.2	2.3	NA	2.5	NA
	Hydroxide	mg/L	<1	<1	<1	<1					<1	<1	<1	<1	<1	<1	NA	<1	NA
	Nitrate	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.04	NA
	Nitrite+Nitrate, Nitrogen	mg/L	<0.01	<0.01	<0.01	<0.01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Ammonia as Nitrogen	mg/L	2.4	2	2	2.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Total Kjeldahl Nitrogen	mg/L	2.3	2.2	1.9	2.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Total Nitrogen	mg/L	2.3	2.2	1.9	2.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sulphate	mg/L	750	740	750	720	450	280	400	520	740	750	740	750	750	740	NA	740	NA
	Sum of Ions	-	4,740	4,830	4,710	4,610	3,320	3,030	3,440	4,110	4240	4280	4320	4270	4270	4360	NA	4370	NA
	Charge Balance Error	%	-2.00%	-2.10%	0.20%	1.00%	-1.8	-1.7	-0.81	-1.34	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trace Metals	Aluminum	mg/L	0.0084	0.024	0.009	0.017	0.032	0.6	0.37	0.21	0.021	NA	NA	NA	0.005	NA	0.0021	NA	0.0024
	Antimony	mg/L	<0.0002	<0.001	<0.001	<0.001	NA	NA	NA	NA	<0.002	NA	NA	NA	<0.002	NA	<0.0002	NA	<0.0002
	Arsenic	ug/L	3.3	2.5	2.8	<0.5	1.1	1.3	0.7	0.6	<1	NA	NA	NA	<1	NA	0.3	NA	0.2
	Barium	mg/L	0.011	0.012	0.011	0.012	0.21	0.055	0.041	0.073	0.013	NA	NA	NA	0.011	NA	0.01	NA	0.01
	Beryllium	mg/L	<0.0001	0.0005	<0.0005	<0.0005	NA	NA	NA	NA	<0.001	NA	NA	NA	<0.001	NA	<0.0001	NA	<0.0001
	Boron	mg/L	2	2.2	2.2	2.2	2.8	3	4.2	3.3	2.1	NA	NA	NA	2.0	NA	2.0	NA	1.9
	Cadmium	mg/L	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	NA	NA	NA	<0.0001	NA	0.00001	NA	0.00001
	Chromium	mg/L	<0.0005	<0.002	<0.002	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	NA	NA	NA	<0.005	NA	<0.0005	NA	<0.0005
	Cobalt	mg/L	<0.0001	<0.0005	<0.0005	<0.0005	NA	NA	NA	NA	0.001	NA	NA	NA	<0.001	NA	0.0001	NA	0.0001

	Constituent	Units	PW-2[1]			PW-4[1]	140-05-055H[2]	150-05-014H[2]			Prototype Well								
			187.1-344.2			189.0-372.0	234-249	186-207	207-228	228-249	191.5-282.5								
			Mannville				Kimberlite	Mudstone	Mannville		Mannville								
			4/8/2007	4/11/2007	4/15/2007	2/21/2007					10/26/2010	10/29/2010	11/2/2010	11/4/2010	11/7/2010	11/11/2010	11/12/2010	11/14/2010	11/14/2010
	Copper	mg/L	0.0007	<0.001	0.002	0.001	0.0052	0.0015	0.0014	0.0013	0.01	NA	NA	NA	0.005	NA	0.0032	NA	0.0024
	Iron	mg/L	0.39	0.38	0.36	0.33	9.1	2.3	2.7	4.3	0.36	NA	NA	NA	0.29	NA	0.24	NA	0.23
	Lead	mg/L	0.0001	0.0005	<0.0005	<0.0005	0.022	0.012	0.014	0.013	<0.001	NA	NA	NA	<0.001	NA	0.0005	NA	0.0005
	Manganese	mg/L	0.14	0.14	0.13	0.14	0.15	0.045	0.085	0.22	0.099	NA	NA	NA	0.092	NA	0.087	NA	0.086
	Molybdenum	mg/L	0.0007	<0.0005	<0.0005	<0.0005	NA	NA	NA	NA	<0.001	NA	NA	NA	<0.001	NA	0.0005	NA	0.0005
	Nickel	mg/L	0.0003	<0.0005	<0.0005	<0.0005	NA	NA	NA	NA	0.002	NA	NA	NA	<0.001	NA	0.0005	NA	0.0005
	Phosphorous	mg/L	0.03	0.04	0.03	0.02	NA	NA	NA	NA	0.06	NA	NA	NA	0.06	NA	0.05	NA	0.05
	Selenium	mg/L	<0.0001	<0.0005	0.0005	<0.0005	0.0001	0.0001	0.0001	<0.0001	<0.001	NA	NA	NA	<0.001	NA	0.0003	NA	0.0002
	Silver	mg/L	<0.0001	<0.0005	<0.0005	<0.0005	NA	NA	NA	NA	<0.0001	NA	NA	NA	<0.0001	NA	<0.00001	NA	<0.00001
	Strontium	mg/L	3.14	3.4	3.3	3.1	NA	NA	NA	NA	2.6	NA	NA	NA	2.5	NA	2.5	NA	2.48
	Thallium	mg/L	<0.0002	<0.001	<0.001	<0.001	NA	NA	NA	NA	<0.002	NA	NA	NA	<0.002	NA	0.0002	NA	<0.0002
	Tin	mg/L	<0.0001	0.0005	<.0005	<0.0005	NA	NA	NA	NA	<0.001	NA	NA	NA	<0.001	NA	<0.0001	NA	<0.0001
	Titanium	mg/L	0.0022	0.003	0.002	0.002	NA	NA	NA	NA	<0.002	NA	NA	NA	<0.002	NA	0.0002	NA	<0.0002
	Uranium	mg/L	<0.01	<0.05	<0.05	<0.5	0.2	1.1	0.7	0.4	<1	NA	NA	NA	<1	NA	<0.1	NA	<0.1
	Vanadium	mg/L	<0.0001	<0.0005	<0.0005	0.0005	NA	NA	NA	NA	<0.001	NA	NA	NA	<0.001	NA	0.0002	NA	0.0002
	Zinc	mg/L	NA	NA	NA	NA	2	0.037	0.082	0.07	0.16	NA	NA	NA	0.21	NA	0.014	NA	0.011
SAR	Sodium Adsirption Ratio (SAR)	-	NA	NA	NA	NA	25.7	73.6	57.8	27.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
	SAR MB 110 Method	-	NA	NA	NA	NA	25.38	72.62	57.05	27.21	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note: 1) Data from Table 17 of 2006-2007 Pre-feasibility Level Hydrogeologic Investigation of Star Kimberlite Area, 2007. 2) Data from Table 5 of Preliminary Hydrogeologic Evaluation of Fort a la Corne JV Project Area and Predicted Ground-water Conditions during Mining, 2005.

Table 5.2.7-11: Groundwater Chemistry Results - Overburden

	Constituent	Units	PW-1[1]	PW-3[1]	140-05-055H[2]			Pumping Well[3]	MW06-01[4]
			29.6-97.5	34.8-108.5	53- 61	78-88	90-96		
			Till		Overburden		Till	Surficial Sand	Surficial Sand
			3/28/2007	2/7/2007				8/20/2007	2/8/2006
General	Conductivity (Electrical / Specific)	µS/cm	1,020	2,200	482	736	6,780	440	382
	Total Dissolved Solids (TDS)	mg/L	666	1,590	272	431	6,000	242	NA
	Total Suspended Solids	mg/L	<1	5	NA	NA	NA	NA	NA
	Total Hardness	mg/L	451	529	231	320	1980	226	NA
	Turbidity	NTU	1.4	9.3	NA	NA	NA	NA	NA
	Total Alkalinity	mg/L	406	552	262	383	497	237	NA
	pH		8.04	8.06	8.8	8.4	8.1	7.2	7.95
	Chemical Oxygen Demand	mg/L	6	45	NA	NA	NA	NA	6
	Organic Carbon	mg/L	2.6	16	NA	NA	NA	NA	1.5
	Organic Carbon, Dissolved	mg/L	2.4	15	NA	NA	NA	NA	1.2
	Inorganic Carbon	mg/L	NA	NA	NA	NA	NA	NA	47
Cations	Calcium	mg/L	105	118	63	87	374	69	59
	Sodium	mg/L	66	339	16	43	1,090	8	4.2
	Magnesium	mg/L	46	57	18	25	254	13	13
	Potassium	mg/L	7.5	7.5	3.7	5.2	17	1	1
Anions	Carbonate	mg/L	<1	<1	7	12	<1	NA	<1
	Bicarbonate	mg/L	495	673	305	443	606	289	240
	Chloride	mg/L	2	41	2	2	296	9	7
	Fluoride	mg/L	0.25	0.27	0.26	0.39	0.23	NA	0.13
	Hydroxide	mg/L	<1	<1	NA	NA	NA	NA	<1
	Nitrate	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1	0.35
	Nitrite	mg/L	NA	NA	NA	NA	NA	<0.05	NA
	Nitrite+Nitrate, Nitrogen	mg/L	<0.01	<0.01	NA	NA	NA	<0.1	NA
	Ammonia as Nitrogen	mg/L	0.63	2.9	NA	NA	NA	NA	NA
	Total Kjeldahl Nitrogen	mg/L	0.9	4.4	NA	NA	NA	NA	NA
	Total Nitrogen	mg/L	0.9	4.4	NA	NA	NA	NA	NA
	Sulphate	mg/L	190	630	9.4	44	3200	<6	5.4
	Sum of Ions	-	912	1,870	424	661	5,840	NA	330
	Charge Balance Error	%	-0.20%	0.40%	0.49	0.13	2.03	NA	NA
Trace Metals	Aluminum	mg/L	NA	NA	0.21	1.6	0.071	<0.01	<0.0005
	Antimony	mg/L	0.0066	0.0068	NA	NA	NA	0.0005	<0.0002
	Arsenic	ug/L mg/L	0.0003	<0.0002	3.4	11	2.8	0.0057	0.2
	Barium	mg/L	12	12	0.22	0.1	0.083	0.757	0.31
	Beryllium	mg/L	0.031	0.086	NA	NA	NA	<0.0005	<0.0001
	Boron	mg/L	<0.0001	<0.0001	0.13	0.18	0.39	0.015	<0.01

	Constituent	Units	PW-1[1]	PW-3[1]	140-05-055H[2]			Pumping Well[3]	MW06-01[4]
			29.6-97.5	34.8-108.5	53- 61	78-88	90-96		
			Till		Overburden		Till	Surficial Sand	Surficial Sand
			3/28/2007	2/7/2007				8/20/2007	2/8/2006
	Cadmium	mg/L	0.22	0.34	<0.0005	<0.0005	<0.0005	<0.0001	<0.0005
	Chromium	mg/L	<0.0001	<0.0001	<0.005	0.006	<0.005	<0.0004	<0.005
	Cobalt	mg/L	<0.0005	0.0007	NA	NA	NA	0.0005	0.0001
	Copper	mg/L	0.0006	0.0006	0.0043	0.0061	0.0019	0.0034	<0.0002
	Iron	mg/L	0.0021	0.0011	4.1	4.2	13	3.25	0.001
	Lead	mg/L	0.31	1.77	0.0038	0.0071	0.0035	<0.0001	<0.0001
	Manganese	mg/L	<0.0001	0.0001	0.12	0.18	0.45	0.252	0.0037
	Mercury	mg/L	NA	NA	NA	NA	NA	<0.0001	NA
	Molybdenum	mg/L	0.1	0.089	NA	NA	NA	0.0009	0.001
	Nickel	mg/L	0.012	0.0083	NA	NA	NA	0.0018	<0.0001
	Phosphorous	mg/L	0.0028	0.0018	NA	NA	NA	NA	NA
	Selenium	mg/L	0.03	0.48	0.0004	<0.0001	0.0005	<0.0002	0.0001
	Silver	mg/L	0.0002	0.0002	NA	NA	NA	<0.0002	<0.0001
	Strontium	mg/L	<0.0001	<0.0001	NA	NA	NA	0.121	0.08
	Thallium	mg/L	0.54	0.68	NA	NA	NA	<0.00005	<0.0002
	Tin	mg/L	<0.0002	<0.0002	NA	NA	NA	<0.0002	<0.0001
	Titanium	mg/L	<0.0001	0.0001	NA	NA	NA	<0.0003	NA
	Uranium	mg/L	0.0005	0.0012	4.7	2.9	5.1	0.0004	NA
	Vanadium	mg/L	2.1	1.3	NA	NA	NA	<0.0001	NA
	Zinc	mg/L	0.0005	0.0008	0.94	0.078	0.084	0.069	NA
SAR	Sodium Adsirption Ratio (SAR)	-	NA	NA	0.458	1.05	10.7	NA	NA
	SAR MB 110 Method	-	NA	NA	0.45	1.03	10.54	NA	NA
Coliform	Fecal	ct/100mL	NA	NA	NA	NA	NA	NA	NA
	Total	ct/100mL	NA	NA	NA	NA	NA	NA	NA

Note: 1) Data from Table 17 of 2006-2007 Pre-feasibility Level Hydrogeologic Investigation of Star Kimberlite Area, 2007. 2) Data from Table 5 of Preliminary Hydrogeologic Evaluation of Fort a la Corne JV Project Area and Predicted Ground-water Conditions during Mining, 2005. 3) Data from Table 3.2 of Pump Test, NE 26-49-20-W2M, Fort A LA Corne Provincial Forest, Saskatchewan, 2007. 4) Data from Table 3 of Shore Gold 2006, Environmental Investigation, 2006.

Table 5.2.7-12: Groundwater Chemistry Results - MWS - 01

Constituent		Units	Star Exploration Shaft Mine Water Discharge – End of Pipe into Settling Ponds											
			#06005	**#06013**	**#06029**	**#06039**	**#06070**	**#06079**	**#06110**	**#06121**	**#06147**	**#07042**	**#07056**	**#07074**
			4/22/2006	**5/11/2006**	**6/13/2006**	**7/11/2006**	**8/11/2006**	**9/4/2006**	**10/30/2006**	**11/19/2006**	**12/16/2006**	**1/30/2007**	**2/24/2007**	**3/11/2007**
General	Conductivity (Electrical / Specific)	uS/cm	7800	7720	7530	7580	7760	7980	7950	7720	7840	7730	7770	7590
	Total Dissolved Solids (TDS)	mg/L	4350	4420	4290	4430	4460	4470	4540	4500	4510	4130	4480	4470
	Total Suspended Solids	mg/L	NA	NA	0.2	NA	NA	NA	NA	162	575	592	444	3360
	Total Hardness	mg/L	32	104	81	124	101	115	155	120	405	293	135	131
	Turbidity	NTU	1560	289	NA	NA	181	853	37	28	173	388	212	4010
	Total Alkalinity	mg/L	146*	236*	207	248	225	246	256	259	268	259	253	257
	pH	-	9.80*	9.58*	9.63	9.17	9.16	9.12	9.18	8.77	8.92	8.74	8.84	8.94
	Chemical Oxygen Demand	mg/L	51	88	NA	NA	93	109	34	19	26	27	41	97
	Organic Carbon	mg/L	45	12	3	6	2.8	2.1	3.8	3.1	1.4	NA	2	5.8
	Organic Carbon, Dissolved	mg/L	40	10	NA	NA	2.6	2	1.8	0.4	1.5	1.8	2.4	4.3
Cations	Calcium	mg/L	6.3	12	11	15	11	13	16	12	37	22	13	13
	Sodium	mg/L	1640	1740	1370	1590	1630	1730	1730	1680	1500	1610	1650	1660
	Magnesium	mg/L	3.9	18	13	21	18	20	28	22	76	58	25	24
	Potassium	mg/L	54	50	269	44	42	36	41	40	48	28	39	40
Anions	Carbonate	mg/L	<1	98	90	59	53	54	50	31	42	30	32	37
	Bicarbonate	mg/L	<1	88	70	183	167	190	210	253	242	255	243	238
	Chloride	mg/L	2270	2260	1910	2000	2270	2250	2380	2150	2180	2250	2180	2220
	Fluoride	mg/L	0.72	0.73	0.8	0.75	0.66	0.68	0.64	0.76	0.82	0.72	0.64	0.5
	Hydroxide	mg/L	48	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
	Nitrate	mg/L	9.3	5.6	6.9	6.2	8.5	5.4	6.2	12	7.5	8	8.9	9.7
	Nitrite+Nitrate, Nitrogen	mg/L	2.1	1.3	1.6	NA	1.9	1.2	1.4	2.7	1.7	1.9	2	2.2
	Ammonia as Nitrogen	mg/L	1.8	1.9	1.4	1.8	1.8	2	2.1	2.7	2	1.9	1.9	2
	Total Kjeldahl Nitrogen	mg/L	2.3	2.1	1.7	2.9	1.8	1.9	2.2	2.6	2.2	1.9	2.1	2.7
	Total Nitrogen	mg/L	4.4	3.4	12	112	3.7	3.5	2.6	5.3	39	3.8	4.1	4.9
	Sulphate	mg/L	420	410	390	420	400	410	410	410	430	530	420	430
	Oil & Grease	mg/L	NA	44	20	18	8	80	11	106	27	2	<5	<5
	Sum of Ions	mg/L	4130	4340	4600	4710	4870	4610	4570	4790	4610	4670	NA	NA
Trace Metals	Aluminum	mg/L	14	3.7	0.48	4.2	2	12	0.21	1.4	3.6	6.69	2.14	47.7
	Antimony	mg/L	0.0002	0.0002	0.0002	0.0003	<0.0002	<0.001	0.0002	<0.0002	<0.0002	0.0005	<0.0004	<0.0002
	Arsenic	ug/L	NA	1.2	0.7	0.8	0.5	2	0.3	0.3	1	1.2	1.1	4.7
	Barium	mg/L	0.11	0.088	0.032	0.074	0.054	0.4	0.03	0.041	0.06	0.21	0.047	0.93
	Beryllium	mg/L	0.0003	0.0001	<0.0001	0.0001	0.0001	<0.0005	0.0001	0.0001	0.0001	0.0002	<0.0002	0.0015
	Boron	mg/L	1.9	3.4	3.7	2.4	3.8	3.2	2.1	3.9	3.6	2.8	2.8	4.3
	Cadmium	mg/L	0.0002	0.0001	<0.0001	0.0002	<0.0001	<0.0005	0.0001	<0.0001	<0.0001	<0.0001	<0.0002	0.0005
	Chromium	mg/L	0.22	0.053	0.017	0.097	0.076	0.45	0.012	0.043	0.089	0.39	0.15	1.7
	Cobalt	mg/L	0.047	0.007	0.0019	0.021	0.013	0.074	0.0011	0.0068	0.014	0.067	0.016	0.28
	Copper	mg/L	0.036	0.013	0.0011	0.026	0.0069	0.044	0.0073	0.0037	0.012	0.03	0.015	0.13
	Iron	mg/L	40	9.9	2	14.3	8.4	57	1.1	5.1	12	34	10.4	186
	Lead	mg/L	0.015	0.0065	0.0004	0.0067	0.0028	0.018	0.0004	0.0048	0.0042	0.012	0.0042	0.034

	Constituent	Units	Star Exploration Shaft Mine Water Discharge – End of Pipe into Settling Ponds											
			#06005	**#06013**	**#06029**	**#06039**	**#06070**	**#06079**	**#06110**	**#06121**	**#06147**	**#07042**	**#07056**	**#07074**
			4/22/2006	**5/11/2006**	**6/13/2006**	**7/11/2006**	**8/11/2006**	**9/4/2006**	**10/30/2006**	**11/19/2006**	**12/16/2006**	**1/30/2007**	**2/24/2007**	**3/11/2007**
	Manganese	mg/L	0.44	0.15	0.023	0.2	0.11	0.73	0.019	0.082	0.2	0.55	0.17	2.7
	Molybdenum	mg/L	0.0031	0.0056	0.0057	0.0039	0.0031	0.005	0.0025	0.0025	0.0024	0.0024	0.0016	0.0035
	Nickel	mg/L	0.536	0.102	0.022	0.22	0.2	1.42	0.027	0.112	0.25	1.18	0.34	5.75
	Phosphorous	mg/L	NA	NA	NA	0.33	0.36	0.53	0.22	0.21	0.39	1.1	0.65	3
	Selenium	mg/L	0.0004	0.0002	0.0001	0.0001	0.0001	<0.0005	0.0011	<0.0001	0.0007	0.0003	0.0006	0.002
	Silver	mg/L	0.0001	0.001	<0.0001	<0.0001	0.0001	<0.0005	0.0001	<0.0001	<0.0001	0.0003	<0.0002	0.0005
	Strontium	mg/L	0.87	0.7	0.49	0.78	0.67	0.79	0.46	0.67	0.61	0.74	0.61	1
	Thallium	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.001	0.0002	<0.0002	<0.0002	<0.0002	<0.0004	<0.001
	Tin	mg/L	0.0002	0.0002	0.0001	0.0007	<0.0001	0.0025	0.0001	0.0001	0.0001	<0.0001	<0.0002	0.001
	Titanium	mg/L	0.21	0.16	0.028	0.17	0.1	1.23	0.012	0.056	0.11	2.45	0.073	3.91
	Uranium	ug/L	NA	NA	NA	0.7	0.2	1.9	0.1	0.2	0.4	1.5	0.2	3.7
	Vanadium	mg/L	1.2	0.5	0.0098	0.016	0.01	0.049	0.0055	0.0059	0.034	0.036	0.016	0.084
	Zinc	mg/L	0.088	0.054	0.0039	0.03	0.011	0.096	0.0009	0.0094	0.039	0.036	0.023	0.37
VOCs	Benzene	ug/L	NA	NA	0.3	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	NA	<0.2	<0.2
	Ethylbenzene	ug/L	NA	NA	0.3	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	NA	<0.2	<0.2
	HydrocarbonsF1(C6-C10)	ug/L	NA	NA	18	<5	<5	<5	5	NA	<5	NA	<5	<5
	HydrocarbonsF2(C10-C16)	ug/L	NA	<10	<10	<10	<10	<10	41	<10	<10	NA	<10	<10
	HydrocarbonsF3(C16-C34)	ug/L	NA	7980	230	2420	200	360	940	<10	190	NA	1870	7690
	HydrocarbonsF4(C34-C50)	ug/L	NA	2270	190	700	96	120	500	<10	33	NA	500	2790
	Toluene	ug/L	NA	NA	0.6	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	NA	<0.2	<0.2
	Xylene	ug/L	0.043	0.015	0.8	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	NA	<0.2	<0.2

Note: 1) Data from Table MWS-01 of Addendum to the Amendment Application to Sink the Orion South Exploration Shaft into the Kimberlite and to Perform Bulk Sampling (SEP #2007-03), 2007.

The groundwater quality results show that the groundwater chemistry varies with the particular aquifer sampled, with groundwater samples collected from the deep aquifers showing relatively high total dissolved solids (TDS) in comparison to those from the shallow aquifers. As most of the mine water discharged from the open pits is expected to originate from within the Mannville aquifer, the quality of the final discharge from the Project Site is assumed to be similar to that of the Mannville aquifer. This water is characterized by concentrations of chloride in the range of 1,200 to 2,000 mg/L, of sodium in the range of 1,100 to 1,400 mg/L and TDS in the range of 3,100 to 4,500 mg/L.

2009 Groundwater Flow Model

SRK (2009) describes the groundwater flow model prepared in 2009. The groundwater flow system and predictive scenarios described in that report differ from previous efforts in that considerable attention was paid to the potential environmental effects of the Project on the local groundwater systems. Other changes from previous models include expanding the model domain, incorporating the most recent geological model and incorporating an additional 150 to 260 m of the Souris River Formation at the base of the model. The added lower portion of the Souris River Formation was given a lower hydraulic conductivity compared to the upper portion reflecting information from oil and gas wells in the RSA.

The SRK (2009) model also incorporated additional information collected in 2008 and early 2009. This included piezometric information from newly installed monitoring locations and updating the hydraulic conductivity values used in the model from the packer tests completed in three deep boreholes around the Star Kimberlite (SHP-08-004C, SHP-08-006C and SHP-08-008C). This information led to a decision to split the Mannville Group into a less permeable upper zone and a more permeable lower zone, whereas previous versions of the model treated the Mannville aquifer as having a single horizontal hydraulic conductivity value throughout.

The SRK (2009) model recognizes two water bearing systems, including an upper system composed of surficial sands, shallow silts and tills, and a second, deeper system, composed of the sandstones of the lower Mannville Group and the upper carbonates of Souris River Formation. The two systems are separated by the Colorado Group confining layer, except in the vicinity of the buried bedrock valley to the north of the kimberlites, where it is replaced by units representing fluvial sand and gravel deposits within the paleochannel.

In the paleochannel area, recharge to the groundwater systems originates with infiltration of precipitation into the surficial sands. From there, the water potentially infiltrates down through the till layers to the deep groundwater system in the Mannville Group.

In the model, groundwater discharges from the shallow groundwater system to the local creeks and from deep groundwater system to the Saskatchewan River. However, the rate of discharge from the deep groundwater system to the river is limited by the considerable thickness of the Colorado Group shale that underlies the river.

The 2009 groundwater model domain extended 14 km to 21 km from the proposed open pits and was assigned general head boundaries at distances of 100 km or 200 km. The model thickness varied from 605 m to 805 m and the base of the model was assigned as a no flow boundary. The Saskatchewan River was represented by constant head cells, while creeks were simulated by seepage face cells.

Under pre-mining conditions, groundwater recharge within the model domain was simulated as 117,600 m^3/day. Groundwater discharge directly to the Saskatchewan River through springs was simulated as 5,200 m^3/day and to the other creeks was 62,600 m^3/day. Groundwater out flow across the outer model domain in the Mannville Group was 49,800 m^3/day. For comparison, mean yearly flow in the Saskatchewan River is given as almost 37,900,000 m^3/day based on 49 years of data from a Water Survey of Canada station below Tobin Lake (05KD003), indicating simulated groundwater discharge to the river is minimal compared to flow within the river.

5.2.7.7 2010 Groundwater Flow Model

The 2009 model was updated in 2010 (SRK 2010) as an interim measure before the results of planned 20 day pumping test could be completed in 2010. This report has been subsequently replaced by a 2011 version of the model. The 2010 model incorporated information from drilling in 2010.

2010 Drilling and Groundwater Monitoring Results

New monitoring wells and a prototype dewatering test well were drilled in 2010, and results were used to update the understanding of the hydrogeology at the Project Site in 2010. These holes include shallow holes (<100 m), holes drilled to depths of greater than 100 m as part of geotechnical investigations (Clifton 2010a, 2010b), as well as several new monitoring well installations at varying depth. Data from eight shallow holes (Clifton 2010b) along with those from previous sources (Clifton 2007; SRC 2006a) indicate an increase in the hydraulic conductivity value applied to the upper surficial sand.

Static groundwater level data taken from newly installed monitoring wells (Figure 5.2.7-8) were used in the calibration of the 2010 model. The groundwater levels in the Mannville Group formations on the south side of the river were measured to be 395.5 masl in October 2010. Taken in conjunction with other groundwater levels in the Mannville Group rocks in the surrounding area, the groundwater flow paths for the Mannville Group aquifers were interpreted to be from northwest to southeast across the Project Site, but with a east flowing component on the south side of the Saskatchewan River. This groundwater flow pattern suggests that there is a possibility of some limited groundwater discharge from the Mannville aquifer to the Saskatchewan River as the potentiometric surface lies above the valley floor.

The new monitoring wells included two new shallow monitoring wells (PC-004 (7 m deep) and PC11-005 (25 m deep)) drilled in the area above the paleochannel. Static water levels in these wells were approximately 1.1 m below ground surface, which when considering the significant downward gradient from the shallow aquifer to the Mannville Group aquifer in the region, indicates that the shallow sediments are not hydraulically connected to the deep aquifer through the paleochannel sediments.

2010 Groundwater Model

The 2010 groundwater model described by SRK (2010) is similar to the SRK (2009).

The model domain for the 2010 model extends 14 km to 21 km from the proposed pits, and covers an area of 1,015 km^2. Model cell dimensions range from 200 km to 1,800 m long, and between 1 m and 250 m thick. The overall thickness of the model varies between 605 m and 805 m.

The model includes 14 hydrogeologic units. Eleven of these units are represented by layers in the model that cover the entire region. The 11 layers are divided into two water bearing systems separated by the Colorado Group shales. Three of the units are present in localized areas to cover such features as the kimberlites, the overburden materials in the paleochannel, and the till layers within the Saskatchewan River valley. The till within the Saskatchewan River valley represents a modification to the 2009 model that replaces a unit created to represent till adjacent to the Saskatchewan River with one used to represent the upper few metres of till below the river.

The outer model boundaries were simulated by no flow boundaries in the upper layers and by general head boundaries in the lower layers (Mannville Group). The general head boundaries were moved closer to the model boundary from 100 km to 200 km used in the SRK 2009 model, to 20 km to 50 km. This was done to simulate more reasonable distributions of head in the Mannville Group.

Simulation of the Saskatchewan River was not changed from the 2009 model. The simulation of the creeks was changed to incorporate drain nodes as well as the seepage faces that were used in 2009. The model was also changed to include two specific creeks on the south side of the Saskatchewan River. Simulation of recharge remained essentially the same as the 2009 model.

The 2010 groundwater was calibrated to water levels from monitoring locations near the Project Site, using assumed recharge values, and horizontal hydraulic conductivity values derived from the pumping, airlift or slug tests. Vertical hydraulic conductivity values for the

Colorado shale were based on the match of vertical gradients across this unit to hydraulic head profiles from locations at the Project Site.

The following summarizes the changes in hydraulic conductivity values and anisotropy ratios from SRK (2009) to SRK (2010) to reflect the additional field work conducted in 2009 and 2010:

- The horizontal hydraulic conductivity values for most till and shale units were increased by a factor of approximately two between the 2009 and 2010 models. However, the horizontal hydraulic conductivity value for the lower till was decreased by a factor of five. The anisotropy ratio for these units was generally decreased from a factor of 100 to a factor of 10 for all units except the lower till, which remained the same
- The horizontal hydraulic conductivity and vertical hydraulic conductivity of the upper sand was also increased to reflect new slug test data from monitoring wells completed in this layer. The anisotropy ratio remained the same; and
- Another change from SRK (2009) to 2010 was to use a single hydraulic conductivity value for the Mannville Group instead of dividing this group into an upper lower hydraulic conductivity interval and lower higher hydraulic conductivity interval. The vertical hydraulic conductivity of the Mannville Group was also changed to be 10 times less than the horizontal hydraulic conductivity, whereas previously they had been the same.

Under pre-mining conditions, groundwater recharge within the model domain was simulated as 99,500 m^3/day. Groundwater discharge to the Saskatchewan River was simulated as 3,200 m^3/day and to the other creeks was 78,000 m^3/day. Groundwater inflow across the outer model domain in the Mannville Group was 1,100 m^3/day along the north model boundary, and outflow from the Mannville Group was 19,300 m^3/day along other boundaries. With the exception of inflow through the Mannville Group along the north boundary, these values vary from the 2009 model by a factor of up to three. The previous model (SRK 2009) did not report any inflow from the northern boundary under pre-mining conditions. The increase in inflow from the 2009 to 2010 model reflects a change in the interpretation of the regional gradient to include recharge from the north, instead of a large influx of water through the paleochannel to the Mannville Group and from there to the model boundaries.

SRK identified the major uncertainties in the model as:

- data gaps in the understanding of the hydraulic connection between the shallow and deep flow systems at the Saskatchewan River, the paleochannel and elsewhere;
- lateral and vertical distribution of transmissivity in the Mannville Group across the RSA; and
- groundwater flow directions in the Mannville Group particularly to the south of the Saskatchewan River.

5.2.7.8 2010 20-day pumping test

A 20-day pumping test was conducted by pumping from prototype dewatering well, 140-10-89RC, located on the south side of the Orion South kimberlite. Additional information on the pumping test is located in the report titled *Groundwater Modeling of Feasibility Dewatering Requirements for Star and Orion South Pits and Possible Hydrological Impact* (SRK 2011a) found in Appendix 5.2.7-A. The 20-day pumping test was critical in resolving many of the uncertainties identified in the 2010 model.

The prototype dewatering well was constructed from August to October 2010. Problems with the screen installation resulted in the well being effectively screened across the upper Mannville Group and into the upper part of the lower Mannville Group (from 190 to 283 m below ground surface).

The pumping test in the prototype wells was conducted at an average rate of 4,720 m^3/day (approximately 900 gpm) for a period of 20 days from October 25 to November 14 2010. During the pumping test and recovery period, water levels were recorded in 19 monitoring wells and vibrating wire transducers, located at distances of between 53 and 5,776 m away from the pumping well and in various hydrostratigraphic units. The results of the test were used to provide data for a transient calibration of the groundwater model (SRK, 2011a), and provided the following observations:

- There was uniform propagation of the drawdown cone to the north and south of the pumping well;
- A spinner log of the hole determined almost all the water flowing into the well did so at depths of 250 to 255 m and 270 to 280 m below ground surface, at the top of the Lloydminster Formation and across the Cummings Formation. Both these formations are close to the base of the Mannville Group;
- The lower part of the Mannville Group is significantly more permeable than the upper part; and
- There was very limited hydraulic connection between the Mannville Group and the overlying Colorado Group shale noted in monitoring locations near the pumping well.

Several groundwater samples were collected from the prototype well during the pumping test. The results of the sample analysis are provided in Table 5.2.7-10, and were similar in chemistry to other samples collected from the Mannville Group.

5.2.7.9 2011 Deep Isotopic and Chemical Profile Analysis

Drill core samples were obtained from two core holes at the Project Site in 2010 by researchers at the University of Saskatchewan for deep isotropic profile analysis (Hendry et al. 2011). The objective of this work was to develop profiles of naturally occurring conservative tracers (i.e., stable isotopes of water and halogens) to estimate the hydrogeological properties and solute transport mechanisms vertically through the stratigraphic units by matching the profiles to modeled results. One of the holes (OVB-10-207) was drilled approximately one kilometre west of Kimberlite 116/216, and drilled to the Mannville Group to a total depth of 204 m, while the other (140-10-087C) was located close to the Orion South Kimberlite and was drilled into the Souris River Formation to a total depth of 353 m (Figure 5.2.7-6). One core sample was taken every 1 m for the analysis of $\delta^{18}O$ and $\delta^{2}H$, another sample taken every 3 m for the analysis of geotechnical parameters (gravimetric moisture content, bulk density and porosity) and pore water concentrations of anions (i.e., chloride and fluoride), although detailed results are presently only available from 140-10-087C. In addition, 11 samples were collected from the two holes for triaxial hydraulic conductivity testing.

Preliminary results of core, and pumping test response matching analyses were obtained in 2010 and 2011:

- The laboratory hydraulic conductivity tests indicated that the shales have very low permeability at the lab test scale (from 1.7×10^{-7} to less than 10^{-8} m/day in eleven samples).
- Further hydraulic conductivity and specific storage values were estimated by using a one dimensional flow model to analysis of the hydraulic responses to a 20 day pumping test conducted in late 2010. Generally the results of the modelling showed the hydraulic conductivity to be about one order of magnitude higher than the results from the laboratory analysis of samples, and in the order of 10^{-5} m/day for the Colorado Shale and upper Mannville Group.
- Chloride and isotope profiles developed from 140-10-087C, and OVB-10-207 were available for review. The chloride pore water concentration profiles indicated chloride concentrations in the order of 200 to 500 mg/L in the upper part of the profiles, but increased to greater than 1,000 mg/L in the lower part of the holes. This increase occurred in 140-10-087C at a depth of close to 200 m at the contact between the Colorado Group and the Mannville Group rocks, and likely reflects the presence of slightly brackish groundwater in the Mannville Group. The increase in OVB-10-207 at a depth of approximately 120 m, which is coincident with the top of the marine shales of the Colorado Group, and may reflect the presence of relic salts in the shale.
- Preliminary solute transport modelling indicates that solute transport in lower Colorado Shale and Upper Mannville are diffusion dominated, suggesting these units have a very low vertical hydraulic conductivity.

5.2.7.10 2011 Groundwater Flow Model

The 2011 groundwater flow model was updated to incorporate the results of a 20 day pumping test conducted at the site in late 2011. This model is described in the report titled *Groundwater Modeling of Feasibility Dewatering Requirements for Star and Orion South Pits and Possible Hydrological Impact* (SRK 2011a). A copy of this report is found in Appendix 5.2.7-A. The results of the most recent model form the basis of this component of the EIA. The 2011 model was developed from the 2010 model, but changed to incorporate the most recent mining plan, the results of the 20-day pumping test and 2011 isotopic profiles.

The model domain, outer boundary conditions, including recharge, and simulation of the Saskatchewan River and local area creeks are unchanged from the 2010 model (see section 5.2.7.7).

The model includes 16 hydrogeologic units. Eleven of these units are represented by layers in the model that cover the entire region. The 11 layers are divided into two water bearing systems separated by the Colorado Group shales and tills. Five of the units are present in localized areas to cover such features as the kimberlites, the material used to back fill the Star pit, the overburden materials in the paleochannel, and the till layers within the Saskatchewan River valley. New units in the 2011 model are the material used to back fill the Star pit after it is mined which is part of the most recent mine plan, and the addition of a lower till unit for the paleochannel that was required for model calibration. The extent of and materials in the paleochannel was also updated to reflect new information, including more detailed mapping.

Like the 2010 model, the 2011 groundwater model was calibrated to water levels from monitoring locations near the Project Site, using assumed recharge values, and horizontal hydraulic conductivity values derived from the pumping, airlift or slug tests. Vertical hydraulic conductivity values for the Colorado Group shale were based to the match of vertical gradients across this unit to hydraulic head profiles from locations at the Project Site and on a transient calibration to the response of the 20-day pumping test. The calibration of the 20-day pumping test results was accomplished by matching the drawdown slopes in log-time scale using the 2011 regional groundwater model.

Table 5.2.7-13 summarizes the changes in hydraulic conductivity values through the model development from SRK (2009) to SRK (2010) to SRK (2011a), as additional field work was conducted. The key changes to the model from 2010 to 2011 were:

- The vertical hydraulic conductivity values for most till units were decreased by a factor of approximately one half to one fiftieth between the 2010 and 2011 models, which generally brought values closer to those used in the 2009 model; and

- The Mannville Group was divided into an upper less permeable unit and a lower permeable unit in response to the transient calibration of the 20-day pumping test results. As with the changes to the hydraulic conductivity of the tills, the change to the hydraulic conductivity of the Mannville Group generally made the model more similar to the 2009 model than the 2010 model.

In addition to changes to the hydraulic conductivity, the recharge applied to the model where the upper surficial sand was the first unsaturated layer was decreased from 50 to 20 mm/year.

Under pre-mining conditions, groundwater recharge within the model domain was simulated as 47,800 m^3/day. Groundwater discharge to the Saskatchewan River was simulated as 3,400 m^3/day and to the other creeks was 29,520 m^3/day. Groundwater inflow across the outer model domain in the Mannville Group was 1,310 m^3/day along the north model boundary, and outflow from the Mannville Group was 14,190 m^3/day along other boundaries. The largest changes to the pre-mining calibrated water budget from the 2010 to the 2011 were the decrease in net recharge applied to the top of the layer and corresponding decrease in groundwater discharge to the local creeks.

Table 5.2.7-13: Comparison of Hydraulic Conductivity Values Used in the 2009, 2010 and 2011 Groundwater Models, and Storage Parameters used in the 2011 Model

Hydro-geologic Unit	2009 Kh (m/d)	2009 Kv (m/d)	2010 Kh (m/d)	2010 Kv (m/d)	2011 Kh (m/d)	2011 Kv (m/d)	2011 Specific Storage Ss (m-1)	2011 Specific Yield Sy ( )	Comments on 2011 parameters
Upper Surficial Sand	2	2	10	10	10	10	1E-06	0.2	K h values are based on results of slug tests in piezometers constructed in 2005-2010
Upper Surficial Silt/Clay	0.03	0.0001	0.05	0.005	0.05	0.005	1E-04	0.15	
Lower Surficial Sand	0.03	0.0006	0.1	0.01	0.1	0.01	1E-04	0.15	
Lower Surficial Silt/Clay	0.03	0.0001	0.05	0.005	0.03	0.0001	1E-04	0.15	
Uppermost Till within Sask. River Valley	0.3	0.003	0.05	0.005	0.1	0.001	1E-04	0.1	Assumed based on model calibration to pre-mining water levels
Upper Till	0.03	0.0006	0.05	0.005	0.03	0.0001	1E-04	0.1	K h is based on data from 2 pump tests, airlift, packer injection, and falling head tests
Lower Till	0.03	0.0006	0.006	0.00006	0.018	0.00006	1E-04	0.1	

Hydro-geologic Unit	2009 Kh (m/d)	2009 Kv (m/d)	2010 Kh (m/d)	2010 Kv (m/d)	2011 Kh (m/d)	2011 Kv (m/d)	2011 Specific Storage Ss (m-1)	2011 Specific Yield Sy ( )	Comments on 2011 parameters
Shale (Colorado Group)	0.0002	0.0002	0.0004	0.00006	0.0004	0.00006	1E-05	0.01	K h is based on packer tests in testholes at Orion South and Star in 2005 and 2008, and results of model calibration
Sandstone (Upper part of Mannville Group)	0.01	0.0001	1.6	0.16	0.01	0.00033	1E-06	0.02	K and S values based on results of 20 day pumping test
Sandstone (Lower part of Mannville Group)	7.8	7.8	1.6	0.16	3	0.1	1.E-06	0.02	
Uppermost Limestone (Souris River Fm)	0.01	0.001	0.01	0.001	0.01	0.001	1E-06	0.01	K h=0.01 m/day is based on data from PW4 pump test
Limestone (Souris River Fm)	0.001	0.001	0.001	0.0001	0.001	0.0001	1E-06	0.005	K values are assumed to be low
Till within Paleochannel	0.003	0.0002	0.004	0.00006	0.004	0.00006	1E-05	0.1	K values are calibrated to simulate water table near the ground surface

Hydro-geologic Unit	2009 Kh (m/d)	2009 Kv (m/d)	2010 Kh (m/d)	2010 Kv (m/d)	2011 Kh (m/d)	2011 Kv (m/d)	2011 Specific Storage Ss (m-1)	2011 Specific Yield Sy ( )	Comments on 2011 parameters
Paleochannel (lower part)[1]	-	-	-	-	0.1	0.001	1E-05	0.03	Assumed based on geological data and model calibration
Kimberlite	0.002	0.0002	0.0002	0.0002	0.0002	0.0002	1E-06	0.01	K is based on hydraulic testing in borehole 140-05-055H (Orion South) in 2005

Note: kv Vertical hydraulic conductivity, kh = horizontal hydraulic conductivity

[1] new unit in 2011 model.

5.2.7.11 Conceptual Hydrogeologic Model and Baseline Summary

The conceptual hydrogeological model for the Project Site described here represents the summary of the baseline conditions. The conceptual model was developed by refining the 2009 conceptual model with information collected in 2010. This recent information includes drilling and groundwater level results from near the Project Site, a door-to-door well survey, and a detailed review of historical information. The resulting conceptual model is part of a process of continual improvement that has been ongoing since the hydrogeology of the Project Site was first investigated in detail in 2003, and represents the culmination of eight years of study. The information used to develop the conceptual model includes results from drilling, pumping tests, groundwater sampling, well surveys, spring surveys, test shaft construction at two locations, a review of dewatering results from a large scale project in a similar setting at the Francois Finlay Dam at Nipawin, and numerical modelling.

The results of the cumulative work indicate that the entire region can be characterized as having two main aquifers separated by a thick aquiclude of Colorado Group shale and clay/silt till. There may also be some thin sand layers sandwiched within the aquiclude that are used as a source of water for some (a few) local wells.

The aquiclude is an important layer that appears to have almost uniform thickness across the region, except: where partially eroded by the present day Saskatchewan River; where eroded by an ancient river to form a paleochannel to the north and east of the Project Site that was subsequently filled with glacial material; and where eruptively replaced by the kimberlites. At each of these areas, there is a potential of increased hydraulic connection between the aquifers, allowing increased vertical groundwater flow in comparison to other locations. However, the degree of hydraulic connection remains limited by either the remaining low permeability material that was not removed by erosion or by the low permeability material emplaced into these features after or during their formation.

The following briefly describes the aquifers of interest to the proposed development.

A surficial sand aquifer that is commonly used by shallow (<25m) local wells as a water source and that provides water to local creeks. It also provides water to seeps and springs located along the Saskatchewan River valley. This aquifer is wide spread in the region and groundwater flow within the aquifer is generally towards the nearest local creek. Close to the Saskatchewan River valley, water in this aquifer drains into ravines and the valley, but the water within the aquifer is held within the sand layer by an underlying thick layer of silt-clay which restricts under-drainage. This aquifer is replenished by infiltration of precipitation and has relatively good water quality, where not effected by human activities. Because the aquifer is dependent on recharge from precipitation, some owners of shallow wells completed in this aquifer have reported that their wells had gone dry in the past during dry years;

A deep aquifer containing slightly brackish groundwater is not used by local residents and does not have a good connection to local creeks or the Saskatchewan River. The aquifer likely contains very ancient groundwater and is slowly replenished in most areas by percolation through a thick shale (Colorado Group) and silt-clay layer (till) that lies between it and the surficial aquifers. However, there are areas where the overlying silt-clay layer is missing or relatively thin and higher infiltration rates can occur. These areas include: an area to the far north (>50 km) of the Project Site; along the Saskatchewan River, where the river valley has cut deeply into the silt-clay till layer; and along a buried bedrock valley to the north and east of the Project Site that has similar dimensions to the Saskatchewan River and passes under the eastern part of the FalC. Once groundwater enters the aquifer, it flows slowly towards discharge locations to the far east of the Project Site along the Saskatchewan River, where the intervening till and shale aquiclude sediments are relatively thin.

There are several thin water producing sand layers sandwiched within the thick clay-silt layer (till) that lies between the surficial and deep aquifers. The layers are often intermittent and are not found in all locations. The water in these layers is of variable quality, but is often hard and iron rich. The groundwater in these layers is sometimes used for local water supplies, often in conjunction with treatment systems. Water from these layers is generally too deep to feed local creeks, but can feed springs along the slopes of the Saskatchewan River valley. Groundwater flow within these layers is expected to be generally towards the Saskatchewan River, however there may be a component of groundwater flow towards the paleochannel and subsequently through the paleochannel feature to the deeper Mannville Group aquifer.

5.2.8 Surface Water Quality

This Section describes the existing (baseline) surface water and sediment quality in the vicinity of the Project.

5.2.8.1 Introduction

Surface water and sediment quality are described in two study areas. The local study area (LSA) includes watersheds of the nine streams that are tributaries of the Saskatchewan River and the Saskatchewan River itself from approximately 3 km upstream of Caution Creek to 2 km downstream of English Creek (Figure 5.2.8-1). The LSA includes all local watersheds that are potentially affected by the Project footprint. The regional study area (RSA) expands downstream from Gronlid Ferry Crossing station up to Nipawin and includes the Saskatchewan River with immediate catchment areas downstream from the Project.

5.2.8.2 Information Sources and Methodology

A comprehensive water quality monitoring program was conducted at the Project between November 2005 and December 2009. This involved taking field water quality measurements and obtaining water samples for laboratory analyses from numerous stations located within the local study area (LSA) and at three locations on the Saskatchewan River system in the regional study area (RSA).

Water quality information collected by Saskatchewan Environment (SE) at three permanent water quality stations located within the Project RSA has also been provided (Figure 5.2.8-2). This includes two upstream stations, the Muskoday IR (where Highway 3 crosses the South Saskatchewan River) and the Cecil Ferry Crossing (East of Prince Albert on the North Saskatchewan River), and one station downstream of the RSA, the Wapiti bridge crossing (old Gronlid Ferry Crossing where Highway 6 crosses the Saskatchewan River). Sampling frequency differed between stations and detailed information on sampling dates is provided in Appendix 5.2.8-A, Table 1.

Sediment quality monitoring was completed coincident with the benthic invertebrate sampling program (refer to Section 5.3.1.3, Information Sources and Methodology in the Fisheries and Aquatic Resources section) and included obtaining sediment samples from the LSA for particle size and chemical analyses. Sampling was completed in October 2007 or November 2008. The study area includes the lower reaches of eight of the nine streams (Wapiti Ravine was not sampled due to an early freeze-up in 2008) and regions of the Saskatchewan River downstream of each stream and upstream from the mouth of Caution Creek (Figure 5.2.8-3).

Surface Water Quality

All sampled watercourses and their station codes are listed in Table 5.2.8-1, and all water sampling stations within the LSA and RSA are shown on Figures 5.2.8-1 and 5.2.8-2.

Table 5.2.8-1: Surface Water Quality Sampling Locations in the Project LSA and RSA, 2005 to 2009

Watercourse	Station Codes
Streams	
Caution Creek	SA1, SA4, CCS-CN, CCS-01, CCS-02
101 Ravine	SB1, 101-CN
West Perimeter Ravine	SE1, WPR-CN
West Ravine	WRS-01, WRS-02, WRS-03, WRS-04, WRS-CN
East Ravine	SC1, ERS-CN, ERS-01, ERS-02, ERS-03, ERS-04
Duke Ravine	DSS-01, DRS-CN

Watercourse	Station Codes
FalC Ravine	FRS-CN
Wapiti Ravine	WapRS-CN
English Creek	SD1, SD2, EC-CN, ECS-01
Saskatchewan River	SKR1 (upstream of Caution Creek)
	SKR2, NSRS-03 (downstream of English Creek)
	NSRS-01 (upstream of West Ravine)
	NSRS-02 (downstream of East Ravine)
	Gronlid Ferry (on SKR downstream of the LSA)
	Cecil Ferry (on North Saskatchewan River upstream of LSA)
	Muskoday IR (on South Saskatchewan River upstream of LSA)

Data Collection

Field measurements of temperature, dissolved oxygen, pH, specific conductance, and total dissolved solids were recorded at a minimum of one station within each stream and the Saskatchewan River. Water quality samples, consisting of one discrete surface grab sample, were collected from each station at the same time as field measurements were recorded. Each sample was preserved with acid in the field, if necessary, and submitted to the Saskatchewan Research Council (SRC) laboratories in Saskatoon for analysis. The time span and frequency of sampling varied by location (Appendix 5.2.8-A, Table 1).

Water quality data collected for the Saskatchewan River in the LSA were complemented with regional information obtained from the upstream reaches (South Saskatchewan River and North Saskatchewan River), as well downstream from the Project in the Saskatchewan River (Figure 5.2.8-2).

Laboratory Parameters

Surface water samples were collected and analysed for conventional parameters and major ions, metals, and nutrients; in addition, dissolved metals were analysed at several locations. A complete list of parameters that were analysed in the study area is provided in Table 5.2.8-2.

Table 5.2.8-2: Surface Water Quality Parameters Analysed for Watercourses in the Project LSA and RSA, 2005 to 2009

Category	Parameters[1]		
Field Parameters	Dissolved oxygen	Specific conductivity	Temperature
	pH		

Category	**Parameters**[1]		
Conventional Parameters	Chemical oxygen demand	Total hardness	Turbidity
	pH	Total alkalinity	Total suspended solids
	Specific conductivity	Total dissolved solids	
Major Ions	Bicarbonate	Fluoride	Potassium
	Calcium	Hydroxide	Sodium
	Carbonate	Magnesium	Sulfate
	Chloride		
Total and Dissolved Metals	Aluminum	Copper	Tellurium
	Antimony	Iron	Thallium
	Arsenic	Lead	Tin
	Barium	Manganese	Titanium
	Beryllium	Mercury	Tungsten
	Bismuth	Molybdenum	Uranium
	Boron	Nickel	Vanadium
	Cadmium	Rubidium	Zinc
	Cesium	Selenium	Zirconium
	Chromium	Silver	
	Cobalt	Strontium	
Nutrients	Ammonia as nitrogen	Nitrite	Total organic carbon
	Dissolved organic carbon	Nitrite+Nitrate, nitrogen	Total phosphorus
	Dissolved phosphorus	Total Kjeldahl nitrogen	Total nitrogen
	Nitrate		

Notes: [1]Not all parameters were analyzed at each sampling station and sampling date.

Data Analyses

Surface water quality parameter concentrations were compared to the Saskatchewan Surface Water Quality Objectives (SSWQO) for the protection of aquatic life (SE 2006) and the Canadian Environmental Quality Guidelines (CWQG) for the protection of freshwater life (CCME 2007). A summary of applicable guidelines is presented in Table 5.2.8-3. Exceedances of guidelines were determined for each of the four seasons: spring (April 1 to June 15), summer (June 16 to September 15), fall (September 16 to November 15), and winter (November 16 to March 31). Seasonal delineations were based on typical water flow and ice cover patterns for the study area.

Table 5.2.8-3: Saskatchewan (SSWQO) and Canadian (CWQG) Surface Water Quality Guidelines Available for analysed Parameters in the Project LSA and RSA

Parameters	Units	SSWQO[1]	CWQG[2]
Aluminum	mg/L	0.005-0.1[3]	0.005-0.1[3]
Arsenic	µg/L	5	5
Cadmium	mg/L	0.000017-0.0001[4]	0.000017
Chromium VI[5]	mg/L	0.001	0.001
Copper	mg/L	0.002-0.004[6]	0.002-0.004[6]
Dissolved Oxygen	mg/L	5.5-9.5[7]	5.5-9.5[7]
Iron	mg/L	0.3	0.3
Lead	mg/L	0.001-0.007[8]	0.001-0.007[8]
Mercury (inorganic)	mg/L	0.000026	0.000026
Molybdenum	mg/L	-	0.073
Nickel	mg/L	0.025-0.15[9]	0.025-0.15[9]
Nitrate	mg/L	-	13
Nitrite	mg/L	-	0.06
pH	pH units	-	6.5-9.0
Selenium	mg/L	0.001	0.001
Silver	mg/L	0.0001	0.0001
Thallium	mg/L	‘-	0.0008
Uranium	µg/L	15	-
Zinc	mg/L	0.03	0.03

Notes: [1] SSWQO = Saskatchewan surface water quality objectives for the protection of aquatic life (SE 2006).
[2] CWQG = Canadian water quality guidelines for the protection of freshwater aquatic life (CCME 2007).
[3] Aluminum: pH < 6.5 = 0.005 mg/L; pH ≥ 6.5=0.100 mg/L.
[4] Cadmium: total hardness 0 – 48.5 mg/L = 0.000017 mg/L; total hardness 48.5 – 97 mg/L = 0.000032 mg/L; total hardness 97 – 194 = 0.000058 mg/L; total hardness >194 = 0.0001 mg/L.
[5] SSWQO contain a guideline for only hexavalent chromium (Cr VI); comparisons of total chromium concentrations with this guideline are conservative.
[6] Copper: total hardness 0 – 120 mg/L = 0.002 mg/L; total hardness 120 – 180 mg/L = 0.003 mg/L; total hardness >180 = 0.004 mg/L.
[7] Dissolved oxygen: minimum of 6.0 mg/L for early life stages of warm water biota, 5.5 mg/L for other life stages of warm water biota, 9.5 mg/L for early life stages of cold water biota, and 6.5 mg/L for other life stages of cold water biota.
[8] Lead: total hardness 0 – 60 mg/L = 0.001; total hardness 60 – 120 mg/L = 0.002; total hardness 120 – 180 mg/L = 0.004 mg/L; total hardness >180 = 0.007 mg/L.
[9] Nickel: total hardness 0 – 60 mg/L = 0.025 mg/L; total hardness 60 – 120 mg/L = 0.065 mg/L; total hardness 120 – 180 mg/L = 0.110 mg/L; total hardness > 180 mg/L = 0.150 mg/L.

5.2.8.3 Sediment Quality

The water quality within water bodies partly depends on sediment quality. Many of the potential contaminants of concern often have a preferential affinity for sediment rather than water as they can be bound to the exchange complex of the particles. Sediments can release these potential contaminants over time, and could be a secondary source of water quality deterioration. Sediments and their background conditions in the deposition area were assessed at, or near, the mouth of tributaries and in the Saskatchewan River. Data collection, laboratory parameters and data analyses are described for sediment quality below.

Data Collection

The locations of all sediment sampling stations are provided in Figure 5.2.8-3. Sediment sampling was performed in October 2007 in Caution Creek, 101 Ravine, West Perimeter Ravine, West Ravine, East Ravine, and English Creek, as well as in the regions of the Saskatchewan River near these streams. In November 2008, Duke, FalC, and Wapiti ravines were added to the program, however, sampling could not be completed in Wapiti Ravine due to early freeze-up. In the Saskatchewan River, sediment samples were collected at the same stations as the benthic invertebrate samples. In the streams, sediment samples were collected in depositional areas located near the benthic invertebrate sampling stations since benthic invertebrates were sampled from erosional habitats (refer to Section 5.3.1, Fisheries and Aquatic Resources for more information).

Five replicate sediment stations, spaced a minimum of 20 m apart, were established in each sampling area. Sediment samples were collected using an Ekman dredge (0.052 m^2); the sample collected at each station was a composite of three Ekman grabs to ensure that a representative sample was obtained. Sediment samples consisted of the top ~0-5 cm horizon. Samples were frozen prior to submission to SRC laboratories in Saskatoon for analyses.

Laboratory Parameters

Bottom sediment samples were analysed for macro elements, metals, and nutrients; in addition, texture was analysed at several locations. A complete list of parameters that were analysed in the study area is provided in Table 5.2.8-4.

Table 5.2.8-4: Sediment Quality Parameters Analysed for Watercourses in the Project LSA, 2007 and 2008

Category	Parameters		
Macro Elements and Ions	Calcium	Potassium	Sulphate, acid soluble
	Magnesium	Sodium	
Metals	Aluminum	Cobalt	Silver
	Antimony	Copper	Strontium
	Arsenic	Iron	Thallium
	Barium	Lead	Tin
	Beryllium	Manganese	Titanium
	Boron	Molybdenum	Uranium
	Cadmium	Nickel	Vanadium
	Chromium	Selenium	Zinc
Nutrients	Organic carbon	Phosphorus	
Texture	Gravel	Fine sand	Clay
	Coarse sand	Silt	

Data Analyses

Sediment quality parameters were compared to applicable Canadian sediment quality guidelines (Interim Sediment Quality Guideline (ISQG) and Probable Effect Level (PEL), CCME 2002) and Thompson et al. (2005) Lowest Effect Level (LEL) and are presented in Table 5.2.8-5. Currently there are no provincial sediment quality guidelines available.

Table 5.2.8-5: Sediment Quality Guidelines Available for Analysed Parameters in the Project LSA

Parameters	Units	ISQG[1]	PEL[2]	LEL[3]
Arsenic	µg/g	5.9	17	9.8
Cadmium	µg/g	0.6	3.5	
Chromium	µg/g	37.3	90.0	47.6
Copper	µg/g	35.7	197.0	22.2
Lead	µg/g	35	91.3	36.7
Molybdenum	µg/g			13.8
Nickel	µg/g			23.4
Selenium	µg/g			1.9
Uranium	µg/g			104.4
Vanadium	µg/g			35.2

Parameters	Units	ISQG[1]	PEL[2]	LEL[3]
Zinc	µg/g	123	315	

Notes: [1]ISQG = Interim freshwater sediment quality guidelines (CCME 2002).
[2]PEL = Probable effect level, which is the level above which adverse effects are expected to frequently occur (CCME 2002).
[3]LEL = Lowest effect level represents the concentration below which harmful effects on benthic invertebrates are not expected to occur (Thompson et al. 2005).

5.2.8.4 Surface Water Quality

Complete datasets and descriptive summary statistics for each sampling location are provided in Appendix 5.2.8-A (Tables 2 to 57) for all parameters that fall under the following categories: field measurements, conventional parameters, major ions, nutrients, and metals. The following sets of stations represent water quality in the subsequent watersheds and were pooled for the calculation of descriptive statistics: SA1, SA4, and CCS-CN (Caution Creek); SB1 and 101-CN (101 Ravine); SE1 and WPR-CN (West Perimeter Ravine); SC1 and ERS-CN (East Ravine); SD1, SD2, and EC-CN (English Creek); and SKR2 and NSRS-03 (Saskatchewan River downstream of English Creek).

This Section focuses on parameter concentrations that exceeded SSWQO (SE 2006) and/or CWQG (CCME 2007), as well as potential parameters of interest for examination in the impact assessment. For example, total dissolved solids and major ions are of interest due to a potential increase in total dissolved solids as a result of the release of groundwater from pit dewatering into the Saskatchewan River via the Water Management Reservoir. Seasonal water quality guideline exceedances for each stream and for the Saskatchewan River are presented in Appendix 5.2.8-B (Tables 1 to 11). The frequency of water quality exceedances within the LSA varied between watersheds and is shown in Table 5.2.8-6.

Table 5.2.8-6: Summary of Exceedances of SSWQO1 and/or CWQG2 Guidelines for Surface Water Quality Samples in Streams within LSA, 2006 to 2009

	% Exceedances										
Parameters	**Caution Creek**	**101 Ravine**	**West Perimeter Ravine**	**West Ravine**	**East Ravine**	**Duke Ravine**	**FalC Ravine**	**Wapiti Ravine**	**English Creek**	**Saskatchewan River (LSA)**	**Saskatchewan River (RSA)**
Field and Conventional Parameters											
pH											
Field	28	0	0	16	12	15	0	0	5	5	6
Lab	0	0	0	0	0	0	0	0	0	0	0
Dissolved oxygen (field)	0	17	20	33	17	33	0	33	33	42	49
Nutrients											
Nitrate	0	0	0	2	3	8	0	0	4	0	0
Nitrite	0	0	0	-	0	-	-	-	0	0	
Metals											
Aluminum											
Total	8	50	43	22	24	23	67	33	19	45	36
Dissolved	0	0	0	0	0	10	-	-	0	0	-
Arsenic											
Total	12	0	0	9	10	0	0	0	48	0	0
Dissolved	0	0	0	0	2	10	-	-	14	0	-
Cadmium											
Total	4	13	14	15	13	8	33	33	11	41	7
Dissolved	0	0	0	7	0	10	-	-	7	22	-
Chromium[5]											
Total	20	25	29	21	20	31	33	67	26	37	14
Dissolved	88	50	50	75	74	80	-	-	71	78	-
Copper											
Total	4	0	14	7	6	8	0	33	0	17	14
Dissolved	4	0	50	0	0	10	-	-	7	0	-
Iron											
Total	67	88	57	85	82	46	67	67	96	57	43
Dissolved	13	50	0	18	0	10	-	-	14	0	-
Lead											
Total	0	0	14	1	0	0	0	0	0	0	0
Dissolved	0	0	50	4	0	0	-	-	0	0	-
Mercury[6]											
Total	13	0	50	69	5	0	-	-	0	0	2
Dissolved	0	0	0	0	0	-	-	-	17	0	-
Molybdenum											
Total	0	0	0	0	0	0	0	0	0	0	0
Dissolved	0	0	0	0	0	0	-	-	0	0	-
Nickel											
Total	0	0	0	0	0	0	0	0	0	0	0
Dissolved	0	0	0	4	0	0	-	-	0	0	-
Selenium											
Total	4	0	0	2	1	0	0	0	4	0	0
Dissolved	0	0	0	0	0	0	-	-	0	0	-
Silver											
Total	0	0	0	1	1	0	33	0	0	3	0
Dissolved	0	0	0	4	0	0	-	-	0	0	-
Thallium											
Total	0	0	0	0	1	0	0	0	0	0	0
Dissolved	0	0	0	0	0	0	-	-	0	0	-
Uranium											
Total	0	0	0	0	0	0	0	0	0	0	0
Dissolved	0	0	0	4	0	0	-	-	0	0	-
Zinc											
Total	2	0	0	9	7	8	0	0	4	0	7
Dissolved	0	0	0	0	4	10	-	-	14	0	-

Notes: [1]SSWQO = Saskatchewan surface water quality objectives for the protection of aquatic life (SE 2006).
[2]CWQG = Canadian water quality guidelines for the protection of aquatic life (CCME 2007).
[3]Number of samples (N) ≥ analytical detection limit (DL).
[4]Guidelines (GL) for dissolved components of parameters are not available; therefore, concentrations were compared with guidelines for total concentrations to evaluate exceedances of bioavailable concentrations.
[5]SSWQO contain a guideline for only hexavalent chromium (Cr VI); comparisons of total chromium concentrations with this guideline are conservative.
[6]Mercury guideline is for inorganic mercury, rather than total mercury; therefore, exceedances err on the side of caution.

Metals

Only those metals that exceeded provincial (SSWQO) and/or Canadian (CWQG) guidelines are discussed in this Section. Several guideline exceedances were observed in all streams and in the Saskatchewan River within both the LSA and RSA.

Exceedances of total metals were particularly frequent in West Ravine and East Ravine; in each, concentrations of 11 metals exceeded guidelines at one or more sampling events. Exceedances were also relatively common in Caution Creek (nine metals), West Perimeter Ravine (seven metals) and English Creek (seven metals).

Concentrations of aluminum, cadmium, chromium, and iron exceeded guidelines in all nine streams. The dissolved fraction of these metals was also high and reflects the bioavailable component. Total iron concentrations were most frequently greater than guidelines, with 46% to 96% of samples exceeding guidelines in each stream. Exceedances of the chromium guideline were also frequent; however, because the guideline is for hexavalent chromium rather than total chromium, exceedances are likely lower than those reported.

Copper concentrations exceeded guidelines in seven streams, and arsenic, mercury, and zinc guidelines were each exceeded in five streams. Rarely, selenium, silver, lead, and thallium also exceeded guidelines.

Of the four streams that had adequate data from multiple seasons, most exceedances for total metals were found in winter and summer.

In the Saskatchewan River within the LSA and the RSA, total concentrations of aluminum, cadmium, chromium, copper, and iron exceeded guidelines on at least one occasion. In addition, silver exceeded guidelines once in the LSA, and mercury (once) and zinc (twice) exceeded guidelines in the RSA. Similar to the data from the streams, iron displayed the highest percentage of guideline exceedences in the Saskatchewan River LSA (57% of the samples). Incidences of guideline exceedances were higher in the LSA (aluminum, 45% of samples; cadmium, 41%; chromium, 37%; copper, 17%; iron, 57%; and silver, 3%) than in the RSA (aluminum, 36%; cadmium, 7%; chromium, 14%; copper, 14%; iron, 43%; mercury, 2%; and zinc, 7%). Dissolved cadmium (22% of samples) and dissolved chromium (78% of samples) concentrations exceeded the guidelines for total concentrations in the LSA on several occasions. Dissolved metals were not analyzed for water samples collected from the RSA, thus data are not available. Within the LSA, no winter water samples were collected, and the most total metal and dissolved metal parameters exceeded guidelines in summer (six total metals and two dissolved metals), followed by spring (five total metals and one dissolved metal), and fall (four total metals and one dissolved metal). Within the RSA, exceedances of guidelines were observed for the most total metals in winter (six), followed by summer (four), fall (three), and spring (two).

Nutrients

This Section focuses on ammonia, nitrate and nitrite, and other nutrients for which there are guidelines (CWQG; CCME 2007)

Ammonia concentrations were higher in Caution Creek (median = 0.10 mg/L), West Ravine (median = 0.09 mg/L), English Creek (median = 0.08 mg/L), and East Ravine (median = 0.06 mg/L) than in the other streams, in which median values ranged from 0.005 mg/L (Duke Ravine) to 0.04 mg/L (101 Ravine).

Nitrate showed infrequent exceedances of the guideline (13 mg/L, CCME 2007) in four of the streams: West, East, and Duke ravines and English Creek. All exceedances of nitrate, except one, occurred during winter. The single exception was in East Ravine during fall sampling. No exceedances of the nitrite guideline (0.06 mg/L) were observed in any stream.

In the Saskatchewan River within the Project's LSA and RSA, ammonia levels were similar to those in the streams (median values of 0.04 and 0.01, respectively).

No exceedances of the nitrate and nitrite guidelines were observed in the Saskatchewan River within the LSA. For the RSA stations, total nitrate and nitrite were not analyzed; dissolved nitrate was instead compared with the nitrate guideline and no exceedances occurred.

Field Parameters

Dissolved oxygen and pH, which are the only field parameters for which there are provincial SSWQO (SE 2006) and federal CWQG (CCME 2007) guidelines are discussed in this Section.

For the most part, surface waters were well-oxygenated, meeting the most stringent dissolved oxygen guideline of 9.5 mg/L, which is required for the early life stages of cold-water biota (CCME 2007; SE 2006). All streams except Caution Creek and FalC Ravine had infrequent occurrences of dissolved oxygen levels below the most stringent guideline value. The only incident of a dissolved oxygen concentration lower than 6.0 mg/L, which is the second lowest guideline value, was in Wapiti Ravine (5.64 mg/L). All values of dissolved oxygen that were below guideline concentrations occurred during summer.

Guideline exceedances for dissolved oxygen were similar in the Saskatchewan River and in the streams in the study area. Guideline exceedances occurred for 5 of the 12 samples (42%) within the LSA. Of the 53 samples from the Saskatchewan River stations in the RSA, dissolved oxygen levels were below 9.5 mg/L in 24 samples (45%), and below 6.5 mg/L (required for non-early life stages of cold-water biota) in 1 sample downstream from the Project LSA. Incidences of dissolved oxygen concentrations below guidelines were highest in spring and summer. In the RSA, 64% of winter samples had values of dissolved oxygen below guidelines; no winter measurements were taken in the Saskatchewan River within the LSA.

Field measurements of pH outside the guideline range of 6.5 to 9.0 (CCME 2007) occurred in Caution Creek (n = 9; 28% of samples), West Ravine (n = 18; 16% of samples), East Ravine (n = 13; 12% of samples), Duke Ravine (n = 2; 15% of samples), and English Creek (n = 1; 5% of samples). All but two of these values outside the recommended range were less than 6.5; pH values greater than 9 were found in West Ravine (9.34) and East Ravine (9.50). Values outside the recommended pH range occurred during all seasons, but were most frequent in winter.

In the Saskatchewan River, four values of pH were outside the CWQG range of 6.5 to 9.0. Field measurements of pH yielded one value greater than 9.0 in river samples within the LSA, and two values greater than 9.0 and one value less than 6.5 in the RSA. As with the streams, no values of pH obtained from laboratory analyses of samples were outside the recommended range of 6.5 to 9.0. Values of pH outside the recommended range occurred in summer and fall.

Major Ions

Parameters discussed in this Section include total dissolved solids, conductivity, calcium, chloride, magnesium, sodium, and sulphate.

Total dissolved solids were higher in the West Ravine samples (except WRS-01) than in all other streams. The median values from stations in the West Ravine (except WRS-01) ranged from 882 to 1010 mg/L, whereas the range of median values from all other stream stations was 225 to 339 mg/L. High variability in total dissolved solids concentrations within seasons makes seasonal variation difficult to discern; however, values did have some tendency to be lower in spring. A similar pattern in conductivity also occurred, with four West Ravine stations having median conductivities that ranged from 1560 to 2325 µS/cm and all other stream stations having medians ranging between 357 and 580 µS/cm. Following these patterns, concentrations of calcium, chloride, magnesium, sodium, and sulphate were elevated in West Ravine, compared to the other streams.

Water samples from the Saskatchewan River in the LSA and RSA had salinity parameters similar to those found in the tributaries, excluding West Ravine. In the LSA, median values of total dissolved solids and specific conductance in river samples ranged from 270 to 282 mg/L and 422 to 458 µS/cm, respectively. In the RSA, median values of specific conductance at the three stations varied from 428 to 480 µS/cm; total dissolved solids were measured at only one station, which had a median value of 335 mg/L.

5.2.8.5 Sediment Quality

Sediment quality is discussed in terms of sediment texture and sediment chemistry, including metal and nutrient composition.

Sediment Texture

Sediment texture by particle size measured in eight streams within the LSA is presented in Appendix 5.2.8-B (Table 12). Sediments from the streams consisted predominantly of coarse sand and fine sand. These two particle sizes comprised more than 90% of the sediments, by weight, in all streams except Duke Ravine (~82%), FalC Ravine (~83%), and English Creek (~74%). Compared with all other sampling areas, sediments from English Creek contained relatively more fine sand than coarse sand, and more silt.

Sediments from the Saskatchewan River (Appendix 5.2.8-B Table 13) contained mostly sand and silt. Four of the sampling areas (those downstream from Caution Creek, 101 Ravine, East Ravine, and Duke Ravine) contained predominantly fine sand and coarse sand (77 to 96% of sediment weight). The remaining six areas had sediments with mostly fine sand and silt (74 to 84% of sediment weight).

Sediment Chemistry

A summary of the sediment chemistry in the Project LSA is presented in Appendix 5.2.8-B (Table 14 for streams and Table B15 for the Saskatchewan River). Also included in the tables are the applicable ISQG, PEL, and LEL values (CCME 2002; Thompson et al. 2005). Metals that did not exceed any of the three guidelines were not included in the summary tables; however, all data are presented in Appendix A (Tables 58 and 59).

Metals

The only metals with concentrations greater than guidelines in any stream sediment samples were arsenic and vanadium. All streams except 101 Ravine contained sediments with arsenic concentrations greater than the ISQG of 5.9 µg/g; and five of the streams (Caution Creek, West Ravine, East Ravine, Duke Ravine, and English Creek) had median values >5.9 µg/g. Two streams had sediments with median arsenic concentrations greater than Thompson et al.'s (2005) LEL of 9.8 µg/g: Caution Creek (median = 9.9 µg/g) and English Creek (median = 19 µg/g). Sediments from English Creek and FalC Ravine contained samples with vanadium concentrations greater than Thompson et al. (2005) LEL of 35.2 µg/g; median values were 42 and 26 µg/g for English Creek and FalC Ravine, respectively.

The metals that exceeded guidelines in the Saskatchewan River sediments were arsenic, nickel, and vanadium. Arsenic concentrations were greater than the ISQG (5.9 µg/g) in all sampling areas, except those downstream of East Ravine and West Ravine. Sediments in five sampling areas had median values higher than 5.9 µg/g: upstream of Caution Creek (median = 6.1 µg/g); downstream of West Perimeter Ravine (6.1 µg/g); downstream of FalC Ravine (6.5 µg/g); downstream of Wapiti Ravine (7.3 µg/g); and downstream of English Creek (7.0 µg/g). No samples had arsenic concentrations that exceeded the LEL (9.8 µg/g) or PEL (17 µg/g) guidelines.

Nickel was above the LEL concentration (23.4 µg/g) in samples downstream of Caution Creek, West Perimeter Ravine, FalC Ravine, and Wapiti Ravine. Downstream of Wapiti Ravine was the only area with a median nickel concentration (26 µg/g) higher than 23.4 µg/g.

All sampling areas in the Saskatchewan River, except those downstream of East Ravine and 101 Ravine, had stations with vanadium levels greater than the LEL concentration (35.2 µg/g). Median vanadium concentrations were greater than 35.2 µg/g at six sampling areas: upstream of Caution Creek (44 µg/g); downstream of West Perimeter Ravine (44.5 µg/g); downstream of Duke Ravine (37 µg/g); downstream of FalC Ravine (56 µg/g); downstream of Wapiti Ravine (70 µg/g) and downstream of English Creek (48 µg/g).

Nutrients

Nutrient concentrations were high in English Creek relative to the other streams. The median organic carbon content and phosphorous concentration in English Creek were 1.09% and 460 µg/g, respectively, while the medians ranged from 0.01 to 0.80% and 140 to 290 µg/g, respectively, in the other streams.

In general, sediment samples from the Saskatchewan River contained higher nutrient contents than those from the streams. Median organic carbon contents from the river sampling areas ranged from 0.02% (downstream from East Ravine) to 2.2%, with the highest median values observed downstream from West Perimeter Ravine (1.28%), downstream from FalC Ravine (1.80%), and downstream from Wapiti Ravine (2.2%). The lowest median phosphorous concentrations were in sediments from sampling areas downstream of 101 Ravine (320 µg/g) and downstream of East Ravine (320 µg/g), while the highest were from sediments downstream of Wapiti Ravine (620 µg/g), downstream of West Perimeter Ravine (660 µg/g), and downstream of English Creek (670 µg/g).

Macro Elements

There was much variability in macro element concentrations among the streams. The greatest relative differences in concentrations were found in calcium, with median values that ranged from 3,280 µg/g (Caution Creek) to 23,100 µg/g (English Creek), and sulphates, with medians that ranged between 100 µg/g (East Ravine and FalC Ravine) and 650 µg/g (English Creek). Median concentrations of three of the five analyzed macro elements (calcium, magnesium, and acid-soluble sulphates) were higher in English Creek than in all of the other streams. Caution Creek tended to have low concentrations of macro elements. West Ravine, which had high ion concentrations in surface water samples, had the highest median sediment sodium concentration (380 µg/g); however, all other macro element concentrations were low relative to the other streams.

Concentrations of calcium, magnesium, and potassium tended to be higher in the Saskatchewan River than in the streams, while values of sodium and acid-soluble sulphate were similar to those in the inflowing streams. In the Saskatchewan River sampling areas, median concentrations of macro elements were lowest downstream of 101 Ravine (calcium, 25,800 µg/g; magnesium, 5,600 µg/g), downstream of East Ravine (potassium, 685 µg/g; acid-soluble sulphate, 95 µg/g), and downstream of Caution Creek (sodium, 170 µg/g). The highest median concentrations occurred downstream of Wapiti Ravine (calcium, 47,400 µg/g; magnesium, 15,000 µg/g; potassium, 6,180 µg/g; acid-soluble sulphate, 910 µg/g) and downstream of West Perimeter Ravine (sodium, 365 µg/g).

5.2.8.6 Summary

The surface water quality study conducted from 2005 through 2009 provides comprehensive baseline data for the Project LSA. The surface water quality in all streams, as well as in the reaches of the Saskatchewan River within and outside the Project LSA, documented baseline variability in water quality. Additionally, these baseline studies established that some water quality parameters may naturally occur at levels outside the levels recommended by provincial SSWQO (SE 2006) and federal CWQG (CCME 2007) guidelines. More specifically, in water concentrations of total iron and aluminum frequently exceeded the provincial/federal guidelines of 0.3 mg/L and 0.1 mg/L, respectively. These exceedances were observed throughout the streams and in reaches of the Saskatchewan River system in both the LSA and RSA. The high levels of iron were most notable, with the median iron concentration in a total of 21 of the 28 stations sampled being higher than the guideline value. Guideline exceedences of total copper and chromium were also observed in all study areas and several dissolved metal concentrations often exceeded guidelines for total concentrations in the streams. Metal guideline exceedances were most common in winter and summer.

Salinity varied across the study area, with total dissolved solids, conductivity, and major ion concentrations being higher in samples from West Ravine than in the other streams and the Saskatchewan River stations in the LSA and RSA. Within West Ravine, water quality in the furthest upstream part of the watershed had salinity parameters more similar to samples from the other streams than samples from the remaining West Ravine stations. The elevated salinity parameters measured at the majority of the stations in West Ravine could be attributed to seepage of process water into West Ravine during the exploration phase of the Project.

Sediment concentrations of macro elements, metals, and nutrients were variable. Among the streams, English Creek had the highest concentrations of macro elements and nutrients. Three metals (arsenic, nickel, and vanadium) frequently occurred at concentrations greater than one or more guideline values (ISQG, PEL, and LEL) in the streams and Saskatchewan River study areas.

These water and sediment quality parameter concentrations and their variations in the LSA and the RSA represent baseline conditions and will be used along with guidelines in the assessment of potential impacts of the Project on the local environment during construction and operations.