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ENVIRONMENT

Subject:
DRAFT
Groundwater Flow Provincial Information Requests
Star and Orion South Diamond Project

Date:
January 14, 2013

Contact:
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Our ref:
AC000820

Dear Mr. Richardson:

ARCADIS Canada, Inc. (ARCADIS) was retained by Shore Gold Inc. (Shore), to summarize required data and provide a formal response to selected provincial review comments on the revised Environmental Impact Statement (EIS) for the Star and Orion Diamond Project dated August 2012. The scope of work was outlined by ARCADIS in our proposal dated November 23, 2012.

## 1.0 BACKGROUND

The Province of Saskatchewan requested further information regarding multiple aspects of water management associated with the Star and Orion Diamond Project (Comment No. 1 and associated comments such as No. 58 of the Revised EIS). Based on the requests and subsequent meetings with the Saskatchewan Ministry of Environment (MOE), ARCADIS has prepared this letter report to provide a more complete discussion of the potential groundwater flow and contaminant transport patterns for the following:

- Processed Kimberlite Containment Facility (PKCF)
- Coarse Processed Kimberlite (CPK) pile
- Proposed Treatment Wetland in Duke Ravine
- Recovery Stockpile
- Polishing or Recycle Pond

The locations of these facilities are shown on Figure 1. In addition, ARCADIS has provided a discussion regarding the potential leaching of metals from the walls of the Star Pit.

## 2.0 CONCEPTUAL GROUNDWATER FLOW MODEL

In order to evaluate the potential groundwater flow, is it worthwhile to first review the shallow stratigraphy. A complete discussion of the geological and hydrogeological setting of the Star - Orion South Diamond Project Site (Site) is provided in Section 5.2.7 of the revised EIS (AMEC, 2012). A brief overview of the geological and hydrogeological setting is provided below.

The general stratigraphic sequence beneath the proposed facilities, in descending order, is typified by:

- Stratified surficial deposits (SSD)
- Saskatoon Group Tills
- Sutherland Group Tills

The SSD are composed of materials of late glacial/Holocene Age and include: glaciolacustrine clays, deltaic and outwash silt and sand. 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. Glaciofluvial sediments were then deposited on top of the glaciolacustrine clays 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. As a result, there is a silty sand sub-unit of the SSD on top of a lower clay portion of the SSD unit (this clay forms an upper aquitard). In some locations there is also a lower sand layer beneath the upper clay layer followed by another lower clay layer, however, these units are not present in all cases.

The Sutherland 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 Site, the upper contact of the Sutherland Group occurs as an oxidized surface with an elevation of between 360 and 370 metres above sea level (masl; Clifton, 2008). These Saskatoon and Sutherland Group Tills form the upper portion of the regional intermediate aquitard at the Site that separate the upper aquifer complex in the SSD from the deep bedrock aquifer in the Mannville Group.

The surficial sand portions of the SSD form the upper water table aquifer at the Site. This upper aquifer plays an important role in providing base flow to local creeks in the area, including springs along the Saskatchewan River valley. It is also used as a domestic water supply aquifer by many local residents. The groundwater flow within the aquifer generally is a subdued reflection of topography towards local streams. Based on previous work, the horizontal hydraulic conductivity of the surficial sand is estimated to be approximately 2 x $10^{-4}$ m/s (Judd-Henrey et. al., 2006) to $10^{-5}$ m/s (Klohn Crippen Berger [KCB], 2010).

Based on the local drilling and hydraulic testing results, the upper clay unit is expected to exert a major influence on shallow groundwater flow. The horizontal hydraulic conductivity of the upper clay unit is estimated to be $10^{-7}$ m/s (KCB, 2010). Infiltrating precipitation from the surface would be expected to flow vertically down to the water table and would recharge the groundwater regime. Given the permeability contrast between the surficial sand and upper clay units, horizontal flow in the surficial sands of the SSD should dominate. The assumption that the top of the silty clay portion is generally a subdued reflection of the surface topography, means that, in general, the shallow groundwater divides would follow surface water divides and that the groundwater flow direction would follow the surface topography. Given the fact that the top of the silty clay portion of the SSD was subject to glacio-fluvial erosion after it was deposited, it is also likely that there is some difference between the surface topography and the top of the silty clay portion of the SSD unit.

The groundwater and contaminant flow from the specific facilities are discussed in more detail below.

### 2. 1 PKCF

The fine processed kimberlite (PK) is produced from the initial washing and from the classifying circuits. These materials will be stored in the PKCF. The fine PK size distribution less than 1 mm and will consist of the following (KCB, 2010):

- Fines; 1 mm to +500 micron
- Ultra Fines; -500 micron in size

It is currently estimated that the fine PK will typically contain:

- 5% clay sized particles (< 2 microns)
- 45% silts sized particles (> 2 microns but <75 microns)
- 50% fine sand sized particles (> 75 micron but <500 microns)

The fine PK production rate will vary with ore type, however, is expected to average 1,000 tonne per hour (KCB, 2010). The fine PK would be pumped to the PKCF as a slurry with about 20% (by weight) solids.

In the area of both the PKCF and CPK pile, the observed thickness of the surficial sand portion of the SSD is 0 to 6.5 m thick, whereas the upper surface of the underlying clay has been observed to be between 6.5 to 16 m below the current ground surface and has a thickness of about 9.5 m (KCB, 2010). The PKCF will be excavated into the natural surficial materials, to create a smooth surface and the remove all vegetation and topsoil. The initial dykes of the PKCF will be built from SSD material sourced from initial pit excavation or adjacent sands. The inner slope of the starter berms will be capped with the till and/or from the clay portion of the SSD. After the initial operations, the dykes will be built up by running the fine PK through a cyclone. The fine portion of the fine PK will be disposed of in the PKCF but the coarser portion will be used to build up the dykes. The cyclone will dewater the coarser portion (1 mm to + 500 um). The PKCF will be surrounded with both diversion ditches to divert clean water around these facilities where needed and also toe or drainage ditches. These drainage ditches will collect runoff and shallow groundwater flow from the facility. The toe or drainage ditches will be approximately 3 m deep from existing grade and, if possible, will be keyed into the upper clay layer of the SSD. The drainage within the drainage ditches will flow by gravity to low points around the facility and will be pumped back to the PKCF and/or the treatment wetland.

After construction but prior to operations, precipitation will collect in the PKCF. This precipitation will infiltrate vertically until it reaches the water table aquifer (generally about 3-4 metres below the original ground surface) and then travel horizontally, generally following the topography of the top of the clay surface of the upper clay layer of the SSD. To examine the travel time for groundwater under natural conditions, ARCADIS performed a preliminary 2-dimensional (2D) analytical calculation of groundwater travel time from the proposed PKCF prior to the commencement of operations, prior to build-up of a settled low permeability fine PK layer at the base of the PKCF. This solution and related assumptions are described in Appendix A. Based on the assumptions described in Appendix A, the time required for groundwater to travel from the centre of the facility to Duke Ravine is 1.9 years. The time required for groundwater to travel from the edge of the dyke to Duke Ravine, the nearest assumed discharge point is 1.1 years. The estimated time for precipitation to infiltrate through natural materials at the PKCF to the water table in the upper sand aquifer and connect is only about 1 day.

Following commencement of operations at the PKCF (Figure 2a), the fine PK slurry would be pumped into the PKCF. The main focus of the PKCF is to settle out the solids in the fine PK so that the water can be reused. Initially, it is expected that the water in the slurry would infiltrate into the subsurface and flow vertically until it reaches the water table aquifer (generally about 3-4 metres below the original ground surface) (Figure 2a). Once it has entered the water table aquifer, assuming that the top of the upper clay layer of the SSD is a subdued reflection of the surface topography, the groundwater flow from most of the PKCF would then flow to the south, and west (see Figure 1). Groundwater flow beneath the northeast section of the PKCF facility would eventually flow eastward toward English Creek. The majority of the groundwater flow beneath the PKCF would be westward and southward towards Duke Ravine and also the PKCF Ravine, situated approximately 500 m north of the crest of the Saskatchewan River valley, to the southeast of the PKCF..

During the initial operations, the fine PK would start to settle out onto the bottom of the PKCF and lower dyke walls. Estimates of the hydraulic conductivity of the fine PK tailings material were previously obtained from grain size distributions of the fine grained materials that were produced from the previous pilot processing plant. While the fine PK produced by the pilot plant is slightly greater in size than what is anticipated for the full scale processing plant, using a variety of empirical methods, a conservative estimate of the hydrualic conductivity of these materials were obtained (Judd-Henrey, 2006). In 2006, three samples of PK from the pilot plant were selected in order to represent the observed size range of the tailings and the estimated hydraulic conductivity from these samples ranged from $4x10^{-10}$ to $3.x10^{-6}$ m/s. Generally, the fine PK had a hydraulic conductivity that was at least two orders of magnitude lower than that of the surficial sand layer of the SSD.

As a result, as this layer of fine PK builds up on the base and walls of the PKCF, this layer would reduce the infiltration of water from this facility into the subsurface and begin to form a low permeability barrier on the inside of the PKCF. Based on the knowledge obtained with the pilot plant and the 20% solid volume in the fine PK slurry, it is expected that this layer would develop quickly.

During the early stages of operation (Figure 2b), the low permeability barrier would continue to develop. This barrier will begin to effectively create a low permeability layer which would greatly restrict vertical flow of water through this sequence, and the movement of water through the base of the PKCF would become minimal. However, infiltration of water from the PKCF would still occur through the upper portions of the dyke wall, where no settling of fines had yet occurred. The groundwater would then flow towards Duke Ravine to the west and towards English Creek in the east (Figures 1 and 2b).

Using the same preliminary 2-dimensional (2D) analytical solution of groundwater travel time, the travel times from the proposed PKCF after a buildup of about 12 metres of fine PK (this would likely occur after about 2 years of operations) were estimated. Based on the assumptions described in Appendix A, the time required for process water in the PKCF to move vertically through the fine PK to the water table, at the center of the facility, and then to travel from the centre of the facility to Duke Ravine is estimated to be 117 years. The total time required for groundwater to travel from the edge of the dyke to Duke Ravine through the dyke (around the buildup of fine PK) is about 1.9 years. It is interesting to note that the predicted groundwater travel time was significantly longer (more than 100 years) after 12 m of fine PK had built up in the PKCF and the estimated mass flux through the fine PK would also significantly reduced. The estimated travel time from the edge of the PKCF is a conservative estimate as expected rapid reduction in the hydraulic conductivity of the dykes due to suspended sediments in the process water blocking the flow paths was not considered in this estimate of the travel time. This reduction in hydraulic conductivity was not considered at this time as it is very difficult to estimate the magnitude of this effect It is worthwhile to note that this blinding off of the hydraulic conductivity of the dykes will occur on an on-going basis such that most of the flow through the dyke will be restricted to the uppermost portion of the dyke, that has been recently flooded due to the increasing water level in the PKCF. It is also expected that most of this groundwater would be captured by the drainage ditches (90% as stated in the Revised EIS; Shore Gold 2012).

During late stages of operation (Figure 2c), the dykes would continue to be developed and increase in size. This would accompany the continued deposition of the low permeability layer of fine PK in the bottom of the facility and the increasing elevation of the water surface within this facility. The fine PK in the bottom of the facility would reach a considerable thickness along the bottom and lower portions of the dykes. This thick sequence of low permeability material would effectively inhibit the vertical movement of water downwards through this sequence. This would result in the main path of water movement being laterally through the newly exposed upper portions of the dyke walls and through the dykes themselves. Water that moves though the dykes would, with time, seep into the surface either along the bottom of the dyke and/or be collected in the drainage ditch at the bottom of the dykes.

As indicated in revised EIS (Shore Gold, 2012), the PKCF would not be used during the mining of the Orion South kimberlite. During this time, the fine PK would be pumped into the mined-out Star Pit, which would be allowed to begin to fill with water and fine PK. As a result, the liquid level in the PKCF would begin to decline as ponded water exfiltrates into the surrounding dykes and/or evaporates. At closure, the top of the PKCF would be re-contoured in order for precipitation to drain off the facility in a controlled manner. After that point, any remaining water infiltration through the PKCF would be minimal (Figure 2d) as a cap of at least 1 m clay or till would be placed in low lying areas on the PKCF for reclamation and minimize further water inputs (see response to Provincial SIR #5 for the Revised EIS). As a result the groundwater quality from beneath the PKCF would be expected to improve over time. ..

The concentration of contaminants from the PKCF were estimated in the revised EIS (Shore Gold, 2012). To be conservative in the assessment of contaminant flow from the PKCF, the retardation of some of the contaminants of concern was not considered. .



## 2.2 CPK Pile

The coarse PK is produced from the dense media separator. Two coarse PK streams will be produced and are (KCB, 2010):

- -45 mm to +8 mm
- -8 mm to +1 mm

Both of these size fractions may be stored in the CPK pile, either permananently or on a temporary basis. The proposed production rate of coarse PK duiring operations is 261 tonnes per hour (tph). The coarse PK would be conveyed on a conveyor belt system to the CPK pile, and then mechanically flattened and slightly compacted. As a result, very little water would be initially deposited with the coarse PK fraction, and the CKP pile would be expected to be mainly free draining with only a fraction of the water content held within the pore spaces of the coarse PK. Initially, the chemistry of the water in the CPK pile would contain elevated levels of chloride and certain metals. The concentrations of these contaminants would be expected to decrease slightly over longer periods of time as weathered surfaces would develop, thus reducing the contact between the fresh water that infiltrates into the pile due to precipitation and on-going operations.

Vertical water flow would be expected within and beneath the CPK pile until it reaches the water table (in the highland areas the water table is generally about 2 – 3 metres below the natural ground surface). Some mounding of the water table beneath and/or within the CPK pile may occur. As discussed previously, groundwater flow within the water table aquifer would tend to be predominantly horizontal. It is expected that the impacted groundwater flow beneath the majority of the CPK pile would flow would be to northwest towards the East Ravine (~60%) and most of the remaining groundwater would flow northeast towards Duke Ravine (~40%) (Figures 1 and 3). Figure 3 shows that some of the lateral groundwater flow would be expected to be captured by the drainage ditch which is to be located approximately 5 metres from the edge of the CPK pile. The percent of the lateral flow that these drainage ditches would capture would be dependent on the depth of the ditches, the thickness of the upper sand layer at this location and whether the ditch can be excavated into the upper clay layer. If the drainage ditch was excavated into the upper clay layer of the SSD, then it is likely that the drainage ditch would be able to capture more than 95% of the total groundwater and contaminant flow from the CKP facility (a small portion of the impacted groundwater may flow vertically through the upper clay layer).

The CPK pile, like the PKCF, will be surrounded with both diversion ditch to divert clean water around this facility as needed and also a drainage ditch. The drainage ditch will collect runoff and shallow groundwater flow from the facility. The drainage ditch will be approximately 3 m deep and, if possible, will be keyed into the upper clay layer of the SSD. The drainage within the drainage ditches will flow by gravity to low points around the CPK pile and will be pumped back to the PKCF and/or the treatment wetland.

The concentrations of contaminants from the CPK pile were estimated in the revised EIS (Shore Gold, 2012). As with modeling for the PKCS, to be conservative in the assessment of contaminant flow from the CKP pile, the retardation of some of the contaminants of concern was not considered. .

## 2.3 Proposed Treatment Wetland in Duke Ravine

There are several wetlands in the area that may at some point be used as polishing wetlands. The first polishing wetland will be the wetland in the upper reaches of the Duke Ravine (Figure 1; see ARCADIS 2013 for details). This wetland contains both open water wetland and vegetation dominated depression type wetland components. Currently the wetland has been formed by both the damming by beavers of the Duke Ravine, causing backwater effects, and also by surface runoff and groundwater seepage from the upper sand layer of the SSD into this low lying area (Figure 4).

During operations this area would still be expected to receive approximately the same or greater volumes of shallow groundwater due to the additions of water from the CPK pile and the PKCF (see Figure 3). This prediction is complicated by the fact that the regional groundwater flow (SRK, 2010) predicts that during operations there would be an approximately drawdown or drop in the shallow water levels of about 1 m. This drop in water levels (and a resultant drop in groundwater flows to this area) is predicted due to pit dewatering and pumping of the lower Mannville Group aquifer. The Mannville Group aquifer is located at significant depth (> ~400 m below the bottom of the sand layer of the SSD. It should be remembered that the regional groundwater flow model was designed to predict the regional effects and was not designed to predict site specific surficial effects beneath each individual facility. In addition, this regional groundwater flow model is very conservative rate of infiltration of precipitation into the shallow groundwater flow regime. As a result the groundwater flow model (SRK, 2010) is not the most appropriate tool to describe site specific behavior of seepage beneath these facilities, , in our opinion the previously submitted water balance analyses at the site facilities is the more appropriate tool (Shore Gold, 2012). The previously submitted water balance analysis included an examination of the effects of the proposed development on the local surface water bodies, including Duke Ravine (Shore Gold, 2012). This analysis suggested that the flows in Duke Ravine would slightly increase over the baseline conditions during both operations and closure.

2.4 Polishing or Recycle Pond.

A small polishing or recycle pond is planned between the PCKF and the plant site. The water in this pond would undergo a final settling prior to it being pumped back and used in the processing plant. This pond is to be a small lined facility with a length to width ratio of 4 to 1 to increase residence time in the pond. Water will enter on one side of the pond and will be pumped from the other side. The water level in this pond will generally be maintained at a level above the water table (expected to be about 2-3 m below the natural ground surface), however, the bottom of the pond may encounter the water table.

The groundwater flow in the area of the Polishing Pond is towards the southwest towards Duke Ravine. However, as the pond will be lined, the infiltration of water to the groundwater flow regime will be negligible (Figure 5). Since the bottom of this pond will likely have to be below the average annual water table elevation, some mounding of groundwater on the up-gradient (northeast side of the pond) may occur. If possible, the long axis of the pond should be oriented northeast to southwest, parallel to the direction of the natural groundwater flow to minimize the impacts on the groundwater flow system.

2.5 Recovery Stockpile

The recovery stockpile would consist of temporary stockpiles of dense material from the processed PK that would be periodically audited and may be subjected to further processing to remove additional diamonds (Figure 6). The size of these stockpiles would therefore change during site operations and is expected that these piles will not be left in place at closure (i.e. they will either be processed or conveyed to either the CPK pile and/or the PKCF and encapsulated in till or clay as per response to Provincial SIR #33 on the Revised EIS).

These recovery stockpiles are also to be subdivided into two piles; finer and coarser material piles. Given the partial processing of these materials and the fact that they are conveyed to this location, both piles are expected to be coarser than the fine PK in the PKCF and more similar in size to the coarse PK. They would therefore be expected to be free-draining.

The topography in the immediate area of the plant site will be leveled prior to the construction of the plant site and associated facilities such as the recovery stockpile area. These recovery stockpiles will be lined with a 0.5 m thick till layer which would limit the downward movement of water from these piles, with a layer of CPK on top of the till to act as a wicking layer and buffer any potential acid generation. There would also be a drainage ditch that would collect any drainage from these facilities. The water in this drainage ditch, depending on the water quality, would be pumped to the plant or PKCF.

Due to the presence of the 0.5 m of clay till liner underneath the stockpiles, with drainage layer above, it is expected that most of the drainage from these piles and the precipitation that falls on these piles will be collected in the drainage ditches that surround them. Based on the natural topography in the area surrounding the recovery stockpiles (Figure 6) any water that flows through the till containment layer, will then move under the natural shallow groundwater flow regime towards the northeast (fine storage pile) or towards the southeast (coarse material stockpile). Both groundwater flow paths would be eventually towards the Duke Ravine

## 3.0 POSSIBLE METAL LEACHING FROM PIT WALLS

An information request was raised by the provincial reviewers regarding metal leaching from the kimberlite wall of the two open pits (Star and Orion South). The final predicted water quality in the Star and Orion South pit lakes is discussed in the revised EIS (Shore Gold, 2012) along with the proposed method of development and closing of these pits. This discussion includes both; a brief summary of the development of theses pits from a water flow perspective; and the resultant pit lakes is provided below; and a discussion of the conservatism that has been built into the estimates of the water quality in these pit lakes and the effect of the metal leaching from the kimberlite along the wall

### *Development of the Pit and Resultant Pit Lakes*

During the advancement of the open pits, a thin layer of kimberlitic material will be left to form the walls for each bench. Leaving this layer of material ensures a more structurally sound wall, allowing for a greater wall slope and ultimately a higher recovery volume of ore for processing. The kimberlite layer separates the pit from the surrounding Colorado Group shale and Mannville Group sandstones. Groundwater flow through the Mannville Aquifer is main source of groundwater concern. The kimberlite has a much lower hydraulic conductivity than the surrounding Mannville Group Aquifer. Based on the values used in the SRK groundwater flow model, the kimberlite had a horizontal and vertical hydraulic conductivity of 0.0002 m/day (SRK, 2011). The horizontal hydraulic conductivity of the Mannville Group was 0.01 to 3 m/day. This indicates the horizontal hydraulic conductivity of the kimberlite is about two orders of magnitude that of the least productive (the upper portion) of the Mannville Aquifer.

The plan is to dewater the Mannville Aquifer during operations so as to minimize the inflow of water from the Mannville Aquifer to the pit. After active mining of the pit is complete, the dewatering of the Mannville Aquifer would stop and the pit will be allowed to fill. While the pit is dewatered, the surrounding portions of the Mannville and Colorado Groups and the kimberlite left around the pit would be dewatered..

At the beginning of closure it is assumed that Star pit will have about 3 m of process water on top of saturated processed kimberlite from mining Orion South. This water will be available to mix with other water sources during pit infilling. The Star pit at the end of infilling will be approximately 40-50 m deep and the Orion South pit lake will be approximately 230 m deep (SRK, 2011). The Star pit infilling process will take about 350 years and will fill to an elevation of 392 masl (more than 30 m below the original groundwater elevation). At the end of infilling, the Star pit will spill over towards the Saskatchewan River through the East Ravine Channel. The SRK model (SRK, 201) predicts that after 100 years, the Orion South pit lake is predicted to be 85% filled. The final elevation for the Orion South pit is predicted to be 411 masl. At this elevation, the Orion South pit lake will not overflow. Therefore the rate of inflow is low and the final elevation is an average of all input and outputs from these pits. Predicted water quality in the upper portion of the Orion South pit and Star pit is presented in the Revised EIS (Shore Gold, 2012)

At closure the sources of water that flow into these pits will include: Mannville Aquifer groundwater, shallow groundwater, precipitation and runoff and surface water. Initially most of the groundwater will originate from the Mannville Aquifer and will have to flow through the Kimberlite layer along the walls. Initially most of the water that flows naturally into these pits is predicted to come from the Mannville aquifer. In the long term, post closure, 80% of the inflow into the Star Pit will eventually come from surface water (SRK 2011). As a result, water quality that may have been affected by any metals picked up as the Mannville water flows through the kimberlite walls will improve over time. The final elevations for both pit lakes is also above the natural piezomteric head elevation in the Mannville Group, so at some point in time after closure there will be a flow reversal so that Mannville groundwater will no longer discharge into the pit lakes, but rather flow will be from the pit lakes into the Mannville Aquifer.

***Metal Leaching***

The estimates for the water quality in the pit lakes and the effect of the metal leaching from the kimberlite are believed to be conservative for a number of reasons (Shore 2012 and SRK 2011) including the:

- conservative methodology used to estimate the leaching of metal components from the kimberlite:
- reduction in any secondary permeability flow paths due to increased normal forces;
- development of weathering surfaces and biofilm on the fracture surfaces through the kimberlite;
- buildup of fine-grained particles on the up-gradient side of the kimberlite; and
- Star pit lake likely becoming a stratified water body with better quality water at surface.

These are discussed in more detail below.

The revised EIS (Shore Gold, 2012) has a discussion of the metal leaching from processed kimberlite (Section 5.2.3) from both Star and Orion South deposits. Based on the results of tailings samples collected and analyzed during previous investigations (Judd-Henrey et al., 2006) and both metal leaching and acid base accounting (revised EIS, Shore Gold 2012), the most abundant elements in the kimberlite tailings in order of decreasing concentration were iron, aluminum, titanium, nickel, sulfide, manganese, barium and chromium. The processed kimberlite on which these metal leaching tests were run, had been mechanically crushed in order to maximize the liberation of diamonds. The processing would therefore greatly reduce the grain size and increase the surface area. The increased surface area would also increase the amount of metals available to be leached. This testing showed that while the concentrations of some components remained stable, some of the metals decreased in concentration with time. Using these results to evaluate leaching from the intact (non-crushed) kimberlite walls is considered a conservative approach.

The excavation of the pit and the dewatering of the rocks and soils are expected to have a major impact on the stress regime around the pit. Prior to the excavation and dewatering of the pit, the weight of the overlying rock and soils is held up in part by the hydrostatic pressure or pressure head at depth. With the reduction of the hydrostatic pressure due to dewatering it is likely that the fractures in the kimberlite would tend to be subject to an increase in the normal pressures which in turn may reduce the cross sectional area (close any secondary permeability or fractures in the kimberlite).

There are also chemical and biological processes that would be expected to reduce the leaching of metals from the kimberllite walls by forming a layer over these kimberlite surfaces. The introduction of air into the secondary permeability of the kimberlite would also tend to weather the exposed surface. This process would start well before the start of closure and so that at closure it is likely that weathered surfaces are present on the most transmissive areas. In addition, once the fractures become re-hydrated, during closure, there is a likelihood that a biofilm may develop on the pit walls and on the most transmissive fracture walls due to the presence of organics (from the atmosphere and from runoff / shallow groundwater inflows) and oxygen. The formation of both weathered surfaces (relative to fresh surfaces) and biofilm would be expected to reduce the rate of metal leaching as groundwater moves through the kimberlite walls.

As previously indicated, during the early portions of closure most of the water that naturally flows into these pits will originate from the Mannville Aquifer and will have to flow through the Kimberlite layer along the walls. The relatively low permeability kimberlite walls would control the rate of groundwater seepage into the pit and with time, fine-grained particles settling out of suspension would collect on the walls and would tend to further reduce the hydraulic conductivity of the pit walls. This affect and the other potential reductions in the permeability of the kimberlite may also increase the likelihood that the deep groundwater in the Mannville aquifer will flow around the kimberlite shells rather than through them.

The Star pit during infilling and into the long term is modeled by the revised EIS water quality model (Shore Gold, 2012) as a fully mixed basin. This is the most simplistic assumption and is the most conservative from a water quality perspective. A more likely scenario is that the lake will stratify and create meromictic conditions where the upper active layer of the lake is sitting over a stagnant dynamically passive lower layer. This will mean that the better quality water from surface water and shallow groundwater sources will be on top of poorer quality water at depth. This will result in the better quality water than what is predicting discarding Saskatchewan River and being ecologically available. As a result the water quality modeling is considered to be conservative.

## 4.0 RECOMMENDATIONS

Monitoring is proposed in the Revised EIS (Shore 2012) in order to confirm the predictions of the groundwater flow from the facilities of the proposed Star -Orion South Diamond Project. This report describes the predicted pathways that process water and other water that has the potential to interact with processed kimberlite may take towards neighbouring ravines. The monitoring program includes the installation of monitoring wells into both the surficial sand layer of the SSD, the upper clay layer of the SSD and any underlying sand layers within the SSD (if present). The monitoring program also includes, but is not limited to, the collection of water samples from the Duke Ravine wetland, Duke Ravine (near the Saskatchewan River) and English Creek.

More detail about the monitoring program will be developed during detailed design and modified as appropriate through construction and operation as more information is obtained at these facilities (e.g. whether the drainage ditch around the PKCF is excavated into the upper clay layer of the SSD and the observed elevation of the top of the clay). Surface water samples and flow measurements will be collected prior to the initiation of construction in order to update data on natural baseline flow rates and quality.

## 5.0 REFERENCES

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US Department of Energy – Argonne National Laboratory, Environmental Science Division – Total Porosity: http://web.ead.anl.gov/resrad/datacoll/porosity.htm , visited December 2012.

## 6.0 CLOSURE AND LIMITATIONS

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We trust the above meets your requirements and look forward to continuing to assist you. If you have any questions or comments regarding the attached, or require any additional information, please do not hesitate to contact Ian Judd-Henrey at 306-249-2141).

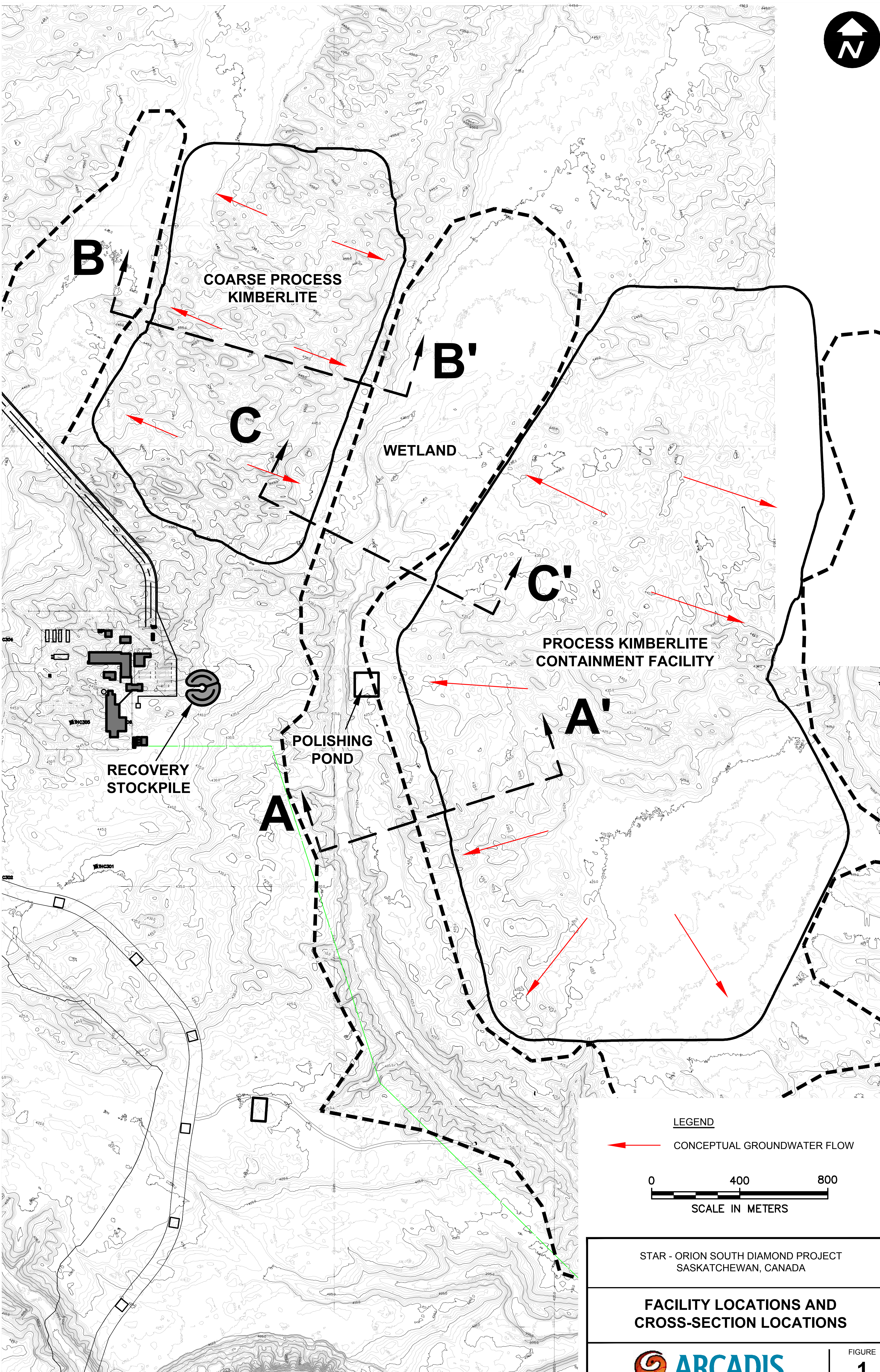
Sincerely,

ARCADIS Canada Inc.

DRAFT

Ian Judd-Henrey, M.Sc., P.Geo.
Principal Scientist

Copies:
[Copies]




STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

FACILITY LOCATIONS AND
CROSS-SECTION LOCATIONS

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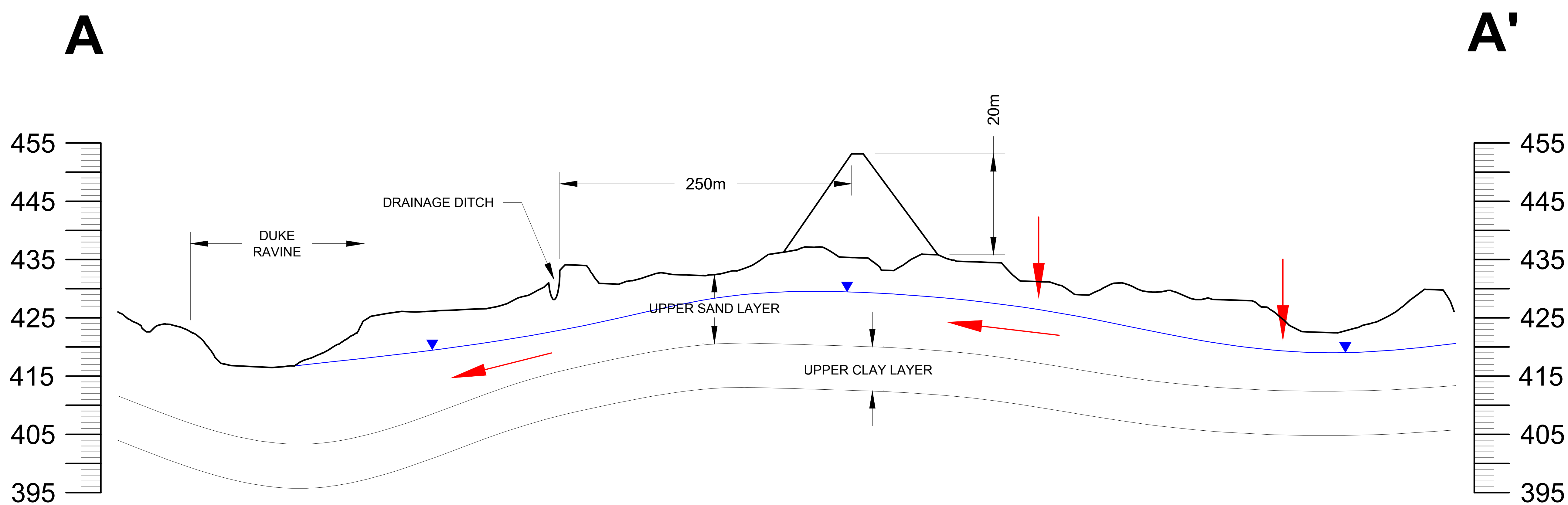
FIGURE
1

CITY:NOVI DIV/GROUP:ENV DB: PIC: PM: TM: TR: PROJECT NUMBER:
LAYOUT: CONTAINMENT SECTION LOCATIONS SAVED: 1/3/2013 2:13 PM ACADVER: 18.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: ARCADIS NOVI.CTB PLOTTED: 1/3/2013 4:51 PM BY: YARBROUGH, TOBI




LEGEND

GROUNDWATER FLOW DIRECTION

CONCEPTUAL WATER TABLE

0 100 200

SCALE IN METERS (APPROXIMATE)

5X VERTICAL EXAGGERATION

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**PKCF - START OF OPERATIONS**

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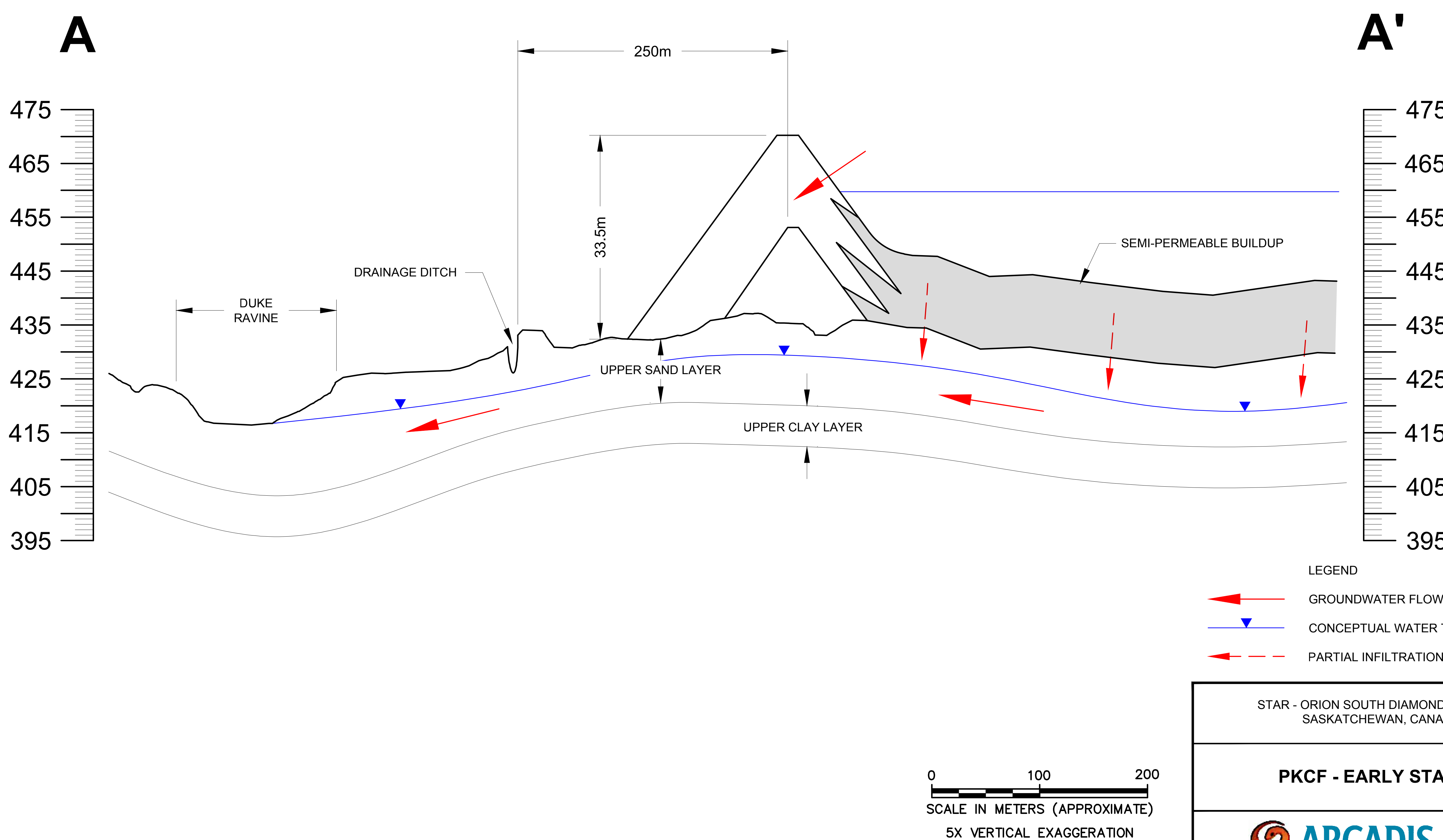
FIGURE **2a**




LEGEND

- GROUNDWATER FLOW DIRECTION
- CONCEPTUAL WATER TABLE
- PARTIAL INFILTRATION

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**PKCF - EARLY STAGES**

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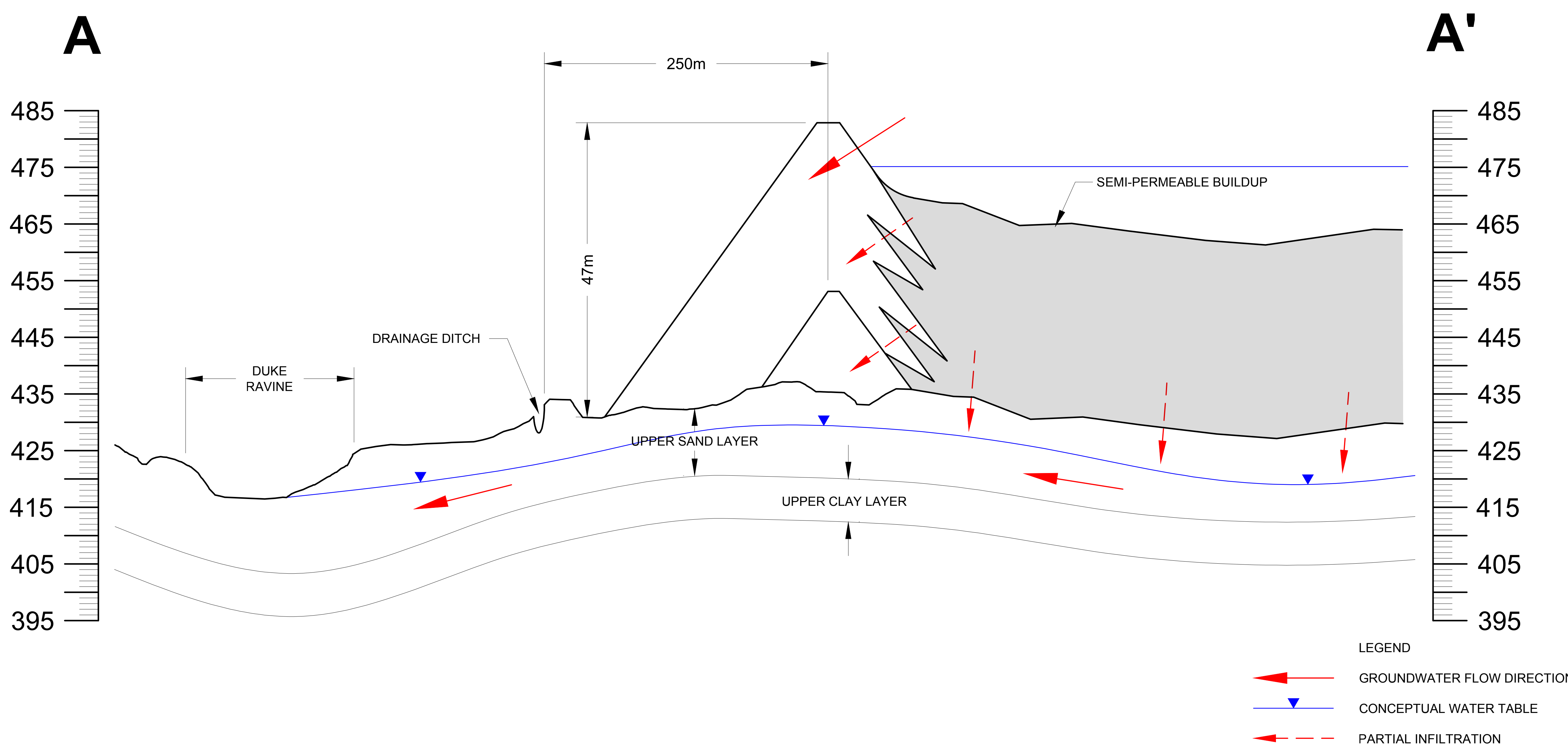
FIGURE **2b**

CITY:NOVI DIV/GROUP:ENV DB: PIC: PM: TM: TR: PROJECT NUMBER:
D:\GIS\Project Files\ShoreGoldProject\CAD_Data\StockpileSections_rev2.dwg LAYOUT: FACILITY AT EARLY STAGES SAVED: 1/7/2013 2:56 PM ACADVER: 18.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: ARCADIS NOVI.CTB PLOTTED: 1/7/2013 3:14 PM BY: YARBROUGH, TOBI




0 100 200

SCALE IN METERS (APPROXIMATE)

5X VERTICAL EXAGGERATION

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**PKCF - LATE STAGE**

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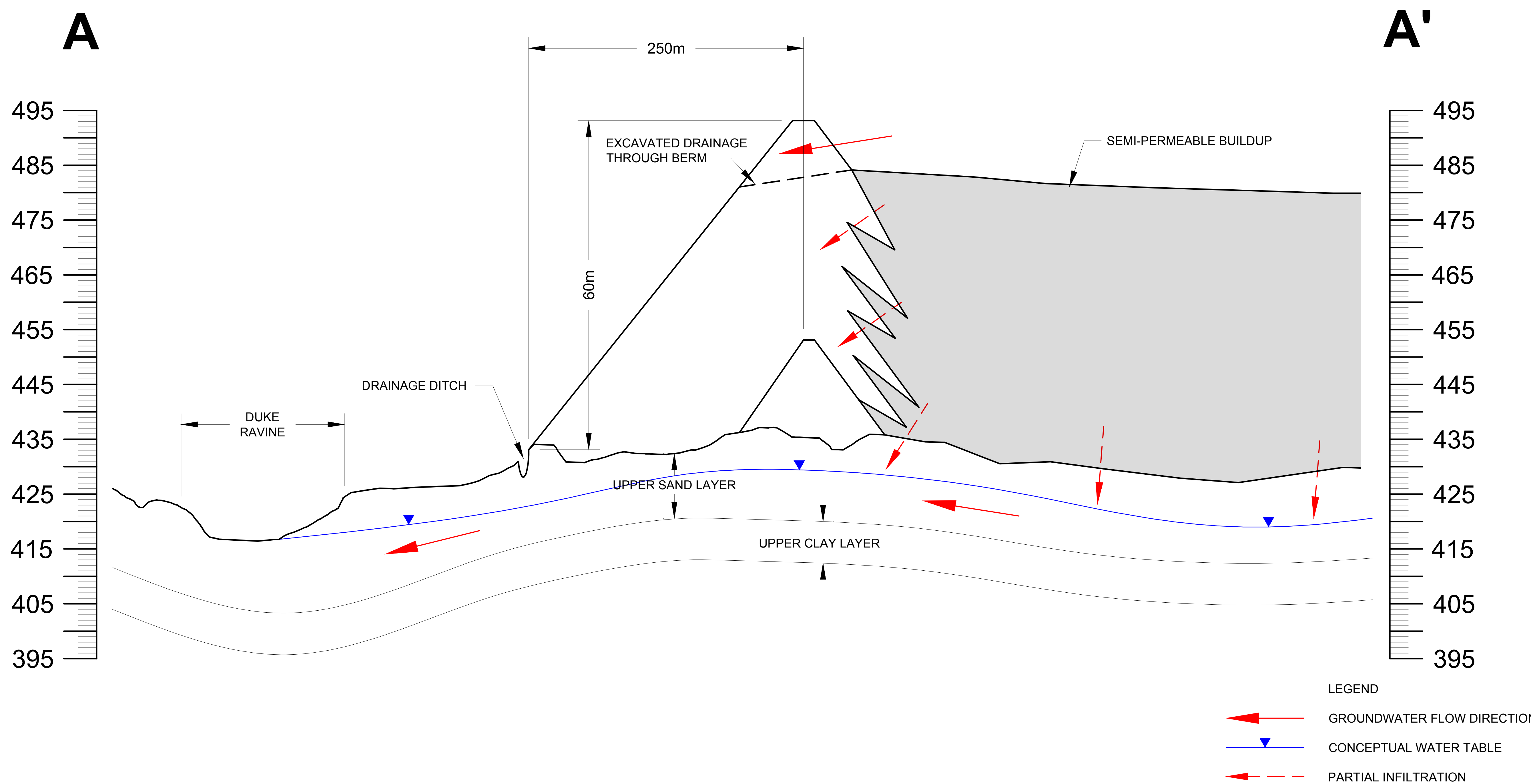
FIGURE **2c**

CITY:NOVI DIV/GROUP:ENV DB: PIC: PM: TM: TR: PROJECT NUMBER: LAYOUT: FACILITY AT LATE STAGE SAVED: 1/7/2013 2:56 PM ACADVER: 18.1S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: ARCADIS NOVI.CTB PLOTTED: 1/7/2013 3:14 PM BY: YARBROUGH, TOBI
D:\GIS\Project Files\ShoreGold\Project\CAD_Data\Stockpile\Sections_rev2.dwg




0 100 600

SCALE IN METERS (APPROXIMATE)

5X VERTICAL EXAGGERATION

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SASKATCHEWAN, CANADA

**PKCF - AT CLOSURE**

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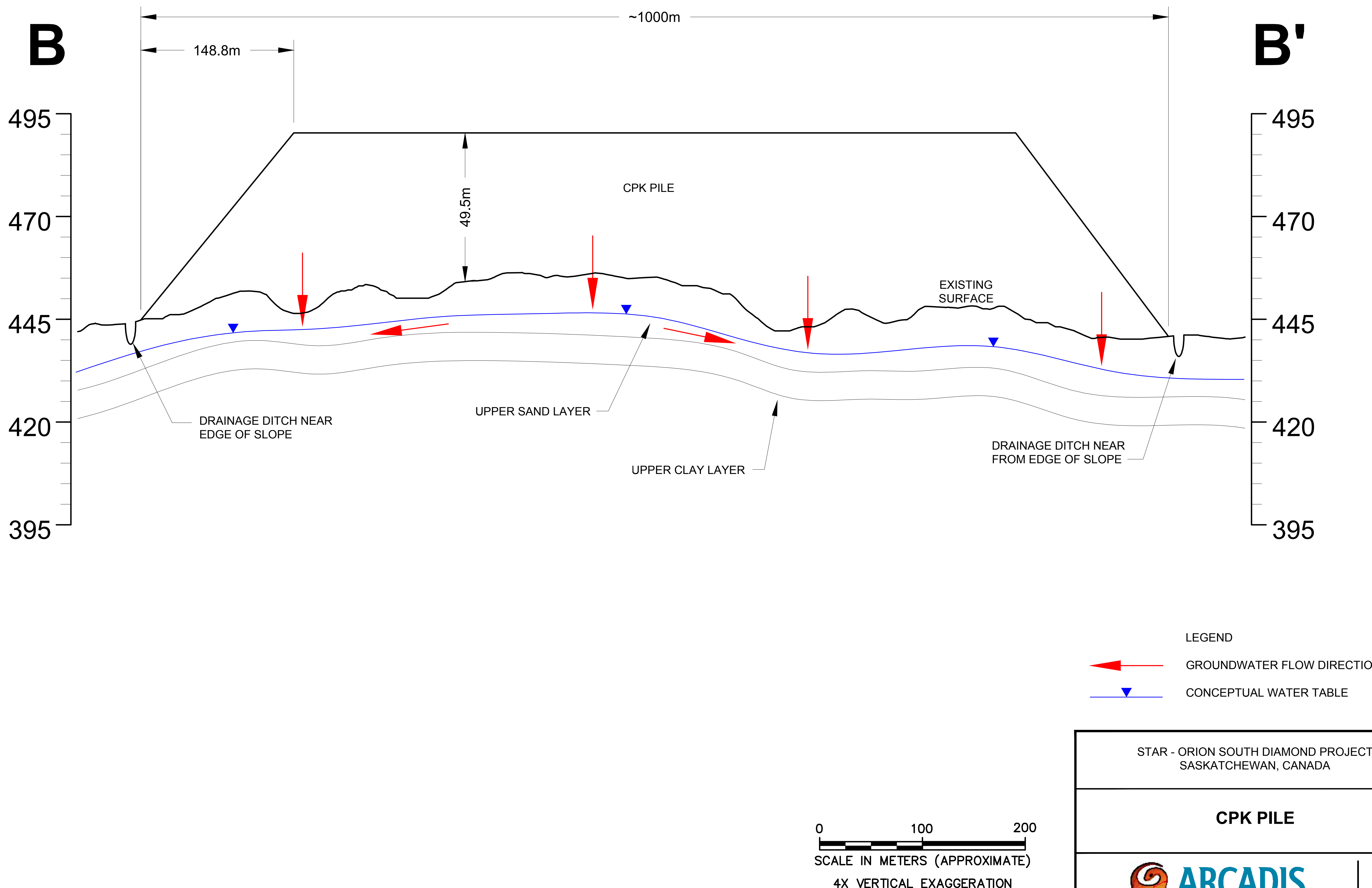
FIGURE
**2d**




STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**CPK PILE**

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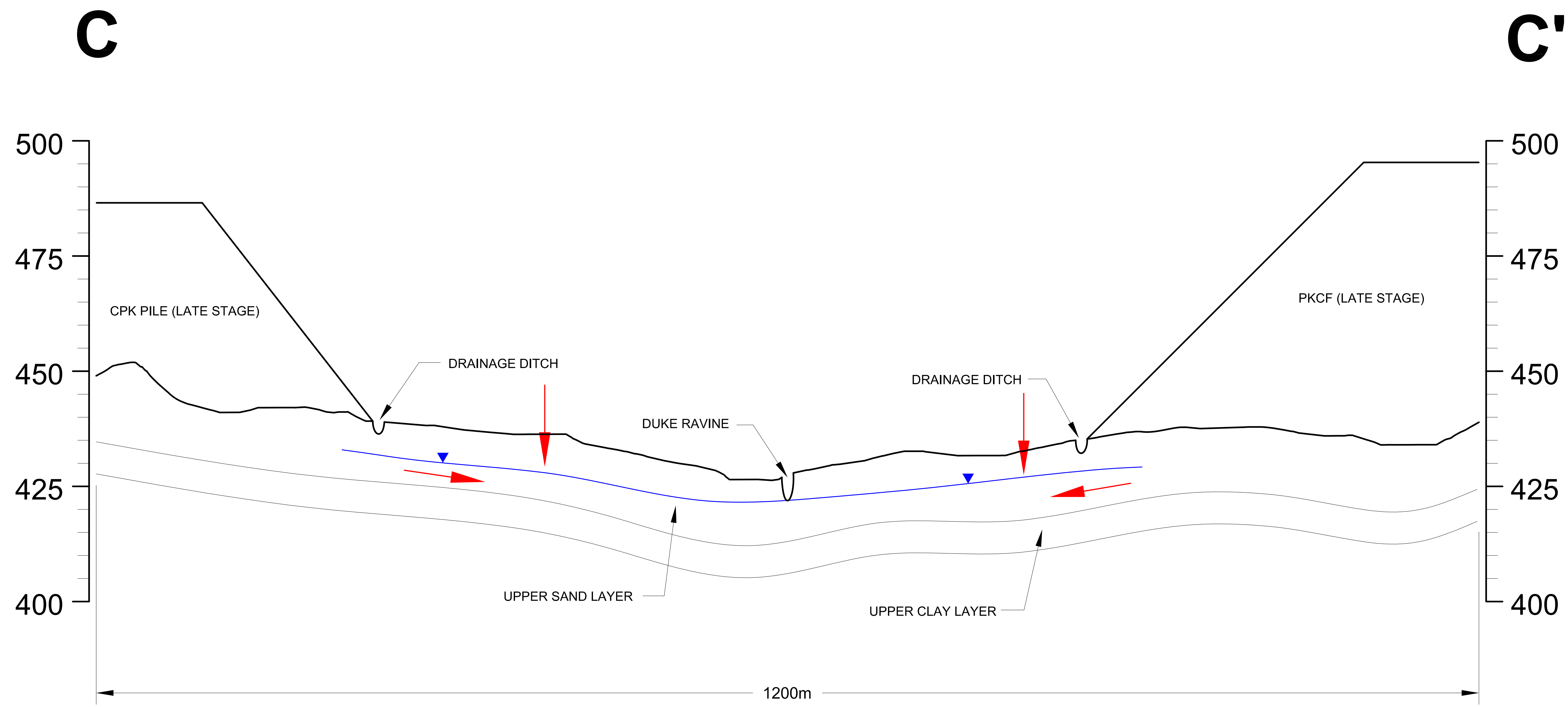
FIGURE
**3**




LEGEND

GROUNDWATER FLOW DIRECTION

CONCEPTUAL WATER TABLE

0 100 200

SCALE IN METERS (APPROXIMATE)

4X VERTICAL EXAGGERATION

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**GROUNDWATER FLOW NEAR DUKE WETLAND**

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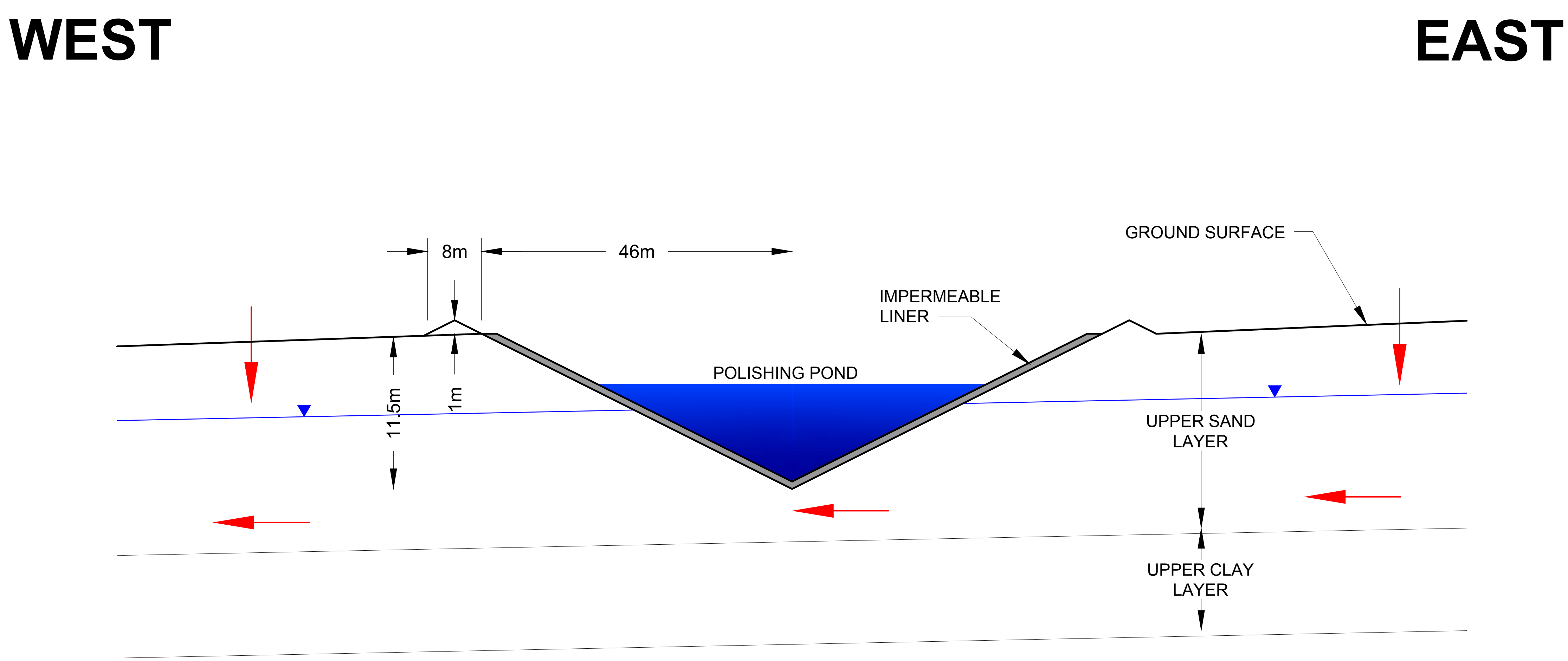
FIGURE 4




LEGEND

GROUNDWATER FLOW DIRECTION

CONCEPTUAL WATER TABLE

0 20 40
SCALE IN METERS (APPROXIMATE)

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**POLISHING POND**

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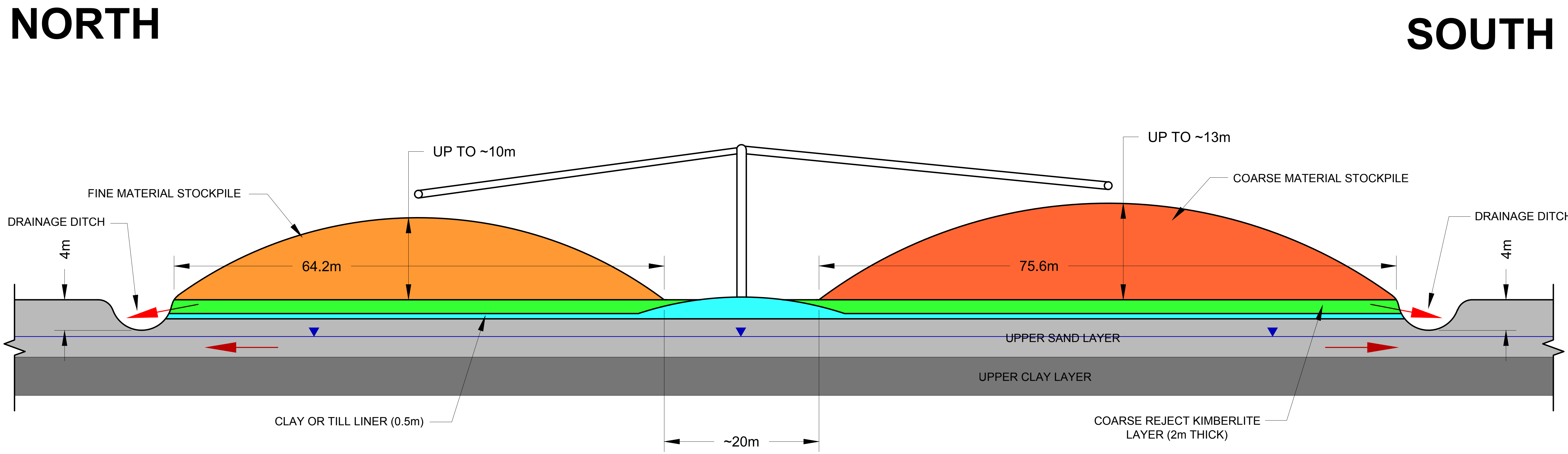
FIGURE 5




LEGEND

GROUNDWATER FLOW DIRECTION

CONCEPTUAL WATER TABLE

NOTE: THE STOCKPILE IS SITUATED ON A CONVEX MOUND WITH THE CENTER BEING 1.5m HIGHER THAN THE CIRCUMFERENCE

0 20 40

SCALE IN METERS (APPROXIMATE)

STAR - ORION SOUTH DIAMOND PROJECT
SASKATCHEWAN, CANADA

**RECOVERY TAILINGS STOCKPILE**

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FIGURE
6

**APPENDIX A:**

**TWO DIMEMSIONAL ANALYTICAL SOLUTION OF TRAVEL TIME FROM THE PKCF**

**TWO DIMEMSIONAL ANALYTICAL SOLUTION OF TRAVEL TIME FROM THE PKCF**

Using these assumed groundwater flow patterns discussed above, ARCADIS completed a preliminary 2-dimensional (2D) analytical solution of groundwater flow from the proposed PKCF for two scenarios. The first scenario was prior to the commencement of operations, prior to build-up of a settled low permeability fine PK layer. The second scenario was after the PK layer had built up to a thickness of about 12 m.

***Scenario 1: Prior to Commencement***

A 2D conceptual solution was developed for the groundwater flow and water infiltration in the area of the PKCF represented by cross-section A-A' (Figure x). The conceptual model was used to determine the time required for a particle of water to infiltrate from the bottom of the PKCF containment area, into the upper sand layer and travel to the nearest natural receptor, Duke Ravine. The retention time is dependent on infiltration rate through the upper surficial sands, the time until connection with the natural groundwater flow and lateral groundwater flow rate through the upper surficial sands. A lateral thickness of 1 m was used as a constraint to effectively make the conceptual model represent a 2D analysis bounded by the upper clay layer. To ensure the most conservative results, the analysis was completed assuming saturated conditions prior to the initial build-up of a low permeability layer within the PKCF. Additionally, for the purposes of simplification, the aquifer was modeled as homogeneous and of uniform thickness. Flow through the aquifer was assumed to be laminar throughout (i.e. 1 > Reynolds Number > 10). The horizontal hydraulic conductivity of the aquifer was obtained from the results from slug testing conducted in Piezometer 402; presented in "Preliminary *Orion South Processed Kimberlite Containment Facility (PKCF) Field Investigation Fort a la Corne, Saskatchewan*" report dated September 01, 2011. The vertical hydraulic conductivity was estimated to be 1/100 of the horizontal hydraulic conductivity. Anisotropic ratios ($K_v/K_v$) have been shown empirically to be typically in this range for sands similar to those of the upper surficial sand layer (Todd, 1980). The typical porosity of fine and coarse grain sands ranges from approximately 0.25 to 0.52 (US Energy), based on the limited data on the upper surficial sand layer grain size and the assumptions made concerning the aquifer, a porosity value of 0.3 was used in the conceptual model.

Table A-1 shows the calculation of the travel time from the centre of the facility to Duke Ravine and the travel time from the inside edge of the dyke adjacent to Duke Ravine. The travel time from the centre of the facility represents the longest retention period, while the travel time from the edge of the facility is the shortest or most conservative time. Based on the results of the analytical solution, the time required for groundwater to travel from the centre of the facility to Duke Ravine is 3.2 years. The time required for groundwater to travel from the edge of the dyke to Duke Ravine is 1.8 years. The estimated time for the water to infiltrate into the upper sand aquifer and connect with the native groundwater is only about 6 days as there is very little separation between the bottom of the PKCF and the water table surface and a high hydraulic gradient.

All of these travel times are only for groundwater. Contaminants dissolved in the groundwater flow system would also undergo retardation and/or dispersion as it flows along the groundwater flow path. Any particulates in the groundwater flow system (including any contaminants sorbed to these particulates) would be subject to filtration in the context of potential contaminant migration. These travel times can therefore be considered to be conservative.

***Scenario 2: After about 2 years of Operations***

Scenario 2 utilizes all the same assumption as Scenario 1, however, takes into consideration approximate two years of operations. The initial starter PKCF is assumed to last for about 2 years, this initial PKCF has dykes of about 20 m. As a result, the depth/thickness of fine PK in the PKCF would be about 12 metres. The hydraulic conductivity of the underlying soils is also expected to be reduced due to small particles becoming trapped in pore spaces of the underlying sand.

In 2006, three samples of PK from the pilot plant were selected to represent the observed size range of the expected tailings. The estimated hydraulic conductivity from these samples ranged from 4 $x10^{-10}$ to $3.x10^{-6}$ m/s. In fact, the majority of the results for this processed kimberlite were less than $10^{-8}$ m/s. Using a horizontal hydraulic conductivity of $10^{-8}$ m/s and assuming the vertical hydraulic conductivity is 10% of the horizontal hydraulic conductivity, the vertical hydraulic conductivity of the PK is estimated to be $10^{-9}$ m/s.

Table A-1 shows the calculation using the new values for hydraulic conductivity and thickness to provide an estimate of the groundwater travel time at this point in PKCF development. Based on the results of the analytical solution, the time required for groundwater to travel from the centre of the facility to Duke Ravine is 117 years, the groundwater needs to flow the accumulated fine PK. The time required for groundwater to travel from the edge of the dyke to Duke Ravine is only 1.9 years, as in this case the water flows through the dyke down to the water table. It is interesting to note that the predicted groundwater travel time was significantly longer (more than 100 years) after 12 m of fine PK had built up in the PKCF and the estimated mass flux through the fine PK would also significantly reduced. The estimated travel time from the edge of the PKCF is a conservative estimate as expected rapid reduction in the hydraulic conductivity of the dykes due to suspended sediments in the process water blocking the flow paths, was not considered in this estimate of the travel time. This reduction in hydraulic conductivity was not considered at this time as it is very difficult to estimate the magnitude of this effect It is worthwhile to note that this blinding off of the hydraulic conductivity of the dykes will occur on an on-going basis such that most of the flow through the dyke will be restricted to the uppermost portion of the dyke, that has been recently flooded due to the increasing water level in the PKCF. It is also expected that most of this groundwater would be captured by the drainage ditches.

## Scenario 1- PKCF Prior to Operations, no Fine PK Accumulation

| Horizontal Gradient Beneath Facility | | | | Vertical Gradient Through Surface | | | | Hydraulic Conductivity | | Darcy's Velocity | | Porosity | Aquifer Average Linear Velocity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Up Gradient Head (m) | Down Gradient Head (m) | Distance Between Points of Head Measurement (m) | Gradient | Bottom of PKCF (m) | Water Table Elev. (m) | Height of Water Surface above Water Table (m) | Gradient | $K_h$ (m/s) | $K_v$ (m/s) | $V_h$ (m/s) | $V_v$ (m/s) | | Horizontal $\tilde{v}_h$ (m/s) | Vertical $\tilde{v}_v$ (m/s) |
| *425* | *410* | *1000* | *0.015* | *420* | *416.4* | *3.6* | *1.00* | *2.0E-04* | *2.0E-06* | *3.00E-06* | *2.0E-06* | *0.3* | *1.00E-05* | *6.67E-06* |

| Reference Point | Distance Traveled | | Travel Time | | |
|---|---|---|---|---|---|
| | $L_h$(1) (m) | $L_v$(2) (m) | $T_h$ (years) | $T_v$ (years) | $T_t$ (years) |
| (3)Pt.1 | *1000* | *3.6* | *3.17* | *0.02* | *3.19* |
| (4)Pt.2 | *560* | *3.6* | *1.78* | *0.02* | *1.79* |

## Scenario 2 - PKCF Operations at Intermediate Stage, 12m Fine PK Accumulation

| Horizontal Gradient Across Facility | | | | Vertical Gradient Through Facility | | | | | Hydraulic Conductivity | | | Darcy's Velocity | | | Porosity | Aquifer Average Linear Velocity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Up Gradient Head (m) | Down Gradient Head (m) | Distance Between Points of Head Measurement (m) | Gradient | Water Surface Elev. (m) | Water Table Elev. (m) | Height of Build-up (m) | Height of Water Surface above Water Table (m) | Gradient | $K_h$ (m/s) | $K_v$ (m/s) | | $V_h$ (m/s) | $V_v$ (m/s) | | | Horizontal $\tilde{v}_h$ (m/s) | Vertical $\tilde{v}_v$ (m/s) | |
| | | | | | | | | | | Build-up | Sand | | Build-up | Sand | | | Build-up | Sand |
| *435* | *410* | *1000* | *0.025* | *435* | *416.4* | *12* | *15* | *1.00* | *2.0E-04* | *1.0E-09* | *2.0E-06* | *5.00E-06* | *1.00E-09* | *2.0E-06* | *0.3* | *1.67E-05* | *3.33E-09* | *6.67E-06* |

| Reference Point | Distance Traveled | | | Travel Time | | |
|---|---|---|---|---|---|---|
| | $L_h$(1) (m) | $L_v$(2) (m) | | $T_h$ (years) | $T_v$ (years) | $T_t$ (years) |
| | | Build-up | Sand | | | |
| (3)Pt.1 | *1000* | *12* | *3.0* | *3.17* | *114.17* | *117.34* |
| (4)Pt.2 | *560* | *-* | *15.0* | *1.78* | *0.07* | *1.85* |

Notes: Assume unit thickness of slice of facility
Assume uniform aquifer thickness
Assume constant head conditions
Assume laminar flow (1< Re <10)
Assume saturated conditions

(1) $L_v$ represents the distance from the top of surface water to the top of the water table

(2) $L_h$ represents the distance from the infiltration point at the facility and the receptor of interest

(3) Pt.1 is located at the approximate centre of the facility and represents the longest possible time between infiltration and discharge to Duke Ravine

(4) Pt. 2 is located at the inside toe of the retaining dyke and represents the shortest possible time between infiltaration and discharge to Duke Ravine. In Scenario 1 flow is assumed to flow vertically down to the water table and then horizontally towards Duke Ravine. In Scenario 2 the shortest travel time is horizontal and vertical through the dyke (i.e. flow around the buildup of the fine PK).