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Alberta Sulphur Terminals Ltd.
Bruderheim Sulphur Forming and Shipping Facility

Volume IIB

1. Introduction

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Executive Summary

Alberta Sulphur Terminals Ltd. (AST), a division of HAZCO Environmental Services (HAZCO) which, in turn, is a division of CCS Income Trust (CCS), is applying to Alberta Environment (AENV) and the Natural Resources Conservation Board (NRCB) for approval to construct and operate a sulphur forming and shipping facility (the Project). The Project will be developed on a portion of Section 35, Township 55, Range 20, West of the 4th Meridian (35-55-20 W4M – the Site), approximately 2.2 km east of Bruderheim, Alberta, in the Industrial Heartland area of Lamont County.

The Environmental Impact Assessment (EIA) study area comprises the Principal Development Area (PDA), Local Study Area (LSA) and Regional Study Area (RSA). The PDA was defined as the area within the Site that will contain the Project including rail and road access for receiving molten sulphur, molten sulphur unloading and transfer facilities, sulphur forming facilities to produce sulphur pastilles, loading and shipping facilities for formed sulphur and sulphur pastilles temporary storage area. The LSA for the majority of disciplines assessed in the EIA is the Site (Groundwater, Historical Resources, Surface Water Quantity and Surface Water Quality) or the Site plus a 200 m buffer zone (Aquatics, Biodiversity and Fragmentation, Land Use and Reclamation, Soil, Vegetation and Wildlife). The RSA for the majority of disciplines is the Site plus a 500 m buffer zone (Surface Water Quantity and Surface Water Quality) or the Site plus a 1,000 m buffer zone (Aquatics, Biodiversity and Fragmentation, Soil, Vegetation and Wildlife).

The EIA will assist regulators and the public in understanding and evaluating the potential effects and benefits of the Project during construction, operation and reclamation. The EIA identifies and assesses peak disturbance, residual impacts and cumulative effects associated with the Project. It evaluates potential impacts to physical, biophysical and historical resources, in addition to potential socio-economic impacts. The EIA also identifies mitigative measures and adaptive management plans to reduce or eliminate potential adverse effects.

For each individual impact assessment, a qualitative, final evaluation rating was used where specific guidelines did not exist. This rating was a combination of quantitative analysis and professional judgment that takes into account the various descriptors for each attribute (direction, magnitude, geographic extent, duration, confidence and reversibility) and the potential effects of the specific impact. This rating was applied to residual impacts and cumulative effects. The following table lists the ratings applied and the level of action required for each.

Table ES-1: Final Impact Rating

Rating	Level of Action
Class 1	The predicted trend in an indicator under projected land use development could threaten the long-term sustainability of the quantity or quality of the indicator in the local and regional study areas. An action plan, developed jointly by regional stakeholders, could be developed to monitor the affected indicator, identify and implement further mitigation measures to reduce any impact, and promote recovery of the indicator, where appropriate. This class of impact might also be applicable to an exceedance of a regulatory guideline or where the impact is expected to have long-term effects.
Class 2	The predicted trend in an indicator under projected land use development will likely result in a decline in the quantity or quality of the indicator. The decline could be to lower-than-baseline but stable levels in the LSA and RSA after closure and into the foreseeable future. In addition to responsible industrial operational practices, monitoring and recovery initiatives could be required if additional land use activities occur in the study area before closure of the projected land use development. This class of impact might also be applicable to an exceedance of a regulatory guideline or where the impact is expected to have mid-term effects, but where recovery will take place shortly after closure of the projected land use development.

Table ES-1: Final Impact Rating (Cont'd)

Rating	Level of Action
Class 3	The predicted trend in an indicator under projected land use development could result in a slight decline in the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development, but resource levels should recover to baseline after closure. In some cases, a short-term, low to moderate magnitude impact could occur, but recovery will take place within five years. No new resource management initiatives are necessary. Responsible industrial operational practices should continue. This class of impact could also be applicable where regulatory guidelines are not exceeded, but where a relative change in magnitude of an indicator occurs.
Class 4	The projected land use development results in no change and no contribution toward affecting the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development. Responsible industrial operational practices should continue. Therefore, no cumulative effects result from the Project.

Volume IIB – Water and Aquatic Ecology

Section 2: Groundwater Quality and Quantity

The hydrogeological assessment confirmed that the Site was generally suitable for the Project, however, an adequate groundwater supply source must be confirmed at the Site. Barring the presence of an adequate groundwater supply, an alternate makeup water supply will need to be secured.

The soil stratigraphy generally consists of surficial topsoil or fill overlying deposits of glacial origin. The surficial deposits are variable both in composition and thickness. Till or till-like clay was encountered in most boreholes. The till was silty and/or contained high-plastic clay, silty sand and/or sand seams. Significant thicknesses of silty sand were encountered south and east of the proposed PDA. The surficial deposits are underlain by sedimentary bedrock comprised of mainly shale and sandstone that extends beneath the completion depth of the boreholes.

The till unit and fine-grained and competent portions of the upper bedrock (i.e., shale intervals) are considered to be aquitards. The primary aquifer is a sandstone interval located in the upper bedrock zone at a maximum depth of approximately 15 metres below ground surface (mbgs). This zone appears to be used as a domestic and potable water supply for most rural residences in the vicinity of the Site. A second deeper sandstone interval was identified between depths of 81–87 mbgs. Due to the weathered or fractured nature of the upper shale portion of bedrock, the overburden groundwater appears to be somewhat hydraulically connected to groundwater in the upper sandstone interval. However, groundwater in the lower sandstone interval and deeper appears to be hydraulically separated by a thick, competent shale unit.

The measured depth to groundwater in the surficial deposits ("A" series) monitoring wells ranged from greater than 0.08 m above ground surface (i.e., flowing conditions) to 2.82 mbgs. Seasonal variations in groundwater surface elevations on the order of 0.1–0.6 m have been observed. The groundwater flow direction in the surficial deposits is interpreted to range from northeast to due north. Hydraulic conductivity testing of the overburden monitoring wells showed two orders of magnitude difference between monitoring wells screened within predominantly clay soils and predominantly silty sand or sand (2.3×10^{-8}–3.0×10^{-6} m/s). Groundwater flow velocities in the surficial deposits are interpreted to range from several centimetres to several metres per year with an average of about 0.2 m/y.

The measured depth to groundwater in the upper bedrock sandstone aquifer ("B" series) monitoring wells ranged from 0.54 m above ground surface in monitoring well 05–01B to 2.94 mbgs. Seasonal variations in groundwater surface elevations on the order of 0.2–0.5 m have been observed. Minimal differences were measured between groundwater surface elevations in the "A" and "B" series nested monitoring wells. Calculation of vertical hydraulic gradients showed very low upward, near-neutral and very low downward gradients. The groundwater flow direction in the sandstone interval is interpreted to be to the northeast but is expected to change to due north based on regional information and the inferred connectivity with the surficial deposits. Hydraulic conductivity testing of the bedrock wells showed two orders of magnitude difference between monitoring wells screened within the shale and the sandstone (1.7×10^{-8}–6.6×10^{-6} m/s). Groundwater flow velocities in the upper bedrock are interpreted to range from several tens of centimetres to several metres per year with an average of about 0.6 m/y.

Based on a two-hour pumping test, an estimated 20-year sustainable yield of 7.8 L/min was calculated within what appeared to be the most productive portion of the upper bedrock sandstone interval. Based on the variable geology, diminished yield could occur over time. A pumping test conducted in the deeper sandstone interval indicated this zone to be poorly yielding and marginal as a water supply source.

Hydrochemistry of groundwater measured in the surficial deposits and upper bedrock was generally the same and indicated groundwater was predominantly sodium-bicarbonate. Therefore, the addition of acidity would be naturally buffered. Total dissolved solids, dissolved sulphate, dissolved sodium and/or dissolved manganese concentrations in all or some of the monitoring wells exceeded the Health Canada (2004) Drinking Water Aesthetic Objective Guidelines. Dissolved sulphate appears to be naturally elevated in the portions of the surficial water bearing zone. Dissolved metal concentrations in the surficial deposits and upper bedrock wells did not exceed applicable guidelines. The potability results are not considered to be a concern in the context of the proposed Project.

A water well search of AENV’s water well database indicated 53 water well records within a 1 km radius of the Site and 176 wells within a 3 km radius (see Appendix V). Of the 53 water wells within the 1 km search radius, 32 were listed as domestic, 10 as domestic and stock, 2 unknown, and the remainder industrial or stock. Six registered water wells were identified downgradient of the Project (i.e., to the north) within several hundred metres from the northern Site boundary. Of these six wells, five have a listed total depth less than 20 mbgs and are thus potentially completed in the same interval as the surficial and upper bedrock aquifers identified at the PDA.

The evaluation of potential groundwater yield was based on a short-term pumping test. A longer term pumping test will be completed to better evaluate the long-term productivity of this zone. This work was originally scheduled for late spring, however, the landowner requesting testing be delaying until calving season was over and livestock were not dependent on water from the well. The pumping test has been rescheduled for June 2007. Assuming that an adequate groundwater supply can be proven on Site, it is anticipated that local groundwater levels and flows within the upper sandstone interval will be significantly affected by water withdrawals associated with the Project. However, these effects are anticipated to dampen relatively quickly with increasing distance from the facility, and at distances greater than about 750 m from the pumping centre(s), effects on regional water levels and flows are expected to be negligible or low in magnitude (i.e., within natural variability of up to 0.5 m). It is, therefore, anticipated that the effect of Project water withdrawals on existing water users should remain negligible or low in magnitude (i.e., within natural variability in groundwater levels) for the entire duration of the Project (estimated to be at least 25 years). Monitoring is recommended to ensure that adequate groundwater levels are maintained to existing nearby users.

The upper bedrock zone is not in direct connection to nearby surface waters and wetlands, which are protected from the effects of water withdrawals by the overlying till. Hence, impact to these environmental resources is expected to be negligible. Groundwater withdrawal from depth is also not expected to affect soil saturation or vegetation on the Site. Monitoring during Project start-up and operation is recommended to confirm these assessments.

Assuming that all mitigation measures are implemented appropriately, it is anticipated that the overall groundwater quality during the Project lifetime will not be significantly affected by Project-related activities or surface releases during construction and operations. Groundwater travel times to the downgradient (northern) Site boundary are on the order of hundreds of years, indicating ample response time for specific mitigation measures to be implemented should a surface release occur.

The final impact rating is considered to be Class 3. Twice-annual groundwater monitoring of the "A" and "B" series wells is proposed to evaluate potential effects to groundwater levels and for early detection of potential contamination. The monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local hydrogeology and possible effects related to the operation of the proposed facility. Proposed long-term environmental monitoring will have to be approved by the Director of Alberta Environment prior to implementation.

Section 3: Surface Water Quantity

The objectives of the surface water hydrology assessment were as follows:

- satisfy the relevant section of the Terms of Reference of the EIA
- assess the hydrological suitability of the Site for the proposed Project
- provide initial hydrological design recommendations
- establish a hydrological monitoring program for the proposed Project

The surface water hydrology assessment confirmed that the Site was suitable for siting the proposed Project.

The conclusions of the assessment are summarized as follows.

- the Site is generally dry most of the year, with ephemeral drainages conveying surface runoff south to north during freshet and rainfall events. A small wetland is present in the northwest corner of the property. Other small wetlands exist on the property as a result of railways blocking natural flow pathways. A small seep is also present near the geographic centre of the property.
- there will be no measurable Project-related or permanent alterations to drainage patterns, waterbodies or wetlands
- there will be no direct water diversions from any drainage channels, waterbodies or wetlands
- the runoff from the immediate plant site will be contained in a pond and reused for process. The area of the immediate plant site is only 3.6% of the total drainage area, and thus containment of this runoff is not expected to have a measurable affect on water levels or aquatic function of drainage channels, waterbodies or wetlands downstream. The pond is designed to contain runoff from the 25 year storm event, and runoff exceeding the 25 year event or cumulative runoff during a very wet season, may be discharged into a nearby ephemeral drainage provided it meets provincial discharge criteria.
- mitigation is not required as measurable impacts are not anticipated
- the Project will not have a measurable impact on cumulative pressures on surface water resources
- water levels will be continuously monitored in the wetland in the northwest corner of the Site to validate the assessment made in the EIA

The hydrological impact assessment concluded that potential adverse effects from development of the Project will be largely of local geographical extent, of low to moderate magnitude, of short to mid-term duration and will be reversible in nature. Confidence for these residual impact assessments is generally moderate to high. The final impact ratings for the construction and operation phases of the Project are Class 3 and after Project closure, Class 4.

The final impact ratings for the construction and operation phases of the Project are Class 3 and after Project Closure, Class 4.

Section 4: Surface Water Quality

The objectives of the surface water quality assessment were as follows:

- satisfy the relevant section of the Terms of Reference of the EIA
- assess the hydrological suitability of the Site for the proposed Project
- provide initial hydrological design recommendations
- establish a hydrological monitoring program for the proposed Project

The surface water quality assessment confirmed the Site is suitable for siting the proposed Project.

Seasonal baseline water quality data were collected in the regional and local study areas. Parameters analyzed included temperature, pH, conductivity, dissolved oxygen, cations and anions, total and dissolved trace elements, suspended sediment, nutrients and hydrocarbons. In general, regional watercourses (Beaverhill Creek and Lamont Creek) demonstrated eutrophic or hypereutrophic trophic signatures, with water being high in nutrient concentration. This is likely a consequence of municipal sewage discharge into Lamont Creek. Seasonality exerts a dominant influence on the water quality of Beaverhill Creek and Lamont Creek, with creek water being higher in salts and trace elements during the winter when flows consist predominantly of groundwater discharge. All water features (including the wetlands on the Site) were highly mineralized (total dissolved solids ranging from 283–1,380 mg/L) and are moderately to highly alkaline. Surface water within the Surface Water Quality LSA is of predominantly Na-HCO_3 hydrochemical type, similar to that of local groundwater chemistry.

In addition, snow quality sampling was also conducted at six locations within the Surface Water Quality LSA to capture the influence of atmospheric deposition. Snow quality data indicated that, in general, snow quality is not influenced substantially by acid generating deposits.

Sediment samples were also collected and analyzed for trace elements and hydrocarbons. Metal concentrations in most sediment samples were generally below Canadian Council of Ministers of the Environment (CCME) Interim freshwater sediment quality guidelines (ISQGs; dry weight) and probable effect levels (PELs) with some exceptions at a few sampling locations (cadmium, zinc, arsenic and copper).

In general, the Project is not expected to have any significant impacts on surface water quality within the study areas. Potentially, the impact of increased runoff during high rainfall events may in some circumstances have a negative direction as sediment loading may increase. This is more of a concern during Project construction. Provided mitigation measures are implemented appropriately, the impacts to surface water quality within the Surface Water Quality LSA and RSA are in general considered to be low to moderate in magnitude, local in geographic extent (i.e., within the Site boundary), short term in duration and reversible.

Baseline surface water and snow quality data collection indicates that regional acid deposition is not having any measurable impact on surface water quality. Assuming that all mitigation measures are implemented appropriately and given the high buffering capability and low sensitivity of waterbodies in the study areas to acid deposition, it is anticipated that impacts to surface water quality from acid deposition arising out of normal operational activities within the Surface Water Quality LSA and RSA will be low to moderate in magnitude, local in geographic extent (i.e., within the Site boundary), mid-term in duration and reversible.

Groundwater pumping test analyses (Volume, IIB, Section 2: Groundwater Quality and Quantity – Section 2.6.4) indicate that Project water withdrawals may lead to the cessation of groundwater inflows to the wetland area in the northwestern quarter section of the PDA. However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total annual water balance inflows, the termination of baseflow to the wetland is considered to have a negligible impact on surface water quality. None of the other drainages on site are considered to be groundwater fed and lowering of groundwater levels will not impact surface water quality in these features.

The time required for groundwater to travel from the PDA to the north property boundary is between 100 and 1,000 years, which is effectively the closest discharge point (wetland). This slow travel time allows for deployment of remediation technologies, and thus potentially contaminated groundwater would not measurably impact surface water features. In addition, the aquifer is not considered vulnerable due to the presence of low permeability surficial till.

The EIA presents comprehensive mitigation plans to minimize the effect of construction, operation, reclamation, upset conditions and acidifying compounds on surface water quality.

Surface water parameters will be monitored (particularly suspended sediments) during construction activities near surface waterbodies. This will be maintained throughout clearing and construction to ensure that water quality guidelines are not exceeded.

Intercepted water will be tested to ensure regulatory water quality requirements for surface water release are satisfied during construction works. A contingency plan for further treatment and disposal of non-compliant water also will be developed. Clean runoff from landscaped and other hard surfaced areas outside the plant footprint will be diverted around the plant site to prevent comingling with localized acidifying compounds within the operations area.

The water quality of the waterbodies within the Surface Water Quality LSA will continue to be monitored before, during and after construction. These results will be compared to baseline levels to validate EIA results. Water quality will be monitored in the on site wetland before and after groundwater withdrawals commence to assess potential impacts. Monitoring of surface water quality in the wetland will be conducted on a reasonable frequency. Grab samples will be collected immediately prior to release of any water to the surrounding environment. Any water that may be discharged from the runoff collection pond will be sampled and tested to comply with the following generic criteria:

- no visible sheen
- 6<pH<9
- chemical oxygen demand (COD) <50 mg/L
- chloride <500 mg/L
- TSS<50 mg/L

Discharge limits for specific contaminants (if and when suspected) will be determined in accordance with the Water Quality Based Effluent Limits Procedures Manual (AENV 1995, as amended). The water quality monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local environment and the potential impact of the Project on it.

There are currently no other planned projects located within the RSA with the potential to affect water quality with respect to Project operations. Similarly, the effects of the Project on surface water quality are predicted to be low to moderate in magnitude and localized in geographical extent (within the Surface Water Quality LSA). The water quality of the receiving regional waterbodies, namely Beaverhill Creek, is generally poor and displays qualities of being in a hypereutrophic state. This is likely due to the discharge of treated effluent from municipal treatment facilities, perhaps compounded by agricultural runoff (e.g., fertilizers). The Project is not anticipated to contribute any eutrifying compounds to Beaverhill Creek, such as nutrients. The presence of the wetland in the northwestern corner of the property, which will act as a retention and natural treatment system, will further prevent any potentially deleterious compounds arising from surface disturbances or upset conditions reaching Beaverhill Creek.

The acid deposition and sensitivity analysis inherently considered cumulative effects, and determined that cumulative impacts resulting from acidifying compounds are not considered to be detrimental to water quality. The Project is not anticipated to release other deleterious compounds into aquatic ecosystems, and, therefore, no cumulative effects are anticipated.

The water quality impact assessment concludes that potential adverse effects from development of the Project will be largely of local geographical extent, of low to moderate magnitude, of short to mid-term duration and reversible in nature. Confidence for these residual impact assessments are considered moderate to high and the final impact ratings are Class 3.

Section 5: Aquatic Resources

The objectives of the aquatic resources assessment were as follows:

- inventory baseline aquatic resource conditions within the study area
- identify and assess potential impacts to aquatic resources that may result from the proposed Project
- recommend mitigation strategies to minimize impacts to aquatic resources
- recommend monitoring initiatives for the Project relating to aquatic resources

Within the Aquatic Resources LSA, two features were identified – Wetland 01 and Wetland 02. Within the RSA, one additional aquatic resource feature was identified – Lamont Creek. Wetland 01 and Lamont Creek were found to contain fathead minnow and brook stickleback. These aquatic environments were characterized as shallow with poor water quality and severe oxygen depletion. Lamont Creek was also found to have multiple beaver dams that are potential fish migration barriers. Wetland 02 was observed to be completely dry in the fall and was found to have no connectivity with any other waterbody at other times of the year;, therefore, would not be considered fish habitat. Wetland 01 and Lamont Creek are considered low value fish habitat. All three aquatic resource features provide a filtering function for surface water runoff as well as habitat for birds, mammals, amphibians and invertebrates.

The impact assessment identified potential sources of impact that could occur at each of three phases of the Project, siting the facility, construction and operation. The aquatic resource indicators used in the assessment include water quality and water quantity. Potential surface disturbance impacts during siting and construction were assessed as Class 4 at application and closure. Operation of the facility could result in impacts from dust deposition, air emissions, wastewater and stormwater discharge, groundwater drawdown and contaminant spills. Operational impacts all have a Class 3 rating at application and a Class 4 rating at closure.

Industrial disturbances to the landscape that have occurred within the RSA include the Canexus sodium chlorate plant, Triton fabrication facility and AltaLink electrical substation. Other anthropogenic disturbances within the RSA include agriculture, road construction and rural residential development.

Mitigation plans to minimize potential Project impacts include:

1. Surface disturbance
    - appropriate siting of the facility to avoid loss of aquatic habitats
    - implementation of appropriate sediment control techniques during construction is recommended
2. Dust deposition
    - protect sulphur piles from wind erosion with a wind screen
    - application of a dust suppression agent and release aid
3. Air emissions

- no mitigation measures are planned due to the low levels predicted

4. Wastewater and stormwater discharge

   Wastewater

   - domestic wastewater will be stored and routinely transported off site

   Stormwater

   - surface water is collected, stored and recycled on site
   - the storage pond is double lined and equipped with leak detection monitoring
   - areas surrounding sulphur handling are sloped away from the facility to prevent surface water run-on
   - storage areas are lined with asphalt and underlain by compacted clay soil to minimize surface water seepage into the ground
   - neutralization of water discharged from the storage pond will be achieved by adding free lime as needed

5. Groundwater drawdown
   - minimize groundwater diversion requirements through the collection, storage and recycling of surface water that falls on the storage areas

6. Contaminant spills
   - liquid products will be stored in steel tanks that include double-containment with leak detection
   - the pad will consist of asphalt over a clay soil liner with surface water runoff and run-on controls and leak detection

A potential cumulative effect on aquatic resources was identified relating to dust deposition and air emissions interacting with sodium chlorate. Sulphur emissions have the potential to acidify surface waters in the vicinity of the Canexus sodium chlorate plant. Sodium chlorate forms chlorine dioxide, a disinfectant, in acid aqueous reaction. Chlorine dioxide is a gas that absorbs readily into water but is unstable and typically converts to chlorite. Chlorine dioxide has been found to be moderately toxic to fish (0.21 mg/L) but chlorite has been found to be only slightly toxic to fish (3.3 mg/L). This impact is predicted to be unlikely to occur given the buffering capacity of the soils.

Planned monitoring activities with respect to surface water and groundwater include:

1. Monitoring water discharged from the Site immediately prior to discharge for:
   - visible sheen
   - $6<pH<9$
   - COD<50 mg/L
   - chloride<500 mg/l
   - TSS<50 mg/L

2. Monitoring groundwater twice annually for water table level, temperature, pH, electrical conductivity and potability

   In addition to the planned monitoring activities, it is recommended that:

   - surface water in Wetland 01 be monitored for turbidity during construction

- surface water in Wetland 01 be sampled twice annually for temperature, pH and dissolved oxygen during operations

The aquatic resources assessment confirmed the proposed Project is not likely to result in adverse impacts to aquatic resources when mitigation strategies are applied.

Table ES-2: Volume IIB Final Impact Summary Table for the Application Case

Potential Impact	Geographic Extent	Magnitude	Direction	Duration	Reversibility	Confidence	Rating
Groundwater Quality and Quantity							
Decreased water levels and flows	Regional	Negligible to low	Negative	Medium-term	Reversible	Moderate	Class 3
Interaction between groundwater and surface water	Local	Negligible	Negative	Medium-term	Reversible	Moderate	Class 3
Groundwater available to existing users	Regional	Low	Negative	Medium-term	Reversible	Moderate	Class 3
Potential effects to groundwater quality	Local	Low to moderate	Negative	Short-term	Reversible	High	Class 3
Surface Water Quality							
Potential Impact from Surface Disturbances							
Increased erosion and basin sediment yield and altering runoff patterns	Local	Low to Moderate	Negative	Short-term	Reversible	Moderate to High	Class 3
Impact of groundwater withdrawal on local water quality	Local	Negligible	Negative	Mid-term	Reversible	High	Class 3
Potential Impact from the Deposition of Acidifying Compounds on Waterbodies							
Project contribution to acid deposition on local waterbodies	Local	Low to Moderate	Negative	Mid-term	Reversible	Moderate to High	Class 3
Potential impact from Upset Conditions							
Accidental spillages or leaks	Local	Low to Moderate	Negative	Short-term	Reversible	Moderate to High	Class 3
Uncontrolled release from runoff collection pond	Local	Low to Moderate	Negative	Short-term	Reversible	Moderate to High	Class 3
Surface Water Quantity							
Changes to flow, water level and drainage patterns	Local	Low to Moderate	Negative	Mid-term	Reversible	High	Class 3
Impact to channel regime and channel alterations	Local	Low to Moderate	Negative	Mid-term	Reversible	High	Class 3
Impact to sediment yield	Local	Negligible to Low	Negative	Short-term	Reversible	Moderate	Class 3
Potential impact from Upset Conditions							
Changes to water level and drainage patterns	Local	Negligible	Negative	Mid-term	Reversible	High	Class 3
Aquatic Resources							
Surface disturbance (siting)	-	-	Neutral	-	-	High	Class 4
Surface disturbance (construction)	Local	Negligible	Negative	-	Reversible	High	Class 4
During Operation							
Dust deposition	Local	Low to Moderate	Negative	Short-term	Reversible	Moderate	Class 3
Air emissions	Local	Low to Moderate	Negative	Mid-term	Reversible	Moderate	Class 3
Wastewater and stormwater discharge	Local	Low to Moderate	Negative	Mid-term	Reversible	Moderate	Class 3
Groundwater drawdown	Local	Negligible	Negative	Mid-term	Reversible	Moderate	Class 3
Contaminant spills	Local	Low to Moderate	Negative	Mid-term	Reversible	Moderate	Class 3

Acronyms, Abbreviations and Defined Terms

Acronym	Definition
$(NH_4)_2SO_4$	ammonium sulphate
35-55-20-W4M	Section 35, Township 55, Range 20, West of the 4th Meridian (the Site)
A	symbol for hole area from the action leakage rate formula
A	cross-sectional area available for flow
A1	Agricultural Use Area 1
A2	Agricultural Use Area 2
AAAQO	Alberta Ambient Air Quality Objectives
AADT	average annual daily traffic
AAF	Alberta Agriculture and Food
AAFRD	Alberta Agriculture Food and Rural Development
abiotic	not biological; not involving or produced by organisms
ACD	Alberta Community Development
acid	molecule that is able to give up a proton (H^+) to, or accept electrons from, a base; gives a solution with a pH of less than 7
acidification	reduction of the pH of soil, waterways and lakes
adaptive planning	flexibility built into design and layout to accommodate future modifications required by changed standards, limits and guidelines
AENV	Alberta Environment
aerobic bacteria	bacteria that require oxygen to survive and grow
AET	areal evapotranspiration
AFSC	Agricultural Financial Services Corporation
AIH	Alberta Industrial Heartland: a large industrial centre in central Alberta including Edmonton, Fort Saskatchewan, Strathcona County, Sturgeon County and Lamont County
AII	industrial total
ALF	available labour force
ALR	action leakage rate – leakage expected to occur through a synthetic impermeable liner having 2 holes of 2 mm in diameter every 1-ha of area
alumina catalyst	medium used to regenerate and recycle amines used to adsorb hydrogen sulphide gas
amine units	process units used to remove hydrogen sulphide from a gaseous process stream using amine compounds
anaerobic bacteria	bacteria that do not require oxygen to survive and grow
ANC	acid-neutralizing capacity
ANHIC	Alberta Natural Heritage Information Centre
ANPC	Alberta Native Plant Council
AO	aesthetic objectives
APA	Agricultural Policy Area
API	American Petroleum Institute

Acronym	Definition
aquatics	aquatic resource conditions, including fish and benthic invertebrate habitat capability and their characteristics in waterbodies
aquifer	an underground porous geological formation that stores or carries water
ARET	accelerated reduction/elimination of toxics
ASIC	Alberta Soil Information Centre
ASL	ambient sound level
ASP	Alberta's Industrial Heartland Area Structure Plan/Lamont County
asphalt bulk sulphur storage pad	storage pad used to stockpile formed sulphur pastilles in preparation for shipment
ASRD	Alberta Sustainable Resource Development
ASRL	Alberta Sulphur Research Ltd.
AST	Alberta Sulphur Terminals Ltd.
ASWQ	Alberta Surface Water Quality
AVI	Alberta Vegetation Inventory
AWI	Alberta Wetland Inventory
BC MWLAP	British Columbia Ministry of Environment, Lands and Parks
bioavailability	the degree to which toxic substances or other pollutants present in the environment are available to potentially biodegradative microorganisms
bitumen upgrader	term used for a refining facility that converts bitumen (heavy oil) into a lighter grade synthetic oil that can be further refined to make useable products such as gasoline and diesel
BSL	basic sound level
BTEX	benzene, toluene, ethylbenzene and xylenes
buffer	a solution or liquid with a chemical constitution allowing it to neutralize acids or bases without a great change in pH
^{o}C	degrees Celsius
CA	annual crop total
Ca^{2+}	calcium ion
$CaCO_3$	calcium carbonate
CALPUFF	California Puff Model
camlock	fitting used to quick-connect pipes and hoses
CanSIS	Canadian Soil Information System
capital spending	expenditures by a company for plant and equipment
carbonate alkalinity	carbonate alkalinity is a measure of the amount of negative carbonate and bicarbonate ions in solution
CASA	Clean Air Strategic Alliance
CCME	Canadian Council of Ministers of the Environment
CCS	CCS Income Trust
CCS	Canadian Crude Separators

Acronym	Definition
CDWQG	Canadian Drinking Water Quality Guidelines
CEA	cumulative effects assessment
CEPA	Canadian Environmental Protection Act
CGCM3	Coupled Global Climate Model 3
Class II waste disposal facility	landfill facility that is designed and permitted to dispose of non-hazardous solid wastes in the Province of Alberta
clay soil liner	low permeability containment layer constructed using compacted clay soil
CLU	contemporary land use
cm	centimetre
$cm\ y^{-1}$	centimetres per year
CN	Canadian National Railway
CNR	Command Notification System
CO	carbon monoxide
CO_2	carbon dioxide
CO_3^{2-}	carbonate ion
COD	chemical oxygen demand – used to indirectly measure the amount of organic compounds in water
collection hopper	receptacle that collects formed sulphur pastilles and directs those pastilles onto a conveyor belt
Compliance Source Emissions Testing	testing implemented on sources of air emissions, such as combustion stacks, to verify that those emissions comply with regulated standards
conditioning unit	unit in the sulphur forming process that regulates the rate and temperature of the liquid sulphur that is fed into the process
COPC	chemicals of potential concern
COSEWIC	Committee on the Status of Endangered Wildlife
CP	perennial crop total
CPNVI	Central Parkland Native Vegetation Inventory
CPR	Canadian Pacific Railway
CPR1	cardiopulmonary resuscitation
CPR2	uncultivated pasture total
CPUE	catch per unit effort
CR	concentration ratio
CSA	Canada Standards Association
CSL	comprehensive sound level
CWQ	Canadian Water Quality
CWS	Canada-wide Standards
dBA	A-weighted decibel
dBC	C-weighted sound levels
degassed sulphur	sulphur that contains less than 10 ppm by weight of hydrogen sulphide

Acronym	Definition
DFO	Department of Fisheries and Oceans
DO	dissolved oxygen
DOC	dissolved organic carbon
double containment system	containment system for storing potentially hazardous liquids that includes two independent containment layers
draw down tube	tube used to control (reduce) fluid levels in a containment vessel
duplex filter	filter designed to remove two types of impurities, such as particulate and organic matter
dust suppression package	process component that suppresses dust that may be emitted to atmosphere at a material transfer point
EC	electrical conductivity
EC20	concentration that affects 20% of text organisms
EC50	concentration that affects 50% of test organisms
EIA	Environmental Impact Assessment
elemental	a pure substance that cannot be broken down into different kinds of matter
emergency response	the action taken after an event to minimize the consequences of an emergency
EMS	environmental management system
EMS	Emergency Medical Services
EOC	Emergency Operations System
EPEA	*Environmental Protection and Enhancement Act*
ER	exposure ratio
ERP	Emergency Response Plan
ESA	Environmental Significant Areas
EUB	Alberta Energy and Utilities Board
FAP	Fort Air Partnership
feed tank	tank at the beginning of the sulphur processing system that is used to control the rate of sulphur feed to the forming process
ferrous iron	iron with an oxidation number of +2
fish/trap-hour	fish catch rate; fish caught per hour
FMZ	Fur Management Zone
FOLC	The Friends of Lamont County for Responsible Industrial and Community Development
FONG	open, non-patterned graminoid dominated fen
formed sulphur	sulphur that has been formed into solid pastilles using the Rotoformer process
fugitive dust	dust that is not emitted from definable point sources
fugitive sulphur emissions	sulphur emissions that are not emitted from definable point sources
FWHIS	Fish and Wildlife Historical Information System
g	the gravitational constant (9.8 m/s^2)
$g\ s^{-1}$	grams per second

Acronym	Definition
GHG	greenhouse gases
GIS	geographic information system
GJ/mon	gigajoules per month
gm/t	grams per tonne
groundwater	water beneath the earth's surface in underground streams and aquifers
gypsum	a soft white mineral composed of hydrous sulfate of lime
H	Hour
H&S	Health and safety
H^+	hydrogen ion; the symbol for a proton
H_2CO_3	carbonic acid
H_2O	Water
H_2S	hydrogen sulphide
H_2SO_4	hydrogen sulphate
ha	hectare
HADD	harmful alteration, disruption, or destruction of fish habitat
HAZCO	HAZCO Environmental Services
HCO_3	bicarbonate
HDPE	high density polyethylene
HEC	human equivalent condition
HHRA	Human Health Risk Assessment
HNO_3	nitric acid
HP	horsepower
HRIA	Historical Resources Impact Assessment
HRV	historical resources value
hw	the symbol for liquid depth from the action leakage rate formula
hydraulic conductivity	the extent to which a given substance allows water to flow through it
hydrogen plant feedstock	plant that is used to generated hydrogen gas, which is in turn used in the heavy oil upgrading and/or oil refining process
hydrogeological	pertaining to the geology of ground water with emphasis on its chemistry and movement
i	hydraulic gradient in the surficial deposits
I/C	Industrial/Commercial District
ICS	Incident Command System
infrastructure	basic facilities, such as transportation, communications, power supplies and buildings, that enable an organization, project or community to function
interstitial water	subsurface water contained in pore spaces between grains of rock and sediment
IPCC	Intergovernmental Panel on Climate Change
ISQG	Interim Freshwater Sediment Quality Guidelines

Acronym	Definition
ITE	Institute of Transportation Engineers
K	hydraulic conductivity
K	degrees Kelvin
K^+	potassium ion
keq H^+/(ha•y)	kiloequivalents of hydrogen ions per hectare per year
kg	kilogram
kg s^{-1}	kilograms per second
kg/d	kilograms per day
kg/ha/y	kilograms per hectare per year
kg/t	kilograms per tonne
km	kilometres
km/h^{-1}	kilometres per hour
km^2	square kilometre
kPa	kiloPascals
kraft pulp	pulp produced by a process where the active cooking agent is a mixture of sodium hydroxide and sodium sulphide
Kw	kilowatt
L/min	litres per minute
L/s	litres per second
LCC	Lamont County Council
Le Chatelier’s Principal	used to predict the effect of changing the amount of reactants, products, temperature or system volume on the composition of a chemical system at equilibrium
leak detection layer	layer located between the primary and secondary containment layers that is used to monitor the integrity of the primary containment layer
LEK	local environmental knowledge
L_{eq}	energy equivalent sound level
Level I fire	minor fire that can be isolated or controlled and is not of a serious nature
Level II fire	fire that cannot be isolated or controlled, but can be managed by local fire and emergency response service
Level III fire	fire that cannot be isolated or controlled and cannot be managed by local fire and emergency response service
L_{max}	maximum sound level for a given time period
load out conveyor	conveyor used to transfer formed sulphur onto rail cars
LOAEL	lowest observed adverse effect level
LOS	level of service
LSA	Local Study Area
LST	local standard time
LUB	Land Use Bylaw
LZ	landing zone

Acronym	Definition
m	metre
m/m	metres per minute
m/s^{-1}	metres per second
m/y	metres per year
m^2	metres squared
m^2/day	metres squared per day
m^3	cubic metres
$m^3\ h^{-1}$	cubic metres per hour
m^3/day	metres cubed per day
m^3/s	metres cubed per second
m^3/y	metres cubed per year
MAC	maximum acceptable concentrations
Man-hours	number of workers multiplied by hours worked
masl	metres above sea level
mbgs	metres below ground surface
MDBP	Municipal Development Plan Bylaw
meq	milliequivalents
meq/L	milliequivalents per litre
metallic sulfides	compounds formed by metal elements bonding to sulphides
metering pump assembly	process unit that measures flow volumes and rates through a pump
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre
Mg^{2+}	magnesium ion
mitigation	any action taken to permanently eliminate or reduce the long-term risk to human life, property and function from hazards
mL	millilitre
mL/minute	millilitres per minute
mm	millimetre
mm day^{-1}	millimetres per day
mm/y	millimetres per year
MP	McElroy-Pooler dispersion coefficient
MPC	Municipal Planning Commission
MPOI	maximum points of infringement
MRL	minimal risk limit
MSDS	Material Safety Data Sheets

Acronym	Definition
MVC	motor-vehicle collisions
MWH/mon	power flux per month
N	Nitrogen
n	number of individuals
n.d.	not defined
n/a	not applicable
Na^+	sodium ion
NAAQO	National Ambient Air Quality Objectives
$NaHCO_3$	sodium bicarbonate
NCIA	Northeast Capital Industrial Association
Ne	effective porosity
neutralization sludge	sludge formed by the neutralization of sulphuric acid using either caustic soda or lime
NGO	non-governmental organizations
NH_4NO_3	ammonium nitrate
NIA	noise impact assessment
NO	nitric oxide
NO_2	nitrogen dioxide
NO_2^-	nitrite ion
NO_3^-	nitrate ion
NOAEL	no observed adverse effect level
NO_x	nitrogen oxides
NPRI	National Pollutants Release Inventory
NR CAER	Northeast Region Community Awareness and Emergency Response
NRC	Natural Regions Committee
NRCB	Natural Resources Conservation Board
NTU	nephelometric turbidity unit
O_2	oxygen
O_3	ozone
OEL	Occupational Exposure Limit
off-specification sulphur	sulphur that does not comply with shipping specifications either because of excessive mineral or organic content
OH^-	hydroxide ion
OM	organic matter
oxidation	the removal of electrons from an element or compound
ozone precursors	chemical compounds, such as carbon monoxide, methane, non-methane hydrocarbons and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone
PAH	polycyclic aromatic hydrocarbons

Acronym	Definition
PAI	potential acid input
PDA	Principal Development Area
PEL	probable effect levels
PEMS	Prairie Emergency Medical Systems
PET	potential evapotranspiration
PFRA	Prairie Farm Rehabilitation Administration
PG	Pasquill-Gifford dispersion coefficient or atmospheric stability class
pH	measure of the acidity or basicity (alkalinity) of a material when dissolved in water
piezometer	instrument which measures hydraulic pressures
PM_{10}	particulate matter with mean aerodynamical diameter less than 10 μm
$PM_{2.5}$	particulate matter with mean aerodynamical diameter less than 2.5 μm
PPE	personal protective equipment
ppb	parts per billion
ppm	parts per million
precipitate	separate as a fine suspension of solid particles
protons	positively charged particles forming part of atomic nuclei
psi	pounds per square inch
PSL	permissible sound level
pump hanger	device for vertically positioning a pump
PW	pumping well
Q	symbol for action leakage rate from the action leakage rate formula; groundwater contributions
QA	quality assurance
QC	quality control
R.R.	Range Road
radial stacking conveyor	conveyor that places formed sulphur in a radial pattern
rail transfer loop	rail line placed in an approximately circular pattern
RCMP	Royal Canadian Mounted Police
Rd	road
Receiving tank	tank used to receive liquid sulphur delivered by rail or truck
recirculation loop	water circulation loop that returns spent cooling water to the start of the cooling water circuit
reduction	addition of electrons to an element or compound
RELAD	Regional Lagrangian Acid Deposition
RfC	reference condition
RGDR	regional gas dosimetry ratio
Rotoform emissions	particulate sulphur emissions for the Rotoform process

Acronym	Definition
ROW	right(s) of way
RSA	Regional Study Area
runoff control system	system of ditches and culverts used to collect runoff from the sulphur processing area to the stormwater collection pond
S	Sulphur
s^{-1}	per second
S_2O_3	thiosulfate
SABA	supplied air breathing apparatus
Sandvik Rotoform process	sulphur forming process developed and patented by Sandvik and referred to as the Rotoform process
SAR	sodium adsorption ratio
SAR	species at risk
SARA	*Species at Risk Act*
saturated	most concentrated solution possible at a given temperature
SCA	soil correlation area
SCBA	self-contained breathing apparatus
SEIA	Socio-Economic Impact Assessment
SIL	survey intensity level
Site	Section 35-55-20 W4M
S^o	symbol for elemental sulphur
SO_2	sulphur dioxide
SO_4^{2-}	sulphate ion
sour gas	hydrogen sulfide gas; H_2S
SO_x	sulphur oxides
specific gravity	the ratio of the density of a material to the density of water
spontaneous combustion	self-ignition of combustible material through the chemical action of its parts
stakeholders	people or organizations with an interest or share in an undertaking, such as a commercial venture
sulphur acidification	lowering of pH in soils or water by sulphur dioxide
sulphur forming	process of converting liquid sulphur into solid sulphur particles
sulphur pastille	sulphur pastilles of uniform shape, stability and quality formed by the Sandvik Rotoform process
sulphur recovery	separation and recovery of sulphur from a hydrocarbon refining process
sulphur train	a train used to convey liquid or solid sulphur
sulphuric acid	a strong acid; H_2SO_4
surface water	water that flows in streams and rivers, natural lakes, in wetlands, and in reservoirs constructed by humans
surface water runoff	pond used to collect and contain surface runoff from the sulphur forming and handling

Acronym	Definition
collection pond	area
surge bin	bin used to collect and store surges in solid sulphur pastilles
sweet fuel gas	methane that is used as fuel and does not contain hydrogen sulphide
t/d	tonnes per day
t/y	tonnes per year
TDS	total dissolved solids
THE	total exactable hydrocarbons
temperature conditioned	sulphur that is conditioned and controlled to be in a specific temperature range
TIA	traffic impact assessment
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TOR	Terms of Reference
totalizer	metering device that totals the volume of liquid passed through that meter
TP	total phosphorus
TPH	total petroleum hydrocarbons
TRV	toxicological reference values
TSS	total suspended solids; the weight of particles suspended in water
Twp	Township
UF	urban fringe
USEPA	United States Environmental Protection Agency
USGPM	US gallons per minute
USLE	universal soil loss equation
UTM	universal transverse mercator
V	Velocity
visible sheen	collection of hydrocarbons that is visible on the surface of a waterbody
VOC	volatile organic compounds
W4M	West of the 4th Meridian
vpd	vehicles per day
WA	*Water Act*
WCB	Workers' Compensation Board
wetland	area regularly saturated by surface water or groundwater and characterized by a prevalence of vegetation adapted for life in saturated soil conditions (e.g., swamps, bogs, fens, marshes and estuaries)
WHMIS	Workplace Hazardous Materials Information System – national chemical hazard communication system for regulation of information pertaining to hazardous materials
WMU	Wildlife Management Unit
WVC	wildlife-vehicle collisions
y	year

Acronym	Definition
μeq/L	microequivalents per litre
$\mu g\ m^{-3}$	micrograms per cubic metre
μm	microns (micrometres)
μS/cm	Microsiemens per centimetre

1. Introduction

The proponent, Alberta Sulphur Terminals Ltd. (AST), a division of HAZCO Environmental Services (HAZCO) which, in turn, is a division of CCS Income Trust (CCS), is applying to Alberta Environment (AENV) and the Natural Resources Conservation Board (NRCB) for approval to construct and operate a facility for sulphur receiving and forming, temporary sulphur pastille storage and shipment for export (the Project). The facility is to be developed on a portion of Section 35, Township 55, Range 20, West of the 4th Meridian (35-55-20 W4M – the Site), approximately 2.2 km east of Bruderheim, Alberta, in the Industrial Heartland area of Lamont County (Figure 1.1-1).

The purpose of this Environmental Impact Assessment (EIA) is to assess and report the potential environmental and socio-economic impacts of the Project. The EIA portion of this application has been organized into four sub-volumes:

Volume IIA – Air, Noise and Human Health

1. Introduction
2. Climate and Air Quality
3. Noise and Light
4. Public Health and Safety

Volume IIB – Water and Aquatic Resources

1. Introduction
2. Groundwater Quality and Quantity
3. Surface Water Quantity
4. Surface Water Quality
5. Aquatic Resources

Volume IIC – Terrestrial Ecosystems

1. Introduction
2. Soil
3. Vegetation
4. Wildlife
5. Biodiversity and Fragmentation

Volume IID – Land Use, Historical, Socio-Economics and Public Consultation

1. Introduction
2. Land Use and Reclamation
3. Historical Resources
4. Socio-Economic Assessment
5. Public Consultation Requirements

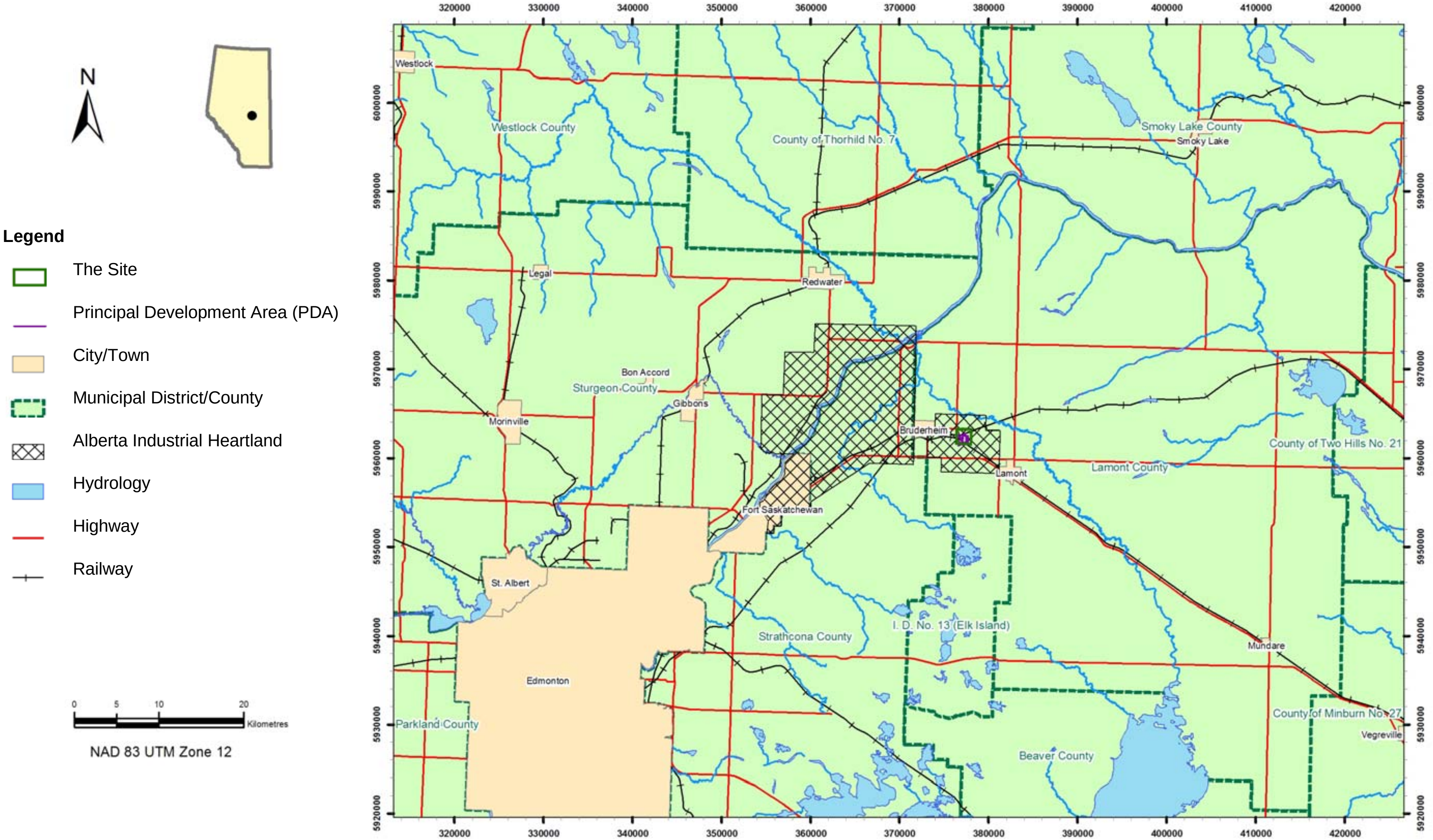

Figure 1.1-1: Regional Setting

This EIA forms part of the application for the Project submitted by AST and has been prepared according to the following requirements:

- AENV: *Environmental Protection and Enhancement Act* (EPEA 1993)
- AENV: Final Terms of Reference (TOR: AENV 2007)
- NRCB*: Natural Resources Conservation Board Act* (NRCB 2001)
- Permit to Divert Groundwater, to be issued by AENV under the Water Regulation of the *Water Act*: to provide up to 24,000 m^3 of cooling water per year to supply water during periods when the volume of water collected in the stormwater runoff control pond is not sufficient to operate the sulphur forming cooling system
- Development Permit issued by Lamont County under the *Municipal Government Act* (Government of Alberta 2000a) to allow construction of surface facilities associated with the Project
- authorization under the *Historical Resources Act* (Government of Alberta 2000b) for clearance to construct the Project

The concordance table that correlates the various clauses of the TOR to the application and EIA can be found in Volume I.

1.1 Project Description

The Project encompasses construction and operation of a facility for sulphur receiving and forming, temporary sulphur pastille storage and shipment for export. All infrastructure and activities will be confined to the lands owned by HAZCO. The Project includes:

- rail and road access for receiving molten sulphur
- molten sulphur unloading and transfer facilities
- sulphur forming facilities to produce sulphur pastilles
- loading and shipping facilities for formed sulphur
- sulphur pastilles temporary storage area

The Project will service oil and gas production and refining operations located in the Fort Saskatchewan area as well as northeastern Alberta. With increased applications, approvals and operation of bitumen upgraders and ongoing sulphur recovery initiatives, a shortage of sulphur forming facilities in Alberta is now apparent. AST will provide oil and gas producers in the area with a state-of-the-art sulphur forming, temporary pastille storage and shipping facility with design elements and monitoring programs that focus on environmental protection.

1.1.1 Sulphur Generation

The sulphur that would be accepted, formed and shipped by the Project is generated primarily by bitumen upgrading facilities located in the Fort Saskatchewan, Fort McMurray and Lloydminster areas. Amine units are part of the upgrader sulphur plant and remove H_2S from all upgrading gas streams, which produces sweet fuel gas (low sulphur content) and hydrogen plant feedstock. The plant consists of H_2S removal units (amine units) and sulphur recovery units, which convert H_2S to elemental sulphur.

The sulphur recovery units oxidize or burn part of the H_2S into SO_2, which then reacts with H_2S to form liquid elemental sulphur and water. The initial reaction takes place in the burners of a reaction boiler and in-line burners before the converters/condensers, known as sulphur "trains". First, second and third stage converters containing a (bauxite) alumina catalyst promote the reaction of H_2S with SO_2 at temperatures from 204–316°C. Modern processes reduce sulphur emissions and improve sulphur recovery.

Sulphur is recovered as a liquid by condensing sulphur vapour from the gases in the steam-generating heat exchangers of each sulphur train. The liquid sulphur is then gathered and stored, and entrained residual H_2S is removed from the stored sulphur.

Upgrading facilities at Lloydminster, Fort McMurray and Fort Saskatchewan currently generate sulphur at a rate of approximately 1 million tonnes/year (t/y). The rate of sulphur production in these areas is expected to rise to approximately 2 million t/y per year by 2008, and 3 million t/y by 2013 as upgrading operations are expanded to accommodate the increased production associated with heavy oil.

1.1.2 Project Components and Development Timing

The primary components of the proposed sulphur forming and shipping facility are:

- infrastructure for the reception of liquid sulphur and shipment of formed sulphur
- storage facilities for liquid and formed sulphur
- sulphur forming facilities
- sulphur transfer and loading infrastructure

1.1.2.1 Sulphur Reception

Liquid sulphur can be received at the facility by railcar, truck or (in future) pipeline. Only liquid sulphur that has been degassed to a maximum of 10 ppm H_2S will be accepted. Upon arrival, the liquid sulphur is unloaded via a pumping station into insulated and heated receiving tanks. Liquid sulphur is then pumped to a feed tank where it is filtered and temperature conditioned prior to being formed.

1.1.2.2 Sulphur Holding

Storage is provided for sulphur in its liquid form, prior to being formed, as well as in its pastille form, prior to being shipped. The sole purpose is to allow efficient operation of the forming facilities, while accommodating delivery and shipping. Liquid sulphur will be stored in 3,000 t, insulated and clad, steel tanks that meet the requirements of EUB Directive 55 (EUB 2001, Internet site) and API 650 (API 1998) modified. The initial development will include three 3,000 t tanks, rising to six – 3,000 t tanks at maximum capacity. Formed sulphur will be stored on a double-lined asphalt pad equipped with run-on and runoff controls. This pad has the capacity to store 90,000 t of finished product, approximately half of which will be established as part of initial construction.

1.1.2.3 Sulphur Forming

After the sulphur is transferred to the receiving tanks, it is pumped through a duplex filter and conditioning unit and cooled to an optimal forming temperature of 125°C. The sulphur enters a recirculation loop that feeds the Rotoform HS® drop forming equipment. The feed to the Rotoformer uses metering equipment and nozzles specifically designed to provide a continuous sulphur feed across a rotating stainless steel belt. The belt is cooled by cold water jets sprayed against the underside of the rotating belt, causing the pastilles to cool and solidify above.

1.1.2.4 Transfer and Shipping Infrastructure

The solid pastilles are deposited into a collection hopper, conveyed to a radial stacking conveyor and the asphalt bulk sulphur storage pad. A wind screen will be built upwind of the sulphur pastille stockpile. Initially, a front-end loader will transfer the stockpiled sulphur to a surge bin equipped with a dust suppression package. The dust treated product will then be deposited on a load-out conveyor equipped with weight measurements and totalizer and onto rail or trucks for shipment. An automated loading system will be introduced as part of future expansion to full production. In this instance, the formed sulphur will be transferred into vertical holding bins that are used to directly load rail cars. The EIA is based on a forming capacity of 6,000 t/d, half of which will be associated with initial construction.

Water utilized by the Rotoform HS® equipment will be sent through a closed loop cooling tower which provides filtration and temperature reduction. Make-up water for the cooling tower will be supplied from a runoff pond which is designed to collect and treat surface water from the Site and also serves as the source of fire protection water. Additional make-up water will be provided by a groundwater supply well.

1.1.2.5 Development Schedule

The proposed facilities will be developed in stages to accommodate the rate of sulphur production generated by existing and proposed oil sands development programs as well as market conditions. The initial stage will include the development of all Project components with sufficient capacity to process approximately 3,000 t/d of sulphur. Subsequent expansions will occur to process approximately 6,000 t/d of sulphur. The anticipated timing for the initial stage of development is summarized in Table 1.1-1 and is dependent on the pace and outcome of the regulatory process.

Table 1.1-1: Initial Development Timing

Task	Anticipated Timeframe
Project disclosure	2005
EIA scoping	Early 2006
EIA implementation	2006
Application submission	Mid 2007
Detailed design	Late 2007
Construction	Early 2008
First operations	Mid 2008
Project lifespan	25 years

The receipt, forming, temporary storage and shipping of formed sulphur will occur continuously over the lifespan of the facility (estimated to be at least 25 years), assuming there is a viable international market for sulphur produced in Alberta.

Failure to meet the proposed timeline, or approve the Project in general, will result in the blocking of incremental volumes of sulphur produced by oil sands upgrading facilities, either in new locations or at existing facilities. For example, sulphur produced by Syncrude is currently being stored in above-ground blocks, and Suncor is considering this option for sulphur generated by its Voyageur upgrader. Sulphur forming facilities are currently not available to the independent upgraders that are scheduled to come on-line in the next few years.

1.2 Spatial Boundaries

1.2.1 Principal Development Area

The Principal Development Area (PDA) is located within a portion of Section 35-55-20 W4M (the Site) and comprises the area of disturbance and development as illustrated in Figure 1.1-1. The PDA contains the forming and shipping facility, located in the west-central portion of the Site, and rail transfer loop used to receive and ship sulphur.

1.2.2 Local Study Area

The LSA for the majority of disciplines assessed in the EIA is the Site (groundwater, historical resources, surface water quantity and surface water quality) or the Site plus a 200 m buffer zone (aquatics, biodiversity and fragmentation, land use and reclamation, soil, vegetation and wildlife).

1.2.3 Regional Study Area

The RSA incorporates the LSA into a larger geographical area where potential regional effects could occur. As with the LSA, the extent of the RSA for each EIA component was determined according to the indicators used. Where no impact (Class 4) is predicted within the LSA, no analysis of regional effects was undertaken.

1.2.3.1 Cumulative Effects Study Areas

Cumulative effects assessments (CEA) are only applicable when other announced, but yet-to-be approved, projects exist that would affect the same area. Cumulative effects were generally assessed within the RSA for each specific EIA component. Where no impact is predicted within the LSA, no analysis of cumulative effects was undertaken (see Section 1.5.3).

1.3 Temporal Boundaries

The Project schedule is preliminary and subject to modification in response to the receipt of regulatory approvals, business considerations and weather factors. Assuming favourable regulatory approval and market conditions, construction of the Project is scheduled to begin in early 2008 with initial sulphur processing starting in mid 2008. The Project is expected to operate for at least 25 years. A detailed schedule is provided in Volume I.

Temporal boundaries used in this assessment vary depending on the disciplines and the resource assessed. Temporal boundaries extend from the June 2006 for the baseline assessments to five years after reclamation of the Project for the Land Use and Reclamation assessment.

1.4 Assessment Criteria

The purpose of the EIA is to assess and report on the potential impacts associated with the construction and operation of the Project. This includes impacts to the biophysical landscape as well as socio-economic and cultural impacts to local communities and historical sites. The EIA also includes preventative, mitigative and compensatory actions to reduce impacts of the Project.

Impact assessments were based upon measured, predicted or reasonably expected changes in some attributes of a selected indicator. The choice of indicators was determined from reviewing other EIAs completed in the Alberta Industrial Heartland for applicability to this region through input from stakeholders and the professional judgment of scientists conducting the EIA.

For each identified indicator, an assessment of the potential residual impact was made using the attributes of:

- direction
- geographical extent
- magnitude
- duration
- confidence
- reversibility

The definition of each attribute used in the assessment is given below.

1.4.1 Direction

The direction of impact may be described as positive (beneficial), negative (detrimental) or neutral:

- Positive: measured or estimated impact represents a real or potential increase in abundance, quality or other attribute of the indicator
- Negative: measured or estimated impact represents a real or potential decrease in abundance, quality or other attribute of the indicator
- Neutral: a “neutral” direction indicates there is no impact to quantify; therefore, no quantitative assessment (e.g., extent, magnitude, duration) is possible; the confidence (based on an understanding of cause and effect relationship(s) and the quality and quantity of available data) in the assessment is discussed below

1.4.2 Geographic Extent

Impacts may be confined to small local areas, or may occur over a large geographic extent. Generally, impacts may be local or regional:

- Local: measured or estimated impact occurs only within the boundaries of the LSA
- Regional: measured or estimated impact occurs beyond the boundaries of the LSA and mainly within the boundaries of the RSA

1.4.3 Magnitude

Three levels of magnitude have been selected:

- Negligible: measured or estimated impact represents a 1% or less change in the indicator (quality, quantity or other attribute) from baseline conditions
- Low to Moderate: measured or estimated impact represents a greater than 1% to 10% change in the indicator (quality, quantity or other attribute) from baseline conditions
- Moderate to High: measured or estimated impact represents a greater than 10% change in the indicator (quality, quantity or other attribute) from baseline conditions

Some disciplines have specific threshold values (e.g., AAAQOs (AENV 2005, Internet site)) that determine the magnitude of the impact, rather than a combination of quantitative analysis and professional judgment that is used where specific guidelines and regulations do not exist.

1.4.4 Duration

Some impacts may persist for short periods of time, others may be virtually permanent. The following designations for duration are used:

- Short-term: measured or estimated impact persists for no longer than five years
- Mid-term: measured or estimated impact persists to the end of the operational life of the Project
- Long-term: measured or estimated impact is measurable beyond the end of the operational life of the Project

1.4.5 Confidence

All measurements or predictions of direction, magnitude, geographic extent and duration of an impact are made on the basis of available data and understanding of the Project. The confidence ratings used are:

- Low: no clear understanding of cause and effect is evident because of the lack of a relevant information base or directly relevant data. This generally applies to conditions relevant to the RSA where no data was collected or available, and no detail is available regarding other planned developments.
- Moderate: a good understanding of cause and effect is evident from the existing knowledge base; however, there is limited data or a lack of directly applicable data. This generally applies to conditions within the LSA where larger-scale data was collected, but the resource in question is very site-specific and could not be surveyed within this year's time frame or models were used but could not be validated.
- High: a good understanding of cause and effect is available from the existing knowledge base and good, directly-applicable data are available. This generally applies to conditions within the LSA where data was collected and information about the Project was available (e.g., footprint).

1.4.6 Reversibility

All disciplines provide basic explanation regarding whether or not the impact is reversible.

1.4.7 Final Impact Rating

For each individual impact assessment, a qualitative, final evaluation rating has been used where specific guidelines do not exist. This rating is a combination of quantitative analysis and professional judgment that takes into account the various descriptors for each attribute (direction, magnitude, geographic extent, duration, confidence and reversibility), and the potential effects of the specific impact. For some indicators, there are specific threshold values that will determine an indicator's ranking (e.g., for air quality, human health). Other indicators have no such threshold value and a combination of objective analysis and subjective professional judgment is used. Impact classification does not always relate directly to standard descriptors used to explain the impact occurring; this is often seen where a relative change of high magnitude is occurring, yet the impact is classified as Class 3 because the overall effect (e.g., impacts to one small stream within a watershed) may be unmeasureable.

The final impact rating is an aggregated, relative, numerical ranking determined by both the analysis of impact and the level of action the author recommends, as a professional, as necessary to address the impact. This ranking is applied to both the Project-specific impacts and cumulative effects residual impacts (see Table 1.4-1).

Table 1.4-1: Final Impact Rating

Rating	Level of Action
Class 1	The predicted trend in an indicator under projected land use development could threaten the long-term sustainability of the quantity or quality of the indicator in the local and regional study areas. An action plan, developed jointly by regional stakeholders, could be developed to monitor the affected indicator, identify and implement further mitigation measures to reduce any impact, and promote recovery of the indicator, where appropriate. This class of impact might also be applicable to an exceedance of a regulatory guideline, or where the impact is expected to have long-term effects.
Class 2	The predicted trend in an indicator under projected land use development will likely result in a decline in the quantity or quality of the indicator. The decline could be to lower-than-baseline but stable levels in the LSA and RSA after closure and into the foreseeable future. In addition to responsible industrial operational practices, monitoring and recovery initiatives could be required if additional land use activities occur in the study area before closure of the projected land use development. This class of impact might also be applicable to an exceedance of a regulatory guideline, or where the impact is expected to have mid-term effects, but where recovery will take place shortly after closure of the projected land use development.
Class 3	The predicted trend in an indicator under projected land use development could result in a slight decline in the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development, but resource levels should recover to baseline after closure. In some cases, a short-term, low to moderate magnitude impact could occur, but recovery will take place within five years. No new resource management initiatives are necessary. Responsible industrial operational practices should continue. This class of impact could also be applicable where regulatory guidelines are not exceeded, but where a relative change in magnitude of an indicator occurs.
Class 4	The projected land use development results in no change and no contribution toward affecting the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development. Responsible industrial operational practices should continue. Therefore, no cumulative effects result from the Project.

1.5 Assessment Scenarios

The assessment was based on three cases – baseline case, application case and cumulative effects case as required by the TOR (AENV 2007). Impacts of the Project were evaluated from a project-specific and cumulative perspective by undertaking comparisons of change within these cases. These generally included comparisons of the environmental characteristics occurring in the baseline case with environmental conditions predicted to occur in the application case and in the cumulative effects case (see Figure 1.5-1).

1.5.1 Baseline Case

The baseline case includes the existing environmental and socio-economic conditions and existing and approved projects and activities as of June, 2006.

1.5.2 Application Case

The application case includes the baseline case plus the Project within the LSA. Construction and operation of the Project will occur sequentially. A maximum worst-case disturbance case was assessed for the application case in which all construction and operation components of the Project were assumed to occur concurrently. This conservative, worst-case approach over-predicted the Project impacts. In some cases, impacts were evaluated at closure (decommissioning and reclamation) to determine residual effects at that time.

1.5.3 Cumulative Effects Case

The cumulative effects case includes baseline, application and existing projects or activities in combination with other planned projects or activities that could occur within the same geographic area (spatial) and within the same time (temporal). The Project Inclusion List in Table 1.5-1 shows existing and planned projects or activities.

Cumulative effects were evaluated where Class 1, 2 or 3 impacts were identified for that particular discipline (as per impact ratings explained in Section 1.4.7). Class 4 ratings indicate that no change would occur as a result of the Project. Therefore, a cumulative effects assessment was not undertaken for issues identified as Class 4.

1.5.3.1 Project Inclusion List

The Project Inclusion List (see Table 1.5-1) includes the various anthropogenic disturbances on the landscape that must be included in the applicable assessment case to effectively determine project and cumulative effects. As the study areas for each component vary, the project inclusion for a particular assessment also varies. Therefore, each component has modified the comprehensive project inclusion list for their assessment. The projects included for cumulative effects include other operators as well as facilities associated with the Project.

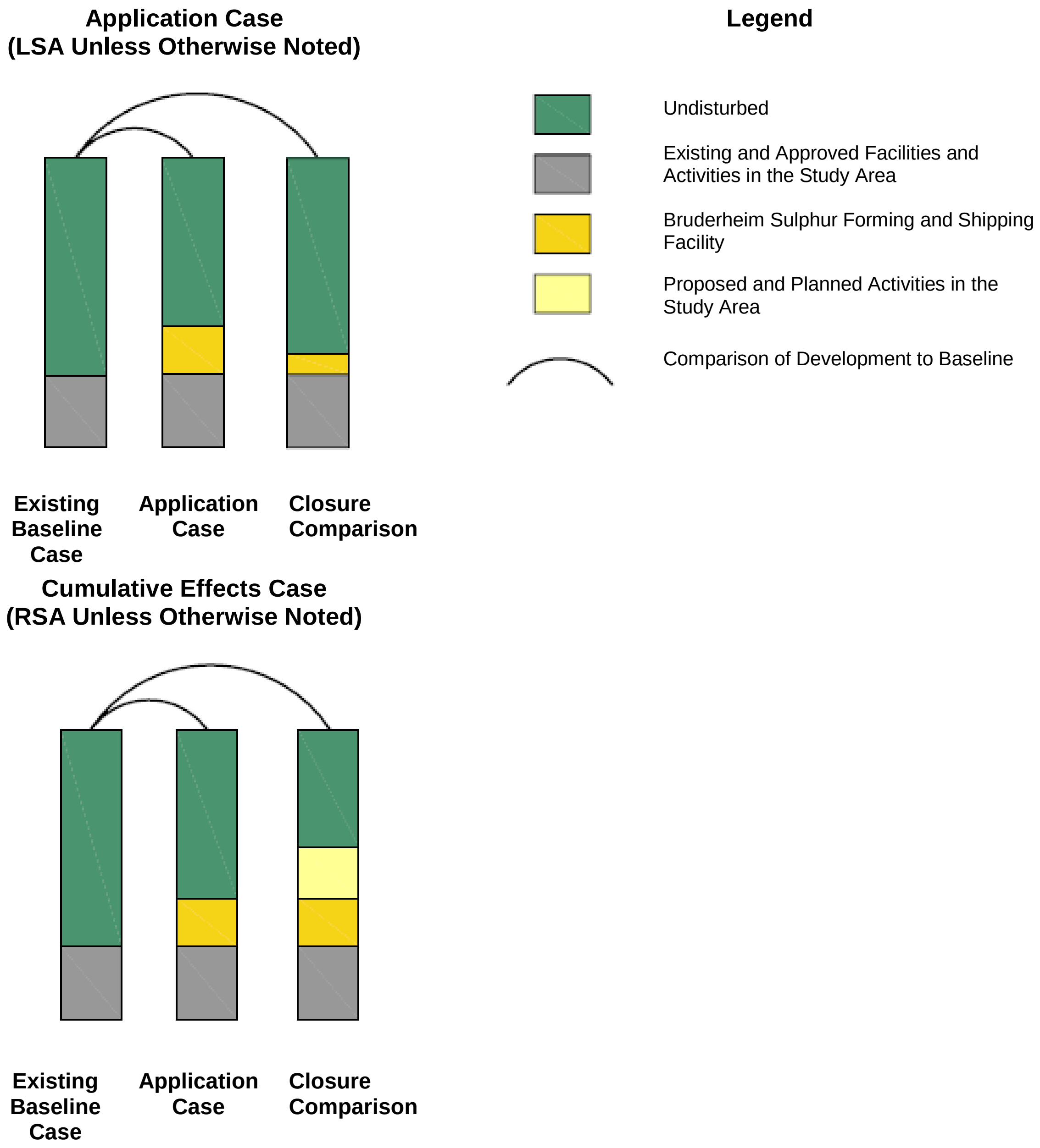

Figure 1.5-1: Comparisons of Change for Impact Assessment

Table 1.5-1: Project Inclusion List

Operator	**Facility**	**Project Status**		
		Existing	**Approved (Not Operating)**	**Planned (Not Approved)**
Access Pipeline	Redwater Trim Blending Facility		X	
Agrium Products Inc.	Fort Saskatchewan Fertilizer Plant	X		
Agrium Products Inc.	Redwater Fertilizer Plant	X		
Air Liquide Canada	Scotford Cogeneration Power Plant	X		
Alberta Sulphur Terminals	Bruderheim Sulphur Forming Facility			X
ARC Resources	Redwater Gas Conservation Plant	X		
ATCO Midstream	Fort Saskatchewan Sour Gas Plant	X		
Aux Sable Canada	Heartland Offgas Project			X
BA Energy	Heartland Bitumen Upgrader		X	
BP Canada Energy	Fort Saskatchewan Fractionation Plant	X		
Bunge Canada	Fort Sask. Oilseed Processing Plant	X		
Canexus Chemicals Canada	Bruderheim Sodium Chlorate Plant	X		
CE Alberta BioClean	Fort Saskatchewan Chemical Plant		X	
Degussa Canada Inc.	Gibbons Hydrogen Peroxide Plant	X		
Dow Chemical Canada	Fort Saskatchewan Chemical Plant	X		
ERCO Worldwide	Bruderheim Sodium Chlorate Plant	X		
Keyera Energy	Fort Saskatchewan Fractionation Facility	X		
Marsulex	Fort Saskatchewan Chemical Plant	X		
Newalta Corporation	Redwater Disposal Facility	X		
North West Upgrading Inc.	North West Upgrader Project			X
Petro-Canada Oilsands Inc.	Sturgeon Upgrader Project			X
Prospec Chemicals	Fort Saskatchewan Xanthate Plant	X		
Provident Energy Ltd.	Redwater Fractionation Facility	X		
Redwater Water Disposal Company	Redwater Waste Disposal Facility	X		
Shell Canada Limited	Scotford Upgrader	X	X expansion	
Shell Canada Products	Scotford Oil Refinery	X		
Shell Chemicals Canada	Scotford Styrene & MEG Plant	X		
Sherritt International Corporation	Fort Saskatchewan Fertilizer Plant	X		X
Synenco Energy Ltd.	Northern Lights Upgrader Project			X
Terasen Pipelines	Heartland Storage Tank Terminal			X
TransAlta Cogeneration	Fort Sask. Cogeneration Power Plant	X		
TransCanada Energy	Redwater Cogeneration Power Plant	X		

1.6 References

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WorleyParsons Komex
resources & energy

Alberta Sulphur Terminals Ltd.
Bruderheim Sulphur Forming and Shipping Facility

Volume IIB – Water and Aquatic Ecology

2. Groundwater Quantity and Quality

Project Number 62720000
June 2007

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APPENDICES

Executive Summary

Alberta Sulphur Terminals Ltd. (AST), a division of HAZCO Environmental Services (HAZCO) which, in turn, is a division of CCS Income Trust (CCS), retained WorleyParsons Komex to conduct a groundwater assessment. Its objectives were as follows:

a) satisfy the relevant section of the Terms of Reference (TOR) of the Environmental Impact Assessment (EIA)
b) assess the hydrogeological suitability of the Site for the proposed Project
c) provide initial hydrogeological design recommendations
d) establish a groundwater monitoring program for the proposed Project

The hydrogeological assessment confirmed that Section 35-55-20-W4M (the Site) was generally suitable for siting AST's proposed sulphur forming and shipping facility (the Project). However, an adequate groundwater supply source must be confirmed at the Site. Barring the presence of an adequate groundwater supply, an alternate makeup water supply will need to be secured for the Project. The aspects of the TOR that are relevant to the groundwater assessment and the respective conclusions of the assessment are summarized as follows.

Discuss baseline groundwater conditions and identify components (e.g., dewatering, well supply) of the Project that will affect groundwater from a local and regional perspective. Provide the following:

a. a discussion of the characteristics of major geological units and their function as potential aquifers, aquitards, and aquicludes in the Study Area;

b. lithologic and stratigraphic continuity of the geologic units in the Study Area;

The soil stratigraphy generally consists of surficial topsoil or fill overlying deposits of glacial origin. Surficial deposits are variable both in composition and thickness. Till or till-like clay was encountered in most boreholes. The till was silty and/or contained high-plastic clay, silty sand and/or sand seams. Significant thicknesses of silty sand were encountered in the central and southeast portions of the PDA. The surficial deposits are underlain by sedimentary bedrock comprised mainly of shale and sandstone that extends beyond the completion depth of the boreholes.

The following are considered to be aquitards: the till unit and fine-grained and competent portions of the bedrock (i.e., shale intervals, except where weathered or fractured in the upper portion of bedrock). The primary aquifer is a sandstone interval located in the upper bedrock zone at a maximum depth of approximately 15 metres below ground surface (mbgs). This zone appears to be used as a domestic and potable water supply for most rural residences in the vicinity of the Site. A second deeper sandstone interval was identified between depths of 81–87 mbgs. Due to the weathered or fractured nature of the upper shale portion of bedrock, the overburden groundwater appears to be partially hydraulically connected to groundwater in the upper sandstone interval. However, groundwater in the lower sandstone interval and deeper appears to be hydraulically separated by a thick, competent shale unit.

c. hydrogeologic information including hydraulic properties, hydraulic heads, flow direction, velocity and connectivity with surface water bodies of the geologic units;

The measured depth to groundwater in the surficial deposits ("A" series) monitoring wells ranged from greater than 0.08 m above ground surface (i.e., flowing conditions) to 2.82 mbgs. Seasonal variations in groundwater surface elevations on the order of 0.1–0.6 m have been observed. The groundwater flow direction in the surficial deposits is interpreted to range from northeast to due north. Hydraulic conductivity testing of the overburden monitoring wells showed two orders of magnitude difference between monitoring wells screened within predominantly clay soils and predominantly silty sand or sand (2.3×10^{-8} to 3.0×10^{-6} m/s). Groundwater flow velocities in the surficial deposits are interpreted to range from several centimetres to several metres per year with an average of about 0.2 m/y.

The measured depth to groundwater in the upper bedrock sandstone aquifer ("B" series) monitoring wells ranged from 0.54 m above ground surface in monitoring well 05–01B to 2.94 mbgs. Seasonal variations in groundwater surface elevations on the order of 0.2–0.5 m have been observed. Minimal differences were measured between groundwater surface elevations in the "A" and "B" series nested monitoring wells. Calculation of vertical hydraulic gradients showed very low upward, near-neutral and very low downward gradients. The groundwater flow direction in the sandstone interval is interpreted to be to the northeast but is expected to change to due north based on regional information and the inferred connectivity with the surficial deposits. Hydraulic conductivity testing of the bedrock wells showed two orders of magnitude difference between monitoring wells screened within the shale and the sandstone (1.7×10^{-8} to 6.6×10^{-6} m/s). Groundwater flow velocities in the upper bedrock are interpreted to range from several tens of centimetres to several metres per year with an average of about 0.6 m/y.

d. *baseline groundwater quantity and quality information of the hydrogeologic units in the Study Area;*

Based on a two-hour pumping test, an estimated 20-year sustainable yield of about 7.8 L/m was calculated within what appeared to be the most productive portion of the upper bedrock sandstone interval. Based on the variable geology, diminished yield could occur over time. Multiple wells will be required to supply the desired quantity of water (up to 24 L/m for the initial development and about 48 L/m at maximum capacity). A pumping test conducted in the deeper sandstone interval indicated this zone to be poorly yielding and not suitable as a water supply source.

Hydrochemistry of groundwater measured in the surficial deposits and the upper bedrock was generally the same and showed groundwater to be predominantly sodium-bicarbonate. Therefore, the addition of acidity would be naturally buffered. Total dissolved solids (TDS), dissolved sulphate, dissolved sodium and/or dissolved manganese concentrations in all or some of the monitoring wells exceeded the Health Canada (2004) Drinking Water Aesthetic Objective Guidelines. Dissolved sulphate appears to be naturally elevated in the portions of the surficial water-bearing zone. Dissolved metal concentrations in the surficial deposits and upper bedrock wells did not exceed applicable guidelines. The potability results are not considered to be a concern in the context of the proposed Project.

Groundwater in the lower bedrock zone is of sodium-chloride type.

e. *maps and cross-sections that include the water table and piezometric surfaces based on identifiable hydrogeologic units and accurate data sources, such as drill holes;*

f. *results of any new hydrogeological investigations, including methodology;*

Maps and cross-sections that include the water table and piezometric surfaces for each significant hydrogeologic unit are presented in the completed hydrogeological assessment report (see Section 2.5.). Results of the groundwater investigations are presented in Section 2.5 while associated methodology is described in Section 2.4.

g. *an inventory of groundwater users in the Study Area. Identify potential groundwater use conflicts and possible means to resolve these conflicts;*

A water well search of Alberta Environment's water well database indicated 53 water well records within a 1 km radius of the Site and 176 wells within a 3 km radius (see Appendix V). Of the 53 water wells within the 1 km search radius, 32 were listed as domestic, 10 as domestic and stock, 2 unknown and the remainder industrial or stock. Well depths were listed for 50 of the 53 wells and a summary of these well depths is shown in Table ES-1.

Table ES-1: Summary of Well Depths

Total Well Depth (m)	Number of Wells Within 1 km of Site
3–10	9
10–20	18
20–30	11
30–40	3
40–50	2
50–60	3
60–70	3
> 100	1

Six registered water wells were identified downgradient (north) of the Project within several hundred metres from the northern Site boundary. Of these six wells, five have a listed total depth less than 20 mbgs and are thus potentially completed in the same interval as the surficial and upper bedrock aquifers that were investigated as part of this study.

It is anticipated that the effect of Project water withdrawals on existing water users should remain negligible or low in magnitude (i.e., within natural variability in groundwater levels) for the entire 25 year duration of the Project. Monitoring is recommended to ensure that adequate groundwater levels are maintained to existing nearby users.

h. *an assessment of potential effects of water withdrawal on groundwater levels, effects on local and regional groundwater regimes, including vertical gradients and discharge areas;*

i. *an assessment of the effects of groundwater withdrawal/dewatering and its implications for other environmental resources, including flows and water levels in local streams, water wells, wetlands, vegetation and soil saturation;*

It is anticipated that local groundwater levels and flows within the upper sandstone interval will be significantly affected by water withdrawals associated with the Project. However, these effects are anticipated to dampen relatively quickly with increasing distance from the facility and at distances greater than about 750 m from the pumping centre(s). Effects on regional water levels and flows are expected to be negligible or low in magnitude (i.e., within natural variability of up to 0.5 m).

The upper bedrock zone is not in direct connection to nearby surface waters and wetlands, which are protected from the effects of water withdrawals by the overlying till. Hence, impact to surface water resources is expected to be negligible. As well, groundwater withdrawal from depth is also not expected to affect soil saturation or vegetation on the Site.

Groundwater monitoring during Project operation is recommended to confirm these assessments. The Project will use groundwater as a makeup source if adequate long-term yield can be ascertained and unless or until an adverse off-site effect becomes apparent. At that point, either a bigger runoff storage pond will be constructed and/or water may be obtained from a regional reservoir.

j. *an assessment of potential effects of project-related activities and surface releases (e.g., accidental contaminant spills) and down-hole wastewater on groundwater quality;*

Assuming that all mitigation measures are implemented appropriately, it is anticipated that overall groundwater quality during the Project lifetime will not be significantly affected by Project-related activities or surface releases during construction and operations. Groundwater travel times to the downgradient (northern) Site boundary are on the order of hundreds of years, indicating ample response time for specific mitigation measures to be implemented should a surface release occur.

k. *justification for the selection of hydrogeologic models used, including identifying any model shortcomings or constraints on findings, and any surrogate parameters that were used as indicators of potential aquifer contamination due to the Project;*

Selection criteria for the models utilized to complete the hydrogeological assessment are included in Appendix VI. These models are considered to be industry standards. The evaluation of potential groundwater yield was based on a short-term pumping test. A multi-day pumping test was originally scheduled for spring 2007 to increase confidence in the groundwater quantity Project effects assessments and determine whether an adequate groundwater supply source is present at the Site. However, the resident requested that testing be delayed until calving season was over and livestock were not dependent on water from the well. The pumping test has been rescheduled for June 2007.

l. *a plan and implementation program for the protection of groundwater resources, addressing the following:*

    i) *groundwater monitoring program for early detection of potential contamination and assistance in remediation planning;*

    ii) *groundwater remediation options to be considered for implementation in the event that adverse effects are detected; and*

    iii) *monitoring the sustainability of groundwater production and dewatering effects.*

Twice-annual groundwater monitoring of the “A” and “B” series wells is proposed to evaluate potential effects to groundwater levels and for early detection of potential contamination. The monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local hydrogeology and possible effects related to the operation of the proposed facility. Proposed long-term groundwater monitoring would typically be specified as part of an Alberta Environment (AENV) approval.

A response plan or action plan will be developed to enable prompt courses of action in the event that routine monitoring detects an impact that may eventually become unacceptable. Following Project approval, a draft response plan should be prepared and submitted to AENV for review, comment and approval.

2. Groundwater Quantity and Quality

2.1 Introduction

This section includes the baseline studies and effects assessments pertaining to groundwater for the Alberta Sulphur Terminals Ltd. (AST) sulphur forming and shipping facility (the Project) which has been proposed for the Bruderheim area (see Figure 2.2-1). Field programs were conducted in 2006 to supplement existing hydrogeological information from investigations conducted in 2005 (Komex 2005; 2006 a, b) and to assess the feasibility of using a lower bedrock groundwater supply zone for the Project. The baseline portion of this document (see Section 2.5) summarizes regional and local geology and hydrogeology, presents field program results and characterizes the current condition of the groundwater resource at and near the Project. The effects assessments portion of this document (see Section 2.6 and Section 2.7) provides an analysis of potential effects of the Project on the quantity and quality of the groundwater resource. A final impact ratings summary table is provided in Section 2.12.

2.2 Terms of Reference

Groundwater is an important ecosystem component that interacts with other ecosystem components. Groundwater in the area surrounding the Project is also important as a water supply source for predominantly domestic and stock use and limited industrial use. Based on these considerations, the Terms of Reference (TOR) (AENV 2007) for the Environmental Impact Assessment (EIA) that address groundwater assessment include the following:

a) a discussion of the characteristics of major geological units and their function as potential aquifers, aquitards, and aquicludes in the Study Area;

b) lithologic and stratigraphic continuity of the geologic units;

c) hydrogeologic information including hydraulic properties, hydraulic heads, flow direction, velocity and connectivity with surface water bodies of the geologic units;

d) baseline groundwater quantity and quality information of the hydrogeologic units in the Study Area;

e) maps and cross-sections that include the water table and piezometric surfaces based on identifiable hydrogeologic units and accurate data sources, such as drill holes;

f) results of any new hydrogeological investigations, including methodology;

g) an inventory of groundwater users in the Study Area. Identify potential groundwater use conflicts and possible means to resolve these conflicts;

h) an assessment of potential effects of project-related water withdrawal on groundwater levels, effects on local and regional groundwater regimes, including vertical gradients and discharge areas;

i) an assessment of the effects of groundwater withdrawal/dewatering and its implications for other environmental resources, including flows and water levels in local streams, water wells, wetlands, vegetation and soil saturation;

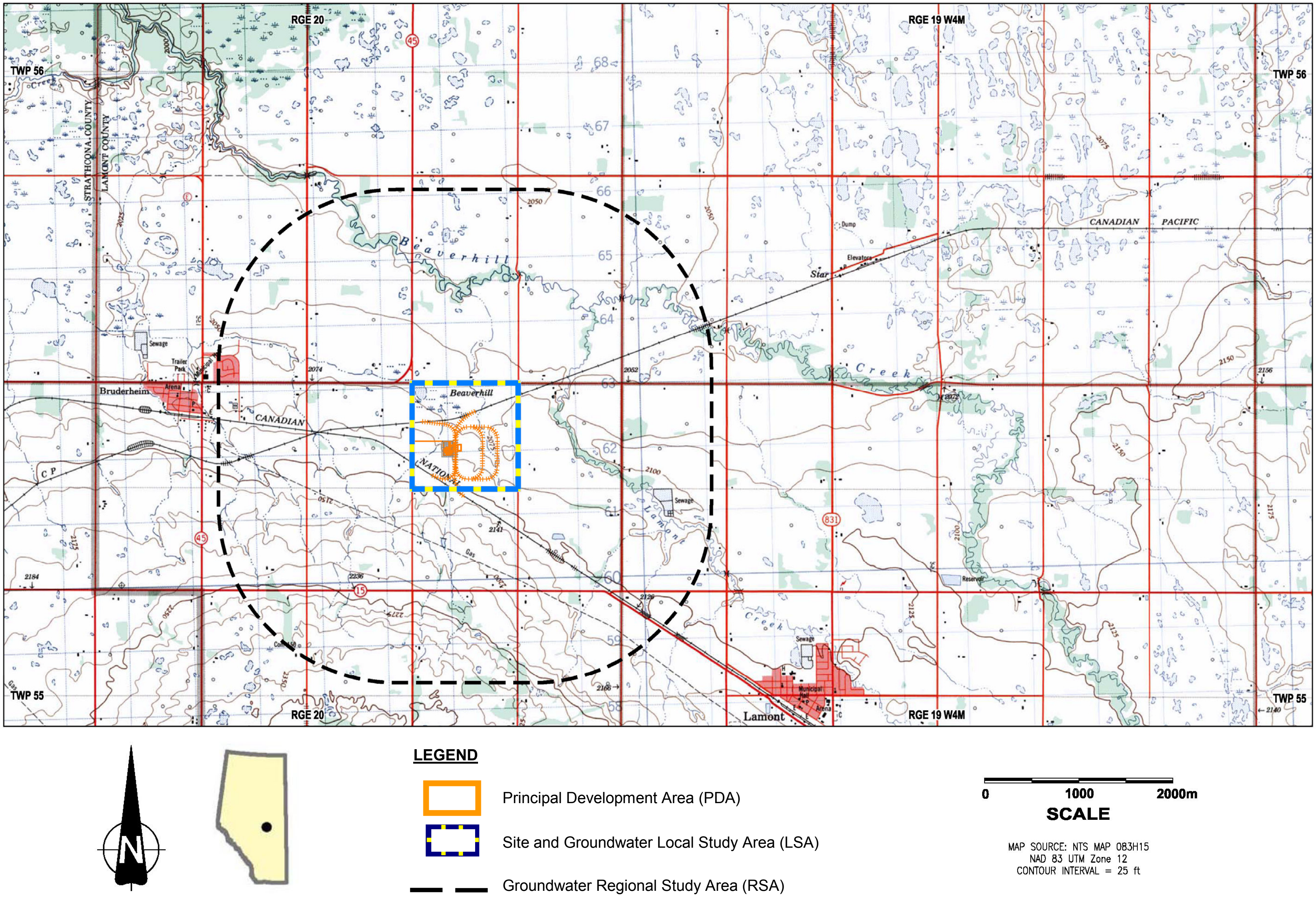


Figure 2.2-1: Property Location, Topography and Drainage Features

j) an assessment of potential effects of project-related activities and surface releases (e.g., accidental contaminant spills) and down-hole wastewater on groundwater quality;

k) a justification for the selection of hydrogeologic models used, including identifying any model shortcomings or constraints on findings, and any surrogate parameters that were used as indicators of potential aquifer contamination due to the Project;

l) a plan and implementation program for the protection of groundwater resources, addressing the following:

  i) groundwater monitoring program for early detection of potential contamination and assistance in remediation planning;

  ii) groundwater remediation options to be considered for implementation in the event that adverse effects are detected; and,

  iii) monitoring the sustainability of groundwater production or dewatering effects.

2.3 Identification of Key Issues

Based on the Project description provided in Section 1: Introduction of this volume, the following components have the potential to affect groundwater quantity or quality:

- water supply: a backup water supply source (groundwater or other) may be required for sulphur cooling whenever there is insufficient water available from the surface runoff-collection pond. The water supply requirements for the Project are presently estimated to be up to 24 L/m for the initial development and about 48 L/m at maximum capacity.
- air emissions: aerial deposition of acidifying compounds on soils could potentially affect groundwater quality
- water management: operation of the surface water collection pond. Under normal operating conditions, the risk of contaminating groundwater is expected to be small as the pond will be double-lined and equipped with a leak detection system. However, the possible consequences of an accidental breach of the pond will be considered.
- upset conditions: chemical spills around the plant area could potentially affect groundwater quality
- based on these operational aspects of the Project and the effects assessment requirements detailed in the TOR, the following key issues related to the Project will be assessed:
  - possible change to local and regional groundwater levels and flows as a result of groundwater withdrawals by the Project
  - possible change to interactions between groundwater and surface water (streams, wetlands) as a result of groundwater withdrawals by the Project
  - possible reduction of the amount of groundwater available to other water well users as a result of groundwater withdrawals by the Project
  - possible reduction in groundwater quality because of potential effects of atmospheric deposition of elemental sulphur, breach of the surface water collection pond or chemical spills
- the potential effects of these key issues are discussed and, where appropriate, analyzed in the context of the local and regional hydrogeology surrounding the Project

2.4 Methods

The groundwater baseline description was put together by gathering information from a review of regional climate, topography, drainage, geology, hydrogeology and water use and from field programs conducted for the Project. Building upon this baseline information, a combination of analytical computational methods and professional judgment was used to test for possible changes in groundwater quantity and quality that could take place as a result of the Project. Details of analytical methods are provided in the sections where they are discussed.

2.4.1 Assessment Scenarios

The TOR specifies that the following assessment scenarios should be considered:

a) baseline case – existing environmental conditions and existing and approved projects or activities

b) application case – baseline case plus the Project

c) cumulative effects assessment case – past studies, existing and anticipated future environmental conditions, existing projects or activities, plus other planned projects or activities

2.4.2 Spatial and Temporal Boundaries

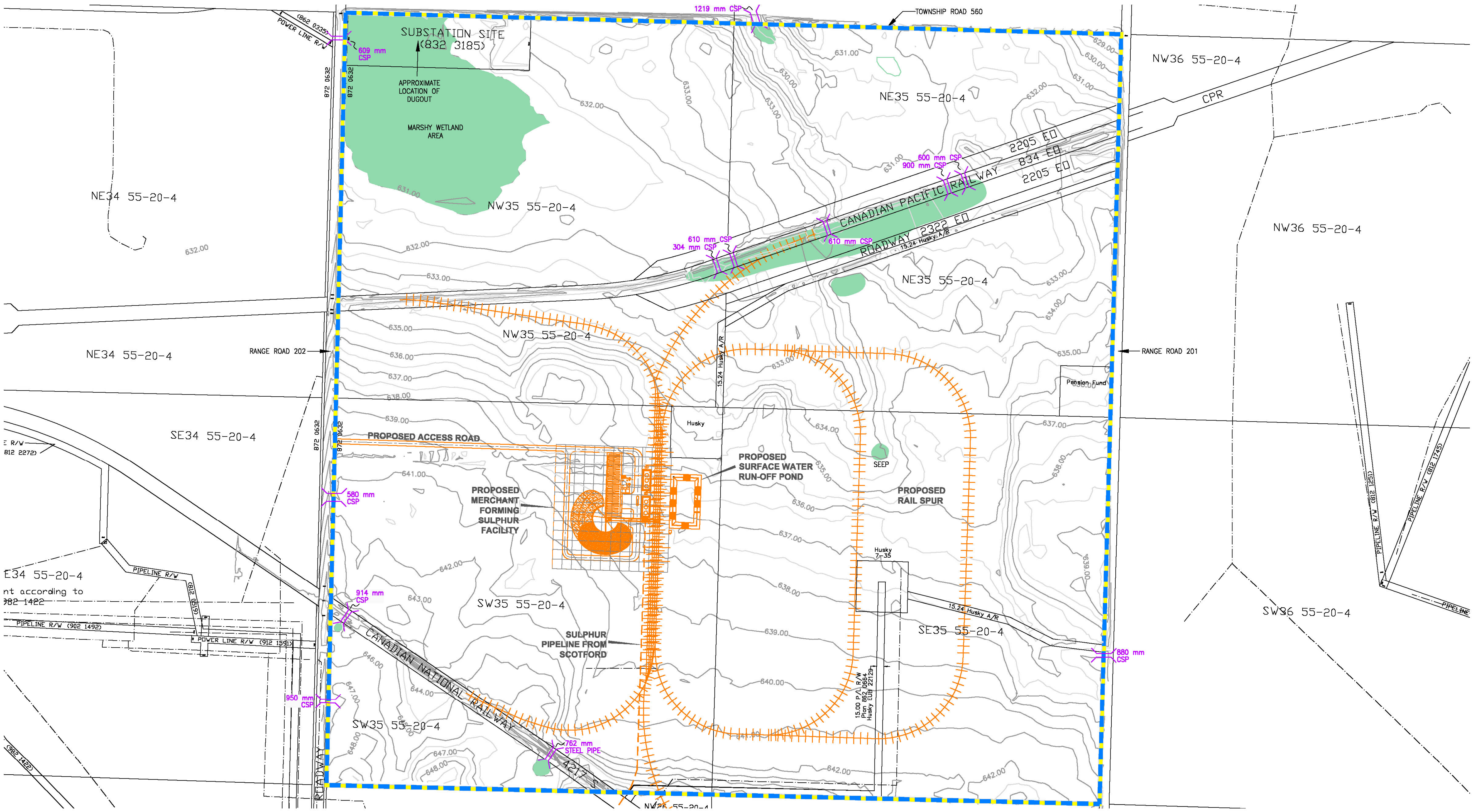
The EIA spatial boundaries comprise the Principle Development Area (PDA), Groundwater Local Study Area (LSA) and Groundwater Regional Study Area (RSA).

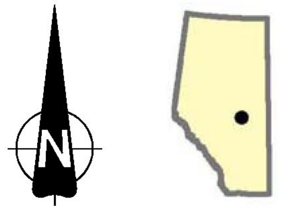
2.4.2.1 Principal Development Area

The PDA is contained within a portion of Section 35-55-20 W4M (the Site) (see Figure 2.2-1) and comprises the area of disturbance and development as illustrated in Figure 2.4-1. The PDA consists of rail and road access for receiving and storing molten sulphur, molten sulphur unloading and transfer facilities, sulphur forming facilities to produce sulphur pastilles, loading and shipping facilities for formed sulphur and sulphur pastilles temporary storage area.

2.4.2.2 Local Study Area

The Groundwater LSA was selected on the basis of groundwater quality considerations. It includes the PDA and those areas that could potentially be affected by accidental spills, breach of the surface water collection pond or air emissions occurring within the PDA. These areas are contained within the Site boundaries (see Figure 2.4-1) and include the slough and wetlands in the northwest portion of the Site. While some very limited atmospheric deposition of elemental sulphur is expected at the regional scale, measurable effects on soil quality (with possible secondary consequences for groundwater quality) are expected to be confined to the PDA (see Volume IIC, Section 2: Soil).





LEGEND

🟧 Principal Development Area (PDA)

▨ Site and Groundwater Local Study Area (LSA)

🟩 Wetland

⋈ Culvert (CSP = Corrugated Steel PPE)

0 1000 2000m

SCALE

MAP SOURCE: NTS MAP 083H15
NAD 83 UTM Zone 12
CONTOUR INTERVAL = 25 ft

Figure 2.4-1: Local Topography and Site Features

2.4.2.3 Regional Study Area

The Groundwater RSA was selected on the basis of groundwater quantity considerations. The RSA is substantially larger than the LSA and considers a radius within 3 km of the Project (see Figure 2.2-1). This is because pumping of groundwater would have potential to produce effects on receptors (surface waters and existing water well users) not only in the LSA, but also beyond the LSA. As indicated above, groundwater quality effects related to the Project are not expected at the regional scale.

2.4.3 Temporal Boundaries

The temporal boundaries for the groundwater assessments were chosen to coincide with current conditions (baseline case), the anticipated lifespan (25 years) of the Project (maximum disturbance) and closure. The maximum disturbance temporal boundary is important from a groundwater quantity perspective and is used to determine the potential effect of the Project after 25 years of groundwater use. The effects of Project water withdrawals on groundwater levels and flows are expected to be greatest after 25 years, rendering the effects assessments worst case and conservative. Closure is considered when all Project facilities have been decommissioned and reclamation has taken place. Groundwater levels and flows would tend to recover relatively rapidly following cessation of water use by the Project. Thus, in the closure assessments, the focus shifts to possible residual groundwater quality effects of the Project (if any).

2.4.4 Project Inclusion List

The project inclusion list considers the various anthropogenic disturbances that must be included in each assessment scenario in order to effectively determine Project effects and cumulative effects.

Table 2.4-1 provides the list of projects included in the scenarios.

Table 2.4-1: Project Inclusion List

Project	Location	Operational Activities
ERCO Worldwide	Northwest section of 34-20-55 W4M (approximately 1.6 km west of northwest quadrant of the Project)	ERCO Worldwide is a sodium chlorate plant that has been in the area since 1990. It is currently not in operation and is due to be shut down completely in 2007.
Canexus Chemicals	Southeast quadrant of Section 34-20-55 W4M (immediately west of the southwest quadrant of the Project)	Canexus Chemicals is a sodium chlorate plant. The plant was constructed in 1990/91 with operations beginning in 1991.
Triton Fabrication	Northwest section of 26-20-55 W4M (immediately south of southwest quadrant of the Project)	Triton provides heavy-industrial general contracting, fabrication and maintenance services to resource and industrial clients throughout western Canada. Triton fabrication has been in the area since the summer of 2004.

2.4.5 Information Review and Data Sources

2.4.5.1 Topography and Drainage

Key data sources on the regional surficial and bedrock geology included:

- Stein (1976)

2.4.5.2 Geology

Key data sources pertaining to the regional surficial and bedrock geology included:

- Alberta Environment online GIS maps (AGS 2005, Internet Site)
- Andriashek (1987a,b; 1988)
- Bayrock (1972)
- Hamilton et al. (1998)
- Stein (1976)

2.4.5.3 Hydrogeology

Key data sources pertaining to the regional hydrogeology included:

- Alberta Environment (1978)
- Farvolden (1963)
- Geoscience Consulting Ltd. (1976)
- Hydrogeological Consultants (1977)
- Stein (1976)

2.4.5.4 Water Use

Key data sources pertaining to the regional hydrogeology included:

- Alberta Environment water well database (AENV 2006, Internet site)

2.4.6 Field Programs

Field work for characterizing baseline hydrogeologic conditions at the Project included:

- siting investigation conducted in May and June of 2005 (Komex 2005)
- supplemental groundwater investigation conducted in November 2005 (Komex 2006a)
- limited soil investigation program completed in December 2005 (Komex 2006b)
- supplemental groundwater monitoring conducted in June 2006
- lower bedrock groundwater exploration program conducted between November and December 2006 (see Appendix I)

A total of 13 monitoring wells were installed during the siting investigation. Six of these wells were completed in the surficial deposits, another six were screened in the upper portion of the bedrock within or near an identified sandstone interval, while one monitoring well was installed deeper into the shale bedrock or middle bedrock. A two-hour pumping test was completed on well 05–01B with results provided in Appendix II. The limited soil investigation program was completed in December 2005 and included the advancement of 21 soil boreholes (05-13–5-33), two of which were completed as shallow groundwater monitoring wells (05–20 and 05–28).

A lower bedrock groundwater exploration program was conducted in November and December 2006 to identify and characterize a possible water supply zone at the Site below the interval of domestic-use wells in the area. The majority of domestic and stock wells have reported depths from about 5–60 m. Groundwater withdrawal from a zone deeper than the domestic use aquifer zones was considered to minimize, to the extent practical, potential effects of groundwater withdrawals from the Project on shallow groundwater flow systems and minimize well interference with existing users. A single test production well (PW06–01) was installed as part of the 2006 lower bedrock groundwater exploration program.

The location of monitoring and test wells is shown in Figure 2.4-2. The well locations were surveyed using a total station that referenced existing survey control markers in the area, with the exception of 05–20 and 05–28. Geologic logs, together with design and completion details, are provided in Appendix III. Well completion details are also summarized in Appendix IV – Table IV-1, together with results from hydraulic conductivity testing. Hydraulic conductivity tests were conducted by measuring the rate of water level rise in the monitoring well subsequent to the bailing. The hydraulic conductivity testing in monitoring well 05–01C was completed with a submersible pump and pressure transducer.

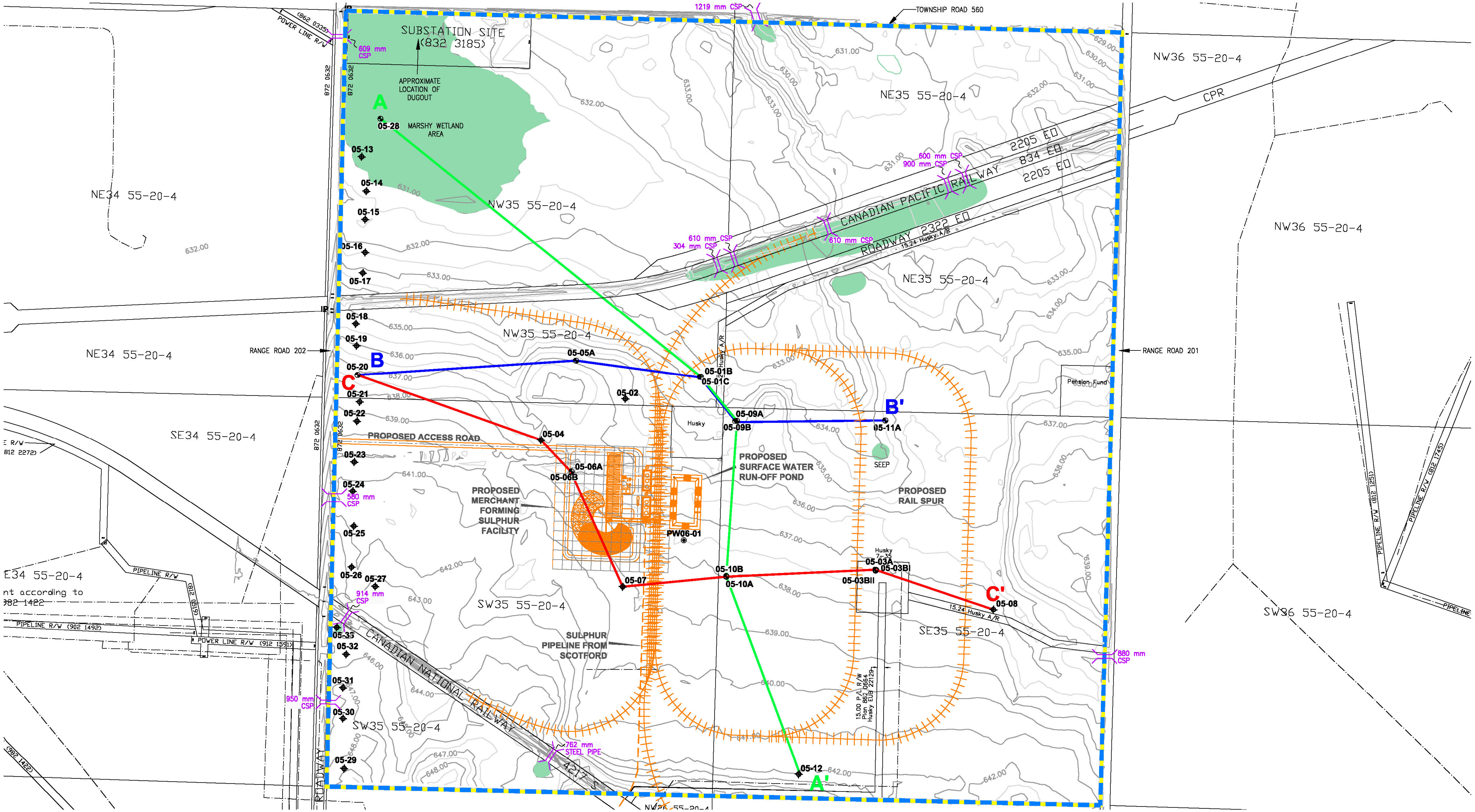
Three monitoring visits were completed to assess groundwater conditions and water quality: June 2005, November 2005 and June 2006. The lower bedrock test production well PW06–01 was monitored and sampled in December 2006. The wells were monitored for well headspace hydrocarbon vapour concentrations and groundwater levels. The hydrocarbon vapour concentrations were recorded using a standardised headspace technique with a portable hydrocarbon vapour analyser calibrated to a hexane standard. Monitoring wells were sampled for naturally occurring parameters. At the time of sampling, field electrical conductivity (EC), pH and temperature were recorded. All groundwater samples were analysed for the following parameters:

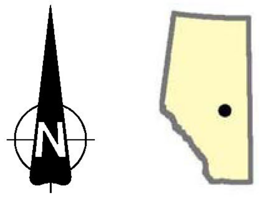
- major soluble ions
- dissolved organic carbon
- dissolved metals

Tables summarizing groundwater monitoring and groundwater quality results to date are provided in Appendix IV (see Table IV-2, Table IV-3 and Table IV-4).

2.4.7 Assessment Methodology

The groundwater baseline characterization was conducted through the above-mentioned compilation of existing regional geologic, hydrogeologic and groundwater use data, supplemented with Project area-specific hydrogeologic information including groundwater chemistry, hydraulic properties and hydraulic heads. These data were used to assess baseline groundwater conditions, including flow directions, velocities and connectivity with surface waterbodies of the geologic units within the LSA. Maps and cross-sections that include identifiable hydrogeologic units and piezometric surfaces were constructed.





LEGEND

🟧	Principal Development Area (PDA)
▨	Site and Groundwater Local Study Area (LSA)
🟩	Wetland
✕	Culvert (CSP = Corrugated Steel PPE)
⌖	Soil Borehole
◐	Monitoring Well Location
⊕	Pumping Test Well Location

0 1000 2000m

SCALE

MAP SOURCE: NTS MAP 083H15
NAD 83 UTM Zone 12
CONTOUR INTERVAL = 25 ft

Figure 2.4-2: Existing Monitoring Network and Cross-sections

For groundwater quantity assessments (i.e., as related to Project groundwater withdrawals), estimated Project impacts were determined from calculated changes in groundwater levels (i.e., drawdowns in the case of nearby water well users) or flows (in the case of receiving surface waters).

Professional judgement, based on results from the baseline conditions groundwater assessments, has been used to assess potential groundwater quality effects related to the Project (e.g., as a result of accidental spills) and provide recommendations for mitigation and emergency response planning. Groundwater quality assessments utilized Health Canada (2004) Canadian Drinking Water Quality Guidelines (CDWQG) for reference purposes only. Two types of Health Canada (2004) Drinking Water Guidelines are reported: aesthetic objectives (AO) based on taste, colour and odour and are, therefore, not directly related to human health; and maximum acceptable concentrations (MAC), which are based on protection of human health (see Appendix IV – Table IV-3 and Table IV-4).

2.4.8 Assessment Criteria

The purpose of the EIA is to assess and report on the potential impacts associated with the construction and operation of the Project. This includes impacts to existing groundwater quantity and quality in a local and regional context. The EIA also includes preventative, mitigative and compensatory actions to reduce impacts of the Project. The possible remaining impacts following these preventative, mitigative and compensatory actions are referred to as residual effects.

Groundwater impact assessments were based upon measured, predicted or reasonably expected changes in three key indicators: groundwater levels, groundwater flows and general groundwater quality. In each case, estimated residual effects were classified using the six attributes listed below and described in detail in Section I: Introduction of this volume:

- direction
- extent
- magnitude
- duration
- confidence
- reversibility

2.4.8.1 Final Impact Rating

For each individual impact assessment, a qualitative, final evaluation rating has been used. This rating is a combination of quantitative analysis and subjective professional judgment that takes into account the various descriptors for each attribute (direction, magnitude, geographic extent, duration, confidence and reversibility) and the potential implications of the specific impact. The final impact rating is an aggregated, relative, numerical ranking determined by both the analysis of impact and the level of action recommended, as necessary to address the impact. This ranking is applied to both the Project-specific impacts and cumulative effects residual impacts (see Table 2.4-2).

Table 2.4-2: Final Impact Rating Summary Table

Rating	Level of Action
Class 1	The predicted trend in an indicator under projected land use development could threaten the long-term sustainability of the quantity or quality of the indicator in the LSA and RSA. An action plan, developed jointly by regional stakeholders, is required to monitor the affected indicator, identify and implement further mitigation measures to reduce any impact and promote recovery of the indicator, where appropriate. This class of impact might also be applicable to an exceedance of a regulatory guideline or where the impact will have long-term effects.
Class 2	The predicted trend in an indicator under projected land use development will likely result in decline in the quantity or quality of the indicator. The decline could be to lower-than-baseline but stable levels in the LSA and RSA after closure and into the foreseeable future. In addition to responsible industrial operational practices, monitoring and recovery initiatives could be required if additional land use activities occur in the study area before closure of the projected land use development. This class of impact might also be applicable to an exceedance of a regulatory guideline or where the impact is expected to have mid-term effects, but where recovery will take place shortly after closure of the projected land use development.
Class 3	The predicted trend in an indicator under projected land use development could result in a slight decline in the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development, but resource levels should recover to baseline after closure. In some cases, a short-term, low to moderate magnitude impact could occur, but recovery will take place within five years. No new resource management initiatives are necessary. Responsible industrial operational practices should continue. This class of impact could also be applicable where regulatory guidelines are not exceeded, but where a relative change in magnitude of an indicator occurs.
Class 4	The projected land use development results in no change and no contribution toward affecting the quantity or quality of the indicator in the LSA and RSA during the life of the projected land use development. Responsible industrial operational practices should continue. Therefore, no cumulative effects result from the Project.

2.4.9 Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) procedures were followed during the field and laboratory analysis portions of the baseline study. Baseline hydrogeology data were used both to establish the conceptual hydrogeologic framework of the Project and to provide data for the effects assessments.

The major areas of QA and QC relied on for the assessments were:

- baseline hydrogeology field data
- baseline hydrogeology laboratory data
- assessment methodologies (computation methods)
- reporting of results

2.4.9.1 *Baseline Field Data Quality Assurance and Quality Control*

Industry standard protocols for piezometer construction and installation were used to ensure collection of groundwater representative of the target formation. Similarly, industry standards for groundwater sampling procedures were followed to ensure the collection of representative samples of formation water from each piezometer. Field sampling QA and QC procedures included collecting both field blanks and trip blanks for subsequent analysis. Proper chain of custody protocol was followed at all times.

2.4.9.1.1 Laboratory Quality Assurance (QA) and Quality Control (QC)

Laboratory QA and QC methods included:

- proper receipt, storage and preparation of samples for analysis
- assessment of ion balance, which is the calculated difference between the sum of the cations and sum of the anions in solution
- analysis of method blanks, which are samples of distilled water prepared in the laboratory and analyzed immediately after field samples to check for carry-over effects in the analytical process or equipment
- laboratory duplicates, which are replicates of field samples prepared in the laboratory and analyzed to check for sample preparation errors
- matrix spikes, which are laboratory prepared samples where a known amount of analyte is added to the sample, and are analyzed to measure extraction and digestion efficacy
- analysis of surrogate recoveries, which are laboratory duplicates to which a known amount of a known substance is added before extraction and analysis. Surrogate recoveries are used to track analyte recovery through the analytical process.
- laboratory control samples which are substances of known composition that are analyzed to test the accuracy of laboratory analytical methods

2.4.9.1.2 Assessment Methodologies (Computational Methods)

Project effects assessment QA and QC relied on the selection of computational methods that are accepted by industry and regulators. It was ensured that data used in the computational methods accurately represented and reproduced field-measured groundwater conditions. Sensitivity analyses were used to quantify the degree of uncertainty in the output of the computation methods and strengthen confidence in results.

2.4.9.1.3 Reporting Quality Assurance and Quality Control

Reporting QA and QC methods included multi-stage report review processes consisting of:

- technical review conducted by scientists familiar with the Project
- administrative review conducted by a scientific technical editor
- senior technical review conducted by peer professional hydrogeologists

2.5 Baseline Case

The baseline case includes existing environmental conditions and existing and approved projects or activities.

2.5.1 Topography, Drainage and Climate

The Project is located in the eastern Alberta region of the interior plains. Regional topography is generally the result of pre-glacial, glacial and recent activity, both erosional and depositional (Stein 1976). Regionally, topographic elevation varies between 580–780 metres above sea level (masl). The area is characterized by undulating to hummocky topography, reflecting variations in till thickness (Bayrock 1972). Drainage for the region is entirely within the North Saskatchewan River Basin (Stein 1976). The North Saskatchewan River is approximately 10 km northwest of the Site.

The Site is located approximately 800 m west of Lamont Creek and approximately 1.5 km south of Beaverhill Creek (see Figure 2.2-1). Topographic data for the PDA shows that the local ground surface is generally dipping gently to the north (see Figure 2.4-1) at a shallow angle of 0.75°. Ground surface elevation decreases from 648 masl in the southern portion of the Site to 628 masl in the northern portion of the Site.

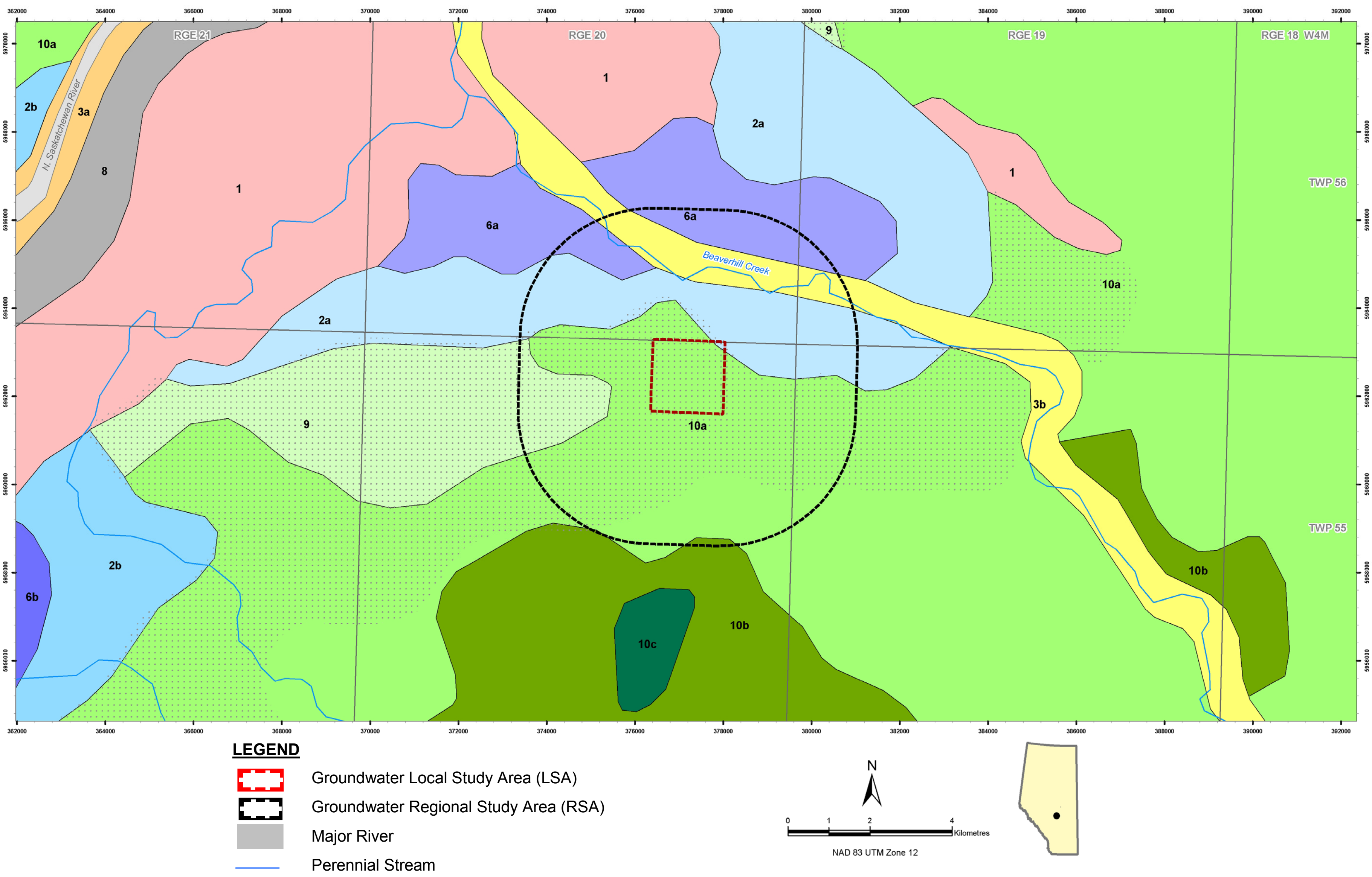
Site drainage is from south to north via two ephemeral streams that drain into wetland areas near the northern perimeter of the Site (see Figure 2.2-1 and Figure 2.4-1). Neither stream was flowing during the June and October 2006 site visits. A slough (pond) and dugout are located in the northwest corner of the LSA and are fed by the western ephemeral stream. A marshy wetland area is also located in the northwest corner of the LSA, alongside Highway 45. This wetland was observed to dry out completely by the end of August 2006. A second, smaller scale, waterlogged marshy area fed by the eastern ephemeral stream is located in the northeast portion of the LSA, along the southern edge of the CPR line. The presence of these two wetland features may be associated with altered drainage patterns following construction of the highway and railway (see Volume IIB, Section 3: Surface Water Quantity). Both ephemeral streams eventually discharge into Beaverhill Creek (see Figure 2.2-1).

Climate normals for the period 1971–2000 based on data collected at the Environment Canada climate station at Fort Saskatchewan indicate that average annual precipitation is about 460 mm, of which about 355 mm is in the form of rain and the remainder is snow. Detailed climate information is provided in Volume IIA, Section 2: Climate and Air Quality.

2.5.2 Surficial Deposits

Regionally, the dominant surficial deposits in the area of the Project consist of Pleistocene, undivided fine grained sediments of fine grained sand, silt and clay and minor gravel beds with undulating topography and local relief generally less than 3 m (see Figure 2.5-1 and Figure 2.5-2). Till, in the form of ground moraine and hummocky moraine, constitutes the bulk of the surficial material in the area and commonly underlies younger deposits. Till in the area is composed of approximately equal proportions of sand, silt and clay and generally contains less than 10% gravel (Bayrock 1972). The till has an uneven thickness, generally less than 12 m, but with local material up to 30 m thick.

The general stratigraphy at the PDA consists of surficial topsoil and/or fill overlying silty sand, clay and/or glacial clay till deposits underlain by weak sedimentary bedrock. The geology is summarized below, with cross-sections shown in Figure 2.5-3, Figure 2.5-4 and Figure 2.5-5 (refer to Figure 2.4-2 for cross-section locations).



Map Source: Shetsen, I. 1990. AGS, AEUB, Quaternary Geology, Central Alberta. Map 213

Figure 2.5-1: Regional Surficial Geology Map

PLEISTOCENE AND HOLOCENE, UNDIVIDED

1	EOLIAN DEPOSIT: fine and medium-grained sand and silt; up to 7 m thick; longitudinal and parabolic dunes scoured by blowouts; undulating to rolling topography.
	LACUSTRINE DEPOSIT: sand, silt and clay with local ice-rafted stones up to 80 m thick; deposited mainly in proglacial lakes, but includes also undifferentiated recent lake sediment; flat to gently undulating topography.
2a	Coarse sediment: sand silt; undulating surface in places modified by wind.
2b	Fine Sediment: silt and clay; flat to gently undulating surface.
	FLUVIAL DEPOSIT: gravel, sand, silt and clay, includes local till and bedrock exposures; up to 20 m thick; present on floor and terraces of river valleys and meltwater channels, and in deltas; flat to undulating topography.
3a	Coarse sediment: gravel, gravel and sand, fine to coarse-grained sand, minor silt beds.
3b	Fine Sediment: fine sand, silt and clay, minor gravel beds.

PLEISTOCENE

6a	Coarse Sediment: sand and silt.
6b	Fine Sediment: silt and clay.
	ICE CONTACT FLUVIAL DEPOSIT: gravel, sand, silt and clay, local till; up to 25 m thick; deposited in ice-walled and supraglacial streams, or in ice-front fans and deltas; undulating to hummocky topography.
7a	Coarse Sediment: gravel, gravel and sand, fine to coarse grained sand.
8	ICE CONTACT LACUSTRINE AND FLUVIAL DEPOSITS, UNDIVIDED: gravel, sand, silt and clay, local till: up to 25 m thick; deposited in intermittent supraglacial lakes and streams, or at margins of ice-floored proglacial lakes; undulating to hummocky topography.
	GLACIAL DEPOSIT (Units 9 through 12a): till consisting of unsorted mixture of clay, silt, sand and gravel, with local water-sorted material and bedrock; the thickness is generally less than 25 m on uplands, but may reach as much as 100 m in buried valleys; flat, undulating, hummocky or rigid topography.
9	DRAPED MORAINE: till of uneven thickness, with minor amounts of water-sorted material and local bedrock exposures; up to 10 m thick; includes local areas of undifferentiated subglacially molded deposit with streamlined features; flat to undulating surface reflecting topography of underlying bedrock and other deposits.
	STAGNATION MORAINE: till of uneven thickness, local water-sorted material; up to 30 m thick; undulating to hummocky topography reflecting variations in till thickness.
10a	Undulating topography, with local relief generally less than 3 m.
10b	Hummocky topography moderately to weakly developed, with irregularly shaped and poorly defined knobs and kettles; local relief 5 to 20 m.
10c	Hummocky topography strongly developed, with generally round well defined knobs, dimpled kettles, doughnut shaped hills and kettles; local relief 5 to 20 m.
░	Surface modified by lake and stream erosion and deposition.

Source: Shetsen, I. 1990. AGS, EUB, Quaternary Geology, Central Alberta Map 213.

Figure 2.5-2: Surficial Geology Legend

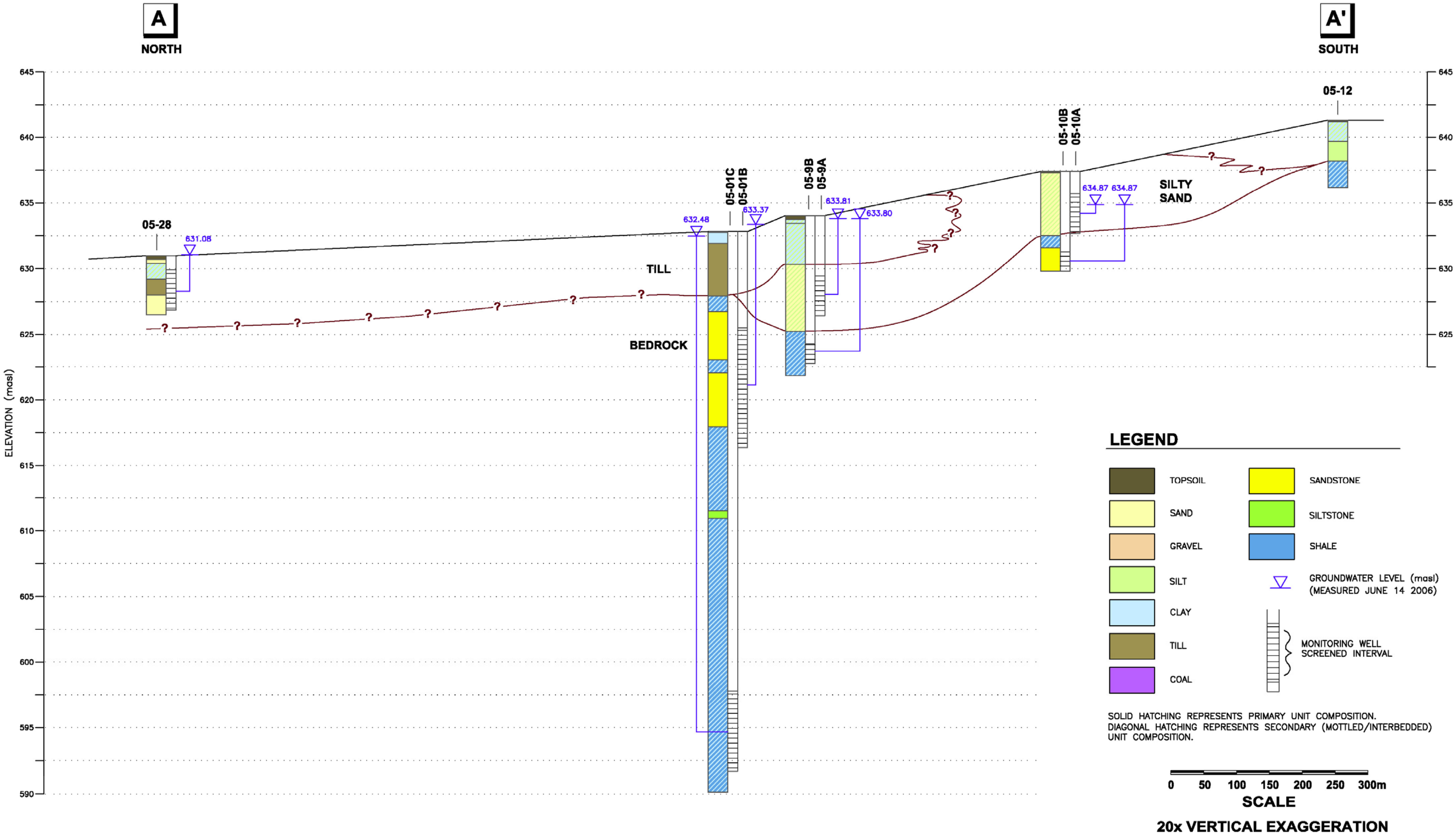


Figure 2.5-3: Cross-section A-A’

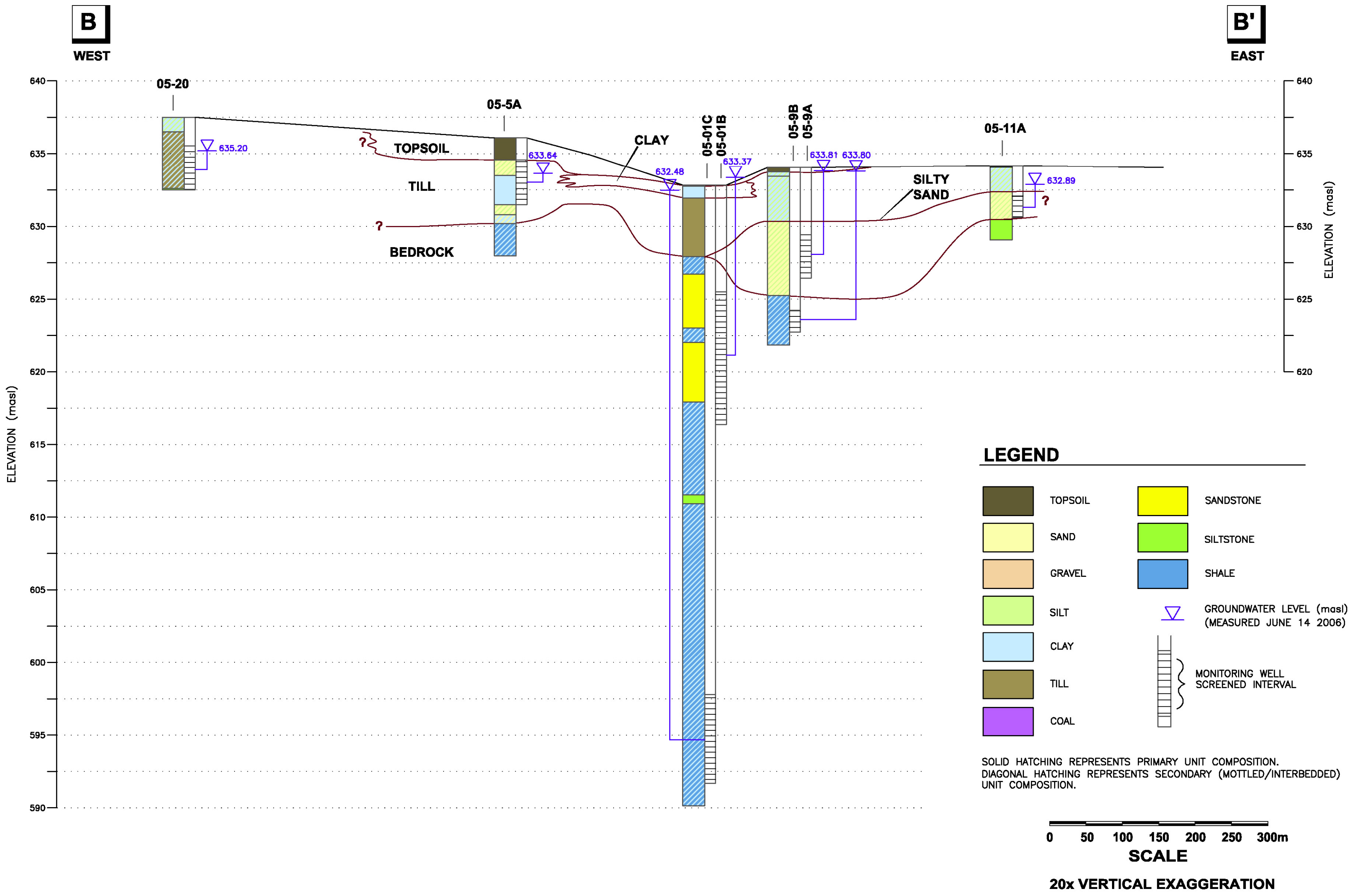


Figure 2.5-4: Cross-section B-B’

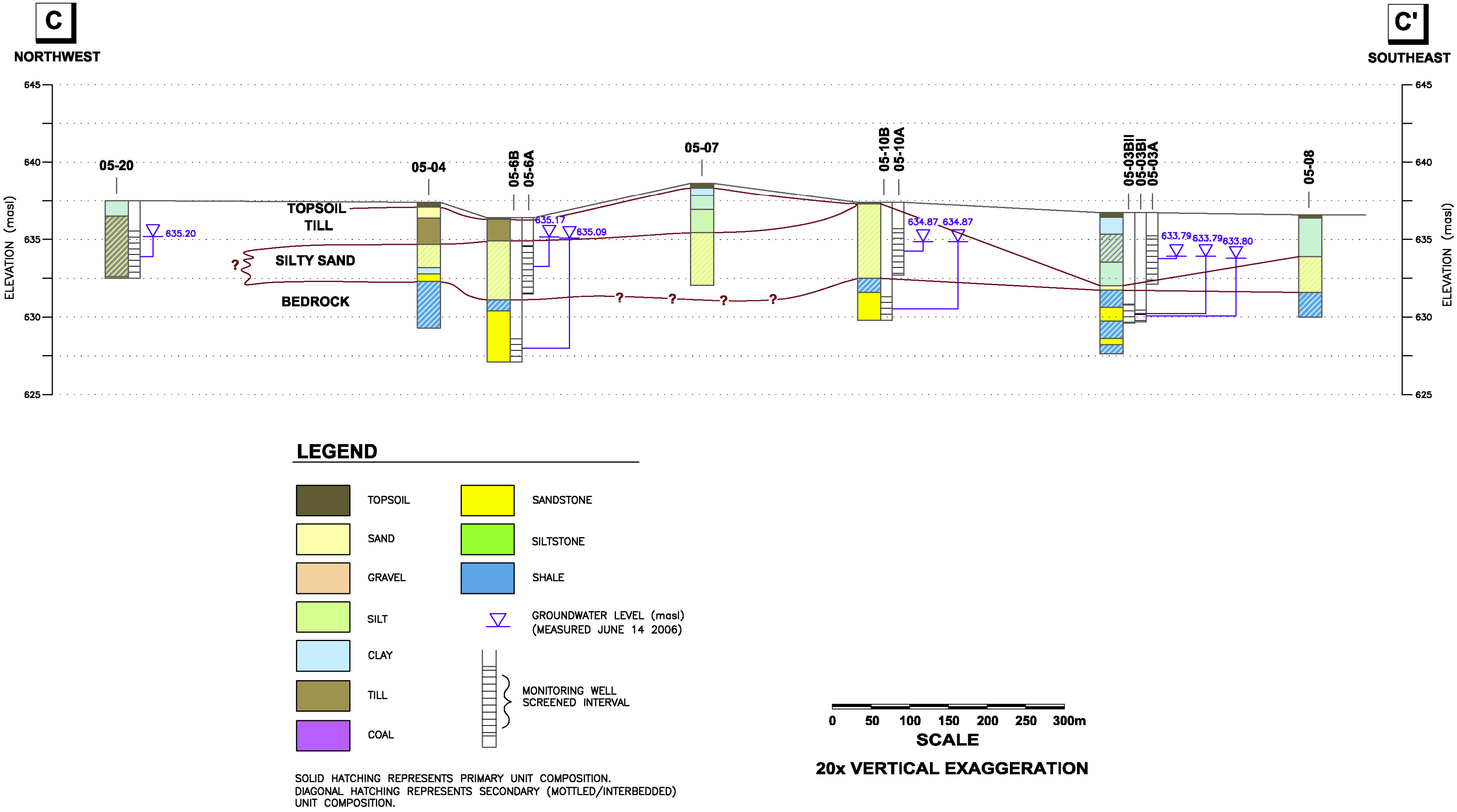


Figure 2.5-5: Cross-section C-C’

2.5.2.1 Topsoil and Fill

Topsoil and fill were encountered in all of the boreholes advanced, with a maximum thickness of 2.3 m of topsoil encountered in borehole 05–02 and a maximum thickness of 1.8 m of fill in borehole 05–11.

2.5.2.2 Surficial Deposits

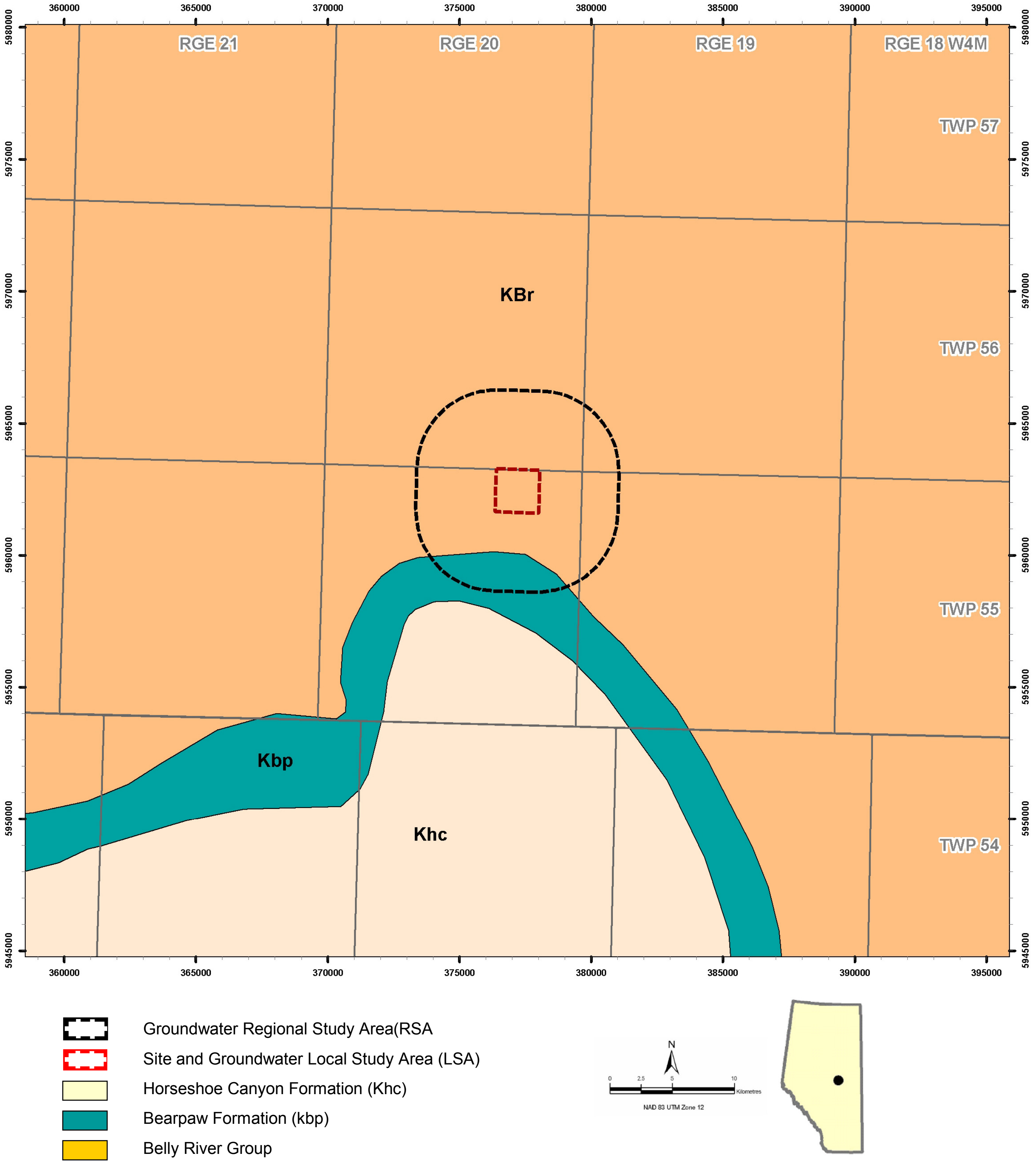
The natural surficial deposits in the PDA are variable both in composition and thickness. Till or till-like clay was encountered in most boreholes. The till was silty and/or contained high-plastic clay, silty sand or sand seams. The maximum thickness of surficial deposits encountered was 6.7 m (05–07) and the average thickness of the surficial deposits was between 4.5 and 5.0 m.

Significant thicknesses of silty sand were encountered in the central and southeast portions of the PDA, in boreholes 05–06, 05–07, 05–09, 05–10 (see Figure 2.5.3 and Figure 2.5-5) and at PW06–01 (see Appendix III). The top of the silty sand was encountered at surface in borehole 05–10 and at approximately 3.7 m below ground surface (mbgs) in borehole 05–09, indicating that the depth to the top of the silty sand appears to dip with the sloping topography (see Figure 2.5-3). The silty sand appears to pinch out in the northwest portion of the PDA, as indicated by the geology encountered at 05–01, 05–05 and 05–20 (see Figure 2.5-4). However, fine grained sand was encountered below the till at 05–28, northwest of the PDA (see Figure 2.5-3).

2.5.3 Bedrock Geology

Regionally, the bedrock topography dips north across the RSA towards Beaverhill Creek and then northwest towards the North Saskatchewan River (Andriashek 1987a). Near surface bedrock geology (within 300 m of ground surface) is mainly of the Late Cretaceous age and consists of the Belly River Formation, Bearpaw Formation and Horseshoe Canyon Formation (Hamilton et al. 1998). The areas where these formations subcrop are shown in Figure 2.5-6. The beds within each formation dip gently southwest with older rocks present in the northeast portion of the region. The oldest bedrock formation that subcrops in the area is the Belly River Formation, which is non-marine in origin, consists of grey to greenish grey, thick bedded, feldspathic sandstone, grey clayed siltstone, grey and green mudstone and concretionary ironstone beds, and has a thickness that ranges from 275–300 m locally (Stein 1976). The Belly River Formation subcrops within the RSA and is the bedrock formation encountered during intrusive investigations, which have extended to 91 m depth.

At the PDA, sedimentary bedrock consists of mainly shale and sandstone. The bedrock materials are typically weak to moderately strong, brown and grey in colour. and contain interbedded layers of siltstone, shale and sandstone throughout. A relatively well-defined sandstone interval appears to be present in the upper portion of the bedrock below the PDA (see Figure 2.5-3, Figure 2.5-4 and Figure 2.5-5). The top of this sandstone interval was encountered at a minimum depth of 5.8 mbgs (05–10B) while the bottom of the sandstone was encountered at a maximum depth of 14.9 mbgs (05–01B/C). The maximum thickness of the sandstone is 7.8 m at 05–01B/C, where the sandstone comprises two intervals separated by about 1 m of shale. The geology encountered at PW06–01 during the lower bedrock groundwater exploration indicated that a competent shale interval exists between depths of about 35 and 61 mbgs. Siltstones and sandstones are predominant between 61 mbgs and the maximum depth of investigation of about 91 mbgs. Sandstone intervals within the Belly River Formation, such as those identified at the PDA, generally are discontinuous and cannot be correlated at scales of about a kilometre or larger (Stein 1976).



Map Source: Hamilton et al. (compilers). 1999 Geological Map of Alberta, AGS, AEUB, Map No. 236, Scale 1:1,000,000.

Figure 2.5-6: Regional Bedrock Geology Map

2.5.4 Hydrogeology

The regional piezometric levels in the area are expected to be between 615–630 masl (Stein 1976). The regional groundwater flow direction appears to be controlled by the topography of the bedrock surface and is generally northward in the vicinity of the Site before turning northwest, towards the North Saskatchewan River. The average expected yield of groundwater in water wells in the area ranges from less than 4 L/m to slightly greater than 100 L/m.

The main regional talweg (buried sand channel deposit that may act as an aquifer and is located within a bedrock valley) is the Beverley Valley talweg in the present day North Saskatchewan River Valley (Andriashek 1987a,b). A tributary talweg appears to originate east of Lamont and runs generally northward to intersect the Beverley Valley buried sand channel about 20 km north-northeast of the PDA. The two talwegs are relatively distant from the PDA and therefore do not influence local groundwater flow patterns.

Information on typical groundwater recharge rates in the region is provided by: Farvolden (1963), Geoscience Consulting Ltd. (1976), Hydrogeological Consultants (1977) and Alberta Environment (1978).

Taken together, these studies suggest typical recharge rates on the order of 1–5% of the annual precipitation of 460 mm over fine-grained till areas (i.e., on the order of 5–25 mm/y) and recharge rates of up to 20% of precipitation (i.e., on the order of 90 mm/y) over sand and gravel areas.

2.5.4.1 Local Hydrostratigraphy

Three main water bearing zones have been identified within the PDA (see Appendix IV – Table IV-1):

- sandy zones within the surficial deposits (till and silty sand) monitored by the “A” series wells
- the sandstone interval in the upper portion of the bedrock, monitored by the “B” series wells (some of these wells are screened in the shale immediately below the sandstone)
- the lower sandstone interval intersected by PW06-01 between depths of 81–87 mbgs

Based on the geologic cross-sections (see Figure 2.5-3, Figure 2.5-4 and Figure 2.5-5), the sandstone interval within the upper portion of the bedrock appears to be limited in spatial extent within the LSA. Sandstone intervals within the Belly River Formation generally are discontinuous and cannot be correlated at scales of about a km or larger (Stein 1976). Thus, while sandstone intervals in the upper bedrock such as the one characterized at the PDA may be prevalent regionally (based on the observation that the majority of existing wells in the region are completed in the 10–30 mbgs depth interval; see below), the lateral connectivity of these intervals at scales of about a km or larger is interpreted to be relatively poor due to the presence of shales and siltstones.

The following are considered to be aquitards: the till unit and fine-grained and competent portions of the bedrock (i.e., shale intervals), except where weathered or fractured. Within the PDA, the upper sandstone interval is separated from the overburden deposits by weathered and/or fractured shale bedrock. The weathered/fractured shale is not expected to be an effective aquitard that impedes vertical connectivity between the surficial deposits and the upper sandstone (see below).

The lower sandstone interval is separated from the upper sandstone interval by the thick (on the order of 25 m) competent shale unit described earlier. This shale unit is expected to act as an effective aquitard, impeding vertical (downward) groundwater flow. Monitoring well 05–01C is screened in this shale unit between depths of 35–41 mbgs ("middle bedrock"; Appendix IV – Table IV-1).

2.5.4.2 Surficial Deposits

In June 2006, the measured depth to groundwater in the surficial deposits ("A" series) monitoring wells ranged from greater than 0.08 m above ground surface (i.e., flowing conditions at 05–28) to 2.82 mbgs (05–03A), with groundwater surface elevations (water table) ranging from 631.08–635.17 masl (see Appendix IV – Table IV-1). Groundwater surface elevation of 635.20 for MW05-20 was estimated, not measured, as this location was not surveyed. Seasonal variations in groundwater surface elevations on the order of 0.1–0.6 m have been observed between June 2005 and June 2006, with highest groundwater levels generally measured in June 2005.

The groundwater flow direction in the surficial deposits is interpreted to be to the northeast in the PDA but appears to change to due north in the northern portion of the Site (see Figure 2.5-7). The hydraulic gradient ($i = \Delta h/\Delta l$) is about 0.005 m/m. Hydraulic conductivity testing (see Appendix IV – Table IV-1) showed two orders of magnitude difference between monitoring wells screened within predominantly clay soils (05–03A, 05–05A) and predominantly silty sand or sand (05–06A, 05–09A, 05–10A and 05–11A). The hydraulic conductivity results reflect the variable geology encountered in the surficial deposits.

Estimates of average linear groundwater flow velocity (v) can be determined using the measured values of hydraulic conductivity (K) and horizontal hydraulic gradient (i) and literature values for effective porosity (n_e) as follows:

$$v = \frac{\mathrm{Ki}}{\mathrm{n_e}}$$

From the groundwater surface elevation contours shown on Figure 2.5-7, the average hydraulic gradient was estimated to be 0.005 m/m. A representative groundwater velocity for the till materials was determined assuming an effective porosity for till of 20% (Daniel 1995) and the geometric mean hydraulic conductivity for wells 05–03A, 05–05A (3.1×10^{-8} m/s), yielding a groundwater velocity estimate of 0.02 m/y through the till. A representative groundwater velocity for the silty sand materials that locally underlie the till was determined assuming an effective porosity for sand of 10% (Daniel 1995) and the geometric mean hydraulic conductivity for wells 05–06A, 05–09A, 05–10A and 05–11A (1.5×10^{-6} m/s), yielding a groundwater velocity estimate of 2.4 m/y through the silty sand.

The lower velocity estimate of 0.02 m/y reflects a situation in which lateral groundwater flow in the surficial deposits is dominated by the presence of till-like materials (i.e., the silty sand is disconnected over larger distances). The upper velocity estimate of 2.4 m/y reflects a situation in which lateral groundwater flow in the surficial deposits is dominated by the presence of the silty sand type materials (i.e., these materials are hydraulically well connected over larger distances). The geometric mean of these two estimates of 0.22 m/y is reflective of intermediate connectivity of the silty sand.

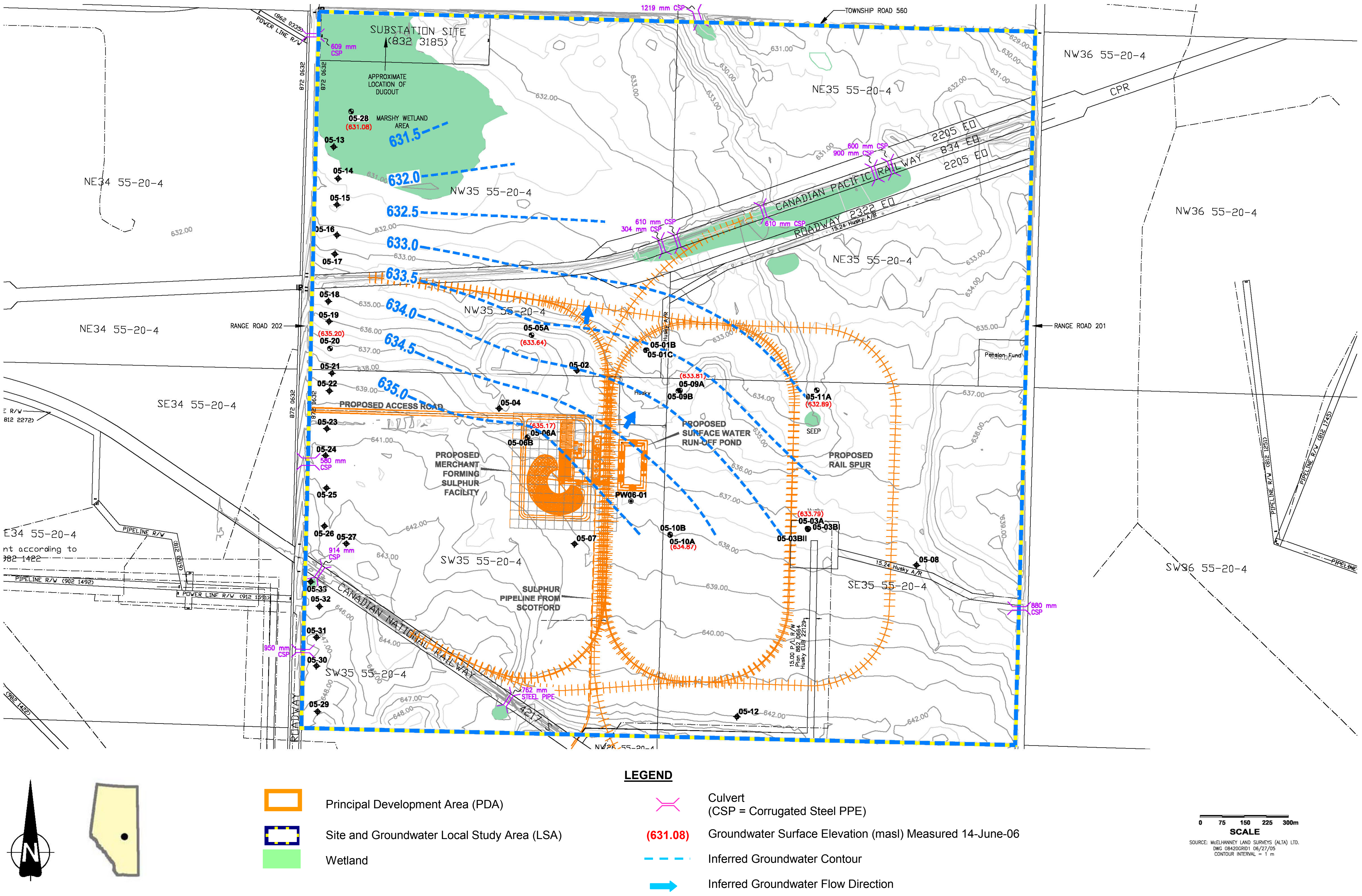


Figure 2.5-7: Surficial Deposits Groundwater Surface Elevations (June 2006)

The main hydraulic characteristics of the surficial deposits are summarized in Table 2.5-1 below:

Table 2.5-1: Summary of Surficial Deposits Characteristics

Lithology	Min. K (m/s)	Max. K (m/s)	Mean K (m/s)	Groundwater Velocity (m/y)
Till	2.3×10^{-8}	4.2×10^{-8}	3.1×10^{-8}	0.02
Silty Sand	8.0×10^{-7}	3.0×10^{-6}	1.5×10^{-6}	2.4
Geometric Mean				**0.22**

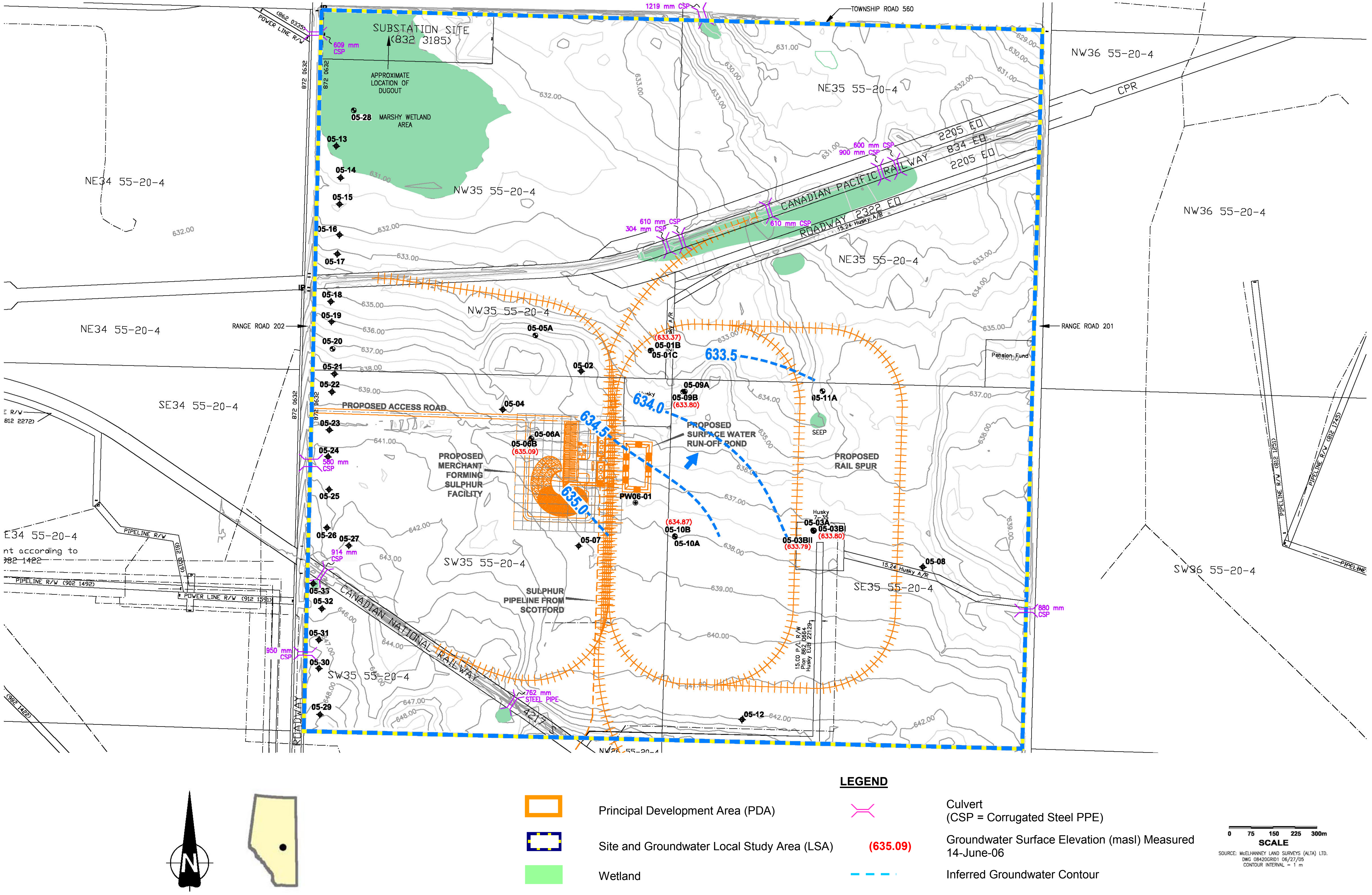
2.5.4.3 *Upper Bedrock Sandstone Aquifer*

In June 2006, the measured depth to groundwater in the upper bedrock ("B" series) monitoring wells ranged from 0.54 m above ground surface in monitoring well 05–01B to 2.94 mbgs, which translated to groundwater surface elevations ranging from 633.37–>635.09 masl (see Appendix IV – Table IV-1). Seasonal variations in groundwater surface elevations on the order of 0.2–0.5 m have been observed between June 2005 and June 2006, with the highest groundwater levels generally measured in June 2005.

Minimal differences were measured between groundwater surface elevations in the "A" and "B" series nested monitoring wells (see Appendix IV – Table IV-1). Calculation of vertical hydraulic gradients showed very low upward (05–03), near-neutral (05–06 in November 2005 and June 2006; 05–09) and very low downward gradients (05–06 in June 2005). These results coupled with the hydrochemical type measured (see below), indicate that the groundwater within the surficial deposits is somewhat hydraulically connected to the upper sandstone aquifer groundwater. This inference is supported by the hydraulic conductivity measurements of the first layer of shale encountered (3.2×10^{-7} m/s in monitoring well 05–03BI) and the weak structure of the shallow bedrock, which indicate that the shallow bedrock is weathered or fractured.

The groundwater flow direction determined from the sandstone aquifer monitoring wells was to the northeast within the PDA (see Figure 2.5-8) but is expected to change to due north in the northern portion of the Site based on regional information (see above), given the interpreted flow directions within the surficial deposits (see Figure 2.5-7) and inferred hydraulic connectivity with this unit. The hydraulic gradient ranged from 0.005–0.009 m/m. Hydraulic conductivity testing (see Appendix IV – Table IV-1) showed two orders of magnitude difference between monitoring wells screened within the shale (05–03BI, 05–06B, 05–09B) and the sandstone (05–01B, 05–03BII, 05–10B). The hydraulic conductivity results reflect the variable geology encountered in the surficial deposits and bedrock.

From the upper bedrock groundwater surface elevation contours shown on Figure 2.5-8, the average hydraulic gradient was estimated to be 0.007 m/m. A representative groundwater velocity within sandstone materials was determined assuming an effective porosity for sandstone of 20% and the geometric mean hydraulic conductivity for wells 05–01B, 05–03BII, 05–10B (1.8×10^{-6} m/s), yielding an estimate of 2.0 m/y. A representative groundwater velocity within shale materials was determined assuming an effective porosity for shale of 10% (Daniel 1995) and the geometric mean hydraulic conductivity for wells 05–03BI, 05–6B, 05–09B (7.7×10^{-8} m/s), yielding an estimate of 0.17 m/y.



SOURCE: McELHANNEY LAND SURVEYS (ALTA) LTD.
DWG 08420GRID1 06/27/05
CONTOUR INTERVAL = 1 m

Figure 2.5-8: Upper Bedrock Groundwater Surface Elevations (June 2006)

The lower velocity estimate of 0.17 m/y reflects a situation in which lateral groundwater flow in the upper bedrock is dominated by the presence of shale materials (i.e., the sandstone interval is disconnected over larger distances). The upper velocity estimate of 2.0 m/y reflects a situation in which lateral groundwater flow in the upper bedrock is dominated by the presence of the sandstone materials (i.e., these materials are hydraulically well connected over larger distances). The geometric mean of these two estimates of 0.58 m/y is reflective of intermediate connectivity of the sandstone interval.

The main characteristics of the upper sandstone aquifer are summarized in Table 2.5-2.

Table 2.5-2: Summary of Upper Bedrock Sandstone Aquifer Characteristics

Lithology	Min. K (m/s)	Max. K (m/s)	Mean K (m/s)	Groundwater Velocity (m/y)
Shale	1.7×10^{-8}	3.9×10^{-7}	7.7×10^{-8}	0.17
Sandstone	2.1×10^{-7}	6.6×10^{-6}	1.8×10^{-6}	2.0
Geometric Mean				**0.58**

Based on the 2 hour pumping test completed on 05–01B, a transmissivity of 4.6 m^2/day (5.3×10^{-5} m^2/s) was calculated (Komex 2005; Appendix II). Based on the inferred connectivity between the upper sandstone interval and the surficial deposits, this estimated transmissivity may reflect the combined properties of the sandstone interval and the overlying silty sand. Using Moell's method (AENV 2003), a 20-year sustainable yield of about 7.8 L/m (1.3×10^{-4} m^3/s) was calculated from the pumping test data.

2.5.4.4 Lower Bedrock Sandstone Aquifer

Only a single well (PW06–01) has been completed in the lower bedrock sandstone aquifer. As such, a lateral groundwater flow direction and velocity cannot be calculated. Comparison of measured groundwater surface elevations for 05–10B and PW06–01 (see Appendix IV – Table IV-1) suggests a slight downward hydraulic gradient between the upper and lower sandstone aquifers on the order of 0.07 m/m. Combined with the hydraulic conductivity testing for 05–01C (4.6×10^{-9} m/s) and assuming an effective porosity for shale of 10% (Daniel 1995), this suggests a downward groundwater flow velocity on the order of 0.1 m/y through the predominantly shale aquitard that separates the upper and lower bedrock aquifers. Based on this estimated downward velocity, it would take about 300 years for groundwater to flow across the 30 m thick shale portion of the aquitard that separates the lower sandstone aquifer from the upper sandstone aquifer. Thus, the deeper groundwater strata appear to be effectively protected by this thick competent shale unit. It can be reasonably concluded that no groundwater connection exists between the PDA and potential receptors deeper than the upper sandstone interval.

Based on the 2.5 hour pumping test completed on PW06–01, a transmissivity of 0.02 m^2/day (2.0×10^{-7} m^2/s) and a long-term sustainable yield (Farvolden method; AENV 2003) of about 0.4 L/m (6.9×10^{-6} m^3/s) were calculated for the lower sandstone aquifer (see Appendix I). These results indicate that the lower sandstone "aquifer" is in fact a poorly yielding groundwater zone, not suitable as a Project water supply. Therefore, the upper sandstone aquifer appears to be the only viable groundwater source for the Project. Project effects assessments regarding groundwater quantity, therefore, assume that the upper sandstone aquifer will be used as the groundwater supply zone.

Regionally, a relatively prolific and continuous sandstone interval does appear to exist at the bottom of the Belly River Formation and this interval has been interpreted as the highest yielding groundwater zone in this formation (Stein 1976). However, mapping by Stein also suggests this sandstone interval to be absent at the Site and in the surrounding area. Thus, a suitable water supply target beyond the current maximum depth of investigation of 91 m does not appear to exist.

Based on the above results, only the surficial deposits and the upper bedrock sandstone aquifer will be considered in the effect assessments.

2.5.5 Existing Groundwater Use

A search of the AENV water well database was completed within a 3 km radius of the Site. The search showed 176 registered water wells (see Appendix V). No water well records were found for the LSA (the Site). Of the 176 identified wells, 53 are located within 1 km distance from the Site and the records of these 53 wells are listed in Appendix V. Of the 53 wells within 1 km distance, 32 were listed as domestic, 10 as domestic and stock, 2 unknown and the remainder industrial or stock. Well depths were listed for 50 of the 53 wells and a summary of these well depths is shown in Table 2.5-3 below.

Table 2.5-3: Summary Of Nearby Registered Water Well Users

Total Well Depth (m)	Number Of Wells Within 1 km of Site
3–10	9
10–20	18
20–30	11
30–40	3
40–50	2
50–60	3
60–70	3
> 100	1

Six registered water wells were identified downgradient of the Project (i.e., to the north) within several hundred metres from the northern Site boundary. Of these six wells, five have a listed total depth less than 20 mbgs and are thus potentially completed in the same interval as the surficial and upper bedrock aquifers investigated as part of this program. These five wells (091467, 100920, 100921, 100922 and 100923) appear to be used by rural residences for domestic and stock purposes.

2.5.6 Hydrochemistry

The regional bedrock groundwater hydrochemistry is predominantly calcium-magnesium carbonate-bicarbonate to the west of the Project and predominantly sodium-potassium carbonate-bicarbonate to the east of the Project. Groundwater mineralization in both bedrock and surficial deposits is generally less than 1,000 parts per million (ppm). The fluoride content of groundwater encountered in bedrock intervals is typically less than 0.5 ppm (Stein 1976).

2.5.6.1 Surficial and Upper Bedrock Aquifers

Within the PDA, groundwater field measured parameters in the majority of surficial deposits and upper bedrock wells were within a similar range reflective of typical groundwater conditions for the PDA. Groundwater temperature has ranged from 4.6–13.5°C while pH has ranged from 6.8–8.9 (see Appendix IV – Table IV-2).

Baseline hydrochemistry in the surficial deposits and upper bedrock wells at the PDA is also similar and indicates that the TDS, dissolved sulphate, dissolved sodium and/or dissolved manganese concentrations in all or some of the monitoring wells exceeded the Health Canada (2004) Drinking Water AO Guidelines (see Appendix IV – Table IV-3). Dissolved sulphate appears to be naturally elevated in the surficial deposits at wells 05–03A, 05–20 and 05–28. These groundwater quality characteristics are not considered to be a design issue in the context of the proposed development. Dissolved metal concentrations in the surficial deposits and upper bedrock wells did not exceed applicable guidelines (see Appendix IV – Table IV-4).

Hydrochemistry of groundwater measured in both the surficial deposits and the upper bedrock monitoring wells was generally the same, predominantly sodium-bicarbonate (see Appendix IV – Table IV-3 and Figure 2.5-9 and Figure 2.5-10), which generally reflects the hydrochemistry of the region. These results indicate that the addition of acidity (potentially from the sulphur forming facility), which adds hydrogen ions, will be resisted in accordance with Le Chatelier's Principle, by conversion of CO_3^{-2} to HCO_3^-, and HCO_3^- to H_2CO_3 and ultimately evolution of CO_2 gas from solution, as follows:

$$2H_2O + CO_2 \Leftrightarrow H^+ + OH^- + H_2CO_3 \Leftrightarrow 2H^+ + OH^- + HCO_3^- \Leftrightarrow 3H^+ + OH^- + CO_3^{2-}$$

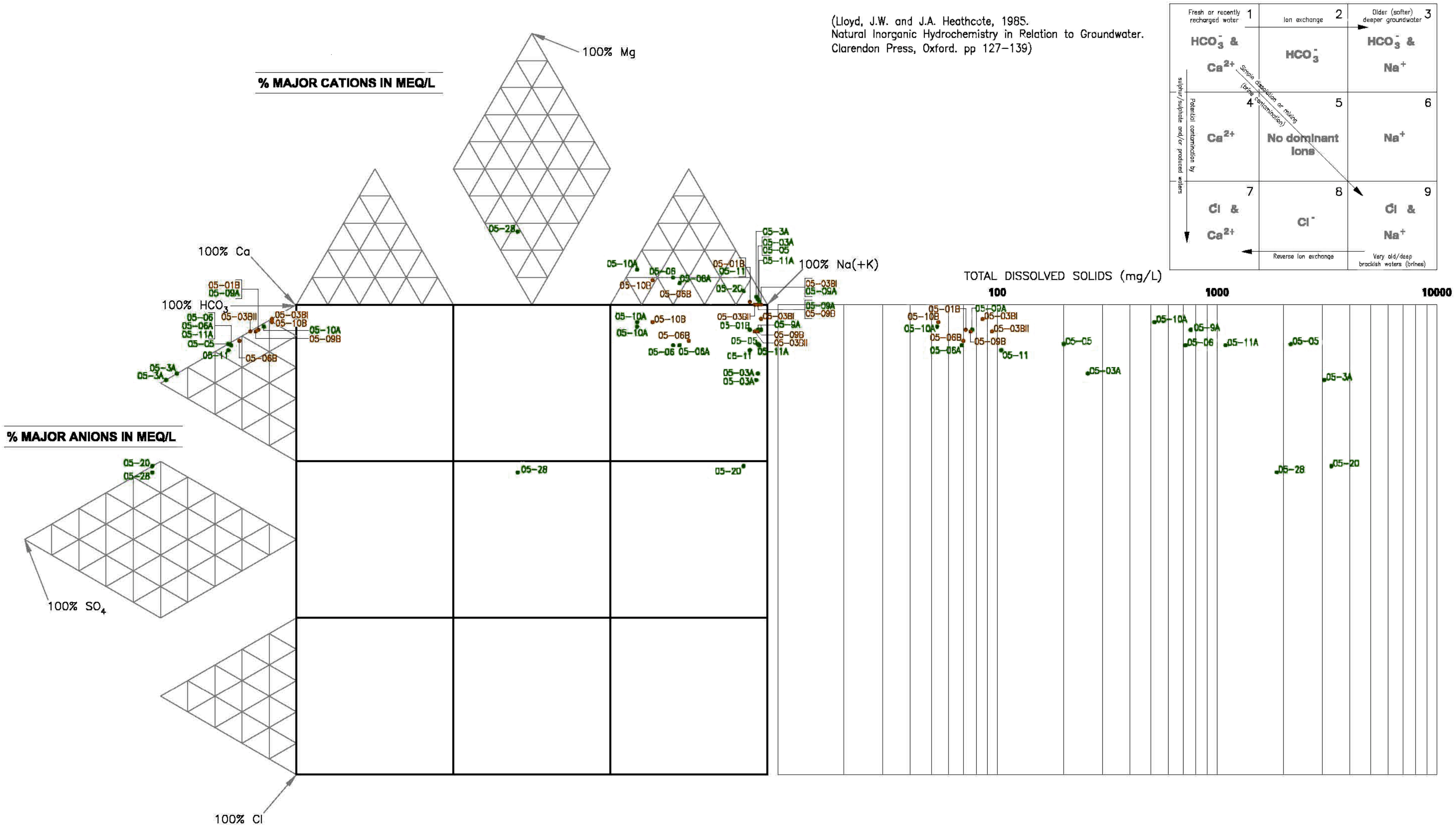
Similarly, the addition of calcium carbonate ($CaCO_3$), a source of CO_3^{2-}, will drive the reaction to the left, consuming hydrogen ions as long as excess CO_3^{2-} is present. Once buffered, the sulphate ion generally combines with calcium to form gypsum, which precipitates out of solution.

2.5.6.2 *Middle Bedrock Shale Aquitard*

Field measured pH values determined for monitoring well 05–01C to date have ranged between approximately 12 and 13 (see Appendix IV – Table IV-2) and indicate this well continues to be influenced by drilling and/or well completion activities, possibly as a result of the low hydraulic conductivity of the shale hampering well development. Groundwater analytical results obtained from this well are, therefore, not believed to reflect the hydrochemistry of formation waters.

2.5.6.3 *Lower Bedrock Sandstone Aquifer*

On December 6, 2006, after completion of the pumping and recovery test, groundwater temperature was 6.3°C while pH was 9.0 (see Appendix IV – Table IV-2). Groundwater analytical results (see Appendix IV – Table IV-3) indicate that groundwater in the lower bedrock zone is of sodium-chloride type with a TDS value of approximately 3,200 mg/L and a chloride concentration of almost 2,000 mg/L. TDS, dissolved chloride, dissolved sodium and fluoride concentrations exceeded Health Canada (2004) Drinking Water AO Guidelines. High chloride concentrations typically indicate relatively old groundwater and thus suggest sluggish groundwater flow in the lower bedrock zone.

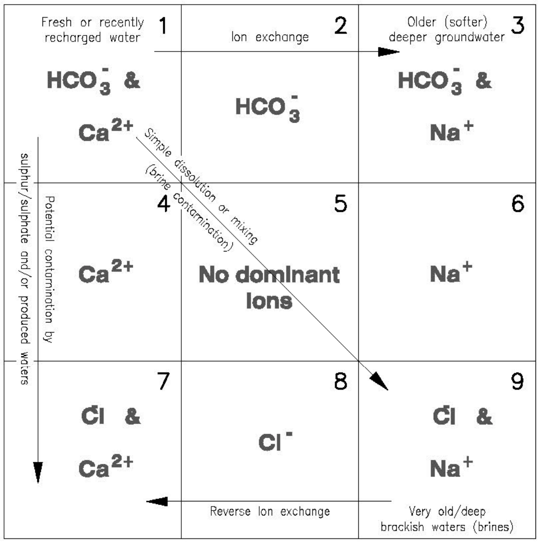


(Lloyd, J.W. and J.A. Heathcote, 1985.
Natural Inorganic Hydrochemistry in Relation to Groundwater.
Clarendon Press, Oxford. pp 127–139)

Notes:

05-10A	**Groundwater Sample from Surficial Deposits Zone**
05-10B	**Groundwater Sample from Upper Bedrock Zone**
“HCO_3 and NA^+”	**Indicates Ion Dominant Fields**

Figure 2.5-9: Groundwater Chemistry – Main Ion Characterization (Expanded Durov Diagram)



(Lloyd, J.W. and J.A. Heathcote, 1985.
Natural Inorganic Hydrochemistry in Relation to
Groundwater. Clarendon Press, Oxford. pp 127–139)

Field 1: HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters (or "fresh" groundwater) in many aquifers.

Field 2: HCO_3^- dominant and cation indiscriminant, with Mg^{2+} often being the dominant cation. However, those samples in which Ca^{2+} and Na^+ are significant, an important partial ion exchange is presumed.

Field 3: HCO_3^- and Na^+ are dominant, indicating ion exchanged water.

Field 4: Ca^{2+} dominant and anion indiscriminant or SO_4^{2-} dominant. Frequently indicates a mixed water or water exhibiting simple dissolution.

Field 5: No dominant anion or cation, indicating water exhibiting simple dissolution or mixing.

Field 6: Na^+ dominant and anion indiscriminant or SO_4^{2-} dominant. This is a water type that is not frequently encountered and indicates probable mixing influences.

Field 7: Cl^- and Ca^{2+} dominant is frequently encountered, the water may result from reverse ion exchange of Na–Cl waters.

Field 8: Cl^- dominant anion and no dominant cation, indicate that the groundwater is related to reverse ion exchange of Na–Cl waters.

Field 9: Cl^- and Na^+ dominant frequently indicate end–point waters (i.e., brackish–type water).

Figure 2.5-10: Legend for Groundwater Chemistry – Main Ion Characterization (Expanded Durov Diagram)

2.5.7 Groundwater and Surface Water Interactions

Silty sand was encountered at surface in borehole 05–10 (see Figure 2.5-3). Based on the geology and measured groundwater elevations (see Figure 2.5-7), the area encompassing borehole 05–10 is likely acting as a local recharge area (exposed to surface water infiltration). This is supported by the measured TDS concentrations. The TDS concentration in monitoring wells 05–10A/B was on the order of 500 mg/L and the TDS concentration in monitoring wells 05–06A/B and 05–09A/B was in the order of 700–800 mg/L (see Appendix IV – Table IV-3 and Figure 2.5-9). The lower TDS concentrations measured in the groundwater in monitoring wells 05–10A/B compared to the groundwater in monitoring wells 05–06A/B and 05–09A/B is likely reflective of the influence of surface water infiltration. Similarly, in monitoring well 05–01B, located downgradient of monitoring well 05–10A/B, the TDS concentration was about 700 mg/L.

A relatively well defined groundwater connection may also exist between the recharge area at 05–10 and the downgradient area at the east end of the PDA encompassed by 05–03BI/ 05–03BII and 05–11A, although TDS values between 900–1,100 mg/L indicate longer groundwater travel times. On the other hand, relatively elevated TDS on the order of 1,900 mg/L and higher for 05–03A, 05–05A, 05–20 and 05–28 indicate relatively sluggish groundwater flow and a poor connection with recharge areas (see Appendix IV – Table IV-3 and Figure 2.5-9).

The dug-out and wetland area in the northwest portion of the LSA (see Figure 2.4-2) appear to represent an area of poor drainage (i.e., not predominantly fed by groundwater) with an inadequate number of culverts (see Volume IIB, Section 3: Surface Water Quantity). Geologic cross-section A-A’ (see Figure 2.5-3) illustrates that hydraulic connectivity between the PDA and the wetland is likely limited by the presence of the till, separating the wetland from the upper bedrock sandstone interval.

Based on the predominant near-neutral vertical hydraulic gradients inferred for the PDA, possible groundwater contributions (Q) to the water balance of the slough were calculated assuming lateral inflow through the surficial deposits and making use of Darcy’s Law:

$$Q = KiA$$

in which K is the hydraulic conductivity of the surficial deposits, i represents the local hydraulic gradient in the surficial deposits and A represents the cross-sectional area available for flow. The cross-sectional area was determined by taking the width of the slough along its southeast perimeter (250 m) and assuming a seasonally average depth of the slough of about 2 m: $A = 500\ m^2$. The local hydraulic gradient was estimated to be 0.008 m/m based on June 2006 measured groundwater surface elevations for 05–20 and 05–28 (see Appendix IV – Table IV-1). Based on the range of measured hydraulic conductivity values for the surficial deposits, this leads to the following groundwater inflow calculations (see Table 2.5-4).

Table 2.5-4: Estimated Annual Groundwater Inflows to Slough

Scenario	Hydraulic Conductivity (m/s)	Groundwater Inflow to Slough (m^3/y)
Min. K	2.3×10^{-8}	3
Median K	4.1×10^{-7}	50
Max. K	3.0×10^{-6}	380

Total annual inputs to the wetland area (runoff, direct rainfall and groundwater) were estimated to be on the order of 80,000 m^3/y (see Volume IIB, Section 3: Surface Water Quantity). The groundwater contribution to these inflows is therefore very minor and estimated to be less than 0.5% on an annual basis. This further emphasizes that the dug-out and wetland area in the northwest portion of the LSA represent an area of poor drainage with only a minor groundwater influence on the surface water balance.

2.6 Application Case – Groundwater Quantity

The potential effects to groundwater quantity from the construction, operation and reclamation phases of the Project are related to the water use requirement for the sulphur forming process of up to 24 L/m during initial Project development (first 8 years) and up to 48 L/m at maximum capacity (subsequent 17 years). Water for sulphur cooling will be obtained from two sources; the surface runoff collection pond and a groundwater or other makeup supply. Water collected in the surface runoff collection pond will be used as a first choice. A makeup water supply will be utilized whenever there is insufficient surface water available to operate the cooling system (See Volume I: Project Description – Section 3).

Calculations performed in the surface water section (see Volume IIB, Section 3: Surface Water Quantity) suggest that approximately 22,650 m^3 of runoff will be generated from the developed area of the PDA annually. This runoff will be collected in the runoff collection pond for cooling purposes. Runoff is expected to occur predominantly between April and September due to a combination of spring snowmelt and summer rainfall. Little runoff is expected between October and March when precipitation is minimal and/or predominantly in the form of snow (see Volume IIB, Section 3: Surface Water Quantity). During the April–September period, about 5,550 m^3 of water may be expected to evaporate from the pond based on its 6,800 m^2 surface area and regional potential evapotranspiration (PET) data. This will leave approximately 17,100 m^3 of water for cooling purposes over the 6 months period. On average, surface water should account for over half of the Project water needs.

The above calculations indicate that a groundwater or other makeup source will be required for the Project annually for the October–March period. During this 6-months period, the makeup source will need to yield up to 24 L/m during initial Project development and about 48 L/m at maximum capacity. In the following section, the suitability of an on-site groundwater supply fpr the Project is explored and associated effects (if any) to other groundwater users and surface waters in the area are assessed. The Project will use groundwater as a makeup source unless or until an adverse off-site effect becomes apparent through monitoring. At that point, either a bigger storage pond will be constructed and/or water may be obtained from an alternate source.

2.6.1 Groundwater Response to Water Withdrawals

Based on the results of the hydraulic conductivity testing in the upper and lower bedrock zones (see Appendix IV, Table IV-1), only the upper bedrock zone appears to be a potentially viable groundwater supply source while the lower bedrock zone is interpreted to be poorly yielding and not suitable as a water supply source. To date, only a short-term (2-hour) pumping test has been conducted in the upper bedrock sandstone aquifer, at test production well 05–01B. A longer term pumping test will be completed to better evaluate the sustainable yield of this zone. A multi-day pumping test was originally scheduled for spring 2007 however, the resident requested testing be delayed until calving season was over and livestock were not dependent on water from the well. The pumping test has been rescheduled for June 2007.

At present, the potential response of the upper bedrock aquifer to long-term water withdrawals is subject to some uncertainty. To accommodate this uncertainty, the potential groundwater response to Project water withdrawals in the upper bedrock sandstone aquifer was calculated allowing for a range of possible scenarios regarding the long-term response to pumping:

- Scenario 1: The upper bedrock aquifer behaves as confined (i.e., it is overlain by significant low permeability strata such as the till encountered at the Site) and will receive no recharge over the entire 25 year Project lifetime. The latter assumption renders this is a very conservative scenario.
- Scenario 2: The upper bedrock aquifer is confined but will receive some inflows from groundwater recharge through the overlying till and/or areas where the till is absent. This is believed to be the most likely scenario.
- Scenario 3: The upper bedrock aquifer can be treated as unconfined (i.e., its response to pumping is dominated by windows in the till, such as the area of silty sand encountered in the central and southeast portions of the PDA). This is the most optimistic of the three scenarios, where the silty sand is exposed at surface (i.e., in the vicinity of 05–10A/B).

Well-established theoretical analytical (type curve) solutions were used to calculate drawdown in the aquifer at various distances from a hypothetical pumping well (0.5 m, 100 m, 1 km, 2 km and 3 km) for the three scenarios. These analytical solutions and their assumptions are described in Appendix VI. Each scenario required input on properties of the upper bedrock sandstone aquifer (all scenarios) while Scenario 2 also required information on till thickness and potential recharge to the aquifer. Properties such as thickness of the aquifer and overlying till and transmissivity of the bedrock aquifer (the latter describes the rate at which water can flow to the well) are relatively well-known from the geologic and hydrogeologic baseline characterizations in the PDA (see Section 2.5.3 and Section 2.5.4) and these properties were used as input to the analytical solutions. For properties that could not be determined directly from the baseline characterizations, realistic ranges of parameters were used. These ranges of parameters were either based on regional information (in the case of groundwater recharge rates) or literature values and will be referred to as low, mid and high cases. The low cases reflect least optimistic estimates of potential aquifer yield, with the high cases indicating most optimistic estimates of potential aquifer yield. Details of the parameter selection are provided in Appendix VI. The results from the 2-hour pumping test indicated a long-term sustainable yield of 7.8 L/m (see Section 2.5.4; Appendix II). Hence, theoretical drawdown for a single 7.8 L/m production well was calculated initially. The results of these calculations are summarized in Table 2.6-1.

Table 2.6-1: Theoretical Drawdown in Upper Sandstone Bedrock Aquifer for Single 7.8 L/m Production Well after 25 Years – Comparison by Scenario and Aquifer Parameters

Scenario	Case	Distance from Pumping Well (m) (Geographical Extent)				
		0.5 (PW)	100 (PDA)	1000 (LSA)	2000 (RSA)	3000 (RSA)
		Drawdown (m)				
Confined aquifer	Low	4.3	2.4	1.5	1.2	1.1
	Mid	4.0	1.9	1.0	0.8	0.6
	High	3.7	1.5	0.6	0.4	0.2
Leaky aquifer	Low	3.7	1.1	**0.2**	**0.07**	**0.03**
	Mid	3.7	0.9	**0.1**	**0.02**	**0.003**
	High	3.3	0.7	**0.1**	**0.007**	**0.001**
Unconfined aquifer	Low	3.7	1.0	**0.2**	**0.03**	**0.0007**
	Mid	3.7	0.9	**0.1**	**0.007**	**0.0003**
	High	3.3	0.8	**0.03**	**0.0003**	**0.00003**

Notes:

PW = pumping well.

Bolded values reflect drawdown below natural (seasonal) variability in water levels of 0.2–0.5 m.

The results summarized in Table 2.6-1 illustrate that for a given pumping rate and distance from the well-greater drawdown will occur in confined aquifers, compared to leaky and unconfined aquifers. The results further illustrate that the high cases (which correspond to more productive aquifers) result in less drawdown at a certain distance from the well. Conversely, the low cases result in greater drawdown for the same distance from the well. These relationships are illustrated graphically in Figure 2.6-1. Theoretical drawdowns less than about 0.2–0.5 m are below inferred natural (seasonal) variability in groundwater levels (see Section 2.5) and are thus considered insignificant.

2.6.2 Groundwater Availability

The results of the 7.8 L/m calculations suggest that drawdown in the immediate vicinity of the pumping well will be about 3.5–4.5 m, depending on the assumed groundwater response to pumping or between 70% and 90% of available drawdown, which at 05–01B was estimated at 5.35 m (see Appendix II). This indicates that the 24 L/m initial makeup water requirement for the plant cannot be obtained from a single well. Instead, a minimum of about three production wells of 7.8 L/m each may be required during the first 8 years of the Project, provided that the wells can be spaced sufficiently far apart so that well interference (i.e., drawdown induced at a certain well by operation of the other wells) is less than about 0.8 m. The results shown in Figure 2.6-1 indicate that under the unconfined and leaky scenarios (2 and 3), this could be achieved by spacing the wells a minimum distance of about 500 m apart. These results further suggest that if the upper bedrock aquifer in fact behaves as confined and non-leaky (i.e., no significant recharge will occur over time), then the multi-well option to satisfy the water use requirements for the plant is likely not achievable because well interference is expected to be significant.

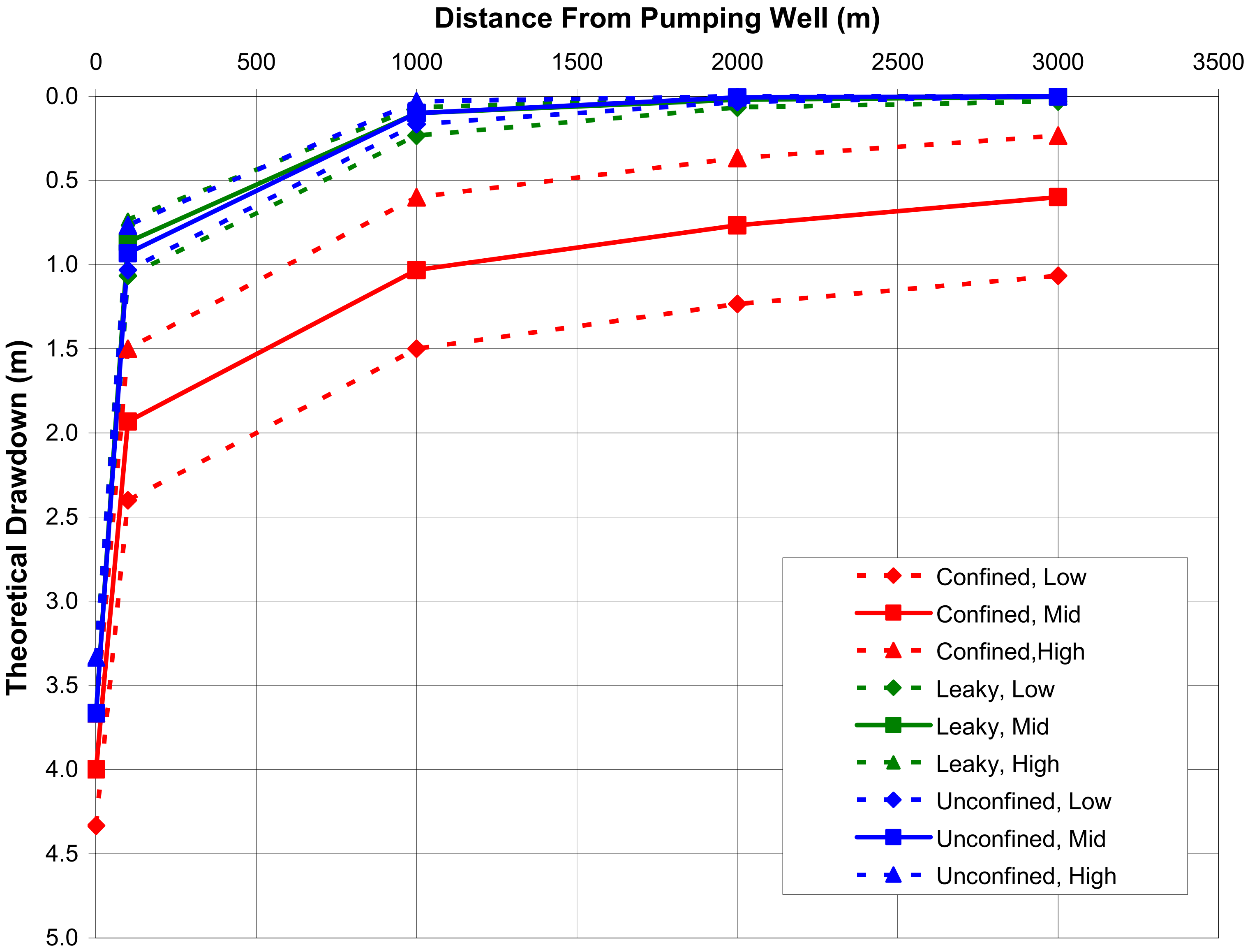


Figure 2.6-1: Theoretical Drawdown in Upper Bedrock Sandstone Aquifer for a Single 7.8 L/min Production Well after 25 Years – Comparison by Scenario and Aquifer Parameters

The multi-well option is likely also unachievable if the large-scale transmissivity of the aquifer (i.e., at the size of the LSA) is in fact lower than the value of 4.6 m^2/d (5.3 x 10^{-5} m^2/s) determined from the 2-hour pumping test conducted at well 05–01B (see Section 2.5 and Appendix II). Based on the variable geology encountered at the Site and the fact that well 05–01B appears to be completed in the most productive portion of the upper bedrock sandstone aquifer encountered to date, diminished yield could occur over time (Komex 2005).

During the maximum capacity phase of the Project, the makeup water requirement during the October to March period is expected to double from 24–48 L/m. To satisfy this increased requirement, the number of production wells could be doubled from three to six. However, a more cost-effective and realistic scenario likely is to retain the use of three wells but pump them continuously (i.e., 12 months per year) at 7.8 L/m. This would require doubling the size of the runoff collection pond to store water pumped during the April to September period. The calculations below are based on this scenario.

Figure 2.6-2 illustrates a hypothetical layout of three production wells with an assumed capacity of 7.8 L/m each that takes into account Site constraints. To this extent, the three wells were located between the existing two rail lines relatively distant from identified surface waters and in the upslope portion central portion of the PDA where silty sand appears to be more prevalent (see Section 2.5.2). This could facilitate enhanced groundwater recharge and thus aquifer sustainable yield. The wells are spaced about 600 m apart. Theoretical drawdown values posted on Figure 2.6-2 correspond to the leaky confined aquifer Scenario 2 (mid case) and to a total of 24 L/m of pumping for 25 years. For simplicity, it was assumed that the wells will be active 12 months per year over the entire 25 year period. This approach is conservative in that it somewhat over-predicts drawdown because during the initial 8 years of the Project groundwater will only be required on an intermittent basis. Theoretical drawdown at each location was calculated from the results presented in Figure 2.6-1 using the principle that drawdown in any point of an aquifer in which more than one well is pumping is equal to the sum of drawdowns that would arise from each of the wells independently (Freeze and Cherry 1979). The drawdowns calculated at the hypothetical production well locations (see Figure 2.6-2) thus account for well interference and suggest that, if the upper bedrock sandstone aquifer at the Site receives a minimum of groundwater recharge on the order 15 mm/y or 3% of annual precipitation (i.e., the Scenario 2 mid-case; Appendix VI), then the three-well option should be achievable. Corresponding potential effects to groundwater quantity and associated receptors are discussed in the following sections.

2.6.3 Potential Effect to Local and Regional Water Levels and Flows

Theoretical drawdowns posted on Figure 2.6-2 illustrate that drawdown in the upper sandstone aquifer within the PDA (i.e., in the area of the hypothetical pumping wells) will be about 1–5 m after 25 years of continuous water withdrawals. It is anticipated that in the vicinity of the pumping wells, these final (maximum) drawdown values will be approached in a relatively short time following Project start-up. The theoretical drawdowns represent between approximately 20 and 95% of the available drawdown of about 5.35 m, as determined at well 05–01B (see Appendix II). Thus effects of Project water withdrawals on local water levels and flows within the PDA are anticipated to be significant.

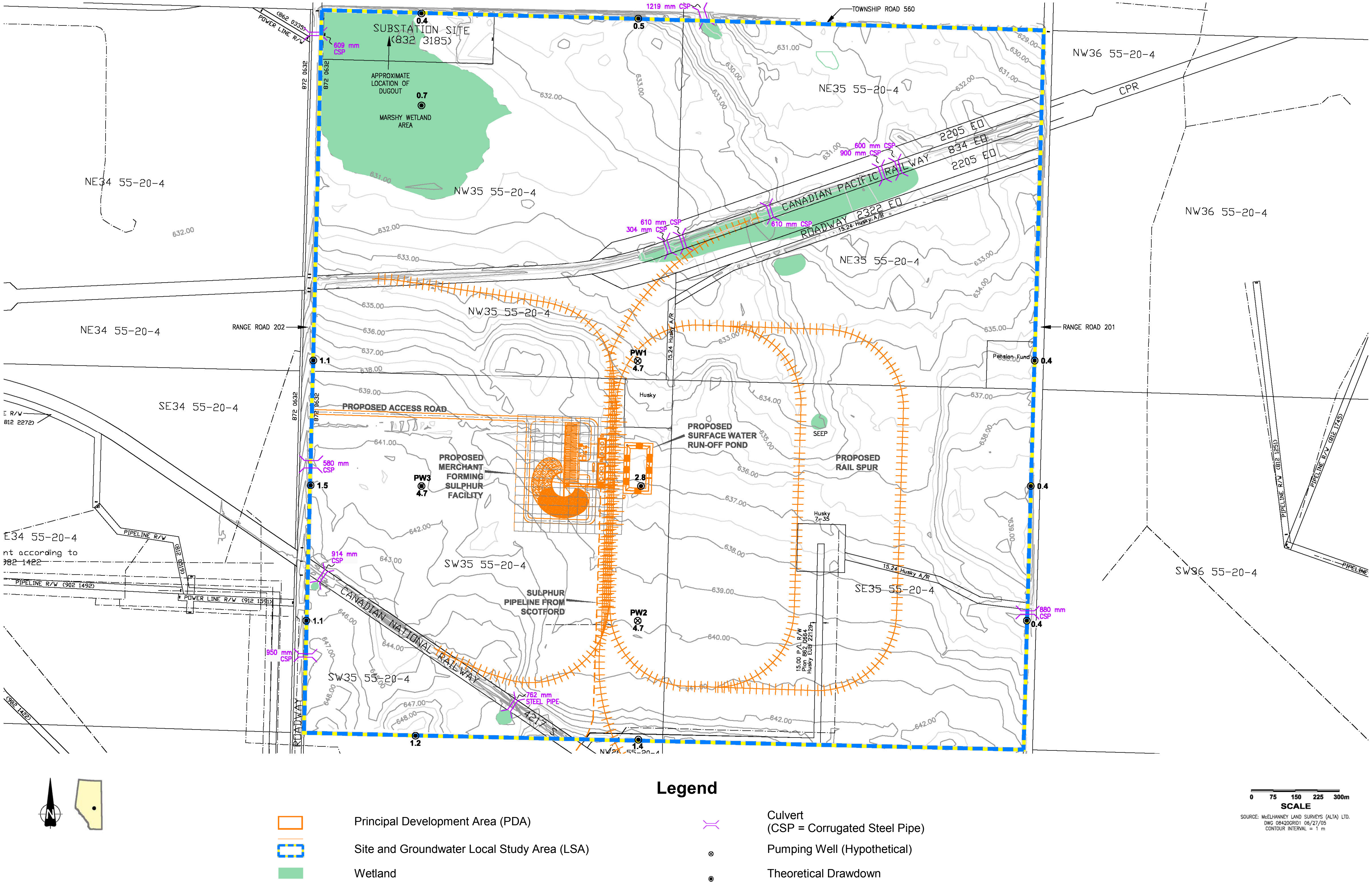


Figure 2.6-2: Theoretical Drawdown in Upper Bedrock Sandstone Aquifer for Hypothetical Configuration of Three Production Wells (7.8 L/min each) after 25 Years

The drawdown values calculated for the northern and eastern Site boundaries (see Figure 2.6-2) indicate that for those areas located a distance greater than about 750 m from the nearest pumping well, drawdown within the upper sandstone aquifer should be less than 0.5 m after 25 years of continuous water withdrawals. This final (maximum) drawdown value represents less than 10% of available drawdown in the upper sandstone aquifer. Furthermore, seasonal variations in groundwater surface elevations were determined to be on the order of 0.2–0.5 m. Thus, considering the location of the hypothetical pumping wells with respect to the Site boundaries, it appears reasonable to assume that at the northern and eastern Site boundaries and at a distance greater than 500 m from the Site's western and southern boundaries, effects of water withdrawals on regional water levels and flows should remain negligible (i.e., within natural variability) or low in magnitude for the entire 25 year duration of the Project.

2.6.4 Potential Impact to Surface Waters

Figure 2.6-2 illustrates that theoretical drawdown in the upper sandstone aquifer near the dug-out and wetland in the northwest portion of the LSA may be on the order of 0.7 m after 25 years of continuous water withdrawals. It is important to note that this does not reflect drawdown of the water table. This is because the water table is not located in the bedrock aquifer, but instead is at or near the land surface, as indicated by monitoring well 05–28 (see Figure 2.5-8 and Figure 2.6-2). Actual drawdown at the water table is therefore anticipated to be less than 0.7 m (and likely negligible to low in magnitude) due to the following two factors:

- the till separating the sandstone aquifer from the wetland provides a degree of hydraulic isolation. This hydraulic isolation depends primarily on thickness and low hydraulic conductivity of the till. These factors are relatively well established from the geologic and hydrogeologic baseline characterization of the Site.
- the presence of a large source of water in the form of the wetland whose inflows are received almost entirely from runoff and direct precipitation (greater than 99% on an annual basis) (see Section 2.5.7), which will further tend to dampen the response of the water table

Groundwater withdrawal from the upper sandstone interval is therefore not expected to affect surface conditions (i.e., wetland areas) or soil saturation and vegetation on the Site.

Over the central portion of the PDA (i.e., between the pumping centres), the water table will likely be drawn down to near the bottom of the till (see Section 2.6.3) and this will affect lateral groundwater inflows from the PDA to the wetland area through the surficial deposits. The theoretical drawdown at PW–1 and PW-3 nearest to the wetland is predicted to be about 4.7 m (see Figure 2.6-2). This level of drawdown is approximately equal to the groundwater level difference determined between monitoring wells 05–20 and 05–28 nearest to the wetland (see Appendix IV – Table IV-1) and therefore, suggests that the lateral hydraulic gradient from the PDA to the wetland will become near-neutral as a result of Project water withdrawals. This indicates that Project water withdrawals may lead to the cessation of groundwater inflows to the slough and wetland. However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total inflows, the effect of pumping on the water balance of the slough and wetland is predicted to be negligible.

2.6.5 Potential Impact to Existing Water Users

The drawdown values calculated for the northern and eastern Site boundary (see Figure 2.6-2) indicate that for those areas located a distance greater than about 750 m from the nearest pumping well, drawdown within the upper sandstone aquifer should be less than 0.5 m after 25 years of continuous water withdrawals. This theoretical final (maximum) drawdown value represents less than 10% of available drawdown in the upper sandstone aquifer. Furthermore, seasonal variations in groundwater surface elevations were determined to be on the order of 0.2–0.5 m. Thus, considering the location of the pumping wells with respect to the Site boundaries, it appears reasonable to assume that at the northern and eastern Site boundary and at a distance of 500 m or greater from the Site's western and southern boundaries, effects of water withdrawals on existing water users should remain negligible (i.e., within natural variability) or low in magnitude for the entire 25 year duration of the Project. Potential effects on specific nearby residents will be evaluated following completion of the long-term pumping test this spring. A survey to verify water well use in the immediate vicinity of the Site will be conducted in conjunction with the long-term pumping test.

2.6.6 Mitigation

Groundwater monitoring wells completed in the surficial deposits and upper bedrock sandstone aquifer within the PDA will be monitored twice annually to evaluate potential impacts to groundwater levels. Piezometer nests have been installed at selected locations to evaluate the vertical groundwater flow direction and monitor potential impact to both the sandstone aquifer and the overlying surficial deposits. Baseline conditions have been established as part of the groundwater component of the EIA.

2.6.7 Classification of Residual Impacts to Water Levels and Flows from Water Withdrawals

2.6.7.1 Operation

Based on the above assessments, significant impacts of Project water withdrawals are not expected at distances greater than 750 m from the supply wells. The overall effect to groundwater levels and flows during the Project lifetime is therefore considered to be negative in direction, regional in extent, negligible to low in magnitude, medium term in duration and reversible.

The confidence in this residual impact assessment is considered moderate, given that some pertinent short-term data could be used to guide the assessment, but will be significantly improved by completing a long term pumping test. The final impact rating is considered to be Class 3, with resource levels expected to recover to baseline after closure.

2.6.7.2 Project Closure

After closure and reclamation of the Project, water withdrawals will no longer be required and local and regional groundwater levels and flows are anticipated to recover relatively rapidly within a time frame of a few years. Following Project closure, the residual (immediate and far-future) effects on groundwater quantity will thus be neutral in direction. The confidence in this prediction is high.

2.6.8 Classification of Residual Impacts to Groundwater-Surface Water Interactions from Water Withdrawals

2.6.8.1 Operation

Results indicate that Project water withdrawals may lead to the cessation of groundwater inflows to the wetland area in the northwestern quarter section of the PDA. However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total annual water balance inflows, the termination of baseflow to the wetland is considered to have a negligible impact. The overall effect of water withdrawals on groundwater-surface water interactions during the Project lifetime is therefore considered to be negative in direction, local in extent, negligible in magnitude, medium term in duration and reversible.

The confidence in this residual impact assessment is considered moderate, while the final impact rating is considered to be Class 3, with resource levels expected to recover to baseline after closure.

2.6.8.2 Project closure

After closure and reclamation of the Project, water withdrawals will no longer be required and groundwater-surface water interactions are anticipated to recover relatively rapidly within a time frame of a few years. Following Project closure, the residual (immediate and far-future) effects on groundwater-surface water interaction will thus be neutral in direction. The confidence in this prediction is high.

2.6.9 Classification of Residual Impacts to Existing Water Users from Water Withdrawals

2.6.9.1 Operation

At the northern Site and eastern boundaries and at a distance of 500 m or greater from the Site's western and southern boundaries, effects of water withdrawals on existing water users should remain negligible (i.e., within natural variability) or low in magnitude for the entire 25 year duration of the Project. The overall effect to existing water users during the Project lifetime is, therefore, considered to be negative in direction, regional in extent, negligible to low in magnitude, medium term in duration and reversible.

The confidence in this residual impact assessment is considered moderate, while the final impact rating is considered to be Class 3, with resource levels expected recover to baseline after closure.

2.6.9.2 Project closure

After closure and reclamation of the Project, water withdrawals will no longer be required and resource levels are anticipated to recover relatively rapidly within a time frame of a few years. Following Project closure, the residual (immediate and far-future) effects on existing water users will thus be neutral in direction. The confidence in this prediction is high.

2.7 Application Case - Groundwater Quality

The potential impacts on groundwater quality from the construction, operation and reclamation phases of the Project are related to:

- aerial deposition of acidifying compounds (air emissions) affecting soil quality with potential secondary effects for groundwater quality
- upset conditions (chemical spills, breach of surface water storage pond)

Associated potential impacts to groundwater quality and general mitigation measures are discussed in the following sections.

2.7.1 Potential Impacts from Acid Deposition (Air Emissions)

A potential effect to groundwater quality is associated with the deposition of elemental sulphur on soil, which then is transformed to sulphuric acid through bacterial oxidation, decreasing soil pH. This transformation and associated reduction in soil pH is resisted through carbonate mineral buffering (calcium carbonate equivalency). Calcium and magnesium carbonates in soil are a reserve source of alkalinity that can neutralize natural soil acidity (organic acids, carbonic acid) or facility derived acidity (e.g., from air emissions). At the Site, calcium carbonate equivalent results range from 4.9% (05–02) to 8.6% (05–11) and pH values are above 7 (Komex 2005). These results indicate a good buffering capacity of the soil such that reduction in soil pH may not occur for an extended period of time. Taking into account these baseline results and predicted elemental sulphur deposition rates for the facility, it was determined that measurable effects on soil quality over the 25 year lifetime of the Project (with possible secondary consequences for groundwater quality) will be confined to the PDA (see Volume IIC, Section 2: Soil).

Dissolved sulphate appears to be naturally elevated in the surficial deposits at wells 05–03A, 05–20 and 05–28 (see Appendix IV – Table IV-3). Any dissolved sulphate formed as a result of atmospheric deposition of elemental sulphur on soil in the immediate vicinity of the facility, may subsequently be transported in groundwater. From the baseline geologic and hydrogeologic conditions, it was determined that groundwater flow systems originating at the PDA are relatively shallow in nature (i.e., involving the silty sand and the upper bedrock sandstone interval) and unlikely to be connected to potential receptors at the regional scale (i.e., distances of about a km or larger) due to the presence of till in the surficial deposits and shales and siltstones in the bedrock. Thus, the only potential natural receptors of groundwater originating from the PDA are interpreted to be the wetlands and other surface waters located within the LSA. The groundwater systems identified below the PDA are also potentially hydraulically connected with up to five registered water wells located within several hundred metres to the north (i.e., downgradient) of the Site (see Section 2.5.5). The corresponding groundwater travel time, based on a 1 km distance between the centre of the PDA and potential receptors and assuming an upper bedrock flow pathway, is estimated to be about 1,700 years using the inferred median velocity of 0.58 m/y (see Section 2.5.4), with uncertainty bounds of 500 years (2 m/y) to almost 6,000 years (0.17 m/y). A comparable range of groundwater travel times would be expected through a surficial deposits exposure pathway given that groundwater velocities appear to be of a similar magnitude range.

The above results indicate ample response time for specific management measures (e.g., monitored natural attenuation or intervention) to be implemented should elevated dissolved sulphate concentrations (i.e., statistically significant above ambient levels) be detected in the bi-annual groundwater monitoring program. Natural attenuation mechanisms include combination of sulphate ions with the abundantly present calcium to form gypsum, which precipitates out of formation (see Section 2.5.6), mechanical dispersion and molecular diffusion.

2.7.2 Potential Impacts from Upset Conditions

Upset conditions might occur during the construction and operational phases of the Project. These conditions are generally the result of accidental events and could result in a temporary negative effect to groundwater quality.

Upset conditions and potential changes to groundwater quality during the construction and operation phase of the Project could result from:

- spillages or releases of elemental sulphur

- accidental release/spillage of process affected water or other chemicals such as dust suppression agents (Dustbind S5) and proprietary sulphur release aid (IPAC SRB Plus)
- uncontrolled release from the runoff collection pond taking place prior to neutralization, testing and sampling

Spilled chemicals could subsequently dissolve and be transported in groundwater. From the baseline geologic and hydrogeologic conditions, it was determined that groundwater flow systems originating at the PDA are relatively shallow in nature (i.e., involving the silty sand and the upper bedrock sandstone interval) and unlikely to be connected to potential receptors at scales of about a km or larger due to the presence of till (in the surficial deposits) and shales and siltstones (in the bedrock). Thus, the only potential natural receptors of groundwater originating from the PDA are interpreted to be the wetlands and other surface waters located within the LSA. The groundwater systems identified below the PDA are also potentially hydraulically connected with up to 5 registered water wells located within several hundred metres to the north (i.e., downgradient) of the Site (see Section 2.5.5). The corresponding groundwater travel time based on a 600 m distance between the northern railway spur at the PDA (presumably the closest point where a spill could occur) and potential receptors and assuming an upper bedrock flow pathway, is estimated to be about 1,000 years using the inferred median velocity of 0.58 m/y (see Section 2.5.4), with uncertainty bounds of 300 years (2 m/y) to 3,500 years (0.17 m/y). A comparable range of groundwater travel times would be expected through a surficial deposits exposure pathway given that groundwater velocities appear to be of a similar magnitude range.

The above results indicate ample response time for specific mitigation measures (e.g., monitored natural attenuation or intervention through remedial action) to be implemented should an upset event occur. Natural attenuation mechanisms may include precipitation reactions (in the case of dissolved sulphate to form gypsum), aerobic or anaerobic degradation (e.g., in the case of fuel spills), mechanical dispersion and molecular diffusion.

2.7.3 Mitigation

Measures will be taken to minimize the risk of releases of substances that could otherwise affect water quality. These measures will include but will not necessarily be limited to the following:

- implementing safe construction and operational work procedures to reduce the potential for accidental spillages/collisions/emissions on site during the construction and operational phase
- developing an Emergency Response Plan to establish response procedures for potential accidental/catastrophic events
- storing and handling potentially hazardous materials in accordance with provincial requirements
- implementing sound management practices to minimize generation of fugitive dust
- collecting runoff from the sulphur forming and storage areas in a perimeter ditch lined with high density polyethylene (HDPE) that feeds into the surface water runoff pond
- ensuring the capacity of the surface water runoff pond exceeds the volume of runoff generated by the 1 in 25 years, 24 hour rainfall event to prevent accidental release/breakthrough
- ensuring the pond is double-lined (60 mil HDPE liner over compacted clay soil) and includes a leak detection system

- recycling and reusing runoff collection water where possible to minimize requirements for controlled releases from the pond
- neutralizing, monitoring, sampling and testing the runoff collection water prior to release, when a controlled release is required
- ensuring the initial sulphur load-out and transfer tank is an in-ground concrete tank surrounded by a permeable leak detection system and secondary compacted clay soil liner
- implementing liquid sulphur storage tanks including leak detection systems
- constructing an asphalt storage pad for sulphur pastilles including primary asphalt containment, a secondary clay soil liner, runoff and run-on controls and a leak detection system

2.7.4 Classification of Residual Effects to Groundwater Quality

2.7.4.1 Construction and Operation

Assuming that all mitigation measures are implemented appropriately and given the buffering capability and low sensitivity of soil and groundwater on site to acid deposition, it is anticipated that groundwater quality within the PDA and LSA will not be measurably affected by acid deposition arising out of normal operational activities.

Assuming that all mitigation measures are implemented appropriately, it is anticipated that the overall groundwater quality within the LSA during the Project lifetime will not be significantly affected by upset conditions during construction and operations. Although upset conditions and potential effects may occur sporadically during the Project lifetime, the geographical extent of these effects is likely local (within the LSA).

Based on the above assessments, the overall effect to groundwater during the Project lifetime is considered to be negative in direction, local in extent, low to moderate in magnitude, short term in duration and reversible.

Uncertainty in the assessments arises from Project operation uncertainty as well as geologic uncertainty (i.e., groundwater velocities and recharge rates and the long-term aquifer response to water withdrawals). On balance, confidence in the groundwater quality Project effects assessments is high given that Project effects are mostly limited to the PDA and LSA, areas that have been relatively well characterized by field investigations. The final impact rating is considered to be Class 3.

2.7.4.2 Project Closure

After closure and reclamation of the Project, facilities will no longer be operational and the potential for acid deposition or upset conditions to occur is no longer present. However, residual effects of acid deposition or upset conditions on groundwater quality (if present) may remain for some time following Project closure given that existing effects will not reverse immediately. These immediate residual effects are expected to be negative in direction, local in extent and negligible to low in magnitude. Far-future effects are expected to be neutral in direction. The confidence in this prediction is moderate.

2.8 Cumulative Effects Case

The assessments conducted in this section of the EIA suggest that Project effects on groundwater quantity and quality will largely be limited to the LSA. Therefore, the potential for the Project to affect groundwater quantity or quality at other nearby projects is negligible due to the limited extent of anticipated Project effects. Similarly, existing projects are not believed to have the potential to affect groundwater quantity or quality within the Site boundaries. As such, the application case for the Project is expected to encompass all the anticipated effects to groundwater resources associated with the Project.

2.9 Management and Monitoring

It is proposed that groundwater monitoring wells completed in the surficial deposits and upper bedrock at the PDA (i.e., “A” and “B” series wells; Figure 2.4-2), be monitored twice annually to evaluate potential effects to groundwater quantity (i.e., water levels) and quality. Groundwater samples will be collected using standard methodologies, preservation, containment and transport techniques. It is proposed that the analytical schedule for ongoing monitoring of the sulphur facility include temperature, pH, electrical conductivity and routine potability parameters. The monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local hydrogeology and possible effects related to the operation of the proposed facility.

Upon Project approval, the design of the monitoring network and monitoring schedule would be submitted to AENV for review, comment and approval.

A response plan or action plan should be developed to enable prompt courses of action in the event that routine monitoring detects an impact that may eventually become unacceptable.

2.10 Follow Up

A multi-day pumping test was originally scheduled for spring 2007 to increase confidence in the groundwater quantity Project effects assessments and to determine whether an adequate groundwater supply source is present at the Site. However, the resident requested testing be delayed until calving season was over and livestock were not dependent on water from the well. The pumping test has been rescheduled for June 2007.

2.11 Summary

A summary of the residual effects assessments is provided in Table 2.11-1. The final impact ratings are considered to be Class 3, as only slight declines were predicted in the quantity or quality of relevant indicators during the life of the Project. The declines in the indicators are expected to propagate only slowly with time and can therefore be adequately managed through the proposed bi-annual monitoring program. Ample response time is available for mitigation in the event that unacceptable impacts are observed. Groundwater levels should quickly recover to pre-development levels once groundwater withdrawal is discontinued. Resource levels should recover to baseline after closure of the Project.

Table 2.11-1: Final Impact Assessment Summary for Construction and Operation Phases

Issue	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Confidence	Final Rating
Decreased water levels and flows	Negative	Negligible to low	Regional	Medium-term	Reversible	Moderate	Class 3
Interaction between groundwater and surface water	Negative	Negligible	Local	Medium-term	Reversible	Moderate	Class 3
Groundwater available to existing users	Negative	Low	Regional	Medium-term	Reversible	Moderate	Class 3
Potential effects to groundwater quality	Negative	Low to moderate	Local	Short-term	Reversible	High	Class 3

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Volume IIB, Section 2: Groundwater Quantity and Quality

Appendix I: Lower Bedrock Groundwater Exploration (PW06-01)

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1. Objective

A lower bedrock groundwater exploration program was conducted in November and December 2006 to identify and characterize a possible water supply zone at the Site below the interval of domestic-use wells in the area. The domestic and stock wells have reported depths ranging from about 5–60 m, with the majority of them ranging from 5–30 m (see Volume IIB, Section 2: Groundwater Quantity and Quality – Section 2.4). Groundwater withdrawal from a zone deeper than the domestic use aquifer zones was considered to minimize, to the extent practical, potential effects of groundwater withdrawals from the Project on shallow groundwater flow systems and to achieve minimal well interference with existing users. The exploration program gave the additional benefit of providing information on the characteristics of the deeper bedrock zone beneath the proposed development.

2. Drilling

On November 14–17, 2006, an air rotary rig operated by Beck Drilling and Environmental Services Ltd. (Beck) was used to drill a 190 mm (7 5/8”) hole through the surficial deposits, using approximately 17 m of 200 mm (8”) surface casing and the bedrock deposits. The geology encountered during drilling was logged directly from the retrieved drill cuttings (see borehole log for PW06-01; Appendix III).

Surficial deposits were encountered from ground surface to about 8 m below ground surface (mbgs). Inter-bedded sandstones, siltstones and shale were encountered from about 8–35 mbgs. A thick shale unit was encountered between about 35 mbgs and 61 mbgs. Below about 61 mbgs, inter-bedded sandstone, siltstone and shales were encountered to the maximum depth of investigation of 91 mbgs. A sandstone interval encountered between 81 and 87 mbgs was identified as the most promising prospective lower bedrock water supply zone, below the depth interval of the majority of registered wells.

3. Pumping Well Installation

On November 23 and 24, 2006, another rig operated by Beck was used to install the water supply well. Detailed specifications of PW06-01 construction, including materials and placement depths, are provided on the borehole log (see Appendix III). A nominal 102 mm (4”) inside diameter (ID) stainless steel, 0.010-slot wire-wrapped screen was placed in the borehole. The screen length was 4.7 m (80.0–84.7 mbgs). The well casing was attached to the screen and extended to 0.85 m above ground surface. The well casing was comprised of 102 mm (4”) ID DR-20 threaded PVC pipe.

Approximately 3.4 m of slough (likely consisting of fine-grained sands and silt from the lower 12 m of the profile) settled at the bottom of the borehole. The filter pack around the screen consisted of 10/20 Colorado Silica sand. The sand was placed above the slough to 2.8 m above the top of the well screen to accommodate any settling and to prevent contact between the bentonite seal (see below) and the well screen.

A primary water-tight seal was placed above the sand pack using coated bentonite tablets. Typically, this seal is adequate to prevent direct leakage between the sand pack and backfill material. However, as an additional insurance of hydraulic isolation between the ground surface and other potential water-bearing horizons, the remaining annulus was grouted to surface with bentonite grout. After the grout settled, bentonite chips were used to complete the well to surface. A lockable surface casing was installed around the well.

The well screen and casing were gently moved up and down in the borehole during sand-pack installation to prevent bridging of the sand. This well movement created the possibility that the friction-fit well bottom cap may have been dislodged. In order to eliminate the possibility of formation or sand-pack materials entering the borehole through the bottom of the well, a 0.29 m layer of approximately 10 mm diameter gravel was placed inside the screen casing. A 0.12 m thick layer of 2.5 cm diameter steel ball bearings was placed above the gravel layer to prevent the migration of gravel into the pump intake.

The static water level on November 27, 2006 was 8.28 mbgs.

4. Pumping Test

On November 27, 2006, a down-hole submersible pump was installed in PW06-01 to accommodate the step test and pumping test. A step test was conducted on November 28, 2006. This test was comprised of a single 20-minute step at a flow rate of 16 L/m. Based on the rate of decrease of the water level during the first step, further steps at higher pumping rates were not attempted as it was determined that maximum available drawdown would rapidly be exceeded.

A constant-rate pumping test was conducted on PW06–01 on November 30, 2006. Drawdown was recorded during the pumping and recovery phase of the test using manual readings with a water level tape and using a pressure transducer. The well was pumped at an average rate of 12 L/m for 30 minutes. The pump turned off a number of times between 9 and 30 minutes after the start of the test, possibly as a result of the loss of head pressure, fines suspended in the water and proximity to the lower flow limit of the pump (8 L/m). The pump was switched off 30 minutes into the test, at which point drawdown was about 43 m. Aquifer recovery was monitored for an additional 120 minutes. Only modest recovery was recorded during this period with residual drawdown after 120 minutes of recovery still being 23 m.

5. Data Analysis

Manual readings were used for the aquifer test interpretation. The Papadopolous-Cooper (1967) type curve solution for a pumping-recovery test in a confined aquifer was used to infer transmissivity (T) and storativity (S) of the lower bedrock aquifer from the drawdown data. The Papadopolous-Cooper type curve solution (shown in blue in Figure I-1) is similar to the Theis (1935) solution (shown in red in Figure I-1) with the exception that the former solution accounts for wellbore storage (i.e., large diameter wells) whereas in the Theis solution, wellbore storage effects are neglected.

The main assumptions of the Theis solution are:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected

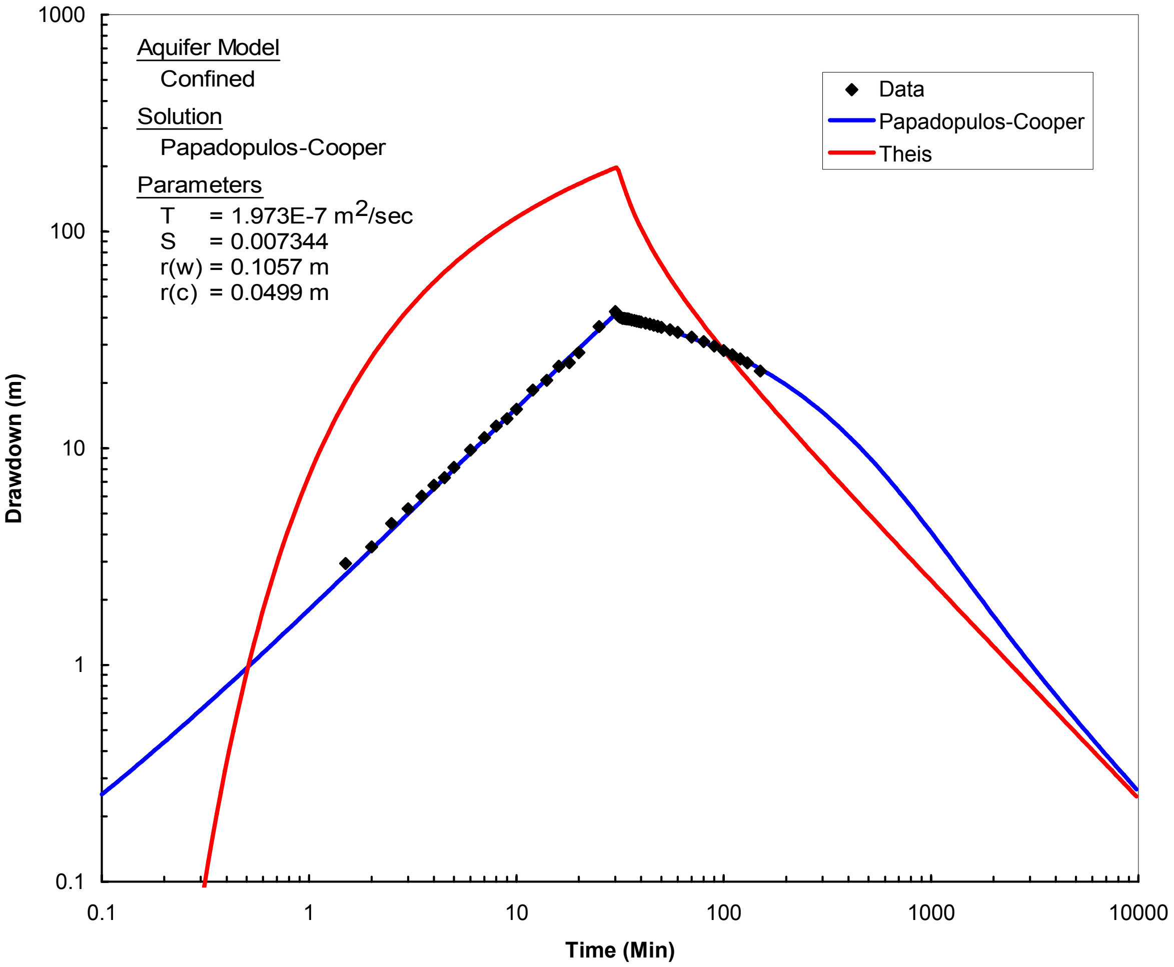

Figure I–1: Aquifer Test Analysis

This last assumption of the Theis solution is overcome with the Papadopolous-Cooper type curve solution.

Aqtesolv© version 3.50 (HydroSOLVE 2003, Internet site) was used to infer aquifer hydraulic properties from the constant rate pumping test. In determining optimal parameters for the Papadopolous-Cooper solution, the well casing radius $r_{(c)}$ was kept fixed at 50 mm while the effective well radius $r_{(w)}$ was calculated from the data together with aquifer T and S. The calculated effective well radius of about 106 mm is in agreement with the expected range of values for a 102 mm (4 inches) well. Aquifer transmissivity and storativity were determined to be 2 x 10^{-7} m^2/s (0.02 m^2/day) and 0.007, respectively. The aquifer test analysis is illustrated graphically in Figure I–1.

Comparison of the Papadopolous-Cooper solution with the Theis solution using identical aquifer parameters illustrates that measured drawdown and recovery for the constant rate pumping test was strongly influenced by wellbore storage effects. The Theis solution predicts a much faster increase in drawdown during pumping and a more rapid recovery following termination of pumping compared to the Papadopolous-Cooper solution. This suggests that during the test, pumped water was to a large extent derived from the well bore. The initial volume of water stored in the well bore was estimated to be about 300 L while approximately 360 L of water appears to have been pumped over the 30 m duration of the test, suggesting that on the order of 85% of the pumped water was derived from the well bore as opposed to the aquifer.

6. Aquifer Long-Term Yield

The long-term yield of the aquifer was estimated using the Farvolden method (AENV 2003):

$$Q_{20} = (0.68)(T)(H_a)x0.7$$

In Farvolden's equation, H_a represents the available drawdown to the top of the aquifer. With the top of the aquifer determined to be about 81 mbgs and the static water level measured at 8.28 mbgs, H_a was calculated as being about 73 m. Therefore, Q_{20} was determined to be about 0.4 L/min (6.9×10^{-6} m^3/s).

7. Conclusion

The results from the pumping test indicate that the lower bedrock sandstone aquifer is a poorly yielding groundwater zone not suitable as a Project water supply.

8. References

8.1 Literature Cited

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Papadopulos, I.S. and H.H. Cooper. 1967. *Drawdown in a well of large diameter*. *Water Resources Research,* 3:241-244.

Theis, C.V. 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Am. Geophys*. Union Trans*.* 16:519–524.

8.2 Internet Sites

HydroSOLVE. 2003. Available at: http://www.hydrosolveinc.com/hydrosolve/aqtesolv.htm. Accessed January 2007.

Volume IIB, Section 2: Groundwater Quantity and Quality

Appendix II: Upper Sandstone Aquifer Pumping Test (05-01B)

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LIST OF FIGURES

1. Upper Sandstone Aquifer Pumping Test (05-01B)

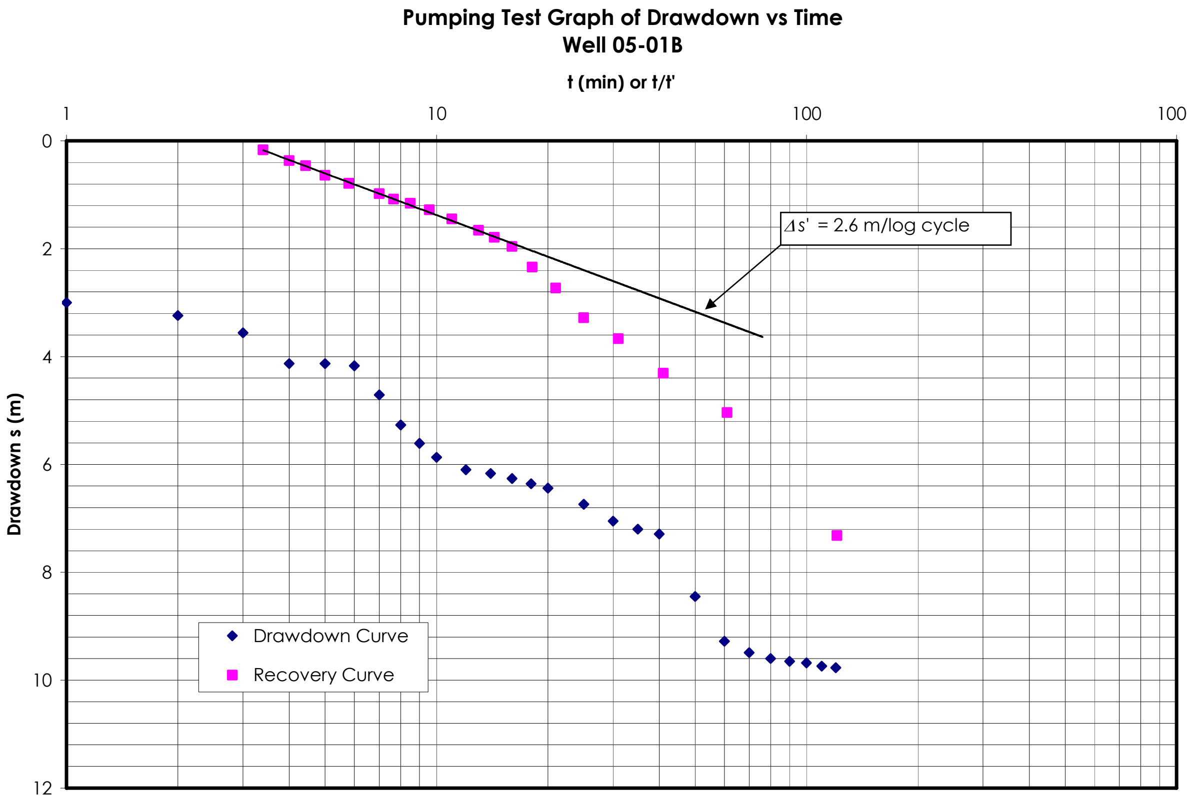

Figure II–1: Pumping Test Graph of Drawdown vs. Time Well 05-01B

Aquifer transmissivity (T) was calculated from the recovery portion of the test using the following equation:

$$T = \frac{2.3Q}{4\pi\Delta s'}$$

In the above equation, Q represents the average pumping rate, 65.5 m^3/day, and Δs' equals the slope of time (t/t') recovery curve, 2.6 m/log cycle, as inferred from the above graph. This yields T = 4.6 m^2/day.

The 20-year yield of the aquifer was estimated using Moell's method (AENV 2003):

$$Q_{20} = 0.7\frac{QH_a}{s_{100} + 5\Delta s'}$$

In Moell's equation, s_{100} represents measured drawdown 100 minutes after the start of the test (9.68 m) and H_a represents the available drawdown to the top of the aquifer. With the top of the aquifer determined to be 6.1 m below ground surface (mbgs) and the static water level measured at 0.75 mbgs, H_a was calculated as being 5.35 m. Therefore, Q_{20} was determined to be 7.8 L/m (1.3×10^{-4} m^3/s).

2. References

2.1 Literature Cited

Alberta Environment (AENV). 2003. *Groundwater Evaluation Guideline*, Information required when submitting an application under the *Water Act*, February 5, 2003.

Volume IIB, Section 2: Groundwater Quantity and Quality

Appendix III: Borehole Logs

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LIST OF ATTACHMENTS

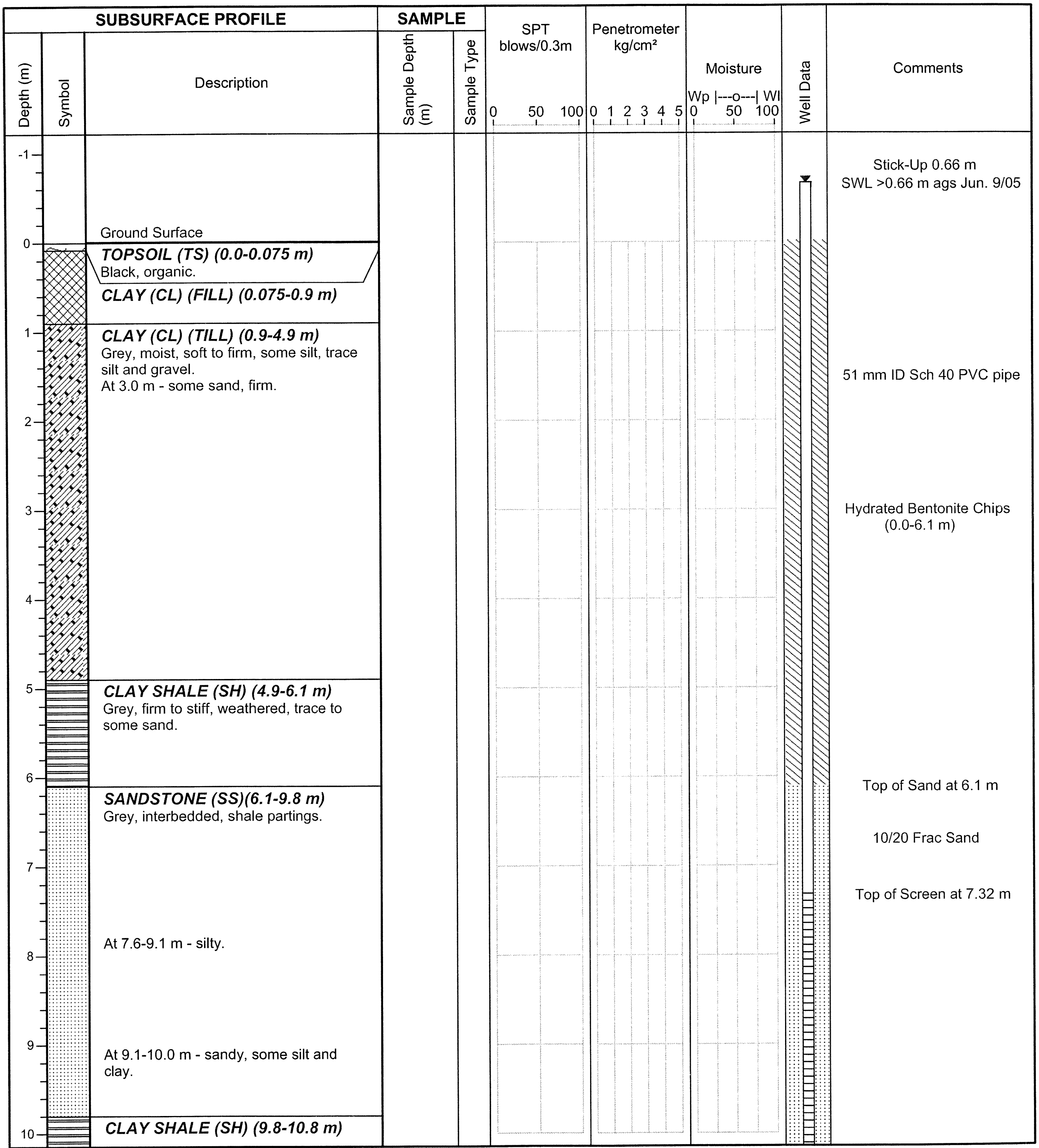
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27, 2005
Compiled By: A. Mullick

Northing: 5962507.25
Easting: 377154.95
Ground Elevation: 632.83
Pipe Elevation: 633.49

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01B

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.075 m)
Black, organic.

CLAY (CL) (FILL) (0.075-0.9 m)

CLAY (CL) (TILL) (0.9-4.9 m)
Grey, moist, soft to firm, some silt, trace silt and gravel.
At 3.0 m - some sand, firm.

CLAY SHALE (SH) (4.9-6.1 m)
Grey, firm to stiff, weathered, trace to some sand.

SANDSTONE (SS)(6.1-9.8 m)
Grey, interbedded, shale partings.
At 7.6-9.1 m - silty.
At 9.1-10.0 m - sandy, some silt and clay.

CLAY SHALE (SH) (9.8-10.8 m)

Comments:

Stick-Up 0.66 m
SWL >0.66 m ags Jun. 9/05

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips
(0.0-6.1 m)

Top of Sand at 6.1 m

10/20 Frac Sand

Top of Screen at 7.32 m

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27, 2005
Compiled By: A. Mullick

Northing: 5962507.25
Easting: 377154.95
Ground Elevation: 632.83
Pipe Elevation: 633.49

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01B
Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m	Penetrometer kg/cm²	Moisture		
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	0 50 100	0 1 2 3 4 5	Wp |---o---| Wl 0 50 100	Well Data	Comments
									9.14 m x 51 mm ID Sch 40 PVC 020 Slot Screen
11 12 13 14		***SANDSTONE (SS)(10.8-14.9 m)*** Grey, interbedded clay shale & siltstone.							Mud Rotary Borehole (127 mm diameter)
15 16		***CLAY SHALE (SH) (14.9-16.46 m)***							
17 18 19 20 21		16.46 m End of Borehole NOTES: No samples collected.							Bottom of Screen/Sand at 16.46 m

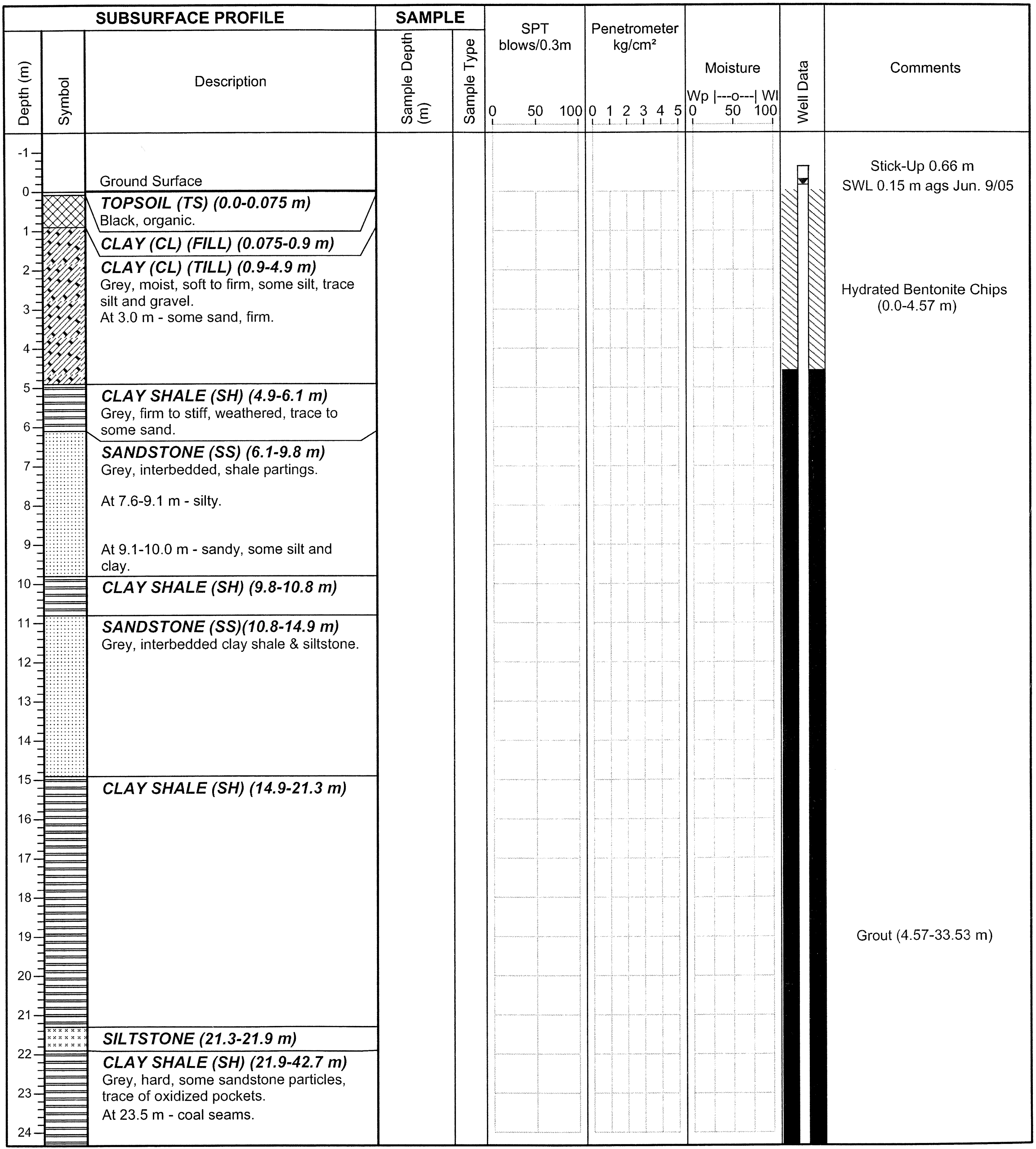
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 26, 2005
Compiled By: A. Mullick

Northing: 5962507.44
Easting: 377156.89
Ground Elevation: 632.84
Pipe Elevation: 633.50

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01C

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.075 m)
Black, organic.

CLAY (CL) (FILL) (0.075-0.9 m)

CLAY (CL) (TILL) (0.9-4.9 m)
Grey, moist, soft to firm, some silt, trace silt and gravel.
At 3.0 m - some sand, firm.

CLAY SHALE (SH) (4.9-6.1 m)
Grey, firm to stiff, weathered, trace to some sand.

SANDSTONE (SS) (6.1-9.8 m)
Grey, interbedded, shale partings.

At 7.6-9.1 m - silty.

At 9.1-10.0 m - sandy, some silt and clay.

CLAY SHALE (SH) (9.8-10.8 m)

SANDSTONE (SS)(10.8-14.9 m)
Grey, interbedded clay shale & siltstone.

CLAY SHALE (SH) (14.9-21.3 m)

SILTSTONE (21.3-21.9 m)

CLAY SHALE (SH) (21.9-42.7 m)
Grey, hard, some sandstone particles, trace of oxidized pockets.
At 23.5 m - coal seams.

Comments:

Stick-Up 0.66 m
SWL 0.15 m ags Jun. 9/05

Hydrated Bentonite Chips
(0.0-4.57 m)

Grout (4.57-33.53 m)

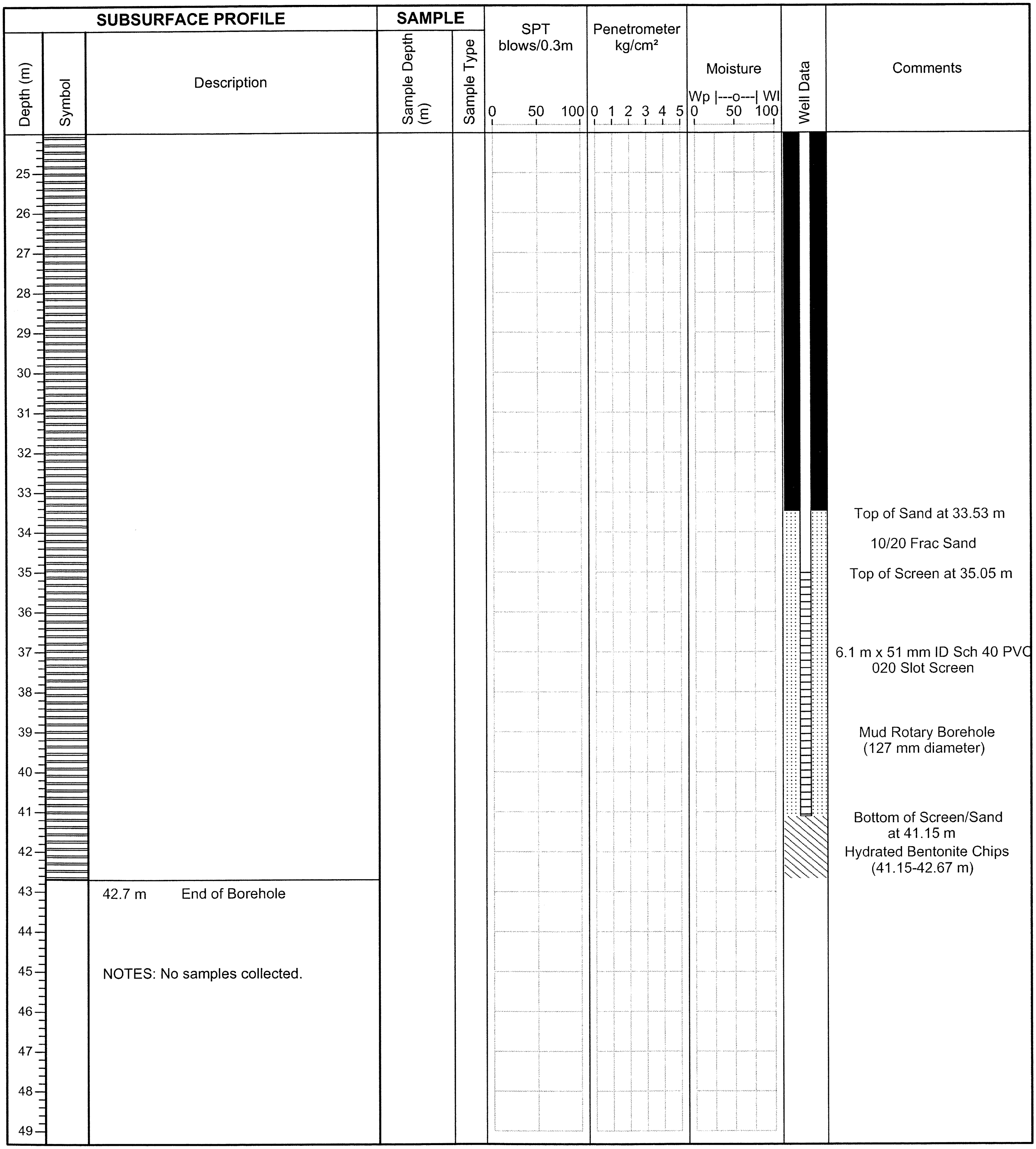
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 26, 2005
Compiled By: A. Mullick

Northing: 5962507.44
Easting: 377156.89
Ground Elevation: 632.84
Pipe Elevation: 633.50

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01C

Project #: C62720000



42.7 m End of Borehole

NOTES: No samples collected.

Top of Sand at 33.53 m

10/20 Frac Sand

Top of Screen at 35.05 m

6.1 m x 51 mm ID Sch 40 PVC
020 Slot Screen

Mud Rotary Borehole
(127 mm diameter)

Bottom of Screen/Sand
at 41.15 m
Hydrated Bentonite Chips
(41.15-42.67 m)

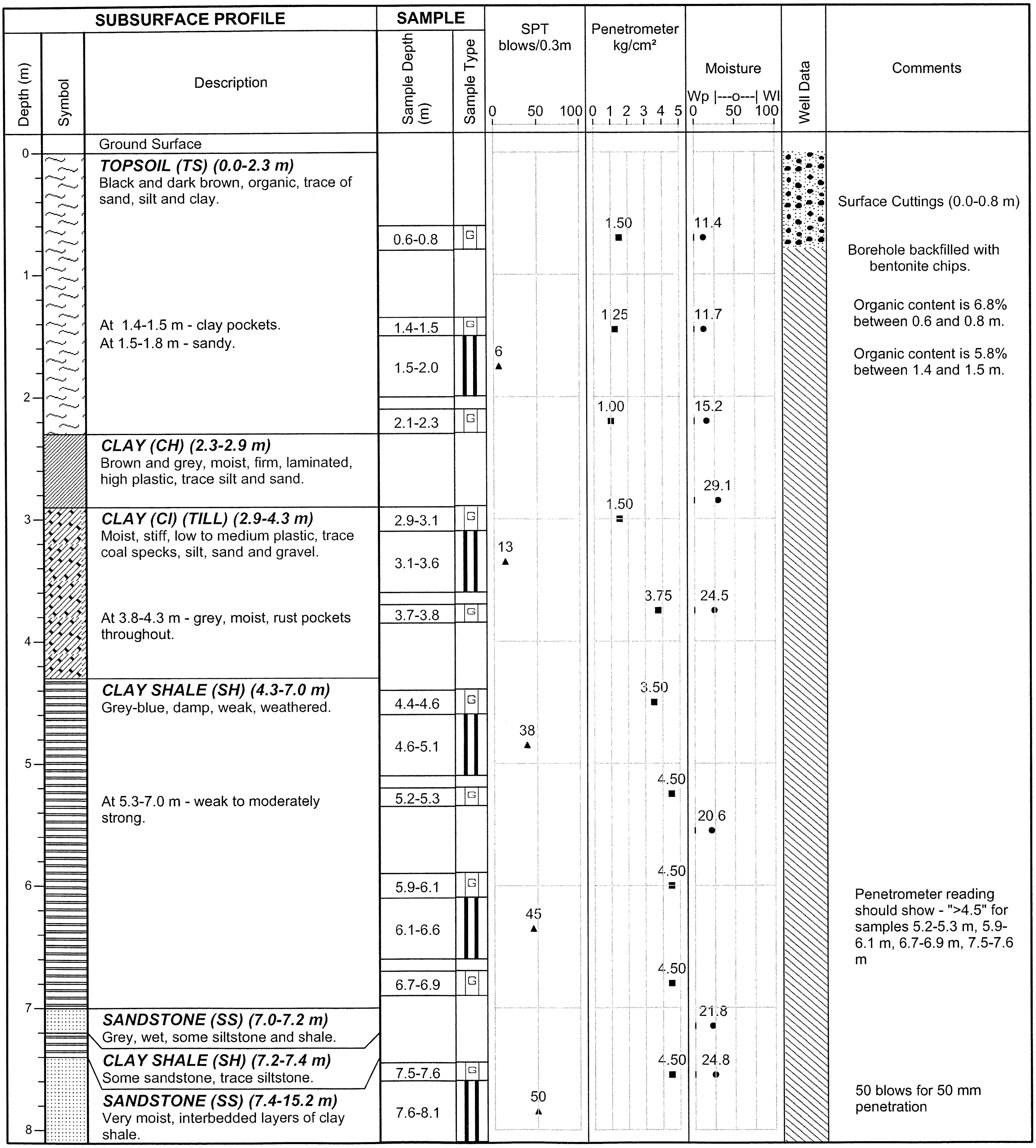
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick

Northing: 5962461.67
Easting: 377000.16
Ground Elevation: 635.86
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-02

Project #: C62720000



SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Comments
Ground Surface						
TOPSOIL (TS) (0.0-2.3 m) Black and dark brown, organic, trace of sand, silt and clay.						Surface Cuttings (0.0-0.8 m)
	0.6-0.8	G		1.50	11.4	Borehole backfilled with bentonite chips. Organic content is 6.8% between 0.6 and 0.8 m.
At 1.4-1.5 m - clay pockets.	1.4-1.5	G		1.25	11.7	Organic content is 5.8% between 1.4 and 1.5 m.
At 1.5-1.8 m - sandy.	1.5-2.0		6			
	2.1-2.3	G		1.00	15.2	
CLAY (CH) (2.3-2.9 m) Brown and grey, moist, firm, laminated, high plastic, trace silt and sand.				1.50	29.1	
CLAY (CI) (TILL) (2.9-4.3 m) Moist, stiff, low to medium plastic, trace coal specks, silt, sand and gravel.	2.9-3.1	G				
	3.1-3.6		13			
At 3.8-4.3 m - grey, moist, rust pockets throughout.	3.7-3.8	G		3.75	24.5	
CLAY SHALE (SH) (4.3-7.0 m) Grey-blue, damp, weak, weathered.	4.4-4.6	G		3.50		
	4.6-5.1		38			
At 5.3-7.0 m - weak to moderately strong.	5.2-5.3	G		4.50	20.6	
	5.9-6.1	G		4.50		Penetrometer reading should show - ">4.5" for samples 5.2-5.3 m, 5.9-6.1 m, 6.7-6.9 m, 7.5-7.6 m
	6.1-6.6		45			
	6.7-6.9	G		4.50		
SANDSTONE (SS) (7.0-7.2 m) Grey, wet, some siltstone and shale.					21.8	
CLAY SHALE (SH) (7.2-7.4 m) Some sandstone, trace siltstone.	7.5-7.6	G		4.50	24.8	
SANDSTONE (SS) (7.4-15.2 m) Very moist, interbedded layers of clay shale.	7.6-8.1		50			50 blows for 50 mm penetration

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick

Northing: 5962461.67
Easting: 377000.16
Ground Elevation: 635.86
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-02

Project #: C62720000

SUBSURFACE PROFILE		SAMPLE						
Depth (m)	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Well Data	Comments
9		9.1-9.6	▮	50				50 blows for 75 mm penetration
		9.8-9.9	G					
10	At 10.5 m - coal fissures.	10.5-10.7	G					
11		11.3-11.4	G					
12		12.0-12.2	G					
13		12.8-13.0	G					
14		13.6-13.7	G					
15		15.1-15.2	G					
	15.2 m End of Borehole							
16								

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Mullick

Northing: 5962105.61
Easting: 377518.50
Ground Elevation: 636.61
Pipe Elevation: 637.50

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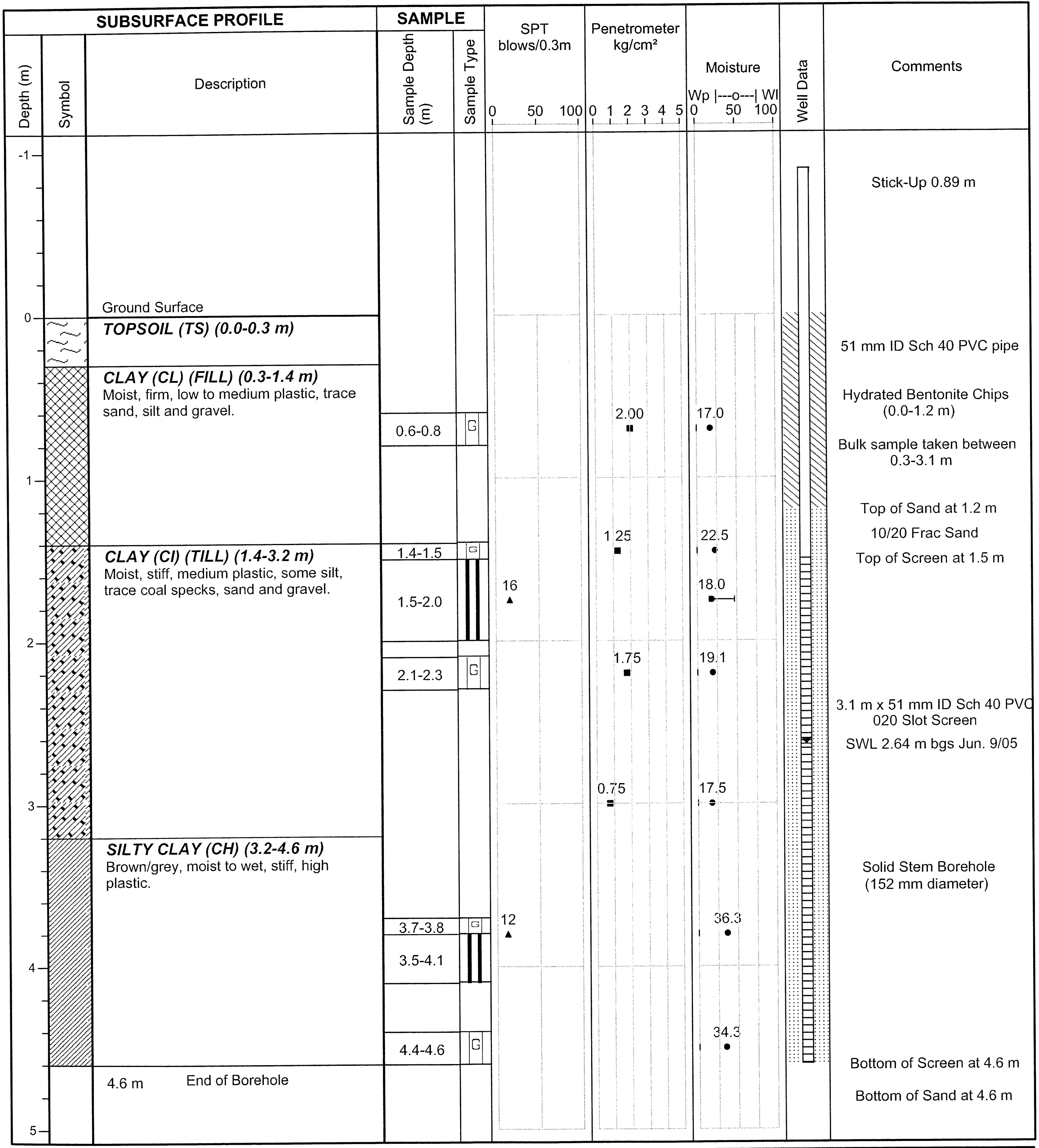
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.3 m)

CLAY (CL) (FILL) (0.3-1.4 m)
Moist, firm, low to medium plastic, trace sand, silt and gravel.

CLAY (CI) (TILL) (1.4-3.2 m)
Moist, stiff, medium plastic, some silt, trace coal specks, sand and gravel.

SILTY CLAY (CH) (3.2-4.6 m)
Brown/grey, moist to wet, stiff, high plastic.

4.6 m End of Borehole

Stick-Up 0.89 m

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips (0.0-1.2 m)

Bulk sample taken between 0.3-3.1 m

Top of Sand at 1.2 m

10/20 Frac Sand

Top of Screen at 1.5 m

3.1 m x 51 mm ID Sch 40 PVC 020 Slot Screen

SWL 2.64 m bgs Jun. 9/05

Solid Stem Borehole (152 mm diameter)

Bottom of Screen at 4.6 m

Bottom of Sand at 4.6 m

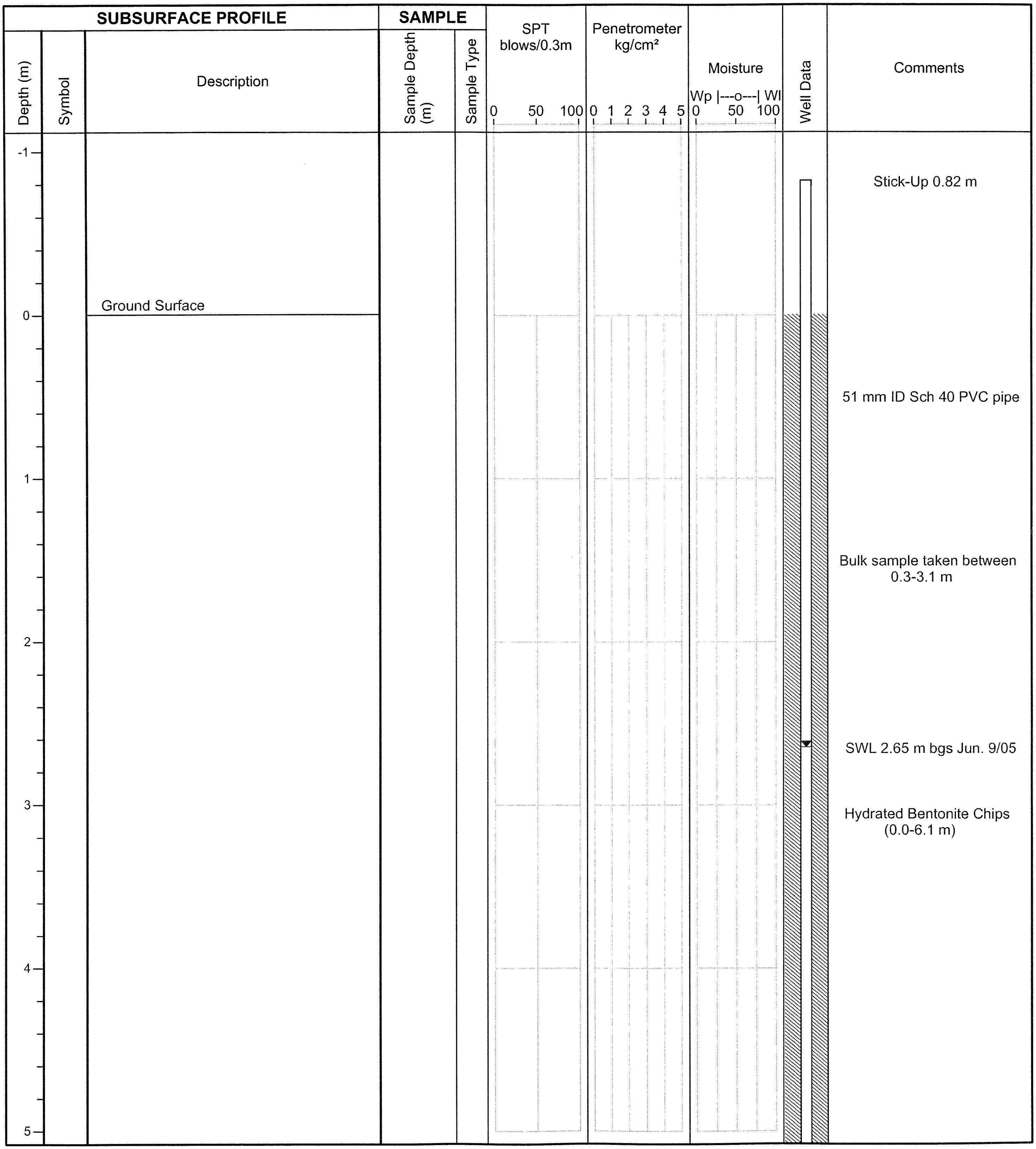
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962105.03
Easting: 377520.48
Ground Elevation: 636.69
Pipe Elevation: 637.51

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BI

Project #: C62720000



Stick-Up 0.82 m

51 mm ID Sch 40 PVC pipe

Bulk sample taken between 0.3-3.1 m

SWL 2.65 m bgs Jun. 9/05

Hydrated Bentonite Chips (0.0-6.1 m)

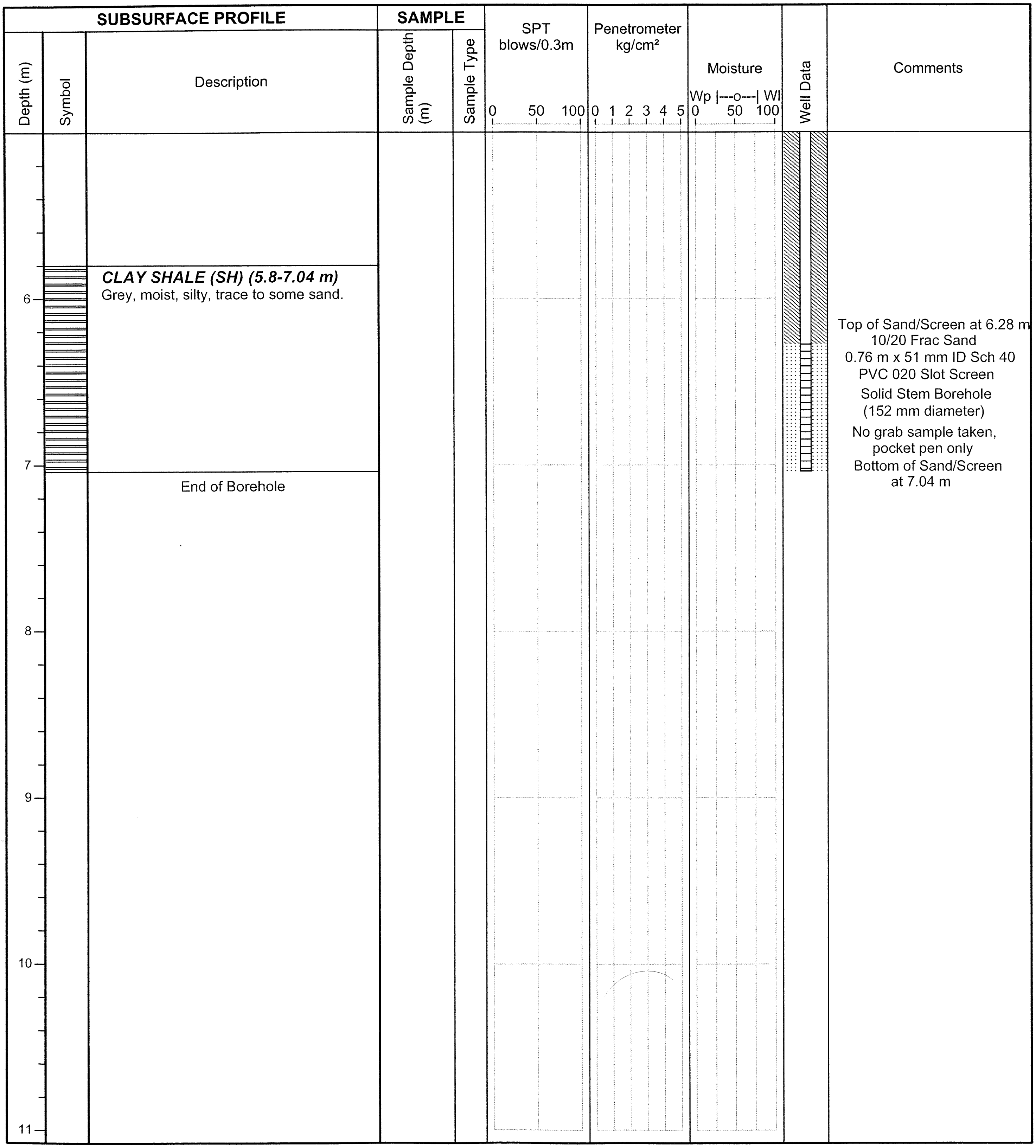
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962105.03
Easting: 377520.48
Ground Elevation: 636.69
Pipe Elevation: 637.51

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BI

Project #: C62720000



CLAY SHALE (SH) (5.8-7.04 m)
Grey, moist, silty, trace to some sand.

End of Borehole

Top of Sand/Screen at 6.28 m
10/20 Frac Sand
0.76 m x 51 mm ID Sch 40
PVC 020 Slot Screen
Solid Stem Borehole
(152 mm diameter)
No grab sample taken,
pocket pen only
Bottom of Sand/Screen
at 7.04 m

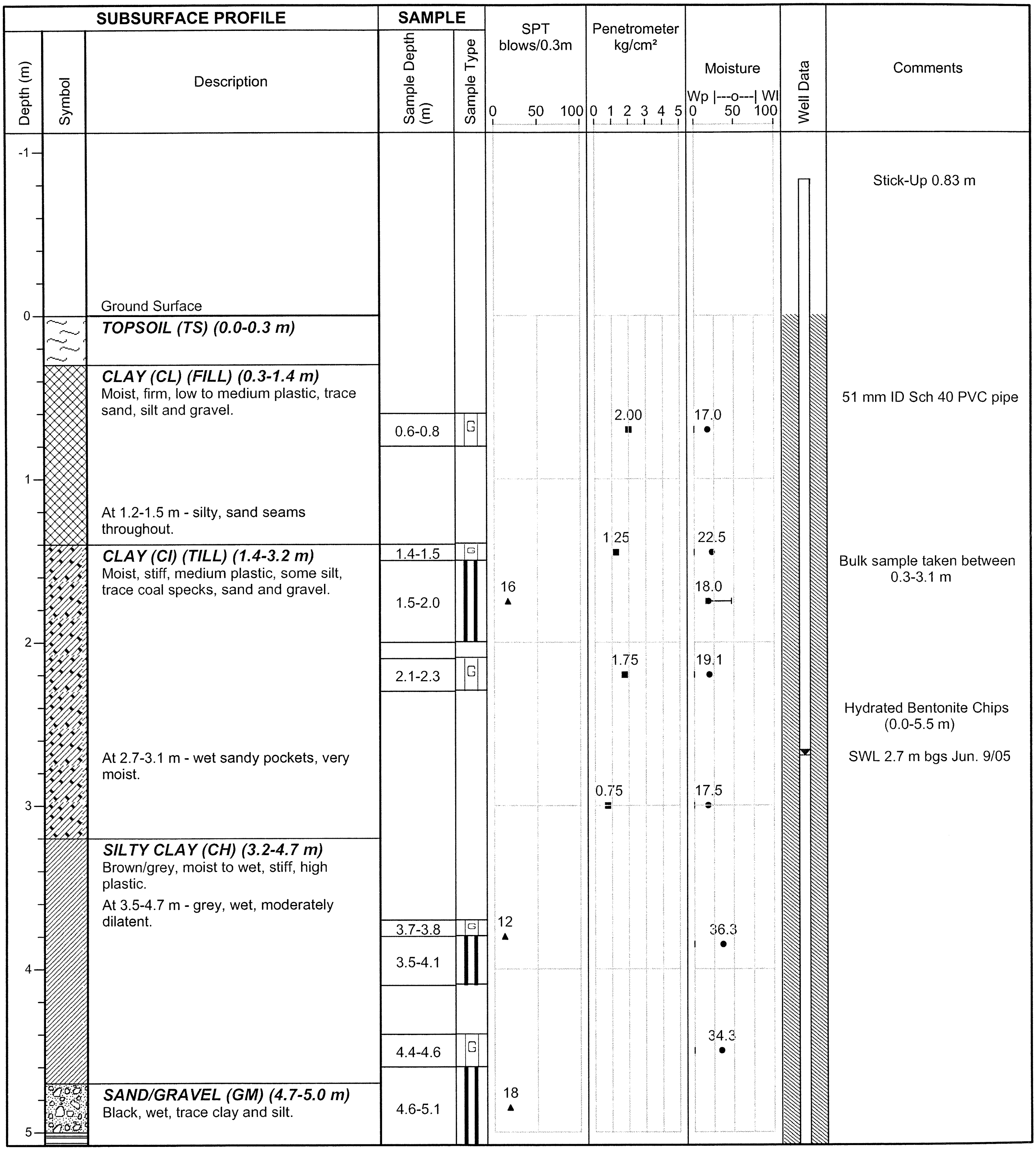
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick/A. Tangedal

Northing: 5962103.80
Easting: 377519.14
Ground Elevation: 636.73
Pipe Elevation: 637.56

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BII

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.3 m)

CLAY (CL) (FILL) (0.3-1.4 m)
Moist, firm, low to medium plastic, trace sand, silt and gravel.

At 1.2-1.5 m - silty, sand seams throughout.

CLAY (CI) (TILL) (1.4-3.2 m)
Moist, stiff, medium plastic, some silt, trace coal specks, sand and gravel.

At 2.7-3.1 m - wet sandy pockets, very moist.

SILTY CLAY (CH) (3.2-4.7 m)
Brown/grey, moist to wet, stiff, high plastic.

At 3.5-4.7 m - grey, wet, moderately dilatent.

SAND/GRAVEL (GM) (4.7-5.0 m)
Black, wet, trace clay and silt.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		2.00	17.0
1.4-1.5	G		1.25	22.5
1.5-2.0		16		18.0
2.1-2.3	G		1.75	19.1
			0.75	17.5
3.7-3.8	G	12		36.3
3.5-4.1				
4.4-4.6	G			34.3
4.6-5.1		18		

Stick-Up 0.83 m

51 mm ID Sch 40 PVC pipe

Bulk sample taken between 0.3-3.1 m

Hydrated Bentonite Chips (0.0-5.5 m)

SWL 2.7 m bgs Jun. 9/05

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick/A. Tangedal

Northing: 5962103.80
Easting: 377519.14
Ground Elevation: 636.73
Pipe Elevation: 637.56

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BII

Project #: C62720000

Depth (m)	SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Comments
	CLAY SHALE (SH) (5.0-6.1 m) Grey, moist, silty, trace to some sand.	5.2-5.3	G			22.1	Top of Sand at 5.52 m 10/20 Frac Sand Top of Screen at 5.9 m
6		5.9-6.1	G				
	SANDSTONE (SS) (6.1-7.0 m) Saturated, hard, weak to moderately strong, trace clay shale and siltstone.	6.1-6.6		32		28.3	1.22 m x 51 mm ID Sch 40 020 Slot Screen No grab sample taken, pocket pen only
	At 6.6-6.7 m - increased clay content, moist.	6.7-6.9			3.00		Solid Stem Borehole (152 mm diameter)
7	***CLAY SHALE (SH) (7.0-8.1 m)*** Brown, damp, hard, some sandstone and shale.						Bottom of Sand/Screen at 7.12 m
		7.5-7.6		33	3.00		No grab sample taken, pocket pen only
		7.6-8.1					
8	***SANDSTONE (SS) (8.1-8.5 m)*** Grey, damp, trace shale and siltstone.						Hydrated Bentonite Chips (7.12-9.1 m)
	CLAY SHALE (SH) (8.5-9.1 m) Grey, damp, trace siltstone and sandstone.						
9	9.1 m End of Borehole						T.D. of Borehole at 9.1 m
10							
11							

Komex-Geotech4-SPT-100-piezo

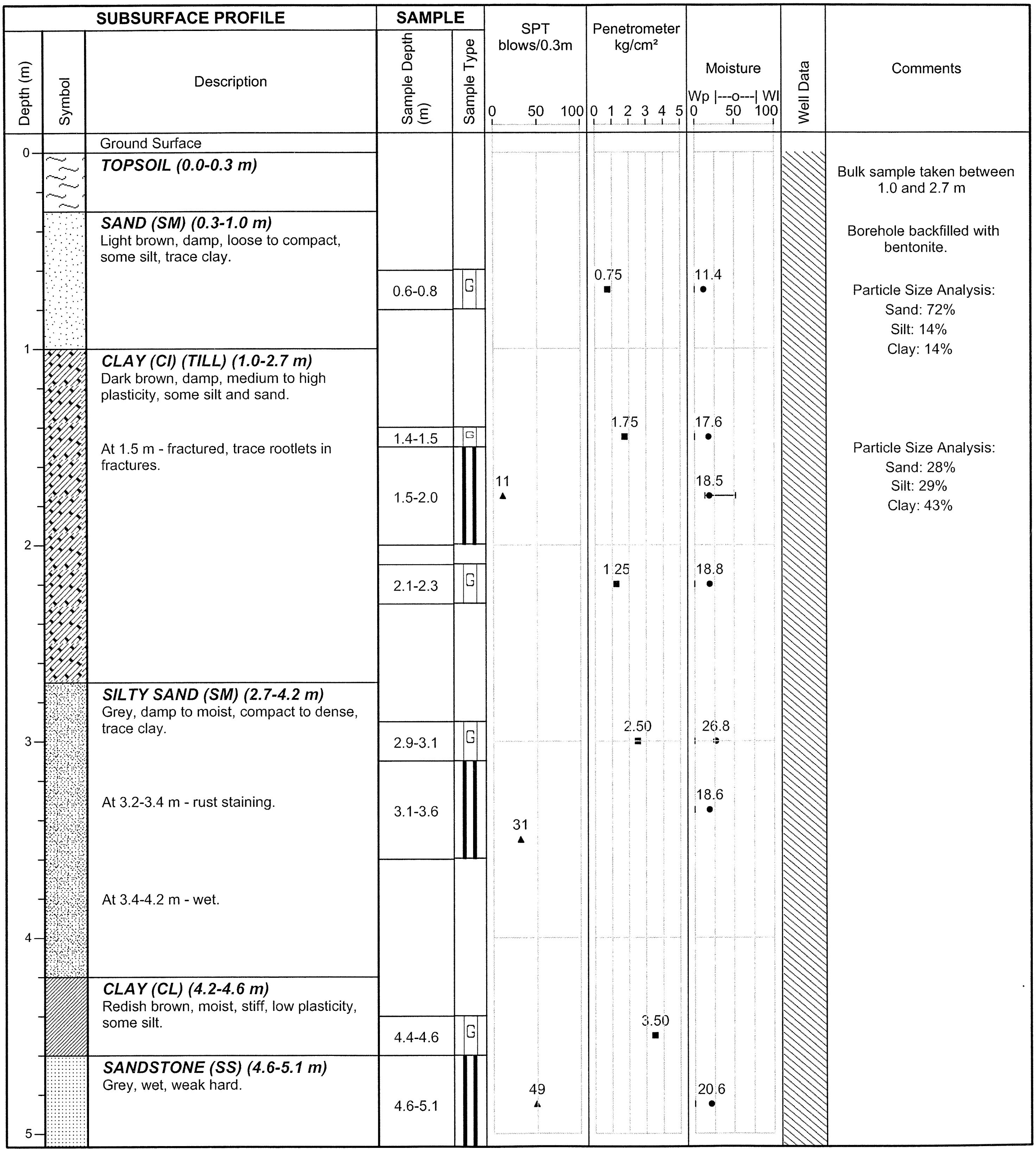
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962375.68
Easting: 376825.02
Ground Elevation:
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-04

Project #: C62720000



Ground Surface

TOPSOIL (0.0-0.3 m)

SAND (SM) (0.3-1.0 m)
Light brown, damp, loose to compact, some silt, trace clay.

CLAY (CI) (TILL) (1.0-2.7 m)
Dark brown, damp, medium to high plasticity, some silt and sand.

At 1.5 m - fractured, trace rootlets in fractures.

SILTY SAND (SM) (2.7-4.2 m)
Grey, damp to moist, compact to dense, trace clay.

At 3.2-3.4 m - rust staining.

At 3.4-4.2 m - wet.

CLAY (CL) (4.2-4.6 m)
Redish brown, moist, stiff, low plasticity, some silt.

SANDSTONE (SS) (4.6-5.1 m)
Grey, wet, weak hard.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		0.75	11.4
1.4-1.5	G		1.75	17.6
1.5-2.0		11		18.5
2.1-2.3	G		1.25	18.8
2.9-3.1	G		2.50	26.8
3.1-3.6		31		18.6
4.4-4.6	G		3.50	
4.6-5.1		49		20.6

Comments:

Bulk sample taken between 1.0 and 2.7 m

Borehole backfilled with bentonite.

Particle Size Analysis:
Sand: 72%
Silt: 14%
Clay: 14%

Particle Size Analysis:
Sand: 28%
Silt: 29%
Clay: 43%

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962375.68
Easting: 376825.02
Ground Elevation:
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-04

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type					
		CLAY SHALE (SH) (5.1-8.1 m) Grey, damp, weak to moderately strong, low plasticity, blocky, friable, trace siltstone.	5.2-5.3	G		1.50			
6			5.9-6.1	G		4.50			Pocket pen >4.5
		At 6.1-6.6 m - Coal fragments throughout.	6.1-6.6		52				
			6.7-6.9	G					
7									
		At 7.6-8.1 m - interbedded fine sandstone layers.	7.5-7.6	G					
8			7.6-8.1						
		8.1 m End of Borehole							
9									
10									

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962541.19
Easting: 376897.89
Ground Elevation: 636.10
Pipe Elevation: 636.84

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-05A

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
-1									Stick-Up 0.74 m
0		Ground Surface							
		TOPSOIL (TS) (FILL) (0.0-1.5 m) Black and brown, silt, trace grass fragments and clay.							51 mm ID Sch 40 PVC pipd
			0.6-0.8	G		1.50	12.4		Hydrated Bentonite Chips (0.0-1.2 m)
1									Top of Sand at 1.2 m Top of Screen at 1.23 m
			1.4-1.5	G		1.75	20.8		10/20 Frac Sand
		SILTY SAND (SM) (1.5-2.6 m) Light brown, moist, compact.	1.5-2.0		12				
2			2.1-2.3	G		1.25	14.3		3.05 m x 51 mm ID Sch 40 PVC 020 Slot Screen
		At 2.3-2.6 m - some gravel.							SWL 2.47 m bgs Jun. 9/05
		CLAY (CH) (2.6-4.6 m) Grey, moist, firm, high plasticity.							
3			2.9-3.1	G		0.50	25.4		
			3.1-3.6		10				Solid Stem Borehole (152 mm diameter)
		At 3.7 m - some silt and sand.	3.7-3.8	G		0.50	26.8		
4									Bottom of Screen/Sand at 4.28 m
		At 4.2-4.6 m - till-like, trace gravel.	4.4-4.6	G		0.75	22.0		
		SILTY SAND (SM) (4.6-5.3 m) Brown, saturated, compact.	4.6-5.1		19				
5									

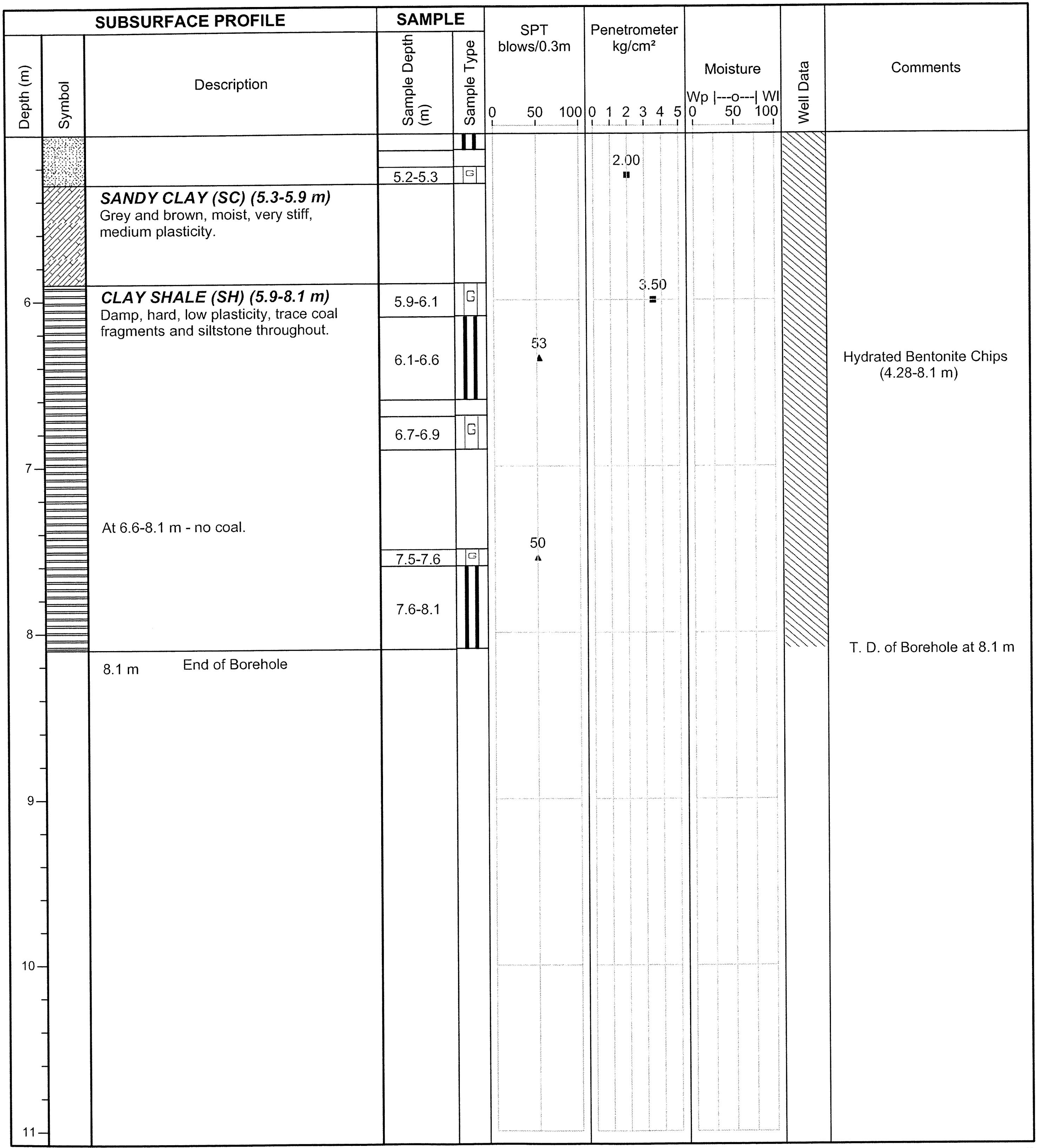
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962541.19
Easting: 376897.89
Ground Elevation: 636.10
Pipe Elevation: 636.84

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-05A

Project #: C62720000



Description	Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Comments
		▮			
	5.2-5.3	G		2.00	
SANDY CLAY (SC) (5.3-5.9 m) Grey and brown, moist, very stiff, medium plasticity.					
CLAY SHALE (SH) (5.9-8.1 m) Damp, hard, low plasticity, trace coal fragments and siltstone throughout.	5.9-6.1	G		3.50	
	6.1-6.6	▮	53		Hydrated Bentonite Chips (4.28-8.1 m)
	6.7-6.9	G			
At 6.6-8.1 m - no coal.	7.5-7.6	G	50		
	7.6-8.1	▮			
8.1 m End of Borehole					T. D. of Borehole at 8.1 m

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962310.17
Easting: 376888.50
Ground Elevation: 636.39
Pipe Elevation: 637.30

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06A

Project #: C62720000

Depth (m)	SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Comments
-1							Stick-Up 0.91 m
0	Ground Surface						
	TOPSOIL (TS) (0.0-0.1m)						
	CLAY (CI) (TILL) (0.1-1.5 m) Brown, moist, stiff, medium plasticity, some silt, trace sand and gravel.						51 mm ID Sch 40 PVC pipe
		0.6-0.8	G		1.50	26.4	Hydrated Bentonite Chips (0.0-1.4 m)
1	At 0.8-1.1 m - wet sand pocket, some gravel, loose-compact.						SWL 1.03 m bgs Jun. 9/05
		1.4-1.5	G		1.75	30.9	Top of Sand at 1.4 m
	SILTY SAND (SM) (1.5-4.9 m) Brown, saturated, compact, rust staining throughout.	1.5-2.0		27			Top of Screen at 1.63 m 10/20 Frac Sand
2	At 2.0-2.1 m - coal seam.						
		2.1-2.3	G		0.75	20.0	
							3.05 m x 51 mm ID Sch 40 020 Slot Screen
3		2.9-3.1	G		0.50	19.5	
		3.1-3.6		50			
		3.7-3.8	G			25.8	Solid Stem Borehole (152 mm diameter)
4	At 3.7-4.9 m - grey, dense.						
		4.4-4.6	G			23.7	
		4.6-4.9		50			Bottom of Screen/Sand at 4.68 m
5	End of Borehole						

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962309.94
Easting: 376887.01
Ground Elevation: 636.41
Pipe Elevation: 637.36

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06B

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Well Data	Comments
-1									Stick-Up 0.95 m
0		Ground Surface							
		TOPSOIL (TS) (0.0-0.1m)							
		CLAY (CI) (TILL) (0.1-1.5 m) Brown, moist, stiff, medium plasticity, some silt, trace sand and gravel.							
			0.6-0.8	G		1.50	26.4		
1		At 0.8-1.1 m - wet sand pocket, some gravel, loose-compact.							
			1.4-1.5	G		1.75	30.9		51 mm ID Sch 40 PVC pipe
		SILTY SAND (SM) (1.5-5.3 m) Brown, saturated, compact, rust staining throughout.	1.5-2.0		27				
2		At 2.0-2.1 m - coal seam.							
			2.1-2.3	G		0.75	20.0		
3			2.9-3.1	G		0.50	19.5		
			3.1-3.6		50				
			3.7-3.8	G			25.8		Hydrated Bentonite Chips (0.0-7.3 m)
4		At 3.7-5.3 m - grey, dense.							
			4.4-4.6	G			23.7		SWL 4.4 m bgs Jun. 9/05
			4.6-5.1		50				
5									

Komex-Geotech4-SPT-100-piezo

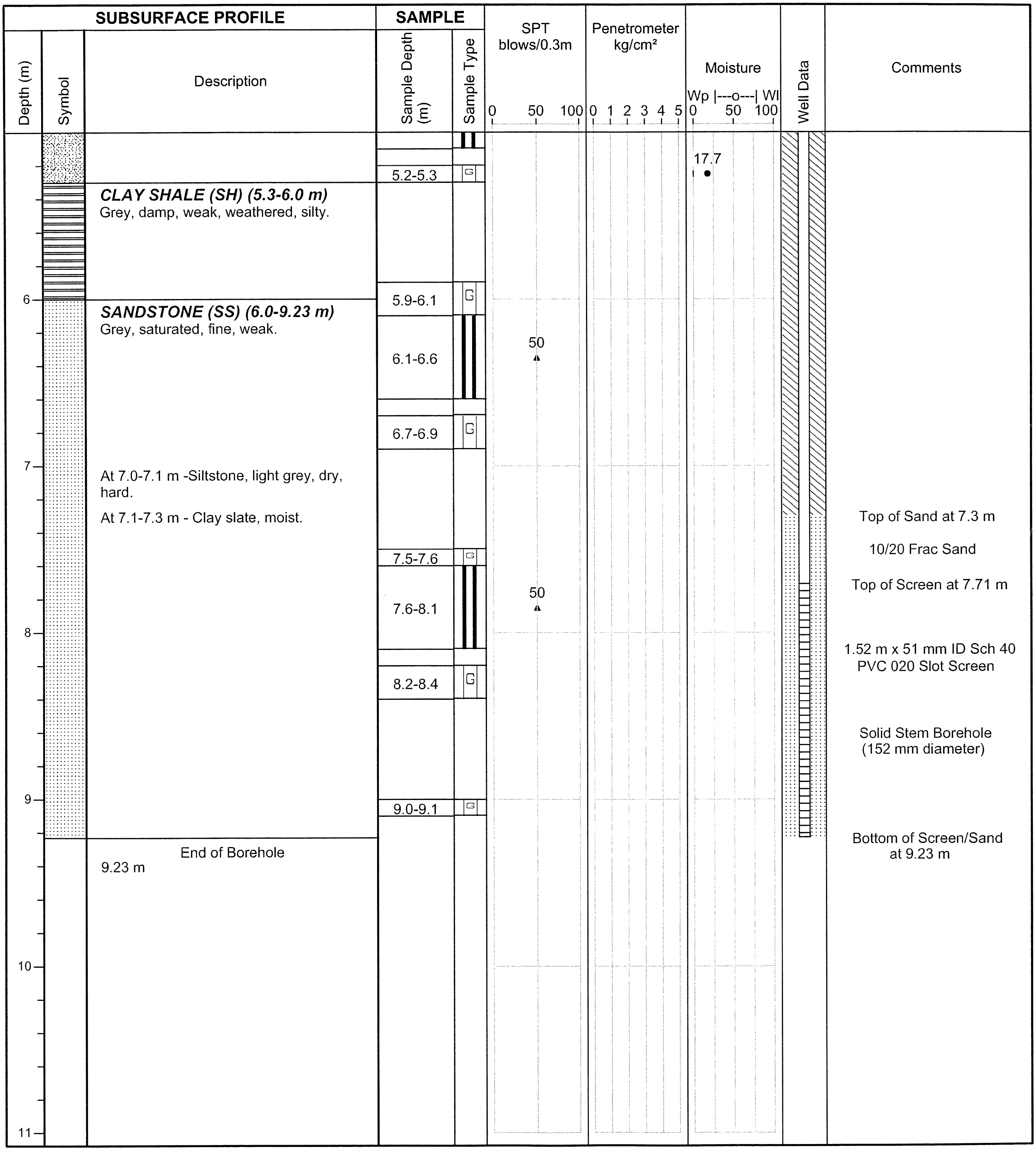
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962309.94
Easting: 376887.01
Ground Elevation: 636.41
Pipe Elevation: 637.36

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06B

Project #: C62720000



CLAY SHALE (SH) (5.3-6.0 m)
Grey, damp, weak, weathered, silty.

SANDSTONE (SS) (6.0-9.23 m)
Grey, saturated, fine, weak.

At 7.0-7.1 m -Siltstone, light grey, dry, hard.

At 7.1-7.3 m - Clay slate, moist.

End of Borehole
9.23 m

Sample Depth (m)	Sample Type	SPT blows/0.3m	Moisture
5.2-5.3	G		17.7
5.9-6.1	G		
6.1-6.6	▮	50	
6.7-6.9	G		
7.5-7.6	G		
7.6-8.1	▮	50	
8.2-8.4	G		
9.0-9.1	G		

Comments:

Top of Sand at 7.3 m

10/20 Frac Sand

Top of Screen at 7.71 m

1.52 m x 51 mm ID Sch 40
PVC 020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 9.23 m

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/29/05
Compiled By: A. Tangedal

Northing: 5962070.14
Easting: 376994.66
Ground Elevation: 638.65
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-07

Project #: C62720000

SUBSURFACE PROFILE		SAMPLE						
Depth (m)	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Well Data	Comments
	Ground Surface							
0	***TOPSOIL (TS) (0.0-0.3 m)***							Borehole backfilled with bentonite
0.3	***CLAY (CI) (FILL) (0.3-0.8 m)*** Brown, damp, medium plasticity, sandy, some gravel (possibly till).	0.6-0.8	G		0.50	30.8		
0.8	***SILTY CLAY (CI) (0.8-1.7 m)*** Brown, moist, stiff to very stiff, medium plasticity	1.4-1.5	G		2.00	27.2		
		1.5-2.0	▮	28				Particle Size Analysis: Sand: 18% Silt: 48% Clay: 34%
1.7	***CLAYEY SILT (CI) (1.7-3.2 m)*** Brown, moist, compact/stiff, some fine sand.	2.1-2.3	G		1.50	25.8		
	At 2.3-3.2 m - some clay.	2.9-3.1	G		1.25	24.8		
3.2	***SILTY SAND (SM) (3.2-6.6 m)*** Moist, dense, trace clay.	3.1-3.6	▮	50				
		3.7-3.8	G		1.25	19.2		
		4.4-4.6	G			20.4		
	At 4.8 m - trace coal fragments. At 4.9 m - saturated.	4.6-5.1	▮	50				

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/29/05
Compiled By: A. Tangedal

Northing: 5962070.14
Easting: 376994.66
Ground Elevation: 638.65
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-07

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	0 50 100	0 1 2 3 4 5	0 50 100		
			5.2-5.3	G					
		At 5.8 m - Grey.							
6			5.9-6.1	G		3.00	17.7		
			6.1-6.6		50				
		6.6 m End of Borehole							
7									
8									
9									
10									

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962022.66
Easting: 377763.62
Ground Elevation: 636.59
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-08

Project #: C62720000

SUBSURFACE PROFILE

Depth (m)	Description
0	Ground Surface
0.0-0.2	***TOPSOIL (TS) (0.0-0.2 m)***
0.2-2.7	***SILTY CLAY (CI) (0.2-2.7 m)*** Brown, moist, stiff, medium plasticity, trace sand and gravel. At 1.5-2.7 m - rust pockets throughout.
2.7-5.0	***SILTY SAND (SM) (2.7-5.0 m)*** Brown, moist, dense, trace clay. At 3.1 m - becomes wet. At 3.1-3.4 m - coal seams, rusting. At 4.8-5.0 m - Grey, silty.

SAMPLE

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl
0.6-0.8	G		1.50	21.0
1.3-1.5	G		1.75	18.9
1.5-2.0	▮	15		
2.1-2.3	G		3.25	13.4
2.9-3.1	G		1.50	16.7
3.1-3.6	▮	31		
3.7-3.8	G			18.6
4.4-4.6	G			19.5
4.6-5.1	▮	35		

Well Data

Comments: Borehole backfilled with bentonite

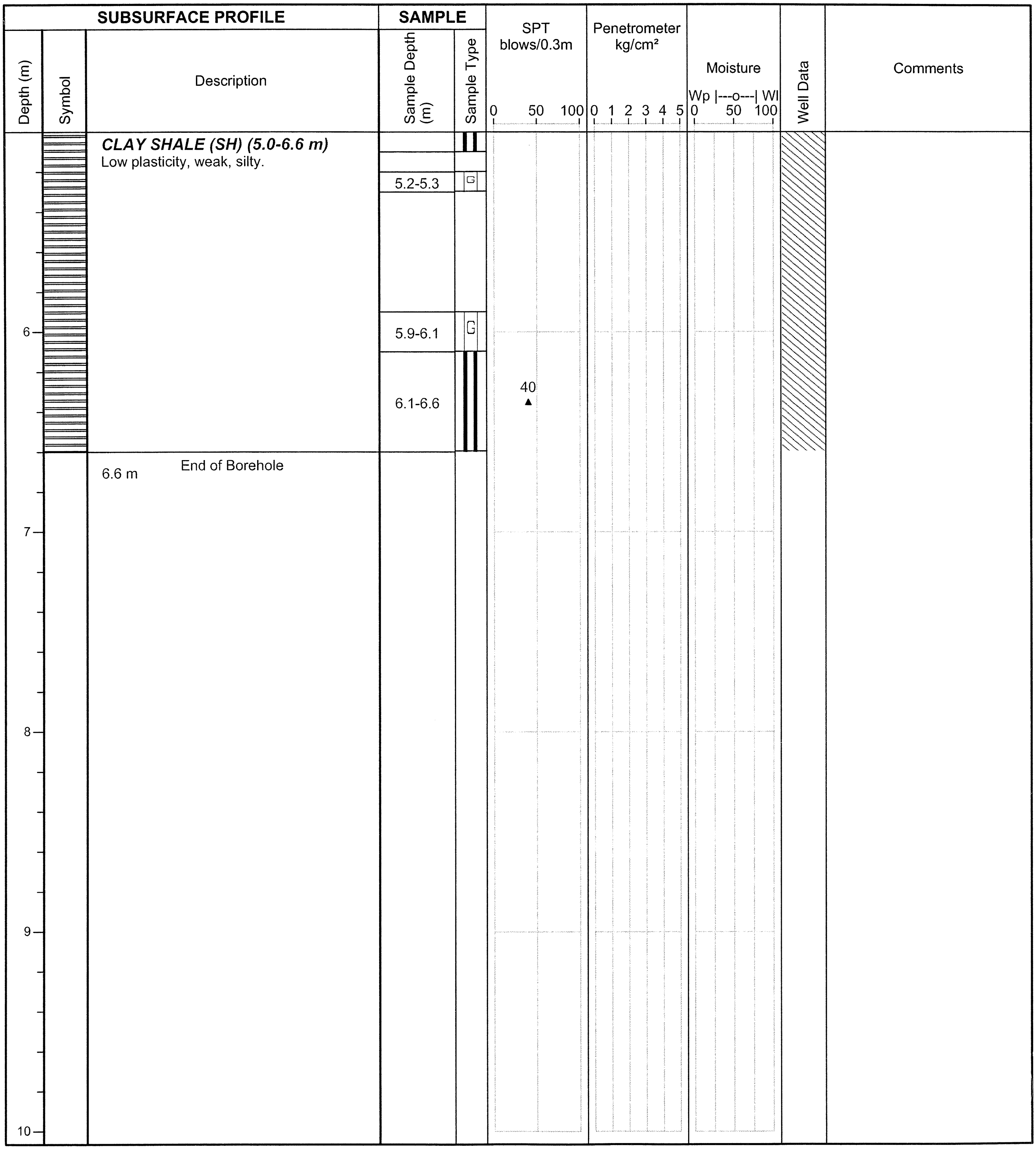
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962022.66
Easting: 377763.62
Ground Elevation: 636.59
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-08

Project #: C62720000



SUBSURFACE PROFILE		SAMPLE		SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Comments
Description		Sample Depth (m)	Sample Type				
CLAY SHALE (SH) (5.0-6.6 m) Low plasticity, weak, silty.		5.2-5.3	G				
		5.9-6.1	G				
		6.1-6.6		40			
6.6 m	End of Borehole						

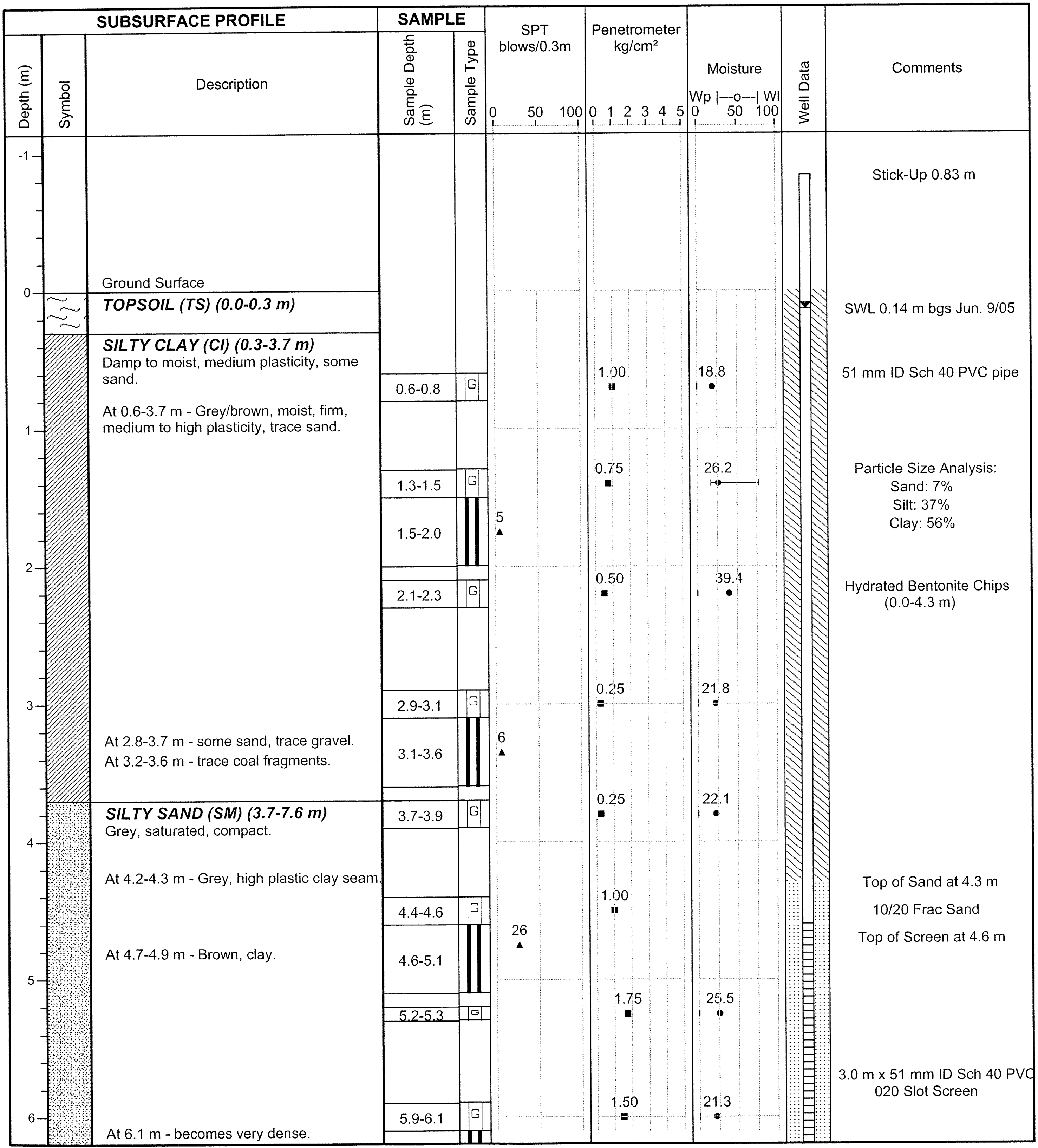
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.77
Easting: 377231.68
Ground Elevation: 634.02
Pipe Elevation: 634.85

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.3 m)

SILTY CLAY (CI) (0.3-3.7 m)
Damp to moist, medium plasticity, some sand.

At 0.6-3.7 m - Grey/brown, moist, firm, medium to high plasticity, trace sand.

At 2.8-3.7 m - some sand, trace gravel.
At 3.2-3.6 m - trace coal fragments.

SILTY SAND (SM) (3.7-7.6 m)
Grey, saturated, compact.

At 4.2-4.3 m - Grey, high plastic clay seam.

At 4.7-4.9 m - Brown, clay.

At 6.1 m - becomes very dense.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.00	18.8
1.3-1.5	G		0.75	26.2
1.5-2.0		5		
2.1-2.3	G		0.50	39.4
2.9-3.1	G		0.25	21.8
3.1-3.6		6		
3.7-3.9	G		0.25	22.1
4.4-4.6	G		1.00	
4.6-5.1		26		
5.2-5.3	G		1.75	25.5
5.9-6.1	G		1.50	21.3

Comments

Stick-Up 0.83 m

SWL 0.14 m bgs Jun. 9/05

51 mm ID Sch 40 PVC pipe

Particle Size Analysis:
Sand: 7%
Silt: 37%
Clay: 56%

Hydrated Bentonite Chips
(0.0-4.3 m)

Top of Sand at 4.3 m

10/20 Frac Sand

Top of Screen at 4.6 m

3.0 m x 51 mm ID Sch 40 PVC
020 Slot Screen

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.77
Easting: 377231.68
Ground Elevation: 634.02
Pipe Elevation: 634.85

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09A

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
			6.1-6.4		50				
			6.7-6.9	G					Solid Stem Borehole (152 mm diameter)
7									
			7.5-7.6	G					Bottom of Screen/Sand at 7.6 m
		End of Borehole							
8									
9									
10									
11									
12									
		12.2 m							
13									

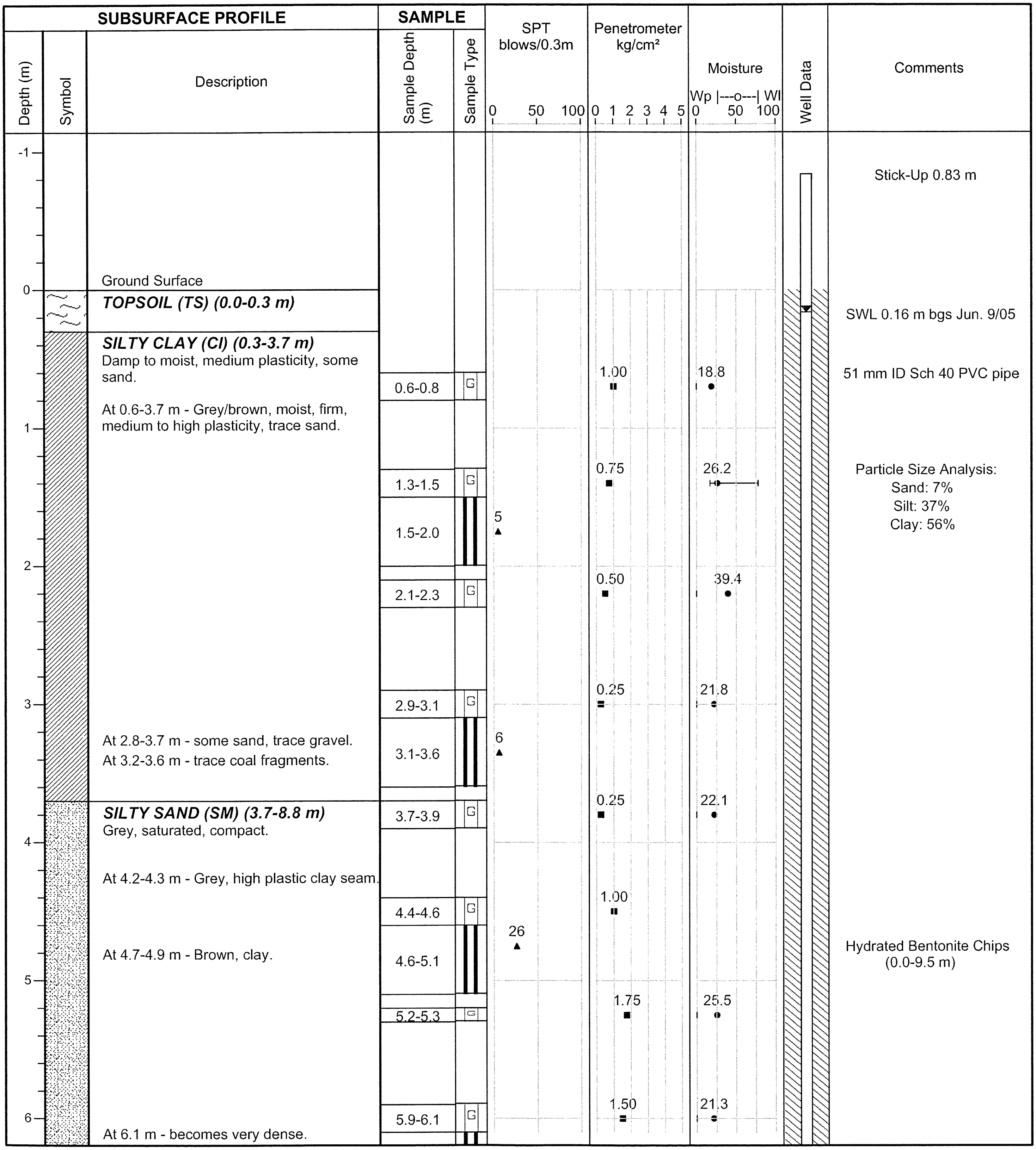
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.12
Easting: 377228.17
Ground Elevation: 634.05
Pipe Elevation: 634.88

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09B

Project #: C62720000



Description

Ground Surface

TOPSOIL (TS) (0.0-0.3 m)

SILTY CLAY (CI) (0.3-3.7 m)
Damp to moist, medium plasticity, some sand.

At 0.6-3.7 m - Grey/brown, moist, firm, medium to high plasticity, trace sand.

At 2.8-3.7 m - some sand, trace gravel.
At 3.2-3.6 m - trace coal fragments.

SILTY SAND (SM) (3.7-8.8 m)
Grey, saturated, compact.

At 4.2-4.3 m - Grey, high plastic clay seam.

At 4.7-4.9 m - Brown, clay.

At 6.1 m - becomes very dense.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.00	18.8
1.3-1.5	G		0.75	26.2
1.5-2.0		5		
2.1-2.3	G		0.50	39.4
2.9-3.1	G		0.25	21.8
3.1-3.6		6		
3.7-3.9	G		0.25	22.1
4.4-4.6	G		1.00	
4.6-5.1		26		
5.2-5.3	G		1.75	25.5
5.9-6.1	G		1.50	21.3

Comments

Stick-Up 0.83 m

SWL 0.16 m bgs Jun. 9/05

51 mm ID Sch 40 PVC pipe

Particle Size Analysis:
Sand: 7%
Silt: 37%
Clay: 56%

Hydrated Bentonite Chips
(0.0-9.5 m)

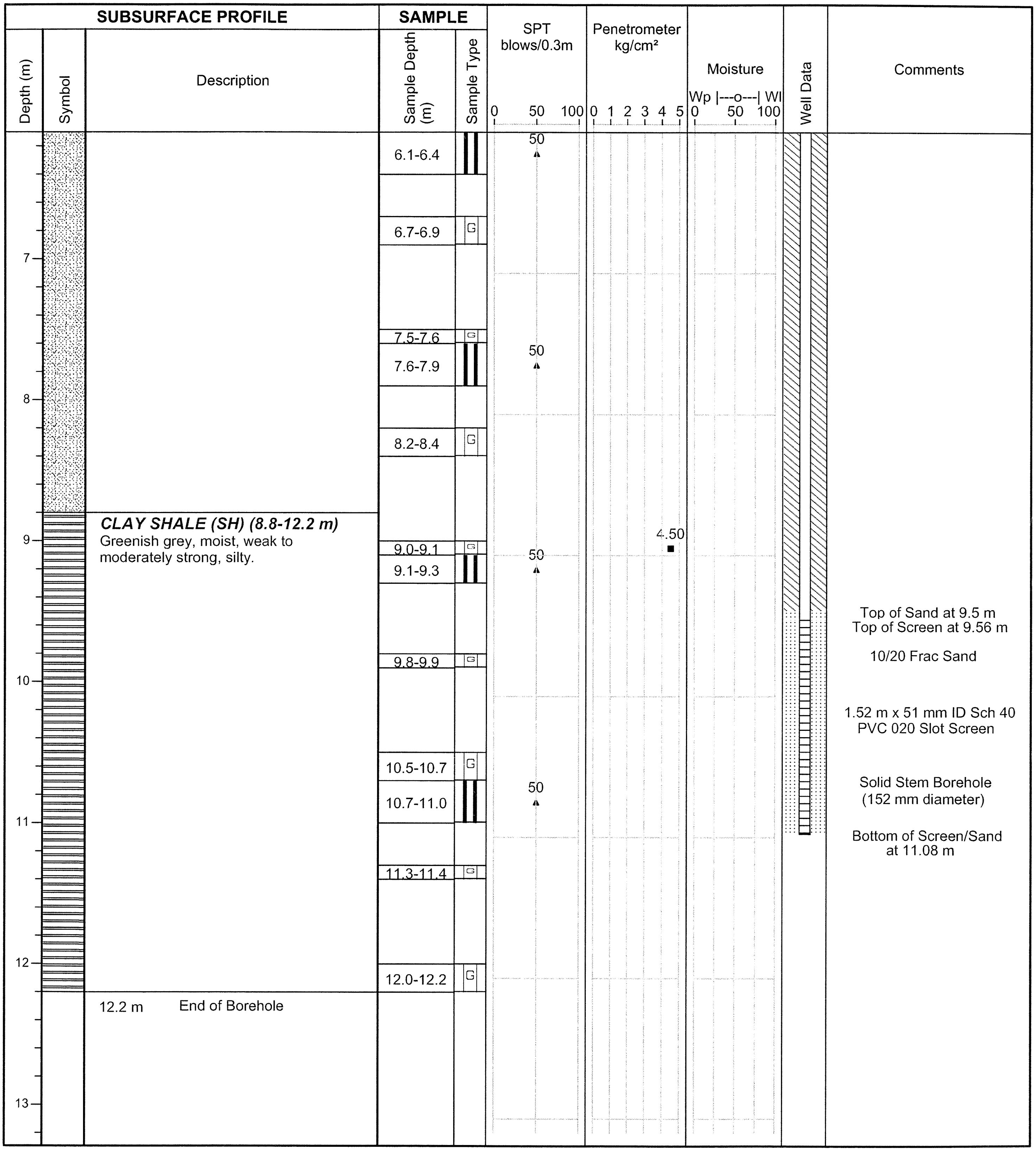
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.12
Easting: 377228.17
Ground Elevation: 634.05
Pipe Elevation: 634.88

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09B

Project #: C62720000



CLAY SHALE (SH) (8.8-12.2 m)
Greenish grey, moist, weak to moderately strong, silty.

12.2 m End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²
6.1-6.4	‖	50	
6.7-6.9	G		
7.5-7.6	G		
7.6-7.9	‖	50	
8.2-8.4	G		
9.0-9.1	G		4.50
9.1-9.3	‖	50	
9.8-9.9	G		
10.5-10.7	G		
10.7-11.0	‖	50	
11.3-11.4	G		
12.0-12.2	G		

Top of Sand at 9.5 m
Top of Screen at 9.56 m

10/20 Frac Sand

1.52 m x 51 mm ID Sch 40
PVC 020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 11.08 m

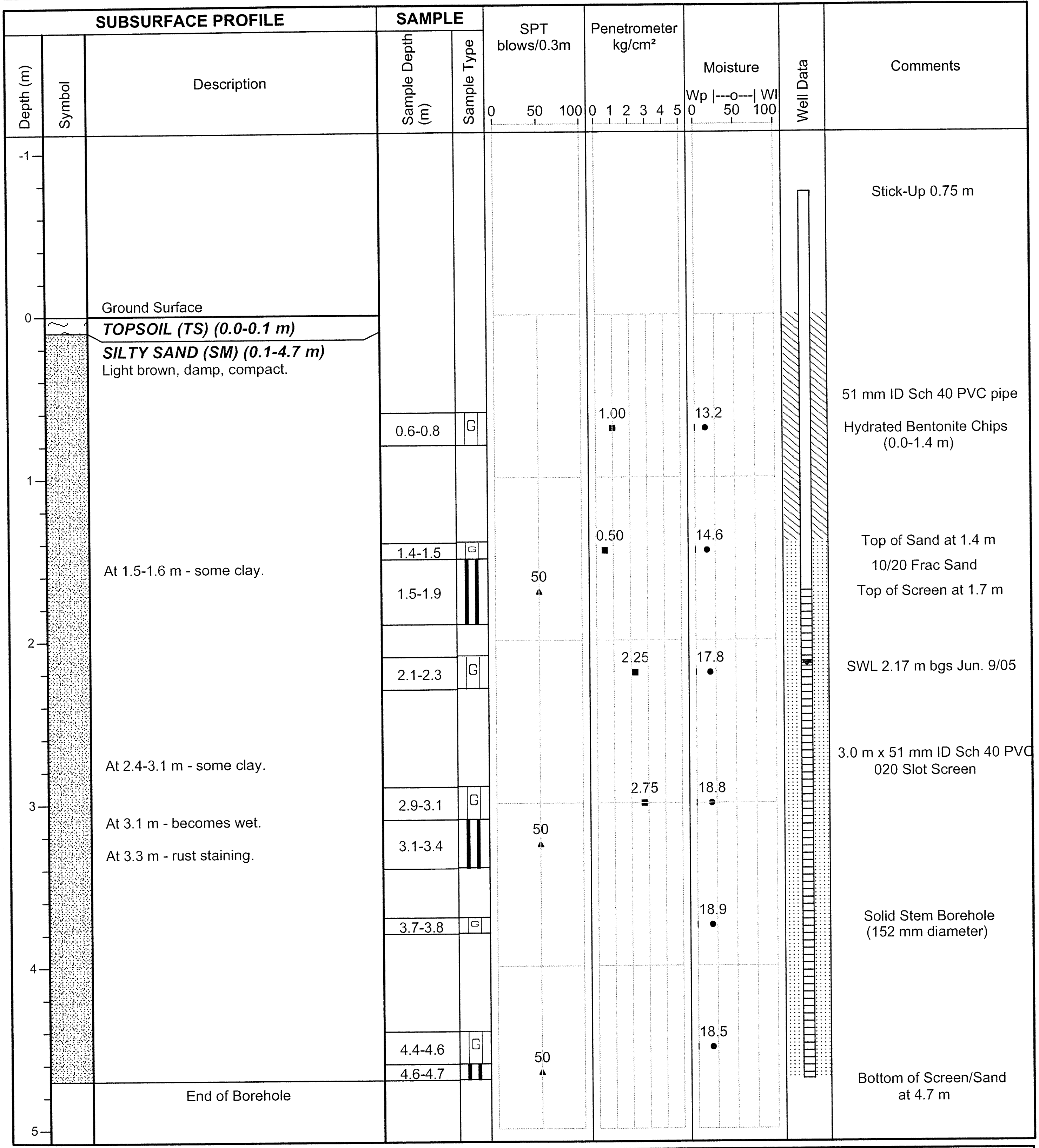
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962090.98
Easting: 377209.59
Ground Elevation: 637.39
Pipe Elevation: 638.14

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10A

Project #: C62720000



Description	Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
Ground Surface					
TOPSOIL (TS) (0.0-0.1 m)					
SILTY SAND (SM) (0.1-4.7 m) Light brown, damp, compact.					
	0.6-0.8	G		1.00	13.2
	1.4-1.5	G		0.50	14.6
At 1.5-1.6 m - some clay.	1.5-1.9	▮	50		
	2.1-2.3	G		2.25	17.8
At 2.4-3.1 m - some clay.					
	2.9-3.1	G		2.75	18.8
At 3.1 m - becomes wet. At 3.3 m - rust staining.	3.1-3.4	▮	50		
	3.7-3.8	G			18.9
	4.4-4.6	G			18.5
	4.6-4.7	▮	50		
End of Borehole					

Comments

Stick-Up 0.75 m

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips (0.0-1.4 m)

Top of Sand at 1.4 m

10/20 Frac Sand

Top of Screen at 1.7 m

SWL 2.17 m bgs Jun. 9/05

3.0 m x 51 mm ID Sch 40 PVC 020 Slot Screen

Solid Stem Borehole (152 mm diameter)

Bottom of Screen/Sand at 4.7 m

File Path/Location: N:\C62720000 | Created by: MANJ/JG | Date Created: Jun. 21/05

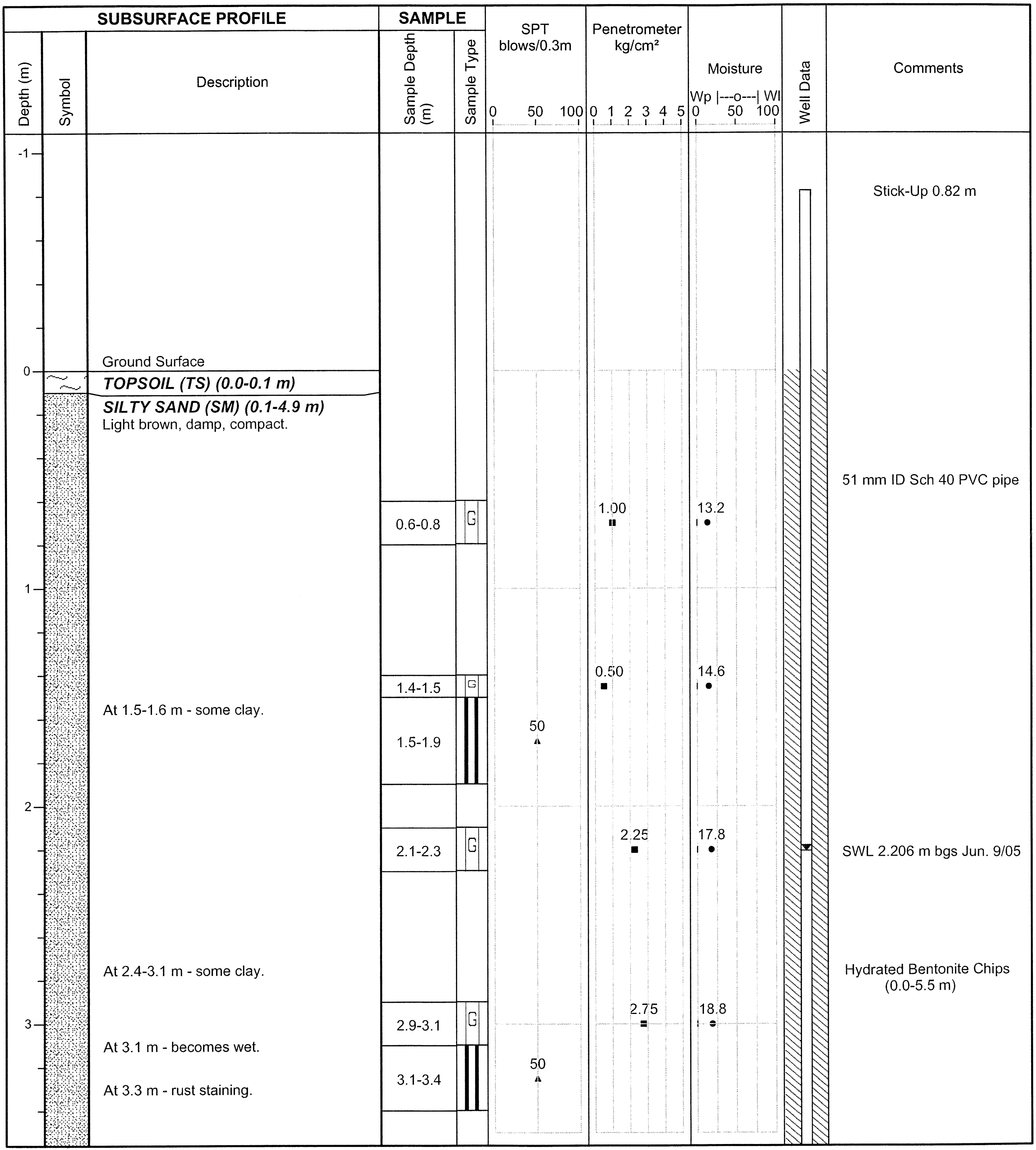
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962092.28
Easting: 377209.55
Ground Elevation: 637.41
Pipe Elevation: 638.23

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10B

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.1 m)

SILTY SAND (SM) (0.1-4.9 m)
Light brown, damp, compact.

At 1.5-1.6 m - some clay.

At 2.4-3.1 m - some clay.

At 3.1 m - becomes wet.

At 3.3 m - rust staining.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.00	13.2
1.4-1.5	G		0.50	14.6
1.5-1.9		50		
2.1-2.3	G		2.25	17.8
2.9-3.1	G		2.75	18.8
3.1-3.4		50		

Stick-Up 0.82 m

51 mm ID Sch 40 PVC pipe

SWL 2.206 m bgs Jun. 9/05

Hydrated Bentonite Chips
(0.0-5.5 m)

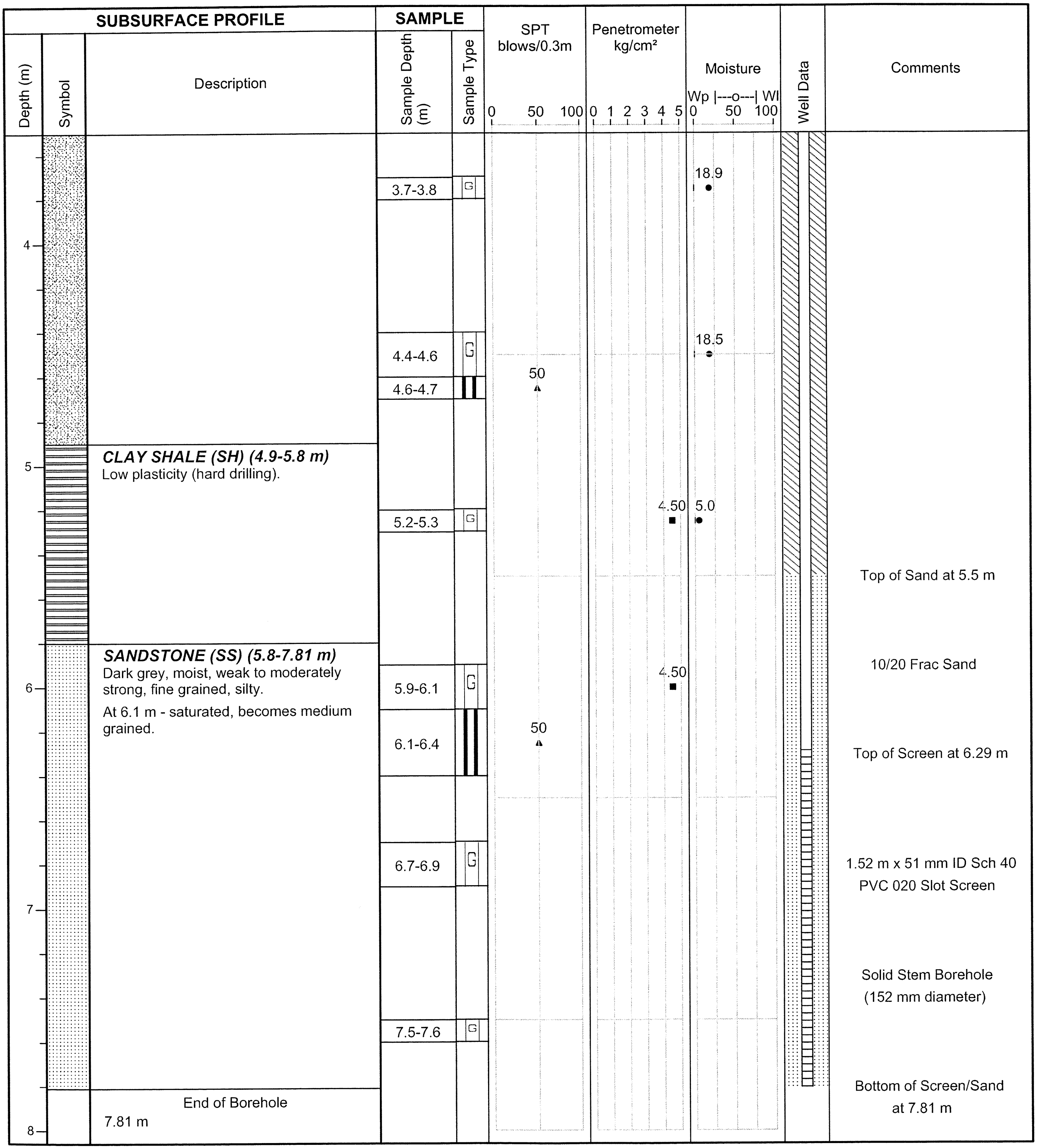
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962092.28
Easting: 377209.55
Ground Elevation: 637.41
Pipe Elevation: 638.23

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10B

Project #: C62720000



CLAY SHALE (SH) (4.9-5.8 m)
Low plasticity (hard drilling).

SANDSTONE (SS) (5.8-7.81 m)
Dark grey, moist, weak to moderately strong, fine grained, silty.
At 6.1 m - saturated, becomes medium grained.

End of Borehole
7.81 m

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
3.7-3.8	G			18.9
4.4-4.6	G			18.5
4.6-4.7		50		
5.2-5.3	G		4.50	5.0
5.9-6.1	G		4.50	
6.1-6.4		50		
6.7-6.9	G			
7.5-7.6	G			

Top of Sand at 5.5 m

10/20 Frac Sand

Top of Screen at 6.29 m

1.52 m x 51 mm ID Sch 40
PVC 020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 7.81 m

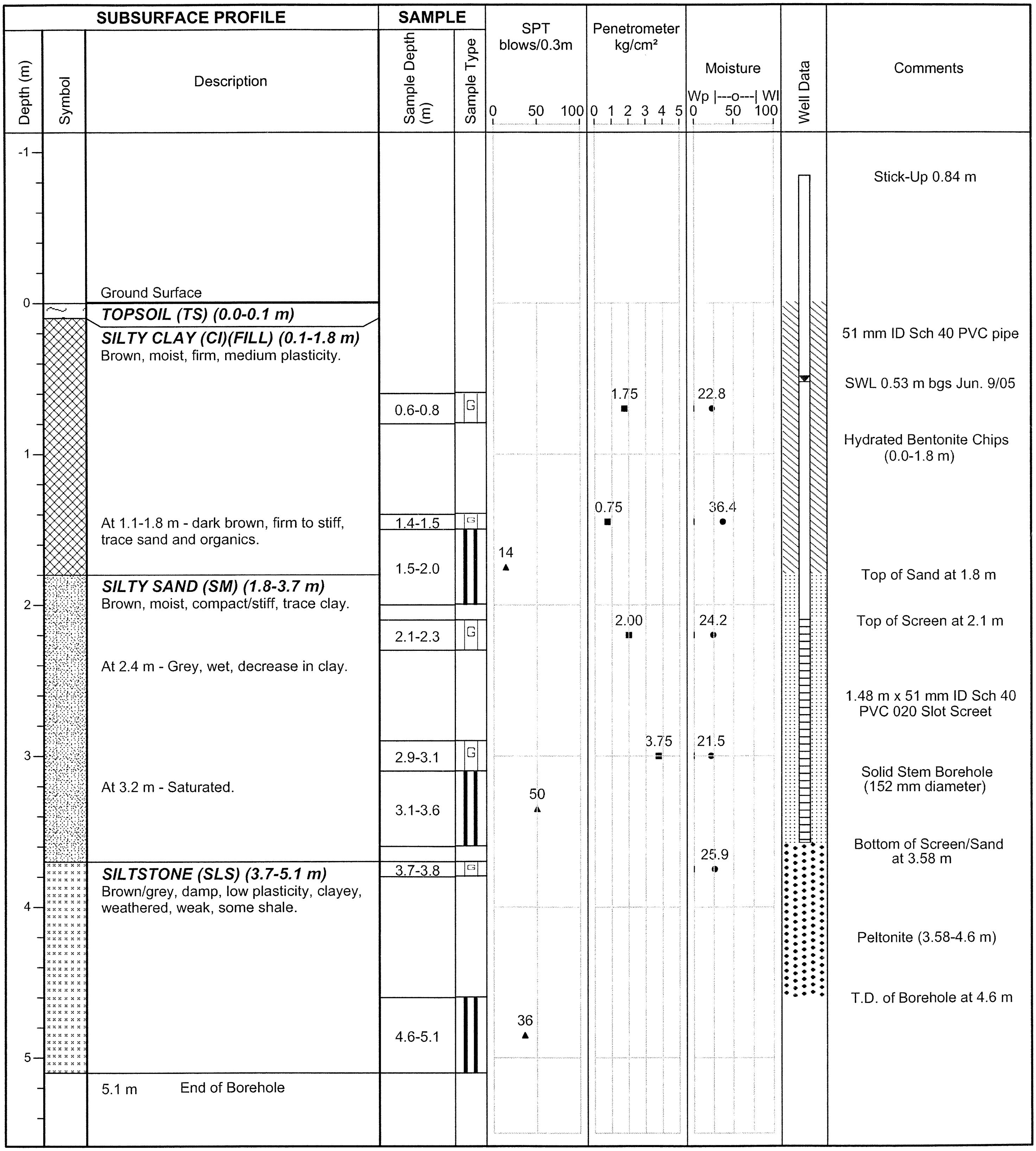
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962416.62
Easting: 377539.35
Ground Elevation: 634.18
Pipe Elevation: 635.02

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-11A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.1 m)

SILTY CLAY (CI)(FILL) (0.1-1.8 m)
Brown, moist, firm, medium plasticity.

At 1.1-1.8 m - dark brown, firm to stiff, trace sand and organics.

SILTY SAND (SM) (1.8-3.7 m)
Brown, moist, compact/stiff, trace clay.

At 2.4 m - Grey, wet, decrease in clay.

At 3.2 m - Saturated.

SILTSTONE (SLS) (3.7-5.1 m)
Brown/grey, damp, low plasticity, clayey, weathered, weak, some shale.

5.1 m End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.75	22.8
1.4-1.5	G		0.75	36.4
1.5-2.0		14		
2.1-2.3	G		2.00	24.2
2.9-3.1	G		3.75	21.5
3.1-3.6		50		
3.7-3.8	G			25.9
4.6-5.1		36		

Comments

Stick-Up 0.84 m

51 mm ID Sch 40 PVC pipe

SWL 0.53 m bgs Jun. 9/05

Hydrated Bentonite Chips (0.0-1.8 m)

Top of Sand at 1.8 m

Top of Screen at 2.1 m

1.48 m x 51 mm ID Sch 40 PVC 020 Slot Screet

Solid Stem Borehole (152 mm diameter)

Bottom of Screen/Sand at 3.58 m

Peltonite (3.58-4.6 m)

T.D. of Borehole at 4.6 m

File Path/Location: N:\C62720000
Created by: MANJ/JG
Date Created: Jun. 21/05

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5961681.18
Easting: 377359.83
Ground Elevation: 641.29
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-12

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
		Ground Surface							
0		***TOPSOIL (TS) (0.0-0.1 m)***							Borehole backfilled with bentonite
		SILTY CLAY (CI) (FILL) (0.1-1.6 m) Brown, moist, stiff to very stiff, medium plasticity, sandy, trace coal fragments and gravel (possibly till).							
			0.6-0.8	G		1.25	26.0		
1		At 0.6-0.7 m - coal fragments throughout.							
			1.4-1.5	G		1.25	22.3		
		SILT (ML) (1.6-3.1 m) Brown, damp, stiff, low plasticity, some clay.	1.5-2.0	█	18				
2			2.1-2.3	G			23.1		
3			2.9-3.1	G			23.2		
		CLAY SHALE (SH) (3.1-5.1 m) Grey, dry to damp, silty.	3.1-3.4	█	50				Bulk sample obtained between 3.1 and 4.6 m
		At 3.2-3.4 m - coal fragments.							
			3.7-3.8	G			15.4		
4									
			4.4-4.6	G			16.3		
5			4.6-5.1	█	51				
		5.1 m End of Borehole							

Project Name: Limited Soil Investigation
Client: CCS Energy Services
Location: 35-55-20 W4M
Drilled by: Clay Drilling Inc.
Drill Date: Dec. 21/05
Compiled by: C. Fedor

Northing:
Easting:
Elevation:

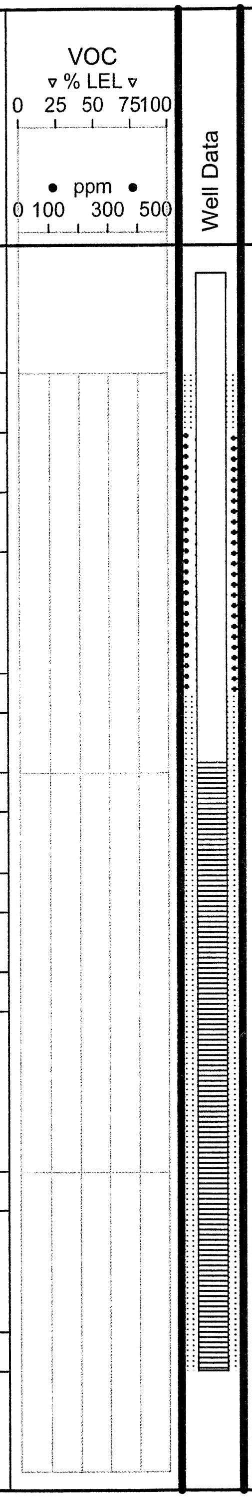
KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole # 05-20

PROJECT # C62720000

SUBSURFACE PROFILE

Depth (m)	Description	Sample Depth (m)	Well Details
			Stick-Up 0.90 m
0	Ground Surface		
	SILTY CLAY (0.0-0.6 m) Some carbonates; frozen; yellow brown.	0.0-0.3 0.3-0.6	Sil 9 Sand (0.00-0.30 m)
	CLAY TILL (0.6-4.9 m) Firm; trace coarse fragments; trace sand; moist; dark yellow brown.	0.6-1.0	Hydrated Bentonite Pellets (0.30-1.61 m) 51 mm ID Sch 40 PVC pipe
1			
	At 1.5-2.5 m: Yellow brown.	1.5	Top of Sand at 1.61m Sil 9 Sand
2		2.0	Top of Screen at 1.95 m
	At 2.5-3.2 m: Firm; trace coarse fragments; abundant mottles; moist; dark brown.	2.5	3.05 x 51 mm ID Sch 40 PVC 020 Slot Screen
3		3.0	Solid Stem Borehole (152 mm diameter)
	At 3.2-5.0 m: Trace coarse fragments; trace gravels; moist; trace fine-grained sand lenses; moist; dark yellow brown.		
4		4.0	
			Botton of Screen at 5.00 m
5	*SILTSTONE BEDROCK (4.9-5.0 m)* Moist; grey.	5.0	TD of Borehole 5.00 m
	End of Borehole		



Project Name: Limited Soil Investigation
Client: CCS Energy Services
Location: 35-55-20 W4M
Drilled by: Clay Drilling Inc.
Drill Date: Dec. 21/05
Compiled by: C. Fedor

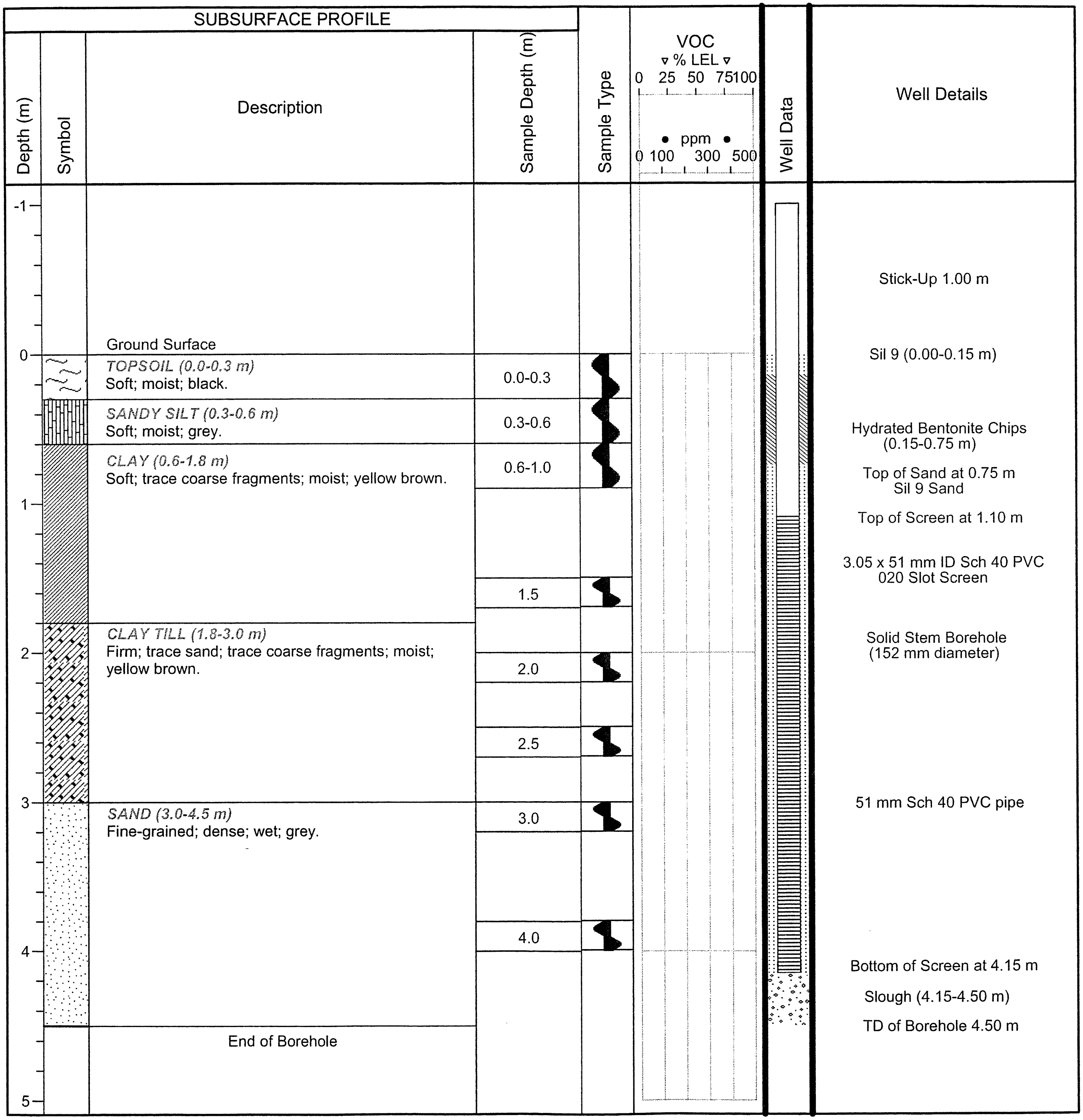
Northing:
Easting:
Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole # 05-28

PROJECT # C62720000

SUBSURFACE PROFILE



Description	Sample Depth (m)
Ground Surface	
TOPSOIL (0.0-0.3 m) Soft; moist; black.	0.0-0.3
SANDY SILT (0.3-0.6 m) Soft; moist; grey.	0.3-0.6
CLAY (0.6-1.8 m) Soft; trace coarse fragments; moist; yellow brown.	0.6-1.0
	1.5
CLAY TILL (1.8-3.0 m) Firm; trace sand; trace coarse fragments; moist; yellow brown.	2.0
	2.5
SAND (3.0-4.5 m) Fine-grained; dense; wet; grey.	3.0
	4.0
End of Borehole	

Well Details

Stick-Up 1.00 m
Sil 9 (0.00-0.15 m)
Hydrated Bentonite Chips (0.15-0.75 m)
Top of Sand at 0.75 m Sil 9 Sand
Top of Screen at 1.10 m
3.05 x 51 mm ID Sch 40 PVC 020 Slot Screen
Solid Stem Borehole (152 mm diameter)
51 mm Sch 40 PVC pipe
Bottom of Screen at 4.15 m
Slough (4.15-4.50 m)
TD of Borehole 4.50 m

File Path/Location: N:\62720000
Created by: LC
Date Created: Jan. 10/05

WorleyParsons Komex
resources & energy

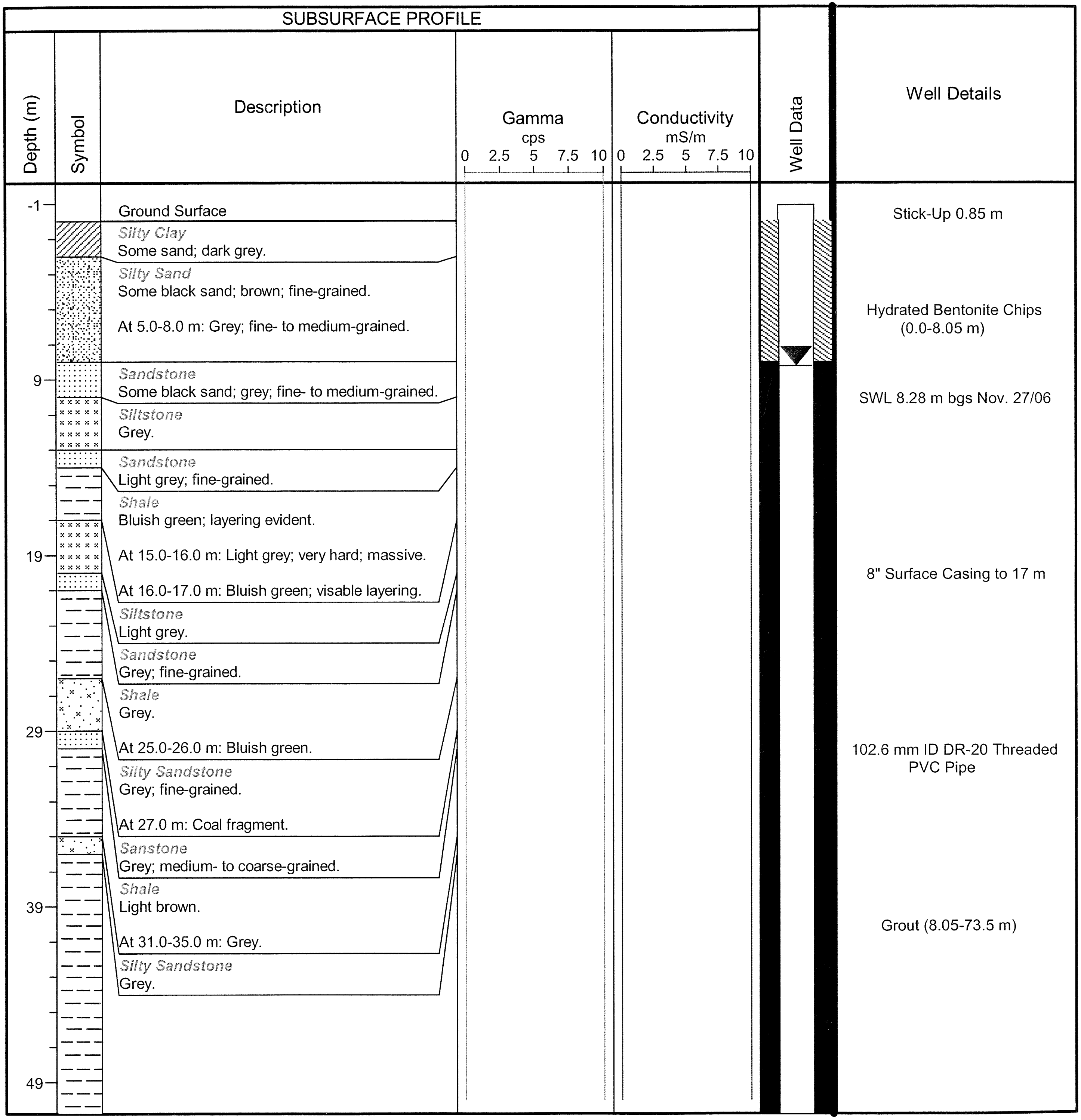
Borehole # PW06-01

PROJECT # C62720105

Project Name: Proposed CCS Sulphur Facility
Client: Hazco Environmental Services Ltd.
Location: SW-35-55-20 W4M
Drilled by: Beck Drilling and Env. Services Ltd.
Drill Date: Nov.14/06
Compiled by: B. Abel

Northing: 5962155.6
Easting: 377123.7
Elevation: 0

SUBSURFACE PROFILE



Ground Surface

Silty Clay
Some sand; dark grey.

Silty Sand
Some black sand; brown; fine-grained.
At 5.0-8.0 m: Grey; fine- to medium-grained.

Sandstone
Some black sand; grey; fine- to medium-grained.

Siltstone
Grey.

Sandstone
Light grey; fine-grained.

Shale
Bluish green; layering evident.
At 15.0-16.0 m: Light grey; very hard; massive.
At 16.0-17.0 m: Bluish green; visable layering.

Siltstone
Light grey.

Sandstone
Grey; fine-grained.

Shale
Grey.
At 25.0-26.0 m: Bluish green.

Silty Sandstone
Grey; fine-grained.
At 27.0 m: Coal fragment.

Sanstone
Grey; medium- to coarse-grained.

Shale
Light brown.
At 31.0-35.0 m: Grey.

Silty Sandstone
Grey.

Stick-Up 0.85 m

Hydrated Bentonite Chips (0.0-8.05 m)

SWL 8.28 m bgs Nov. 27/06

8" Surface Casing to 17 m

102.6 mm ID DR-20 Threaded PVC Pipe

Grout (8.05-73.5 m)

WPK-Piezo-50m-Geophys

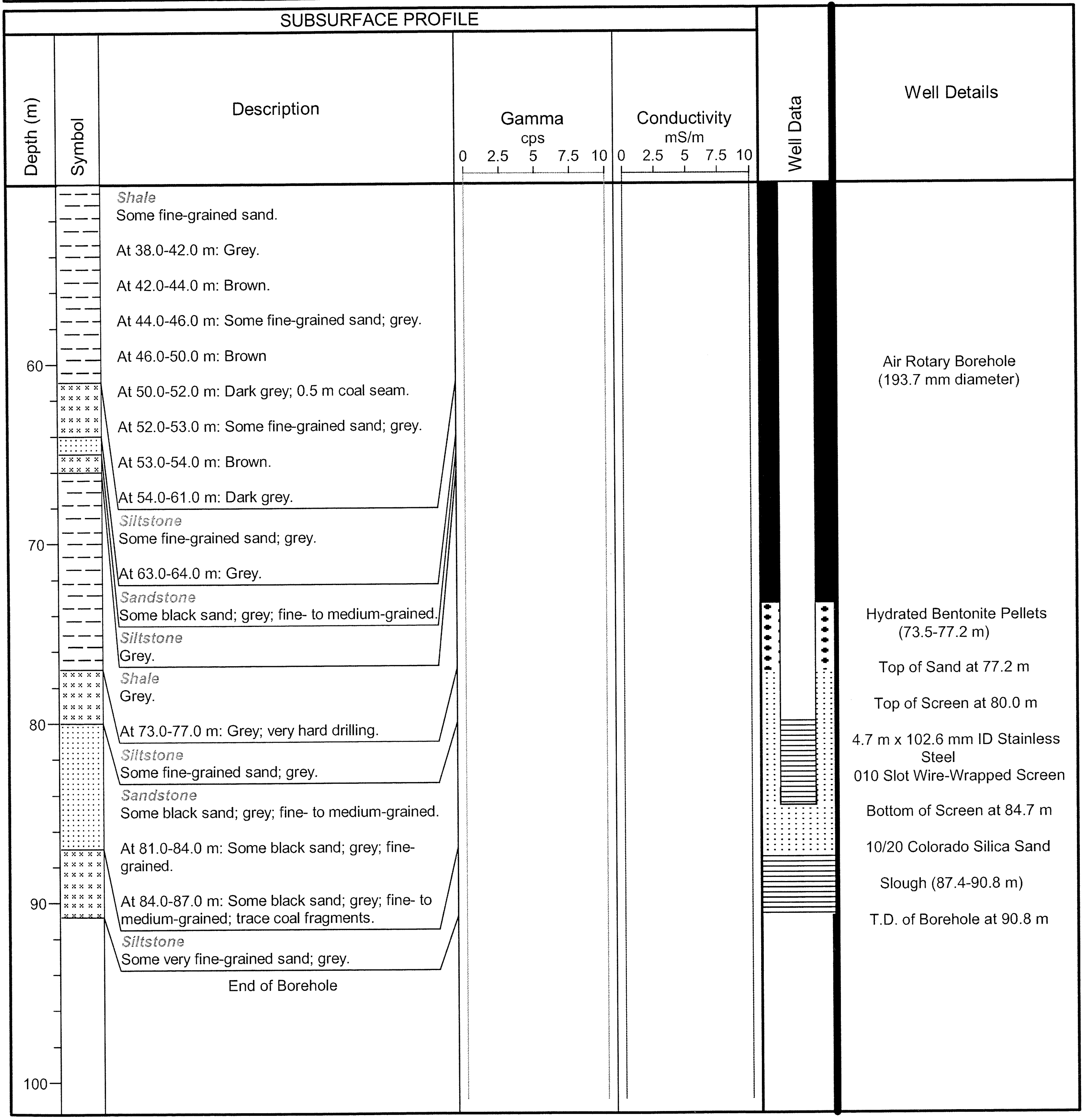
WorleyParsons Komex
resources & energy

Borehole # PW06-01

PROJECT # C62720105

Project Name: Proposed CCS Sulphur Facility
Client: Hazco Environmental Services Ltd.
Location: SW-35-55-20 W4M
Drilled by: Beck Drilling and Env. Services Ltd.
Drill Date: Nov.14/06
Compiled by: B. Abel

Northing: 5962155.6
Easting: 377123.7
Elevation: 0



Shale
Some fine-grained sand.
At 38.0-42.0 m: Grey.
At 42.0-44.0 m: Brown.
At 44.0-46.0 m: Some fine-grained sand; grey.
At 46.0-50.0 m: Brown
At 50.0-52.0 m: Dark grey; 0.5 m coal seam.
At 52.0-53.0 m: Some fine-grained sand; grey.
At 53.0-54.0 m: Brown.
At 54.0-61.0 m: Dark grey.

Siltstone
Some fine-grained sand; grey.
At 63.0-64.0 m: Grey.

Sandstone
Some black sand; grey; fine- to medium-grained.

Siltstone
Grey.

Shale
Grey.
At 73.0-77.0 m: Grey; very hard drilling.

Siltstone
Some fine-grained sand; grey.

Sandstone
Some black sand; grey; fine- to medium-grained.
At 81.0-84.0 m: Some black sand; grey; fine-grained.
At 84.0-87.0 m: Some black sand; grey; fine- to medium-grained; trace coal fragments.

Siltstone
Some very fine-grained sand; grey.

End of Borehole

Air Rotary Borehole
(193.7 mm diameter)

Hydrated Bentonite Pellets
(73.5-77.2 m)

Top of Sand at 77.2 m

Top of Screen at 80.0 m

4.7 m x 102.6 mm ID Stainless Steel
010 Slot Wire-Wrapped Screen

Bottom of Screen at 84.7 m

10/20 Colorado Silica Sand

Slough (87.4-90.8 m)

T.D. of Borehole at 90.8 m

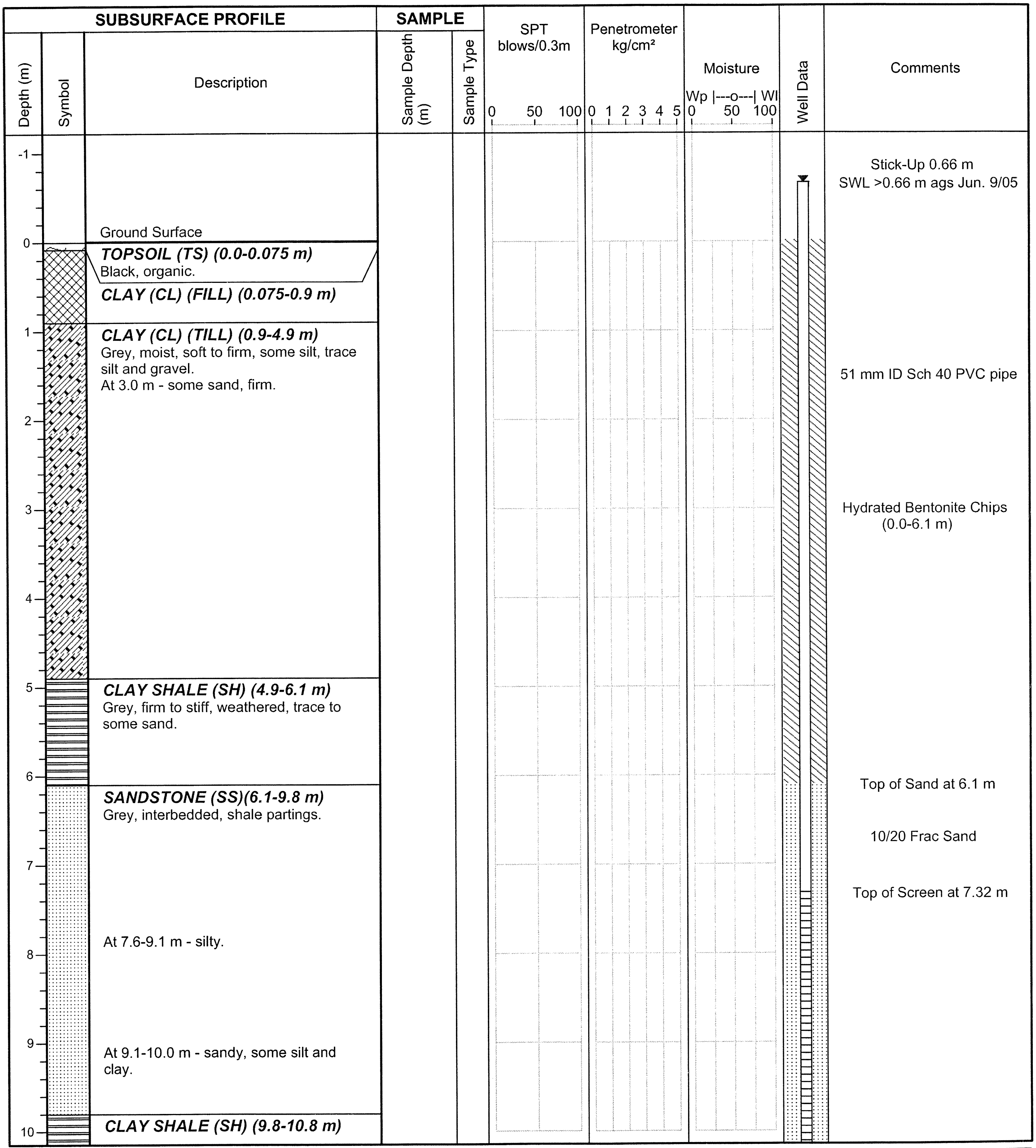
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27, 2005
Compiled By: A. Mullick

Northing: 5962507.25
Easting: 377154.95
Ground Elevation: 632.83
Pipe Elevation: 633.49

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01B

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.075 m)
Black, organic.

CLAY (CL) (FILL) (0.075-0.9 m)

CLAY (CL) (TILL) (0.9-4.9 m)
Grey, moist, soft to firm, some silt, trace silt and gravel.
At 3.0 m - some sand, firm.

CLAY SHALE (SH) (4.9-6.1 m)
Grey, firm to stiff, weathered, trace to some sand.

SANDSTONE (SS)(6.1-9.8 m)
Grey, interbedded, shale partings.

At 7.6-9.1 m - silty.

At 9.1-10.0 m - sandy, some silt and clay.

CLAY SHALE (SH) (9.8-10.8 m)

Comments:

Stick-Up 0.66 m
SWL >0.66 m ags Jun. 9/05

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips
(0.0-6.1 m)

Top of Sand at 6.1 m

10/20 Frac Sand

Top of Screen at 7.32 m

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27, 2005
Compiled By: A. Mullick

Northing: 5962507.25
Easting: 377154.95
Ground Elevation: 632.83
Pipe Elevation: 633.49

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01B

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
									9.14 m x 51 mm ID Sch 40 PVC 020 Slot Screen
11		***SANDSTONE (SS)(10.8-14.9 m)*** Grey, interbedded clay shale & siltstone.							Mud Rotary Borehole (127 mm diameter)
15		***CLAY SHALE (SH) (14.9-16.46 m)***							
		16.46 m End of Borehole NOTES: No samples collected.							Bottom of Screen/Sand at 16.46 m

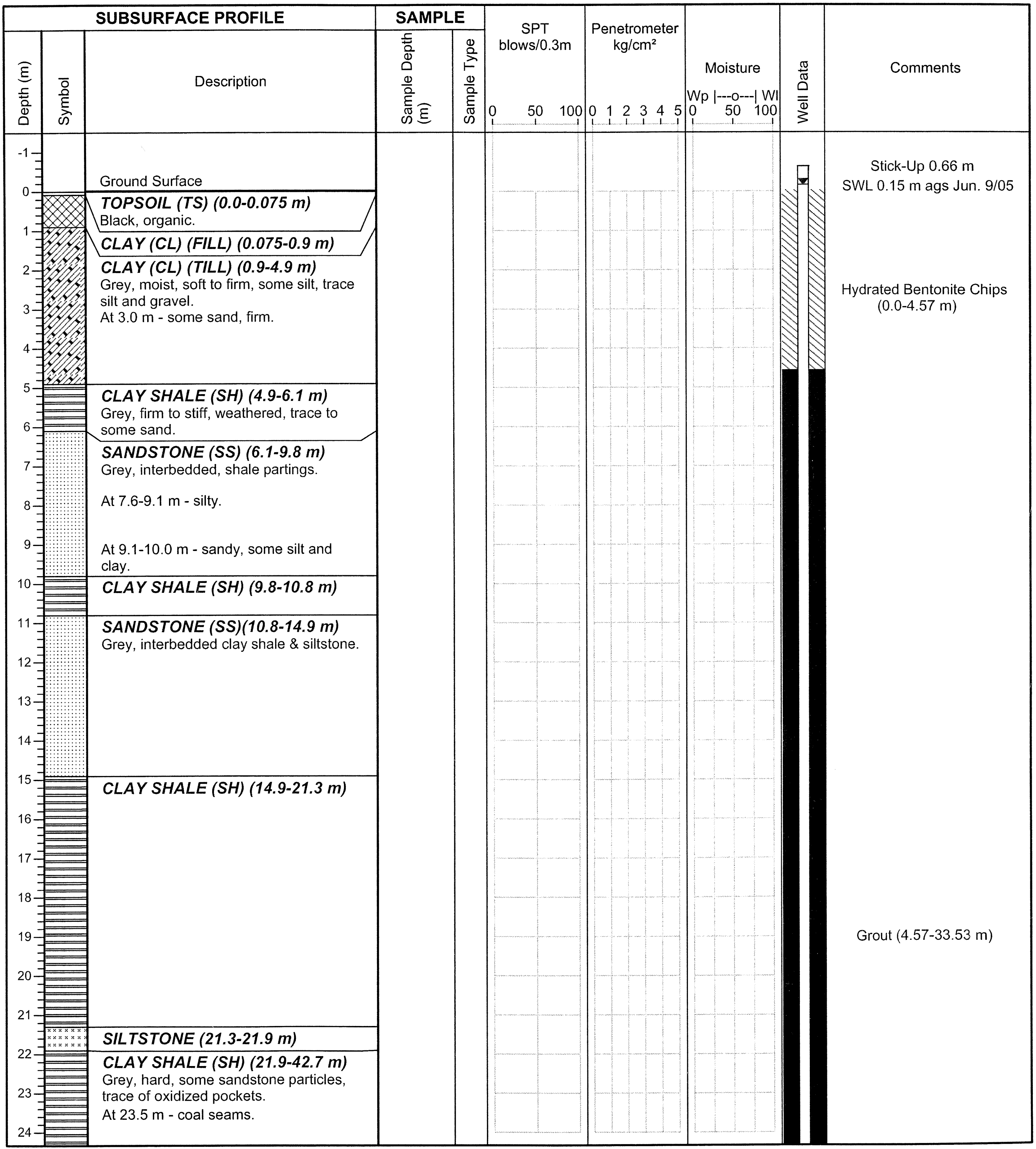
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 26, 2005
Compiled By: A. Mullick

Northing: 5962507.44
Easting: 377156.89
Ground Elevation: 632.84
Pipe Elevation: 633.50

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01C

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.075 m)
Black, organic.

CLAY (CL) (FILL) (0.075-0.9 m)

CLAY (CL) (TILL) (0.9-4.9 m)
Grey, moist, soft to firm, some silt, trace silt and gravel.
At 3.0 m - some sand, firm.

CLAY SHALE (SH) (4.9-6.1 m)
Grey, firm to stiff, weathered, trace to some sand.

SANDSTONE (SS) (6.1-9.8 m)
Grey, interbedded, shale partings.

At 7.6-9.1 m - silty.

At 9.1-10.0 m - sandy, some silt and clay.

CLAY SHALE (SH) (9.8-10.8 m)

SANDSTONE (SS)(10.8-14.9 m)
Grey, interbedded clay shale & siltstone.

CLAY SHALE (SH) (14.9-21.3 m)

SILTSTONE (21.3-21.9 m)

CLAY SHALE (SH) (21.9-42.7 m)
Grey, hard, some sandstone particles, trace of oxidized pockets.
At 23.5 m - coal seams.

Stick-Up 0.66 m
SWL 0.15 m ags Jun. 9/05

Hydrated Bentonite Chips (0.0-4.57 m)

Grout (4.57-33.53 m)

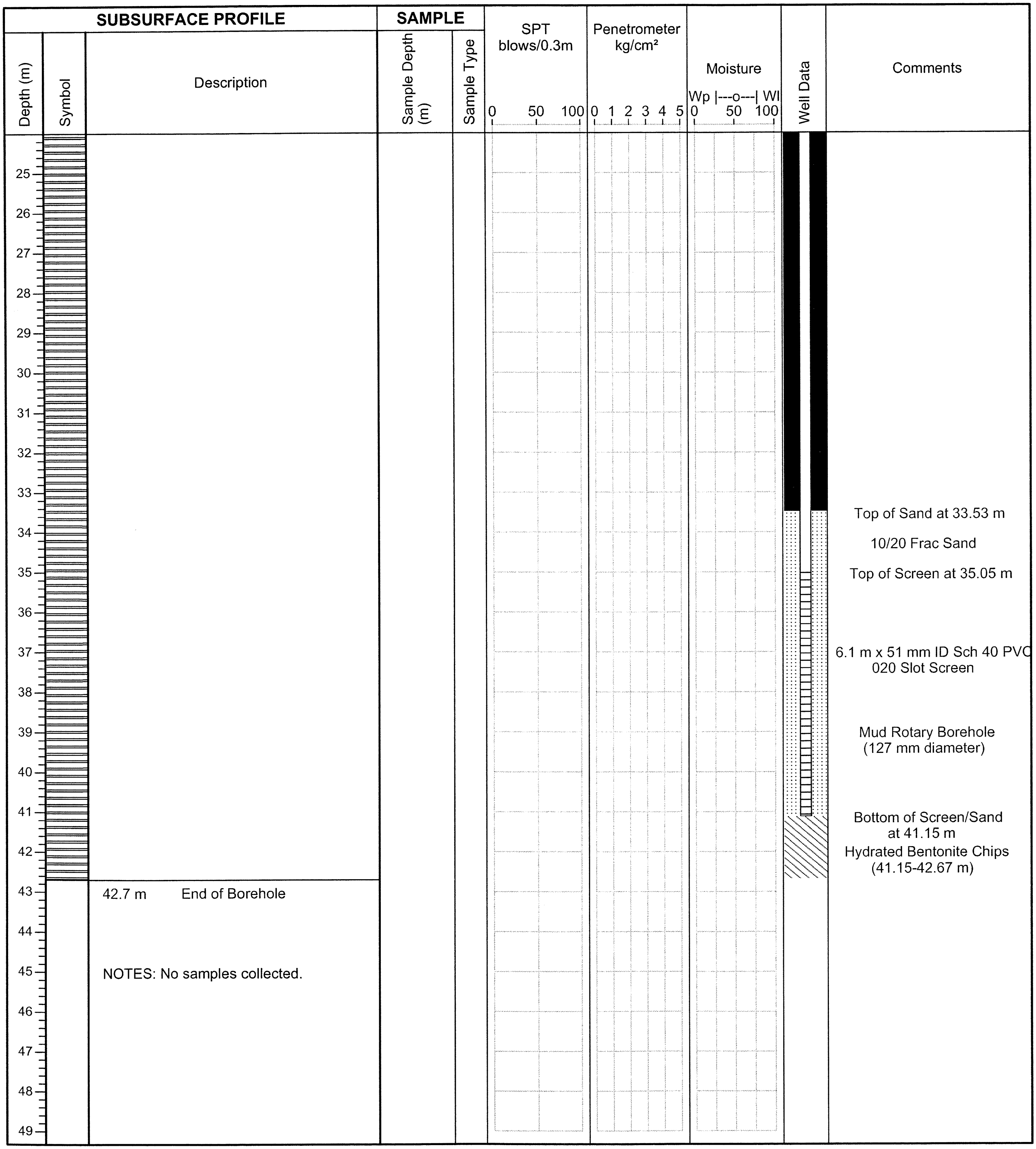
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 26, 2005
Compiled By: A. Mullick

Northing: 5962507.44
Easting: 377156.89
Ground Elevation: 632.84
Pipe Elevation: 633.50

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-01C

Project #: C62720000



42.7 m End of Borehole

NOTES: No samples collected.

Top of Sand at 33.53 m

10/20 Frac Sand

Top of Screen at 35.05 m

6.1 m x 51 mm ID Sch 40 PVC
020 Slot Screen

Mud Rotary Borehole
(127 mm diameter)

Bottom of Screen/Sand
at 41.15 m
Hydrated Bentonite Chips
(41.15-42.67 m)

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick

Northing: 5962461.67
Easting: 377000.16
Ground Elevation: 635.86
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-02

Project #: C62720000

SUBSURFACE PROFILE

Ground Surface

TOPSOIL (TS) (0.0-2.3 m)
Black and dark brown, organic, trace of sand, silt and clay.
At 1.4-1.5 m - clay pockets.
At 1.5-1.8 m - sandy.

CLAY (CH) (2.3-2.9 m)
Brown and grey, moist, firm, laminated, high plastic, trace silt and sand.

CLAY (CI) (TILL) (2.9-4.3 m)
Moist, stiff, low to medium plastic, trace coal specks, silt, sand and gravel.
At 3.8-4.3 m - grey, moist, rust pockets throughout.

CLAY SHALE (SH) (4.3-7.0 m)
Grey-blue, damp, weak, weathered.
At 5.3-7.0 m - weak to moderately strong.

SANDSTONE (SS) (7.0-7.2 m)
Grey, wet, some siltstone and shale.

CLAY SHALE (SH) (7.2-7.4 m)
Some sandstone, trace siltstone.

SANDSTONE (SS) (7.4-15.2 m)
Very moist, interbedded layers of clay shale.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.50	11.4
1.4-1.5	G		1.25	11.7
1.5-2.0		6		
2.1-2.3	G		1.00	15.2
				29.1
2.9-3.1	G		1.50	
3.1-3.6		13		
3.7-3.8	G		3.75	24.5
4.4-4.6	G		3.50	
4.6-5.1		38		
5.2-5.3	G		4.50	20.6
5.9-6.1	G		4.50	
6.1-6.6		45		
6.7-6.9	G		4.50	21.8
7.5-7.6	G		4.50	24.8
7.6-8.1		50		

Moisture: Wp |---o---| Wl

Comments

Surface Cuttings (0.0-0.8 m)

Borehole backfilled with bentonite chips.

Organic content is 6.8% between 0.6 and 0.8 m.

Organic content is 5.8% between 1.4 and 1.5 m.

Penetrometer reading should show - ">4.5" for samples 5.2-5.3 m, 5.9-6.1 m, 6.7-6.9 m, 7.5-7.6 m

50 blows for 50 mm penetration

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick

Northing: 5962461.67
Easting: 377000.16
Ground Elevation: 635.86
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-02

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m	Penetrometer kg/cm²	Moisture	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	0 50 100	0 1 2 3 4 5	Wp |---o---| Wl 0 50 100		
				‖					
9			9.1-9.6	‖	50				50 blows for 75 mm penetration
10			9.8-9.9	G					
		At 10.5 m - coal fissures.	10.5-10.7	G					
11			11.3-11.4	G					
12			12.0-12.2	G					
13			12.8-13.0	G					
14			13.6-13.7	G					
15			15.1-15.2	G					
16		15.2 m End of Borehole							

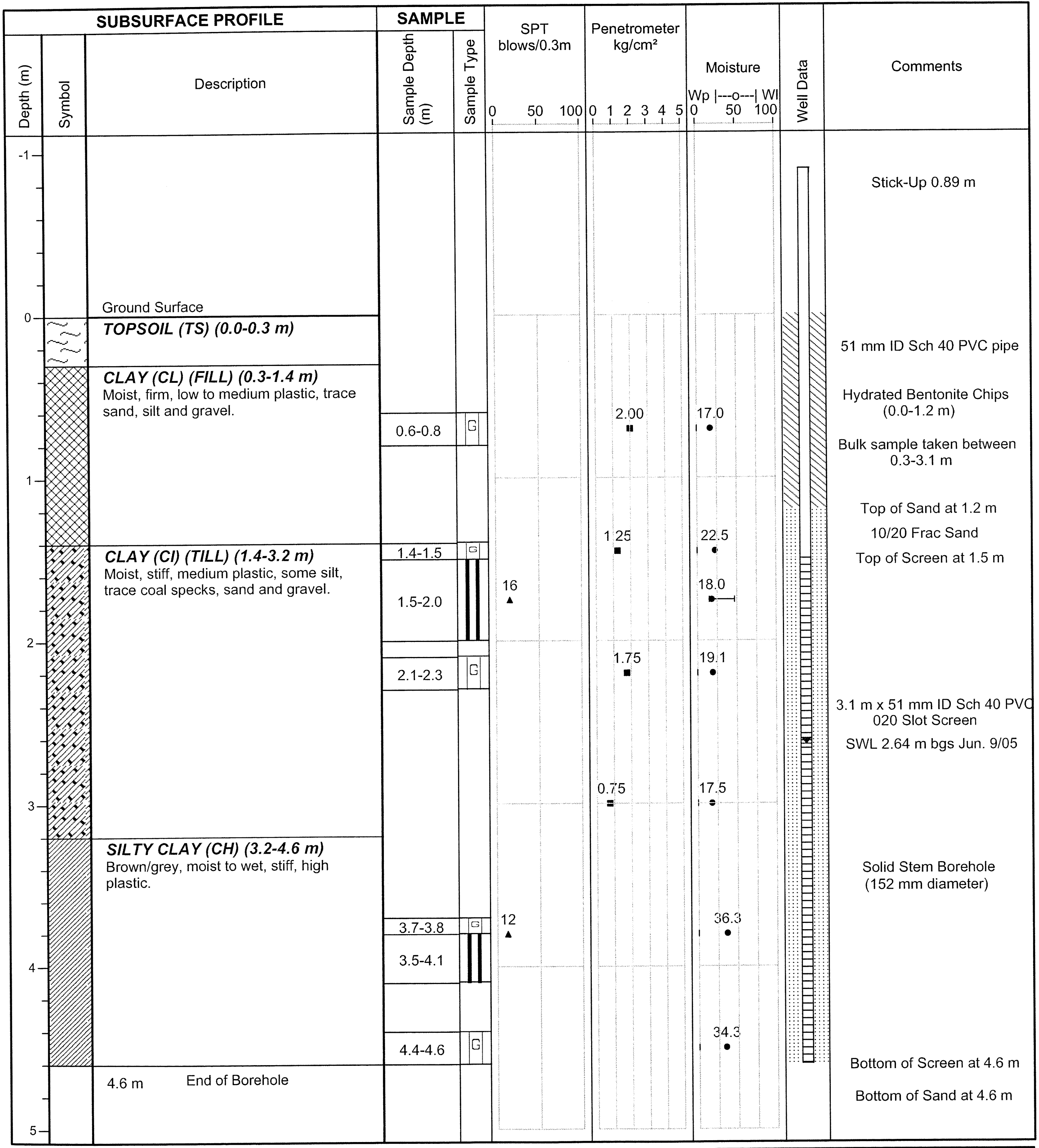
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Mullick

Northing: 5962105.61
Easting: 377518.50
Ground Elevation: 636.61
Pipe Elevation: 637.50

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.3 m)

CLAY (CL) (FILL) (0.3-1.4 m)
Moist, firm, low to medium plastic, trace sand, silt and gravel.

CLAY (CI) (TILL) (1.4-3.2 m)
Moist, stiff, medium plastic, some silt, trace coal specks, sand and gravel.

SILTY CLAY (CH) (3.2-4.6 m)
Brown/grey, moist to wet, stiff, high plastic.

4.6 m End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		2.00	17.0
1.4-1.5	G		1.25	22.5
1.5-2.0		16		18.0
2.1-2.3	G		1.75	19.1
			0.75	17.5
3.7-3.8	G	12		36.3
3.5-4.1				
4.4-4.6	G			34.3

Comments:
Stick-Up 0.89 m
51 mm ID Sch 40 PVC pipe
Hydrated Bentonite Chips (0.0-1.2 m)
Bulk sample taken between 0.3-3.1 m
Top of Sand at 1.2 m
10/20 Frac Sand
Top of Screen at 1.5 m
3.1 m x 51 mm ID Sch 40 PVC 020 Slot Screen
SWL 2.64 m bgs Jun. 9/05
Solid Stem Borehole (152 mm diameter)
Bottom of Screen at 4.6 m
Bottom of Sand at 4.6 m

File Path/Location: Created by: Date Created:

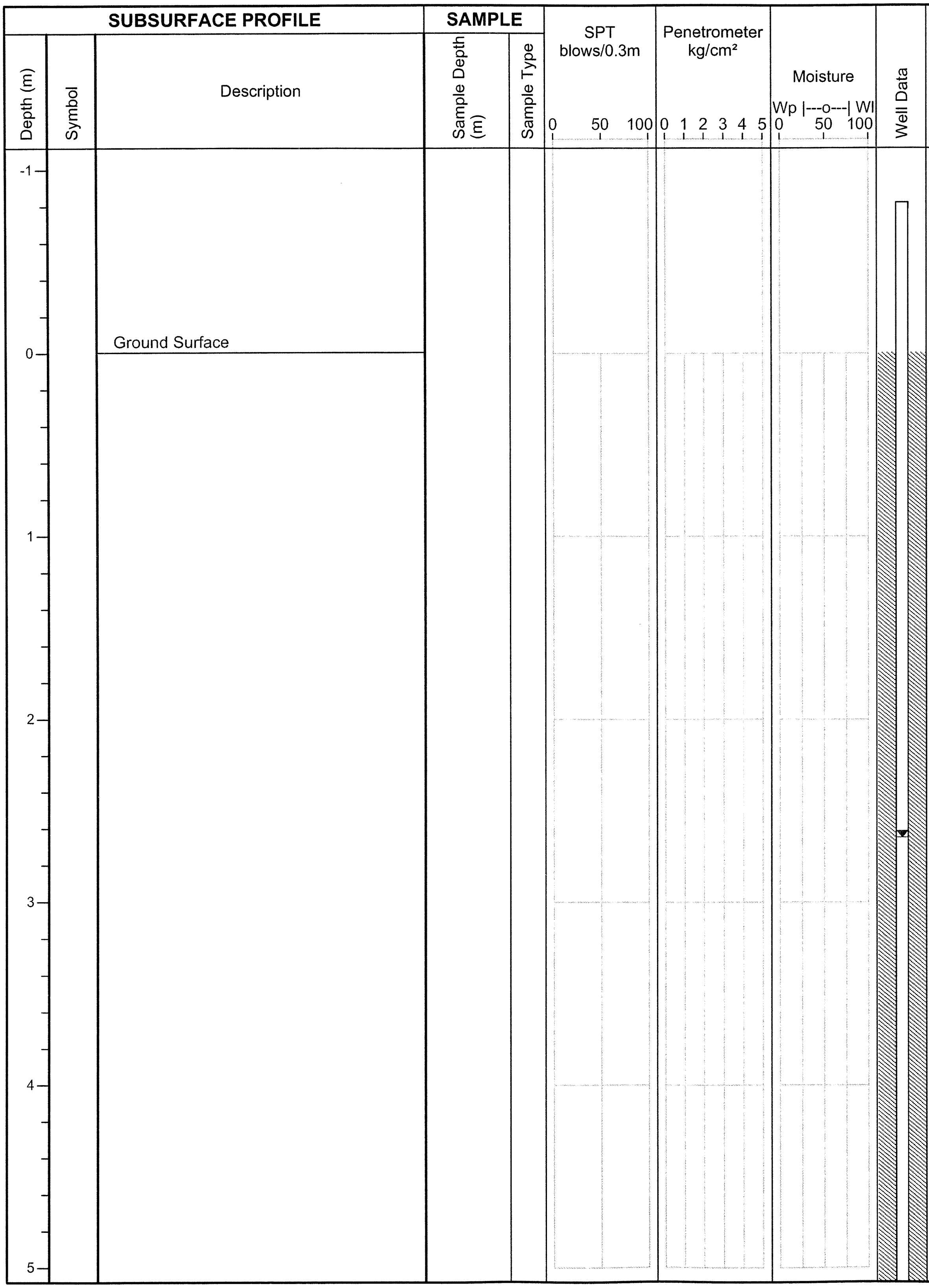
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962105.03
Easting: 377520.48
Ground Elevation: 636.69
Pipe Elevation: 637.51

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BI

Project #: C62720000



Comments

Stick-Up 0.82 m

51 mm ID Sch 40 PVC pipe

Bulk sample taken between 0.3-3.1 m

SWL 2.65 m bgs Jun. 9/05

Hydrated Bentonite Chips (0.0-6.1 m)

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962105.03
Easting: 377520.48
Ground Elevation: 636.69
Pipe Elevation: 637.51

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BI

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
								▨	
6	▤	***CLAY SHALE (SH) (5.8-7.04 m)*** Grey, moist, silty, trace to some sand.						▨	Top of Sand/Screen at 6.28 m 10/20 Frac Sand 0.76 m x 51 mm ID Sch 40 PVC 020 Slot Screen Solid Stem Borehole (152 mm diameter) No grab sample taken, pocket pen only Bottom of Sand/Screen at 7.04 m
7		End of Borehole							
8									
9									
10									
11									

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick/A. Tangedal

Northing: 5962103.80
Easting: 377519.14
Ground Elevation: 636.73
Pipe Elevation: 637.56

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BII
Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	0 50 100	0 1 2 3 4 5	0 50 100		
-1									Stick-Up 0.83 m
0		Ground Surface							
		TOPSOIL (TS) (0.0-0.3 m)							
		CLAY (CL) (FILL) (0.3-1.4 m) Moist, firm, low to medium plastic, trace sand, silt and gravel.	0.6-0.8	G		2.00	17.0		51 mm ID Sch 40 PVC pipe
1		At 1.2-1.5 m - silty, sand seams throughout.							
		CLAY (CI) (TILL) (1.4-3.2 m) Moist, stiff, medium plastic, some silt, trace coal specks, sand and gravel.	1.4-1.5	G		1.25	22.5		Bulk sample taken between 0.3-3.1 m
			1.5-2.0	▮	16		18.0		
2			2.1-2.3	G		1.75	19.1		Hydrated Bentonite Chips (0.0-5.5 m)
		At 2.7-3.1 m - wet sandy pockets, very moist.						▼	SWL 2.7 m bgs Jun. 9/05
3						0.75	17.5		
		SILTY CLAY (CH) (3.2-4.7 m) Brown/grey, moist to wet, stiff, high plastic. At 3.5-4.7 m - grey, wet, moderately dilatent.	3.7-3.8	G	12		36.3		
4			3.5-4.1	▮					
			4.4-4.6	G			34.3		
5		***SAND/GRAVEL (GM) (4.7-5.0 m)*** Black, wet, trace clay and silt.	4.6-5.1	▮	18				

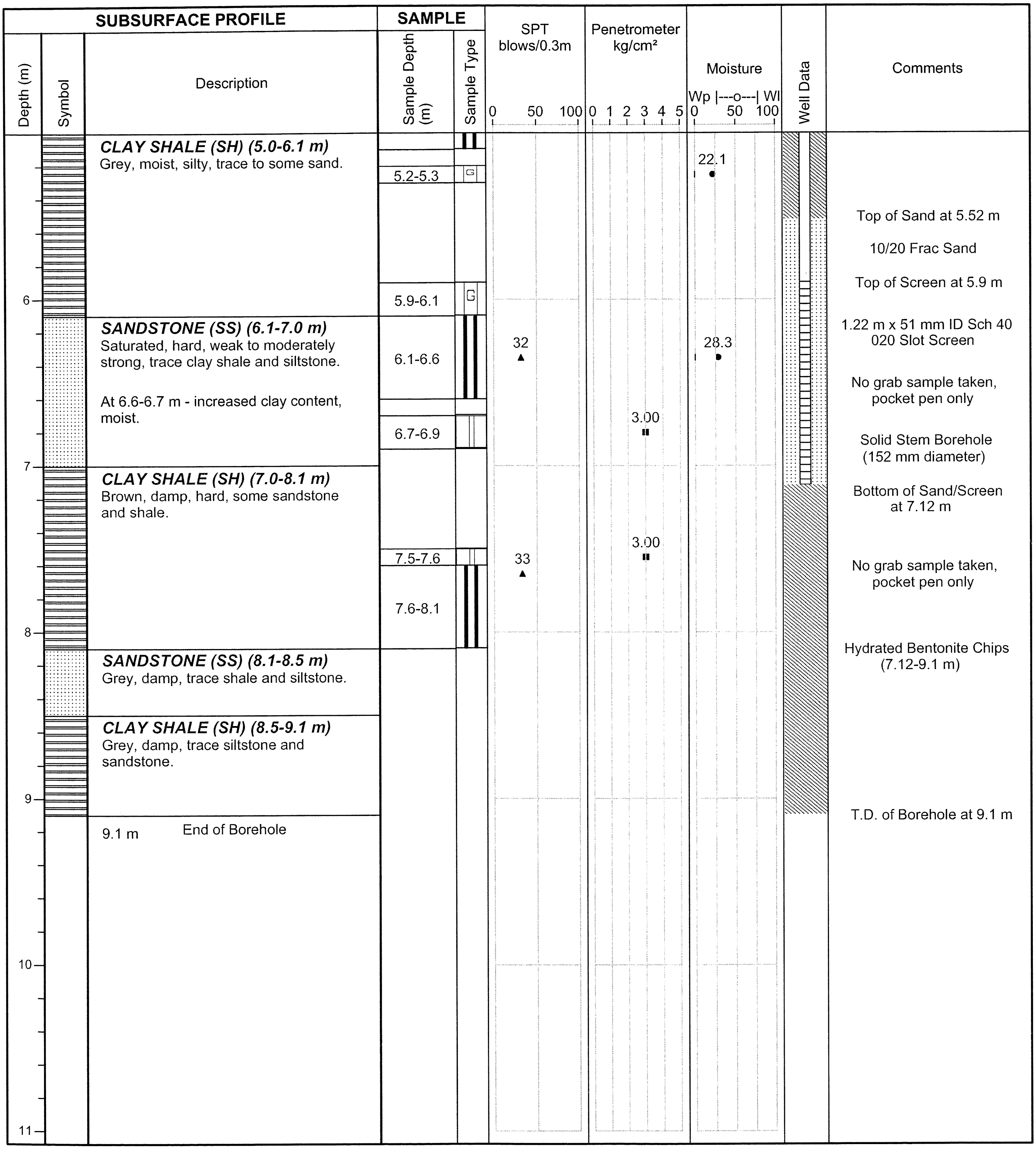
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 27/05
Compiled By: A. Mullick/A. Tangedal

Northing: 5962103.80
Easting: 377519.14
Ground Elevation: 636.73
Pipe Elevation: 637.56

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-03BII

Project #: C62720000



Description	Sample Depth (m)	SPT blows/0.3m	Penetrometer kg/cm²	Moisture	Comments
CLAY SHALE (SH) (5.0-6.1 m) Grey, moist, silty, trace to some sand.	5.2-5.3 5.9-6.1			22.1	Top of Sand at 5.52 m 10/20 Frac Sand Top of Screen at 5.9 m
SANDSTONE (SS) (6.1-7.0 m) Saturated, hard, weak to moderately strong, trace clay shale and siltstone. At 6.6-6.7 m - increased clay content, moist.	6.1-6.6 6.7-6.9	32	3.00	28.3	1.22 m x 51 mm ID Sch 40 020 Slot Screen No grab sample taken, pocket pen only Solid Stem Borehole (152 mm diameter)
CLAY SHALE (SH) (7.0-8.1 m) Brown, damp, hard, some sandstone and shale.	7.5-7.6 7.6-8.1	33	3.00		Bottom of Sand/Screen at 7.12 m No grab sample taken, pocket pen only
SANDSTONE (SS) (8.1-8.5 m) Grey, damp, trace shale and siltstone.					Hydrated Bentonite Chips (7.12-9.1 m)
CLAY SHALE (SH) (8.5-9.1 m) Grey, damp, trace siltstone and sandstone.					
9.1 m End of Borehole					T.D. of Borehole at 9.1 m

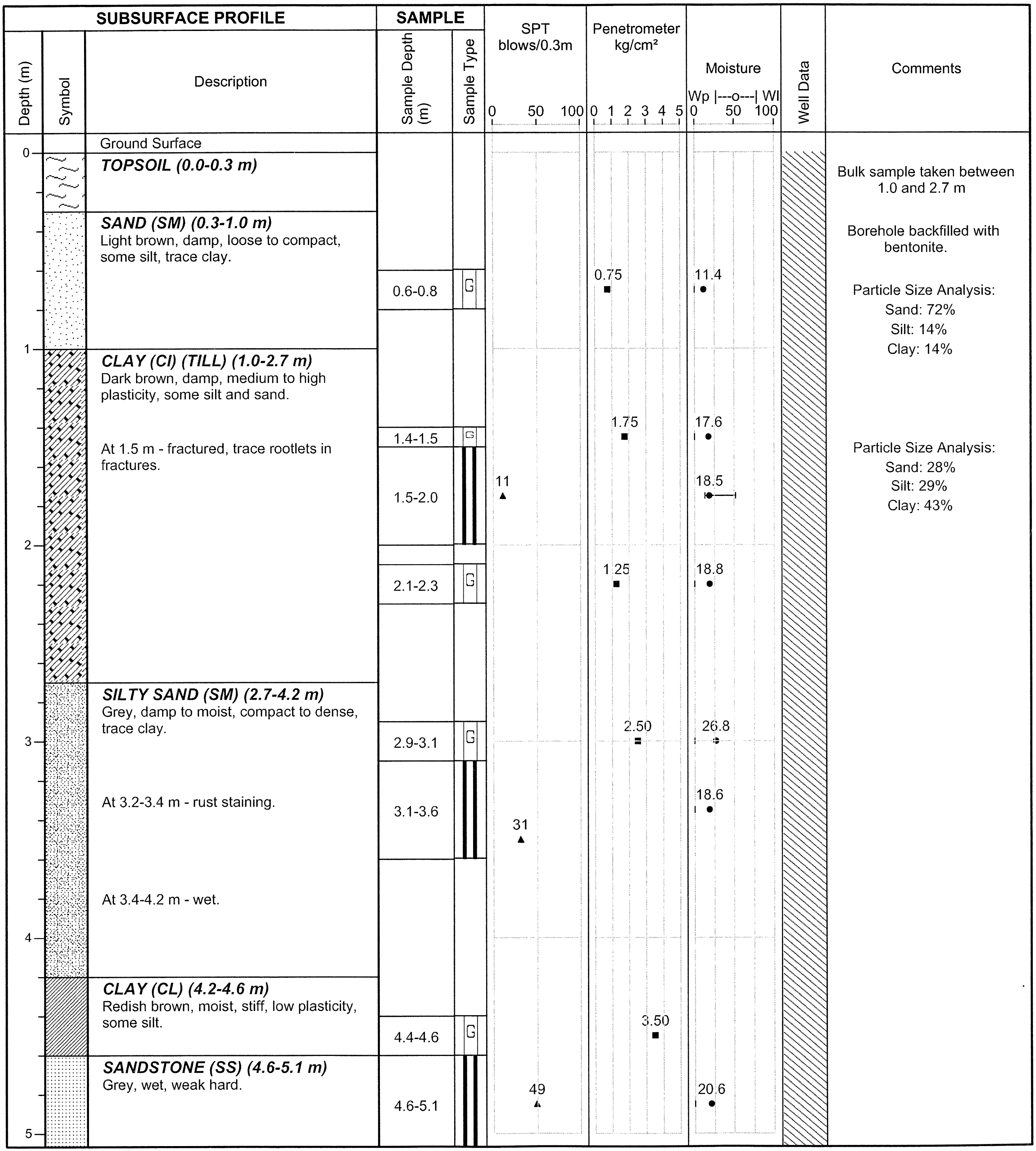
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962375.68
Easting: 376825.02
Ground Elevation:
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-04

Project #: C62720000



Description	Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture	Comments
Ground Surface						
TOPSOIL (0.0-0.3 m)						Bulk sample taken between 1.0 and 2.7 m Borehole backfilled with bentonite.
SAND (SM) (0.3-1.0 m) Light brown, damp, loose to compact, some silt, trace clay.	0.6-0.8	G		0.75	11.4	Particle Size Analysis: Sand: 72% Silt: 14% Clay: 14%
CLAY (CI) (TILL) (1.0-2.7 m) Dark brown, damp, medium to high plasticity, some silt and sand.	1.4-1.5	G		1.75	17.6	Particle Size Analysis: Sand: 28% Silt: 29% Clay: 43%
At 1.5 m - fractured, trace rootlets in fractures.	1.5-2.0		11		18.5	
	2.1-2.3	G		1.25	18.8	
SILTY SAND (SM) (2.7-4.2 m) Grey, damp to moist, compact to dense, trace clay.	2.9-3.1	G		2.50	26.8	
At 3.2-3.4 m - rust staining.	3.1-3.6		31		18.6	
At 3.4-4.2 m - wet.						
CLAY (CL) (4.2-4.6 m) Redish brown, moist, stiff, low plasticity, some silt.	4.4-4.6	G		3.50		
SANDSTONE (SS) (4.6-5.1 m) Grey, wet, weak hard.	4.6-5.1		49		20.6	

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962375.68
Easting: 376825.02
Ground Elevation:
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-04

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type					
		CLAY SHALE (SH) (5.1-8.1 m) Grey, damp, weak to moderately strong, low plasticity, blocky, friable, trace siltstone.	5.2-5.3	G		1.50			
6			5.9-6.1	G		4.50			Pocket pen >4.5
		At 6.1-6.6 m - Coal fragments throughout.	6.1-6.6	‖	52				
7			6.7-6.9	G					
		At 7.6-8.1 m - interbedded fine sandstone layers.	7.5-7.6	G					
8			7.6-8.1	‖					
		8.1 m End of Borehole							
9									
10									

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962541.19
Easting: 376897.89
Ground Elevation: 636.10
Pipe Elevation: 636.84

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-05A

Project #: C62720000

SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl
Ground Surface (0 m)					
TOPSOIL (TS) (FILL) (0.0-1.5 m) Black and brown, silt, trace grass fragments and clay.	0.6-0.8	G		1.50	12.4
	1.4-1.5	G		1.75	20.8
SILTY SAND (SM) (1.5-2.6 m) Light brown, moist, compact.	1.5-2.0	▮	12		
	2.1-2.3	G		1.25	14.3
At 2.3-2.6 m - some gravel.					
CLAY (CH) (2.6-4.6 m) Grey, moist, firm, high plasticity.	2.9-3.1	G		0.50	25.4
	3.1-3.6	▮	10		
At 3.7 m - some silt and sand.	3.7-3.8	G		0.50	26.8
At 4.2-4.6 m - till-like, trace gravel.	4.4-4.6	G		0.75	22.0
SILTY SAND (SM) (4.6-5.3 m) Brown, saturated, compact.	4.6-5.1	▮	19		

Comments:

Stick-Up 0.74 m

51 mm ID Sch 40 PVC pipd

Hydrated Bentonite Chips (0.0-1.2 m)

Top of Sand at 1.2 m
Top of Screen at 1.23 m

10/20 Frac Sand

3.05 m x 51 mm ID Sch 40 PVC 020 Slot Screen

SWL 2.47 m bgs Jun. 9/05

Solid Stem Borehole (152 mm diameter)

Bottom of Screen/Sand at 4.28 m

Komex-Geotech4-SPT-100-piezo

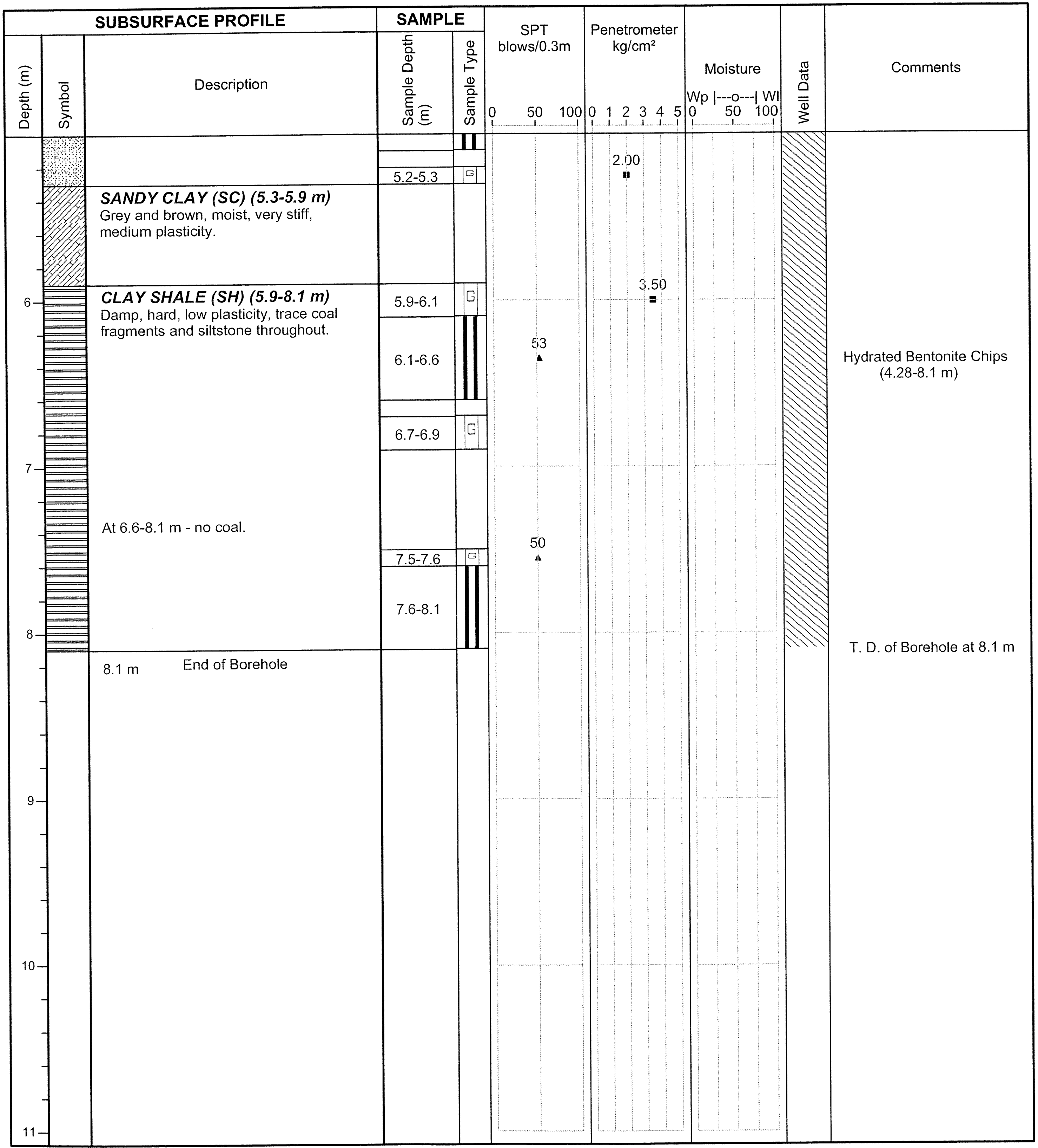
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962541.19
Easting: 376897.89
Ground Elevation: 636.10
Pipe Elevation: 636.84

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-05A

Project #: C62720000



SANDY CLAY (SC) (5.3-5.9 m)
Grey and brown, moist, very stiff, medium plasticity.

CLAY SHALE (SH) (5.9-8.1 m)
Damp, hard, low plasticity, trace coal fragments and siltstone throughout.

At 6.6-8.1 m - no coal.

8.1 m End of Borehole

Sample Depth (m)
5.2-5.3
5.9-6.1
6.1-6.6
6.7-6.9
7.5-7.6
7.6-8.1

Hydrated Bentonite Chips (4.28-8.1 m)

T. D. of Borehole at 8.1 m

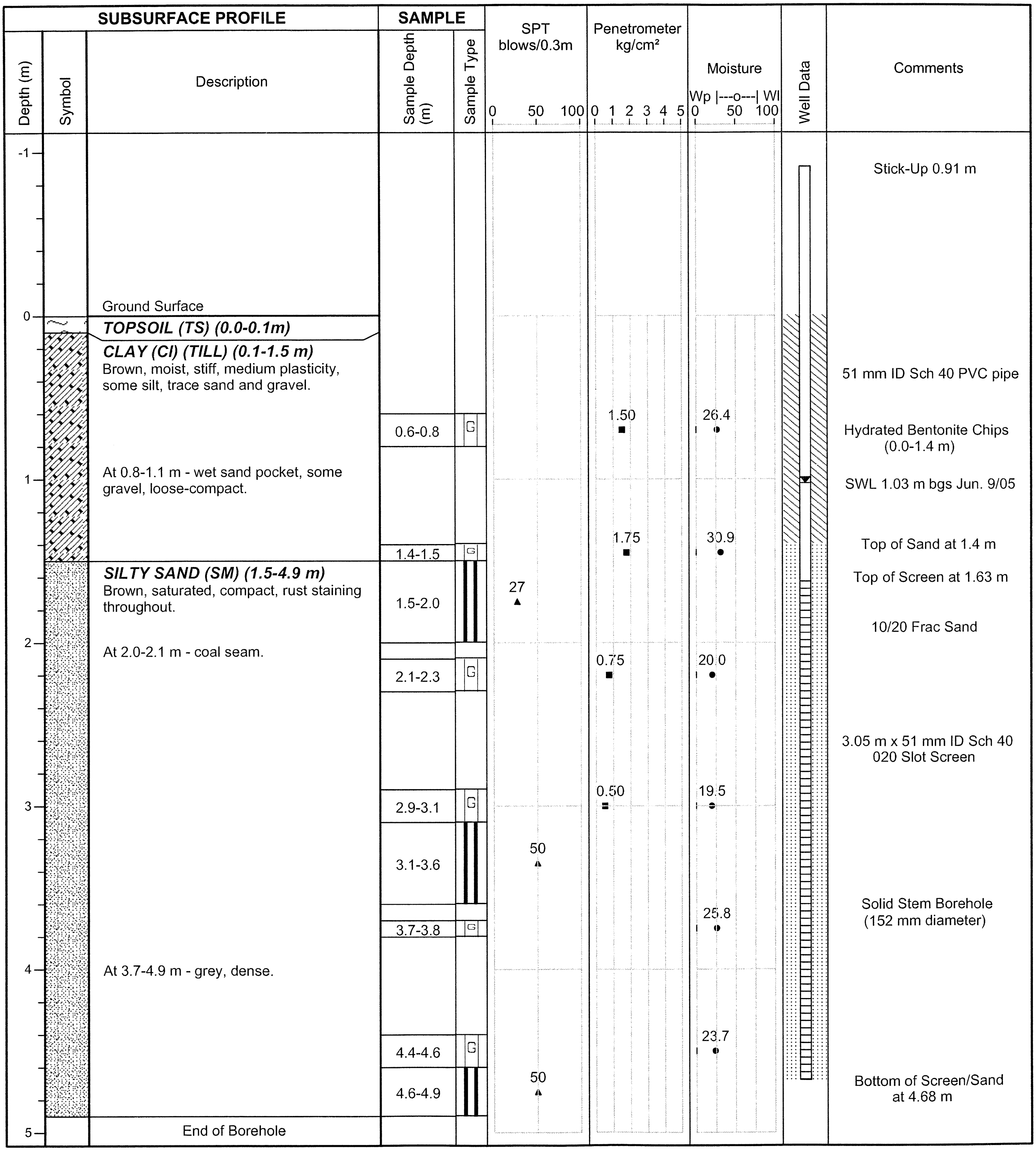
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962310.17
Easting: 376888.50
Ground Elevation: 636.39
Pipe Elevation: 637.30

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.1m)

CLAY (CI) (TILL) (0.1-1.5 m)
Brown, moist, stiff, medium plasticity, some silt, trace sand and gravel.

At 0.8-1.1 m - wet sand pocket, some gravel, loose-compact.

SILTY SAND (SM) (1.5-4.9 m)
Brown, saturated, compact, rust staining throughout.

At 2.0-2.1 m - coal seam.

At 3.7-4.9 m - grey, dense.

End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.50	26.4
1.4-1.5	G		1.75	30.9
1.5-2.0		27		
2.1-2.3	G		0.75	20.0
2.9-3.1	G		0.50	19.5
3.1-3.6		50		
3.7-3.8	G			25.8
4.4-4.6	G			23.7
4.6-4.9		50		

Stick-Up 0.91 m

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips (0.0-1.4 m)

SWL 1.03 m bgs Jun. 9/05

Top of Sand at 1.4 m

Top of Screen at 1.63 m

10/20 Frac Sand

3.05 m x 51 mm ID Sch 40 020 Slot Screen

Solid Stem Borehole (152 mm diameter)

Bottom of Screen/Sand at 4.68 m

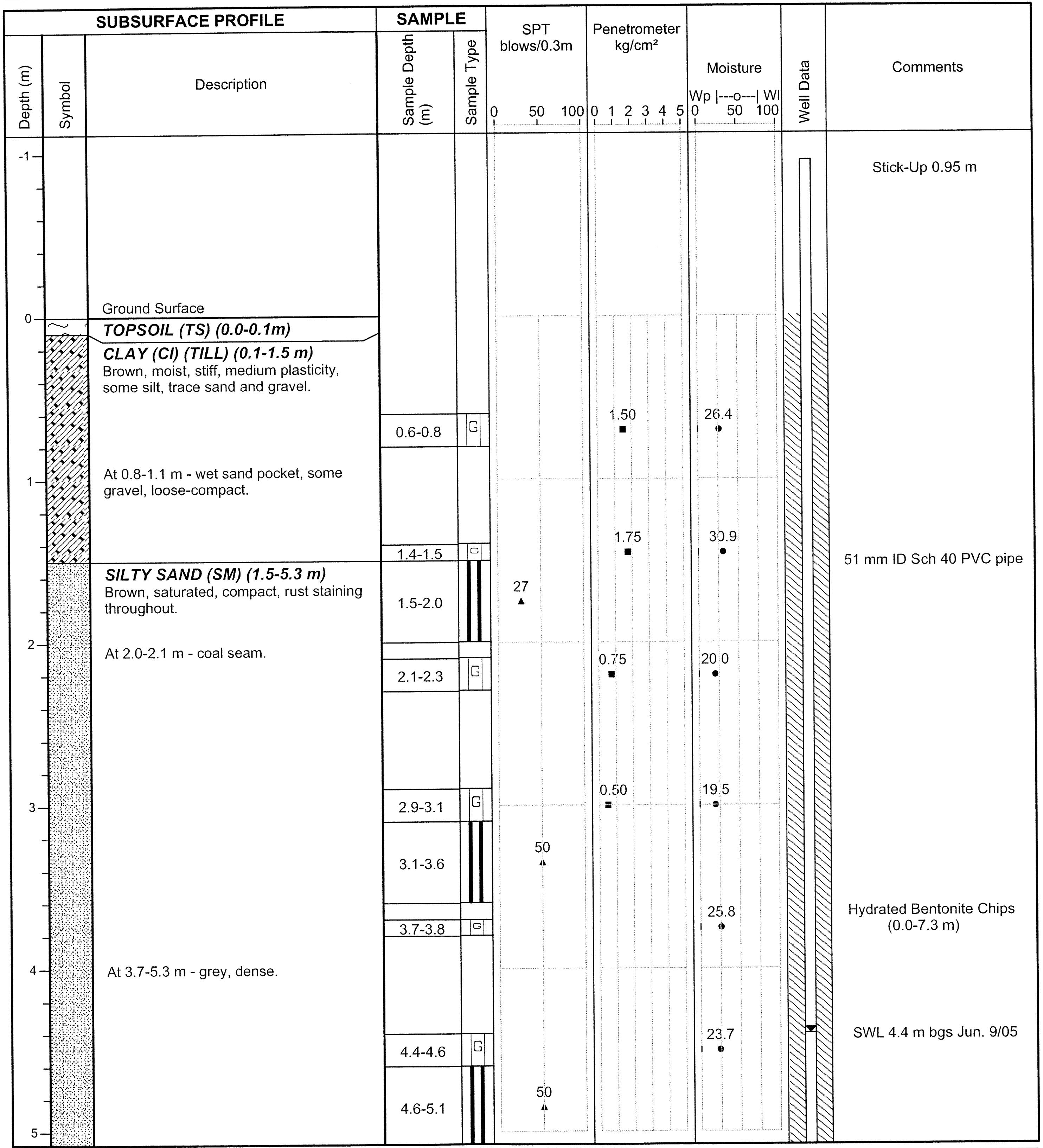
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962309.94
Easting: 376887.01
Ground Elevation: 636.41
Pipe Elevation: 637.36

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06B

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.1m)

CLAY (CI) (TILL) (0.1-1.5 m)
Brown, moist, stiff, medium plasticity, some silt, trace sand and gravel.

At 0.8-1.1 m - wet sand pocket, some gravel, loose-compact.

SILTY SAND (SM) (1.5-5.3 m)
Brown, saturated, compact, rust staining throughout.

At 2.0-2.1 m - coal seam.

At 3.7-5.3 m - grey, dense.

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.50	26.4
1.4-1.5	G		1.75	30.9
1.5-2.0		27		
2.1-2.3	G		0.75	20.0
2.9-3.1	G		0.50	19.5
3.1-3.6		50		
3.7-3.8	G			25.8
4.4-4.6	G			23.7
4.6-5.1		50		

Comments:
Stick-Up 0.95 m
51 mm ID Sch 40 PVC pipe
Hydrated Bentonite Chips (0.0-7.3 m)
SWL 4.4 m bgs Jun. 9/05

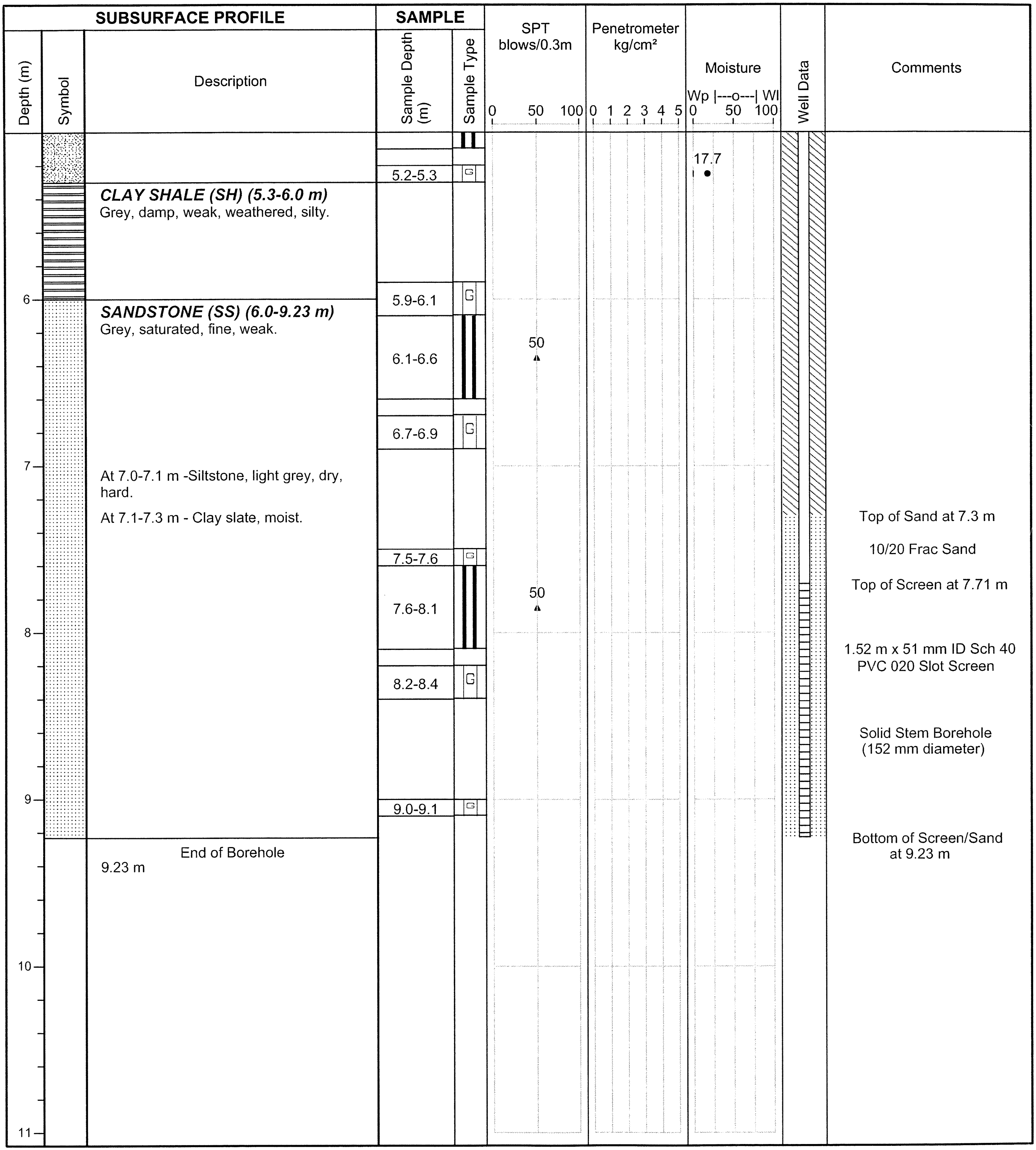
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/05
Compiled By: A. Tangedal

Northing: 5962309.94
Easting: 376887.01
Ground Elevation: 636.41
Pipe Elevation: 637.36

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-06B

Project #: C62720000



CLAY SHALE (SH) (5.3-6.0 m)
Grey, damp, weak, weathered, silty.

SANDSTONE (SS) (6.0-9.23 m)
Grey, saturated, fine, weak.

At 7.0-7.1 m -Siltstone, light grey, dry, hard.

At 7.1-7.3 m - Clay slate, moist.

End of Borehole
9.23 m

Sample depths (m): 5.2-5.3, 5.9-6.1, 6.1-6.6, 6.7-6.9, 7.5-7.6, 7.6-8.1, 8.2-8.4, 9.0-9.1

Top of Sand at 7.3 m

10/20 Frac Sand

Top of Screen at 7.71 m

1.52 m x 51 mm ID Sch 40
PVC 020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 9.23 m

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/29/05
Compiled By: A. Tangedal

Northing: 5962070.14
Easting: 376994.66
Ground Elevation: 638.65
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-07

Project #: C62720000

SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Comments
Ground Surface						
TOPSOIL (TS) (0.0-0.3 m)						Borehole backfilled with bentonite
CLAY (CI) (FILL) (0.3-0.8 m) Brown, damp, medium plasticity, sandy, some gravel (possibly till).	0.6-0.8	G		0.50	30.8	
SILTY CLAY (CI) (0.8-1.7 m) Brown, moist, stiff to very stiff, medium plasticity	1.4-1.5	G		2.00	27.2	Particle Size Analysis: Sand: 18% Silt: 48% Clay: 34%
	1.5-2.0		28			
CLAYEY SILT (CI) (1.7-3.2 m) Brown, moist, compact/stiff, some fine sand.	2.1-2.3	G		1.50	25.8	
At 2.3-3.2 m - some clay.	2.9-3.1	G		1.25	24.8	
SILTY SAND (SM) (3.2-6.6 m) Moist, dense, trace clay.	3.1-3.6		50			
	3.7-3.8	G		1.25	19.2	
	4.4-4.6	G			20.4	
At 4.8 m - trace coal fragments. At 4.9 m - saturated.	4.6-5.1		50			

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 28/29/05
Compiled By: A. Tangedal

Northing: 5962070.14
Easting: 376994.66
Ground Elevation: 638.65
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-07
Project #: C62720000

Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Well Data	Comments
	░			▮				▨	
	░		5.2-5.3	G				▨	
	░	At 5.8 m - Grey.						▨	
6	░		5.9-6.1	G		3.00	17.7	▨	
	░		6.1-6.6	▮	50			▨	
		6.6 m End of Borehole							
7									
8									
9									
10									

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962022.66
Easting: 377763.62
Ground Elevation: 636.59
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-08

Project #: C62720000

SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture Wp |---o---| Wl	Comments
Ground Surface						
TOPSOIL (TS) (0.0-0.2 m)						Borehole backfilled with bentonite
SILTY CLAY (CI) (0.2-2.7 m) Brown, moist, stiff, medium plasticity, trace sand and gravel.						
	0.6-0.8	G		1.50	21.0	
	1.3-1.5	G		1.75	18.9	
At 1.5-2.7 m - rust pockets throughout.	1.5-2.0		15			
	2.1-2.3	G		3.25	13.4	
SILTY SAND (SM) (2.7-5.0 m) Brown, moist, dense, trace clay.						
	2.9-3.1	G		1.50	16.7	
At 3.1 m - becomes wet. At 3.1-3.4 m - coal seams, rusting.	3.1-3.6		31			
	3.7-3.8	G			18.6	
	4.4-4.6	G			19.5	
At 4.8-5.0 m - Grey, silty.	4.6-5.1		35			

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962022.66
Easting: 377763.62
Ground Elevation: 636.59
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-08

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
	▤	***CLAY SHALE (SH) (5.0-6.6 m)*** Low plasticity, weak, silty.						▨	
	▤		5.2-5.3	G				▨	
6	▤		5.9-6.1	G				▨	
	▤		6.1-6.6		40 ▲			▨	
		6.6 m End of Borehole							
7									
8									
9									
10									

Komex-Geotech4-SPT-100-piezo

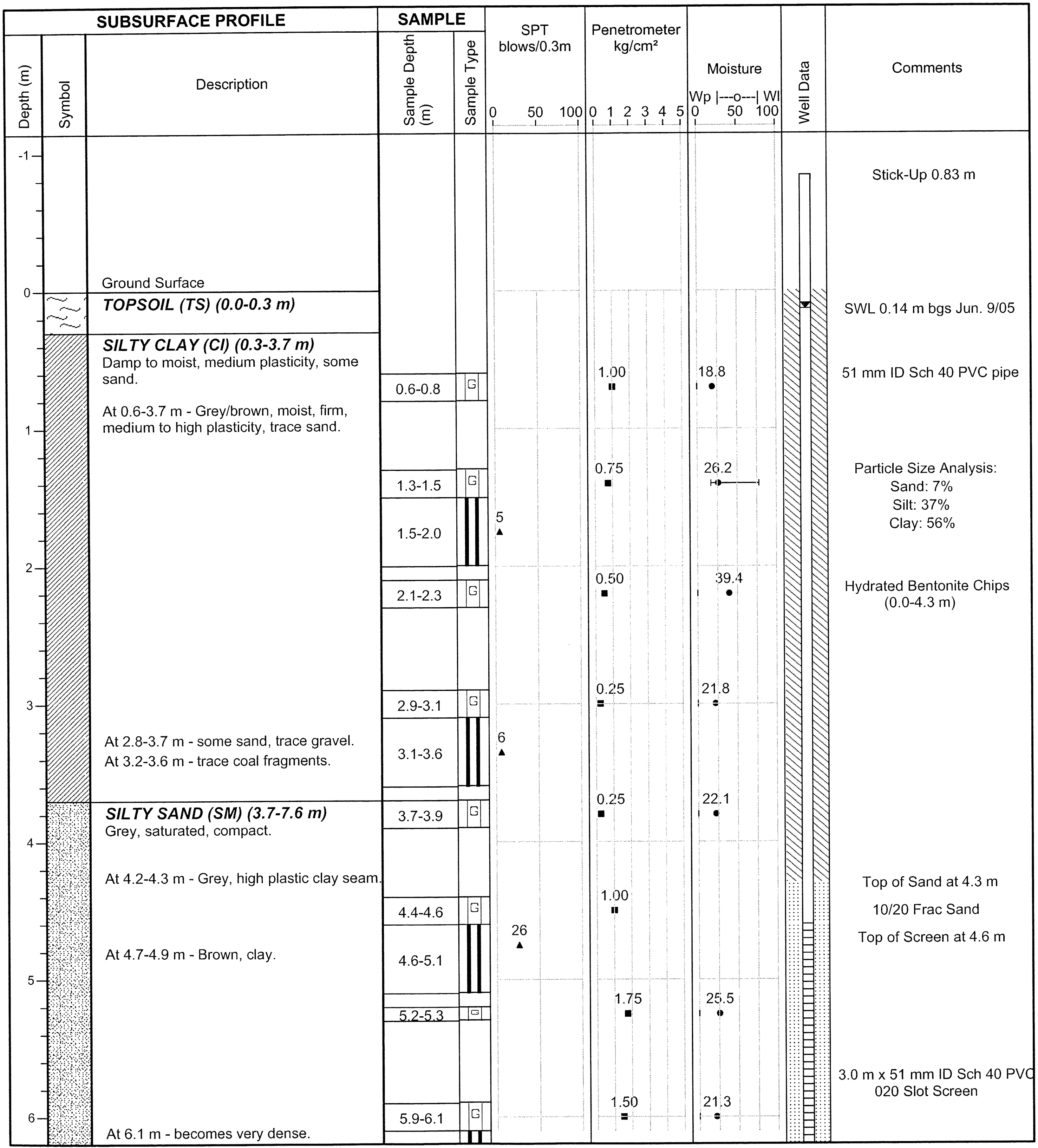
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.77
Easting: 377231.68
Ground Elevation: 634.02
Pipe Elevation: 634.85

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09A

Project #: C62720000



Description	Sample Depth (m)	Sample Type	SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Comments
Ground Surface						Stick-Up 0.83 m
TOPSOIL (TS) (0.0-0.3 m)						SWL 0.14 m bgs Jun. 9/05
SILTY CLAY (CI) (0.3-3.7 m) Damp to moist, medium plasticity, some sand.	0.6-0.8	G		1.00	18.8	51 mm ID Sch 40 PVC pipe
At 0.6-3.7 m - Grey/brown, moist, firm, medium to high plasticity, trace sand.						
	1.3-1.5	G		0.75	26.2	Particle Size Analysis: Sand: 7% Silt: 37% Clay: 56%
	1.5-2.0		5			
	2.1-2.3	G		0.50	39.4	Hydrated Bentonite Chips (0.0-4.3 m)
	2.9-3.1	G		0.25	21.8	
At 2.8-3.7 m - some sand, trace gravel. At 3.2-3.6 m - trace coal fragments.	3.1-3.6		6			
SILTY SAND (SM) (3.7-7.6 m) Grey, saturated, compact.	3.7-3.9	G		0.25	22.1	
At 4.2-4.3 m - Grey, high plastic clay seam.						Top of Sand at 4.3 m
	4.4-4.6	G		1.00		10/20 Frac Sand Top of Screen at 4.6 m
At 4.7-4.9 m - Brown, clay.	4.6-5.1		26			
	5.2-5.3	G		1.75	25.5	
						3.0 m x 51 mm ID Sch 40 PVC 020 Slot Screen
	5.9-6.1	G		1.50	21.3	
At 6.1 m - becomes very dense.						

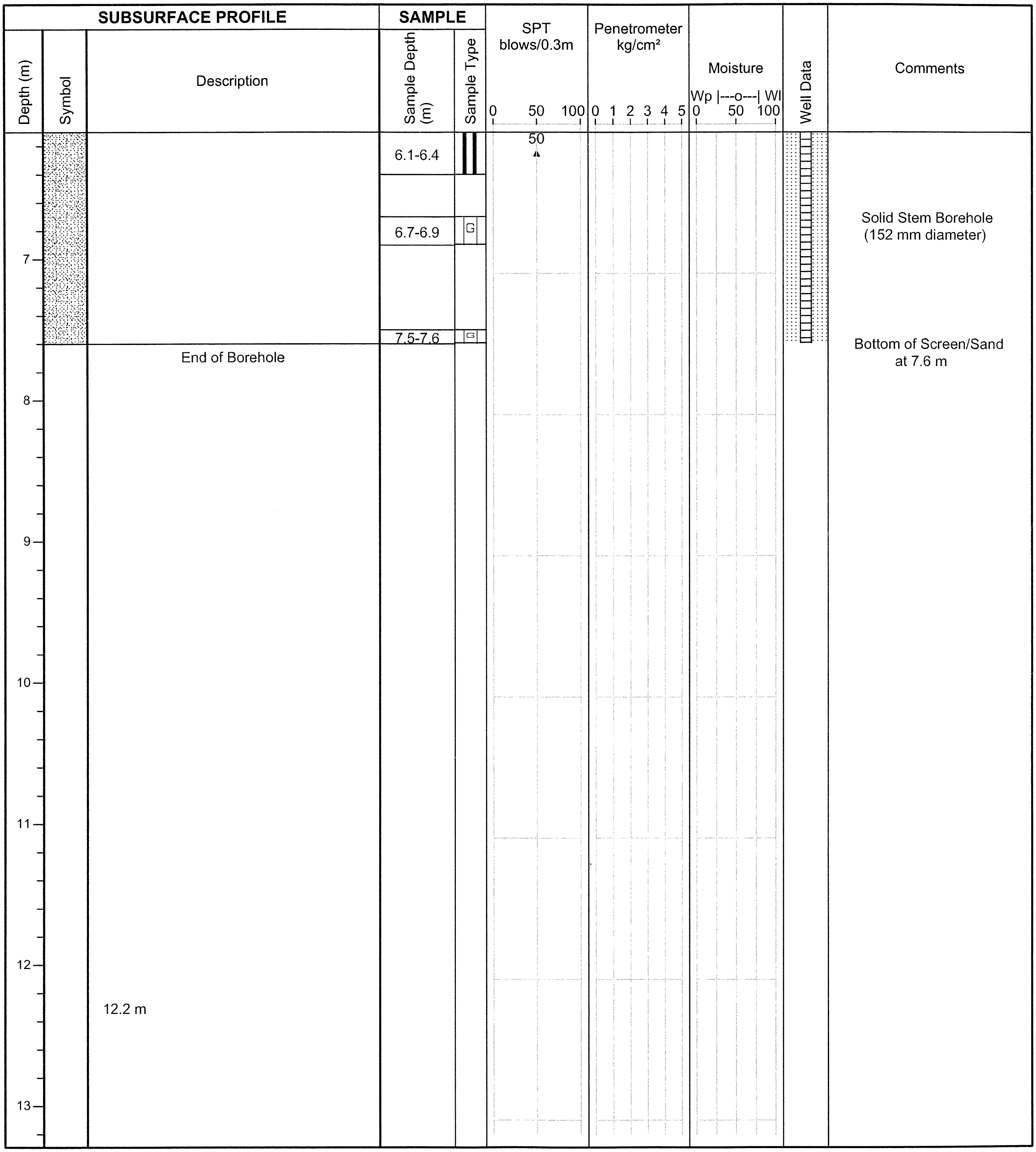
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.77
Easting: 377231.68
Ground Elevation: 634.02
Pipe Elevation: 634.85

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09A

Project #: C62720000



Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.12
Easting: 377228.17
Ground Elevation: 634.05
Pipe Elevation: 634.88

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09B

Project #: C62720000

SUBSURFACE PROFILE		SAMPLE		SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Comments
Depth (m)	Description	Sample Depth (m)	Sample Type				
-1							Stick-Up 0.83 m
0	Ground Surface						
0	***TOPSOIL (TS) (0.0-0.3 m)***						SWL 0.16 m bgs Jun. 9/05
	SILTY CLAY (CI) (0.3-3.7 m) Damp to moist, medium plasticity, some sand.	0.6-0.8	G		1.00	18.8	51 mm ID Sch 40 PVC pipe
1	At 0.6-3.7 m - Grey/brown, moist, firm, medium to high plasticity, trace sand.						
		1.3-1.5	G		0.75	26.2	Particle Size Analysis: Sand: 7% Silt: 37% Clay: 56%
		1.5-2.0	▮	5			
2		2.1-2.3	G		0.50	39.4	
3		2.9-3.1	G		0.25	21.8	
	At 2.8-3.7 m - some sand, trace gravel. At 3.2-3.6 m - trace coal fragments.	3.1-3.6	▮	6			
	SILTY SAND (SM) (3.7-8.8 m) Grey, saturated, compact.	3.7-3.9	G		0.25	22.1	
4	At 4.2-4.3 m - Grey, high plastic clay seam.						
		4.4-4.6	G		1.00		
	At 4.7-4.9 m - Brown, clay.	4.6-5.1	▮	26			Hydrated Bentonite Chips (0.0-9.5 m)
5		5.2-5.3	G		1.75	25.5	
6		5.9-6.1	G		1.50	21.3	
	At 6.1 m - becomes very dense.		▮				

Komex-Geotech4-SPT-100-piezo

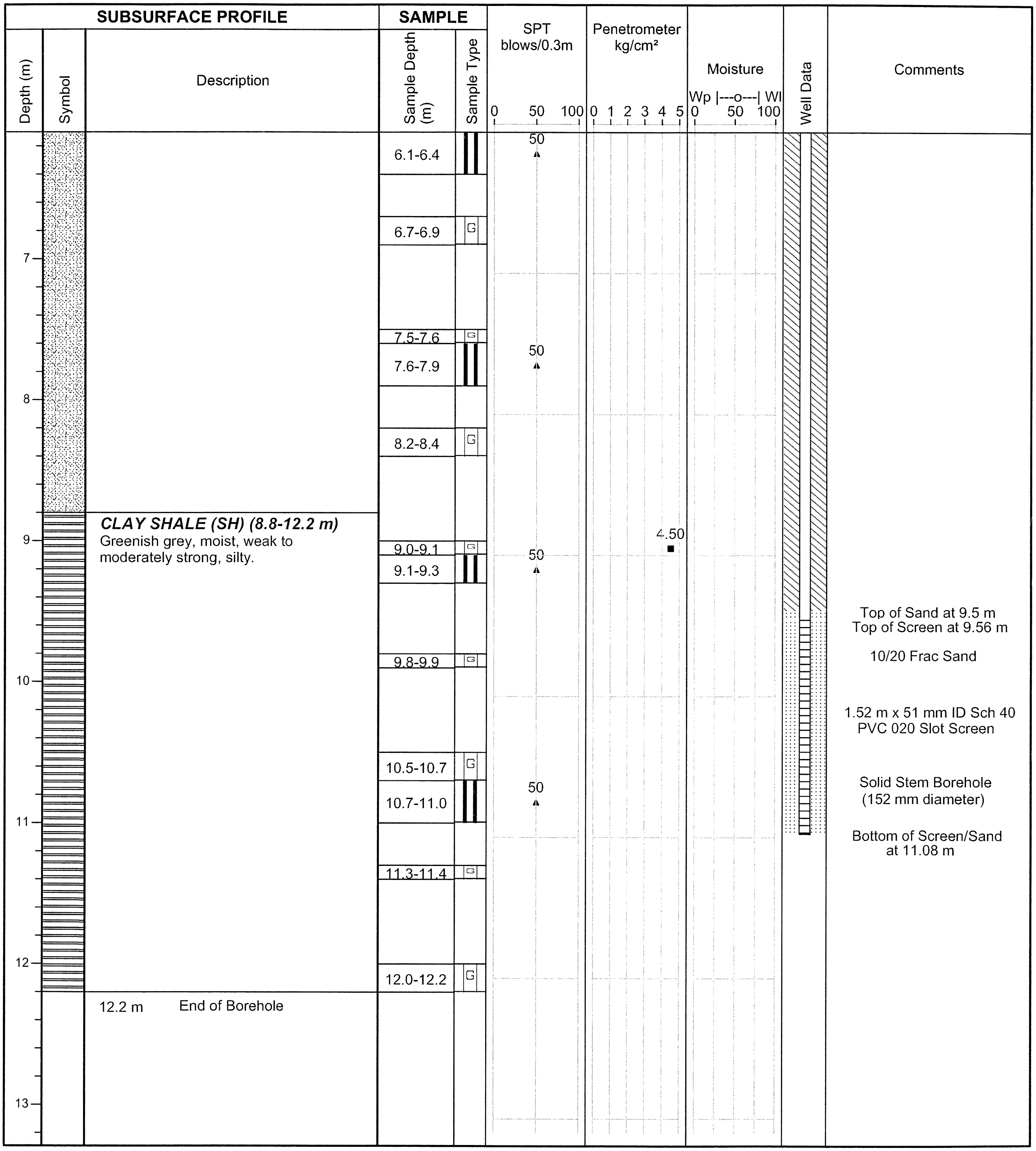
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 29/05
Compiled By: A. Tangedal

Northing: 5962415.12
Easting: 377228.17
Ground Elevation: 634.05
Pipe Elevation: 634.88

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-09B

Project #: C62720000



CLAY SHALE (SH) (8.8-12.2 m)
Greenish grey, moist, weak to moderately strong, silty.

12.2 m End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²
6.1-6.4	‖	50	
6.7-6.9	G		
7.5-7.6	G		
7.6-7.9	‖	50	
8.2-8.4	G		
9.0-9.1	G		4.50
9.1-9.3	‖	50	
9.8-9.9	G		
10.5-10.7	G		
10.7-11.0	‖	50	
11.3-11.4	G		
12.0-12.2	G		

Top of Sand at 9.5 m
Top of Screen at 9.56 m

10/20 Frac Sand

1.52 m x 51 mm ID Sch 40
PVC 020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 11.08 m

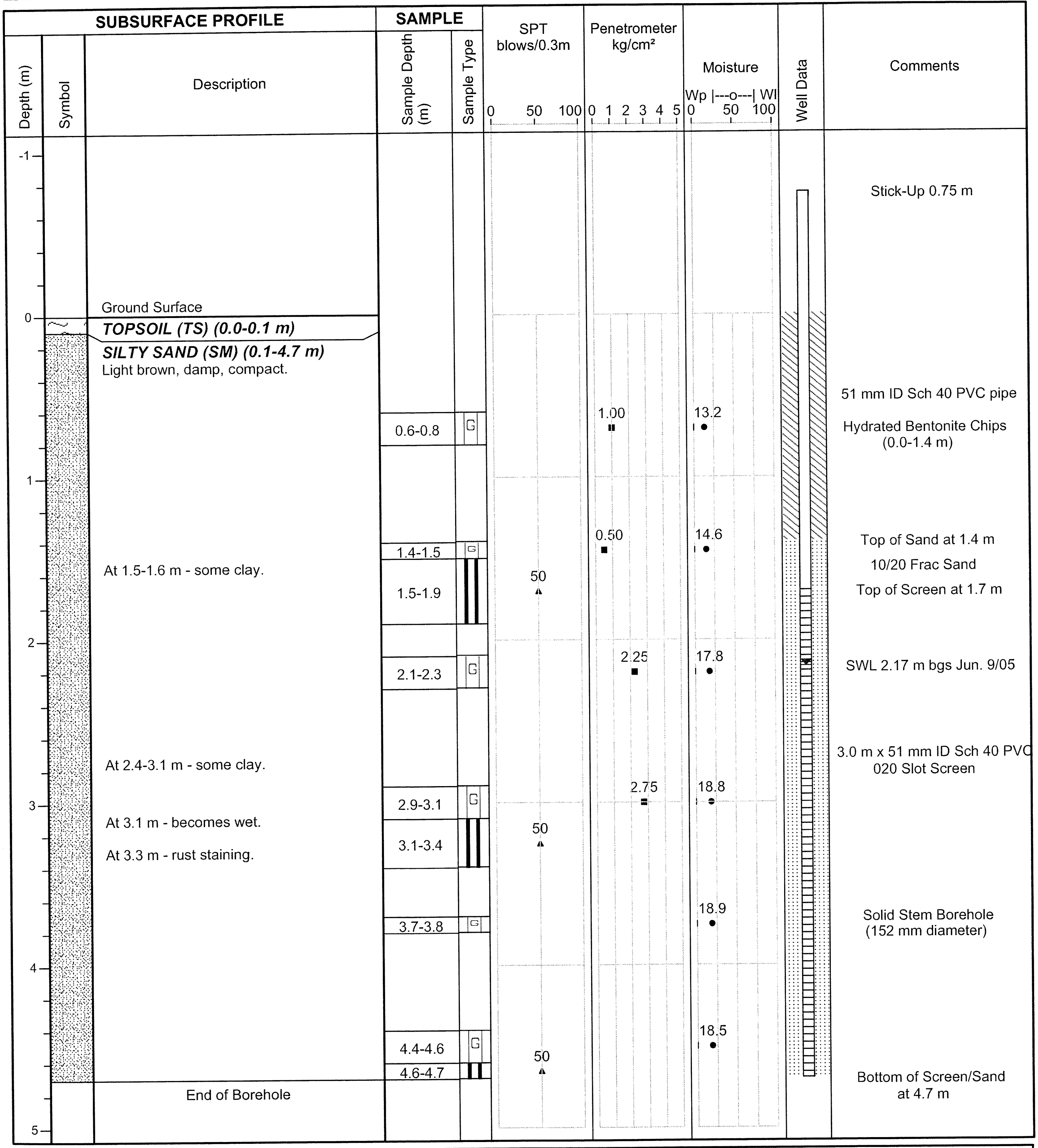
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962090.98
Easting: 377209.59
Ground Elevation: 637.39
Pipe Elevation: 638.14

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10A

Project #: C62720000



Depth (m)	Description
0	Ground Surface
0.0-0.1	***TOPSOIL (TS) (0.0-0.1 m)***
0.1-4.7	***SILTY SAND (SM) (0.1-4.7 m)*** Light brown, damp, compact. At 1.5-1.6 m - some clay. At 2.4-3.1 m - some clay. At 3.1 m - becomes wet. At 3.3 m - rust staining.
4.7	End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.00	13.2
1.4-1.5	G		0.50	14.6
1.5-1.9		50		
2.1-2.3	G		2.25	17.8
2.9-3.1	G		2.75	18.8
3.1-3.4		50		
3.7-3.8	G			18.9
4.4-4.6	G			18.5
4.6-4.7		50		

Comments

Stick-Up 0.75 m

51 mm ID Sch 40 PVC pipe

Hydrated Bentonite Chips
(0.0-1.4 m)

Top of Sand at 1.4 m

10/20 Frac Sand

Top of Screen at 1.7 m

SWL 2.17 m bgs Jun. 9/05

3.0 m x 51 mm ID Sch 40 PVC
020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Bottom of Screen/Sand
at 4.7 m

Komex-Geotech4-SPT-100-piezo

Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962092.28
Easting: 377209.55
Ground Elevation: 637.41
Pipe Elevation: 638.23

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10B

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE		SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Well Data	Comments
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type					
-1									Stick-Up 0.82 m
0		Ground Surface							
	~~	***TOPSOIL (TS) (0.0-0.1 m)***							
		SILTY SAND (SM) (0.1-4.9 m) Light brown, damp, compact.							
									51 mm ID Sch 40 PVC pipe
			0.6-0.8	G		1.00	13.2		
1									
			1.4-1.5	G		0.50	14.6		
		At 1.5-1.6 m - some clay.	1.5-1.9		50				
2									
			2.1-2.3	G		2.25	17.8		SWL 2.206 m bgs Jun. 9/05
		At 2.4-3.1 m - some clay.							Hydrated Bentonite Chips (0.0-5.5 m)
			2.9-3.1	G		2.75	18.8		
3									
		At 3.1 m - becomes wet.							
			3.1-3.4		50				
		At 3.3 m - rust staining.							

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Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962092.28
Easting: 377209.55
Ground Elevation: 637.41
Pipe Elevation: 638.23

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-10B

Project #: C62720000

SUBSURFACE PROFILE			SAMPLE						
Depth (m)	Symbol	Description	Sample Depth (m)	Sample Type	SPT blows/0.3m 0 50 100	Penetrometer kg/cm² 0 1 2 3 4 5	Moisture Wp |---o---| Wl 0 50 100	Well Data	Comments
			3.7-3.8	G			18.9		
4									
			4.4-4.6	G			18.5		
			4.6-4.7		50				
5		**CLAY SHALE (SH) (4.9-5.8 m)** Low plasticity (hard drilling).							
			5.2-5.3	G		4.50	5.0		
									Top of Sand at 5.5 m
		SANDSTONE (SS) (5.8-7.81 m) Dark grey, moist, weak to moderately strong, fine grained, silty. At 6.1 m - saturated, becomes medium grained.							
6			5.9-6.1	G		4.50			10/20 Frac Sand
			6.1-6.4		50				Top of Screen at 6.29 m
			6.7-6.9	G					1.52 m x 51 mm ID Sch 40 PVC 020 Slot Screen
7									Solid Stem Borehole (152 mm diameter)
			7.5-7.6	G					
		End of Borehole 7.81 m							Bottom of Screen/Sand at 7.81 m
8									

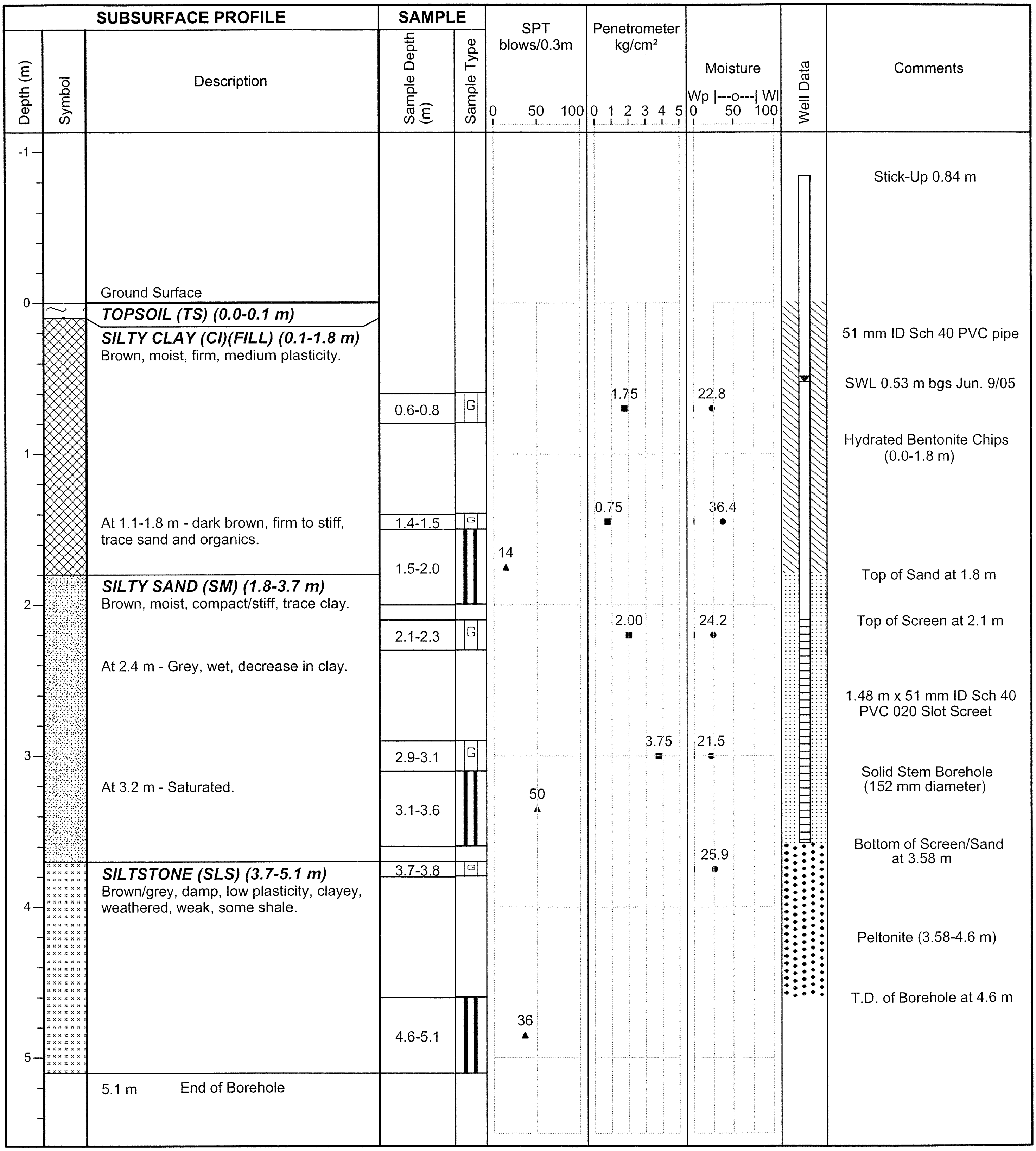
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5962416.62
Easting: 377539.35
Ground Elevation: 634.18
Pipe Elevation: 635.02

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-11A

Project #: C62720000



Ground Surface

TOPSOIL (TS) (0.0-0.1 m)

SILTY CLAY (CI)(FILL) (0.1-1.8 m)
Brown, moist, firm, medium plasticity.

At 1.1-1.8 m - dark brown, firm to stiff, trace sand and organics.

SILTY SAND (SM) (1.8-3.7 m)
Brown, moist, compact/stiff, trace clay.

At 2.4 m - Grey, wet, decrease in clay.

At 3.2 m - Saturated.

SILTSTONE (SLS) (3.7-5.1 m)
Brown/grey, damp, low plasticity, clayey, weathered, weak, some shale.

5.1 m End of Borehole

Sample Depth (m)	Sample Type	SPT blows/0.3m	Penetrometer kg/cm²	Moisture
0.6-0.8	G		1.75	22.8
1.4-1.5	G		0.75	36.4
1.5-2.0		14		
2.1-2.3	G		2.00	24.2
2.9-3.1	G		3.75	21.5
3.1-3.6		50		
3.7-3.8	G			25.9
4.6-5.1		36		

Stick-Up 0.84 m

51 mm ID Sch 40 PVC pipe

SWL 0.53 m bgs Jun. 9/05

Hydrated Bentonite Chips (0.0-1.8 m)

Top of Sand at 1.8 m

Top of Screen at 2.1 m

1.48 m x 51 mm ID Sch 40 PVC 020 Slot Screet

Solid Stem Borehole (152 mm diameter)

Bottom of Screen/Sand at 3.58 m

Peltonite (3.58-4.6 m)

T.D. of Borehole at 4.6 m

Komex-Geotech4-SPT-100-piezo

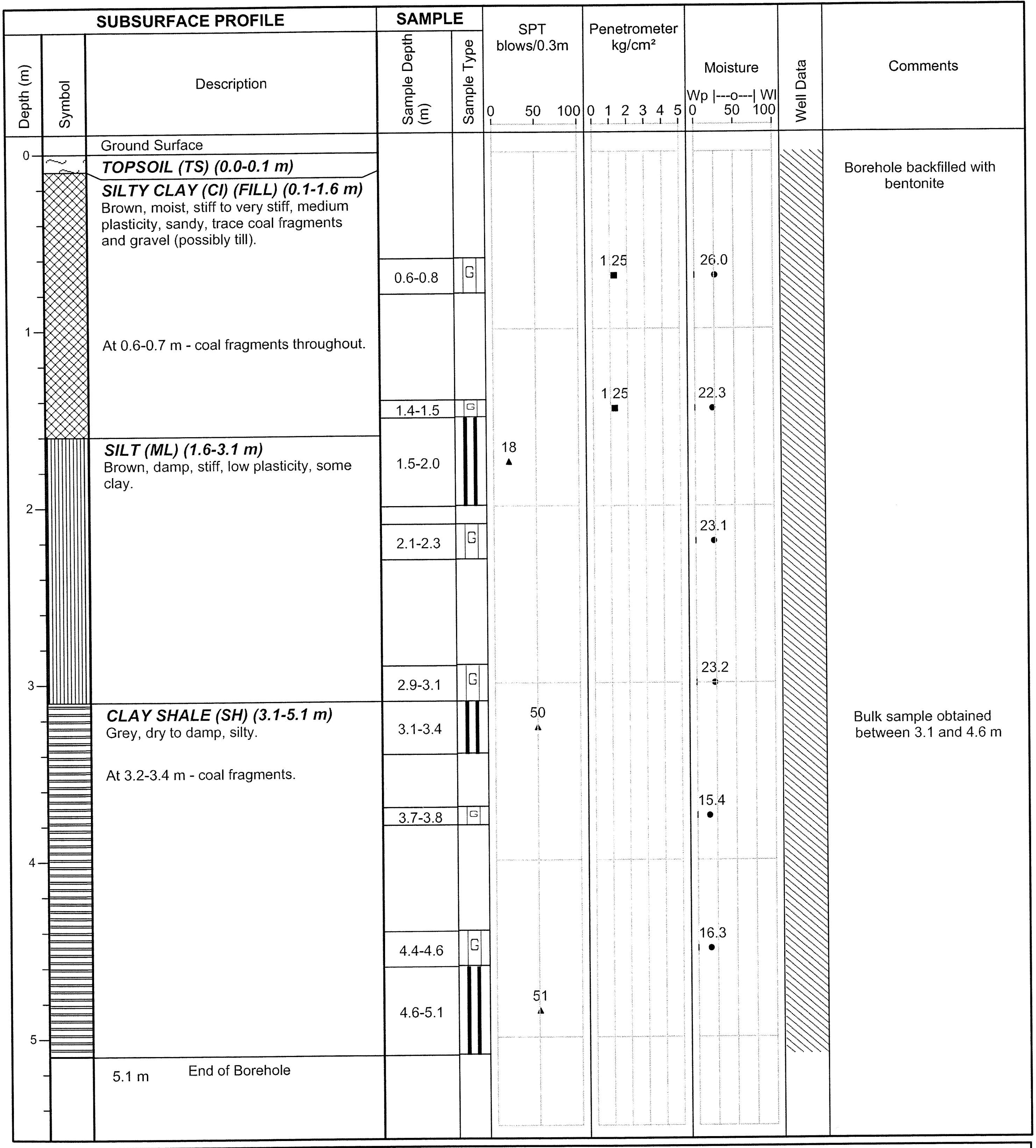
Project Name: Bruderheim Geotechnical Investigation
Client: Hazco Environmental Services Ltd.
Location: 35-55-20 W4M
Drilled By: Beck Drilling and Env. Services Ltd.
Drill Date: May 30/05
Compiled By: A. Tangedal

Northing: 5961681.18
Easting: 377359.83
Ground Elevation: 641.29
Pipe Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole #: 05-12

Project #: C62720000



SUBSURFACE PROFILE Description	SAMPLE Sample Depth (m)	Sample Type	SPT blows/0.3m (0 50 100)	Penetrometer kg/cm² (0 1 2 3 4 5)	Moisture Wp |---o---| Wl (0 50 100)	Comments
Ground Surface						
TOPSOIL (TS) (0.0-0.1 m)						Borehole backfilled with bentonite
SILTY CLAY (CI) (FILL) (0.1-1.6 m) Brown, moist, stiff to very stiff, medium plasticity, sandy, trace coal fragments and gravel (possibly till).						
	0.6-0.8	G		1.25	26.0	
At 0.6-0.7 m - coal fragments throughout.						
	1.4-1.5	G		1.25	22.3	
SILT (ML) (1.6-3.1 m) Brown, damp, stiff, low plasticity, some clay.	1.5-2.0		18			
	2.1-2.3	G			23.1	
	2.9-3.1	G			23.2	
CLAY SHALE (SH) (3.1-5.1 m) Grey, dry to damp, silty.	3.1-3.4		50			Bulk sample obtained between 3.1 and 4.6 m
At 3.2-3.4 m - coal fragments.						
	3.7-3.8	G			15.4	
	4.4-4.6	G			16.3	
	4.6-5.1		51			
5.1 m End of Borehole						

Komex-Soils-5m

Project Name: Limited Soil Investigation
Client: CCS Energy Services
Location: 35-55-20 W4M
Drilled by: Clay Drilling Inc.
Drill Date: Dec. 21/05
Compiled by: C. Fedor

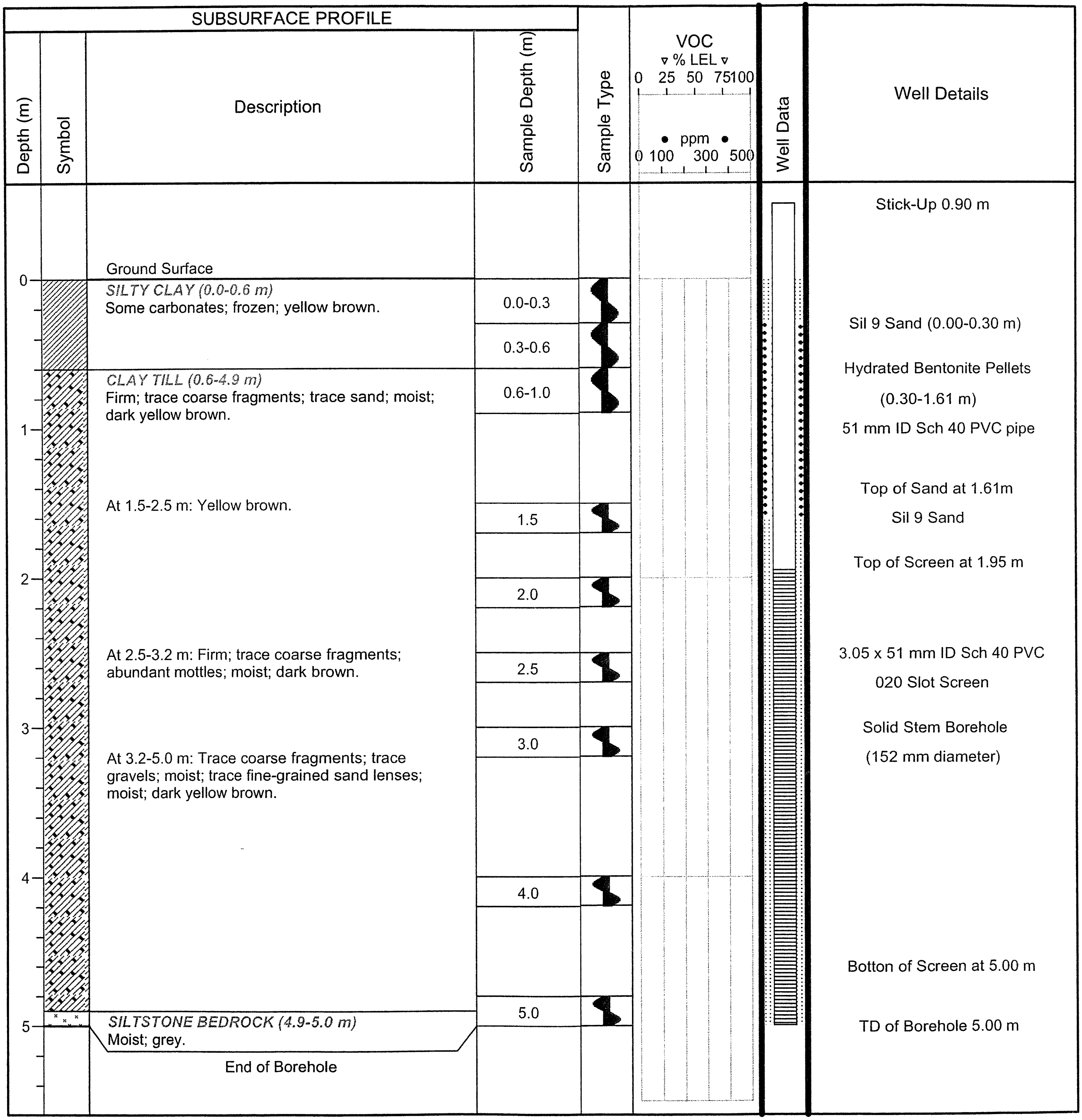
Northing:
Easting:
Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole # 05-20

PROJECT # C62720000

SUBSURFACE PROFILE



Description

Ground Surface

SILTY CLAY (0.0-0.6 m)
Some carbonates; frozen; yellow brown.

CLAY TILL (0.6-4.9 m)
Firm; trace coarse fragments; trace sand; moist; dark yellow brown.

At 1.5-2.5 m: Yellow brown.

At 2.5-3.2 m: Firm; trace coarse fragments; abundant mottles; moist; dark brown.

At 3.2-5.0 m: Trace coarse fragments; trace gravels; moist; trace fine-grained sand lenses; moist; dark yellow brown.

SILTSTONE BEDROCK (4.9-5.0 m)
Moist; grey.

End of Borehole

Sample Depth (m)

0.0-0.3
0.3-0.6
0.6-1.0
1.5
2.0
2.5
3.0
4.0
5.0

Well Details

Stick-Up 0.90 m

Sil 9 Sand (0.00-0.30 m)

Hydrated Bentonite Pellets
(0.30-1.61 m)
51 mm ID Sch 40 PVC pipe

Top of Sand at 1.61m
Sil 9 Sand

Top of Screen at 1.95 m

3.05 x 51 mm ID Sch 40 PVC
020 Slot Screen

Solid Stem Borehole
(152 mm diameter)

Botton of Screen at 5.00 m

TD of Borehole 5.00 m

Project Name: Limited Soil Investigation
Client: CCS Energy Services
Location: 35-55-20 W4M
Drilled by: Clay Drilling Inc.
Drill Date: Dec. 21/05
Compiled by: C. Fedor

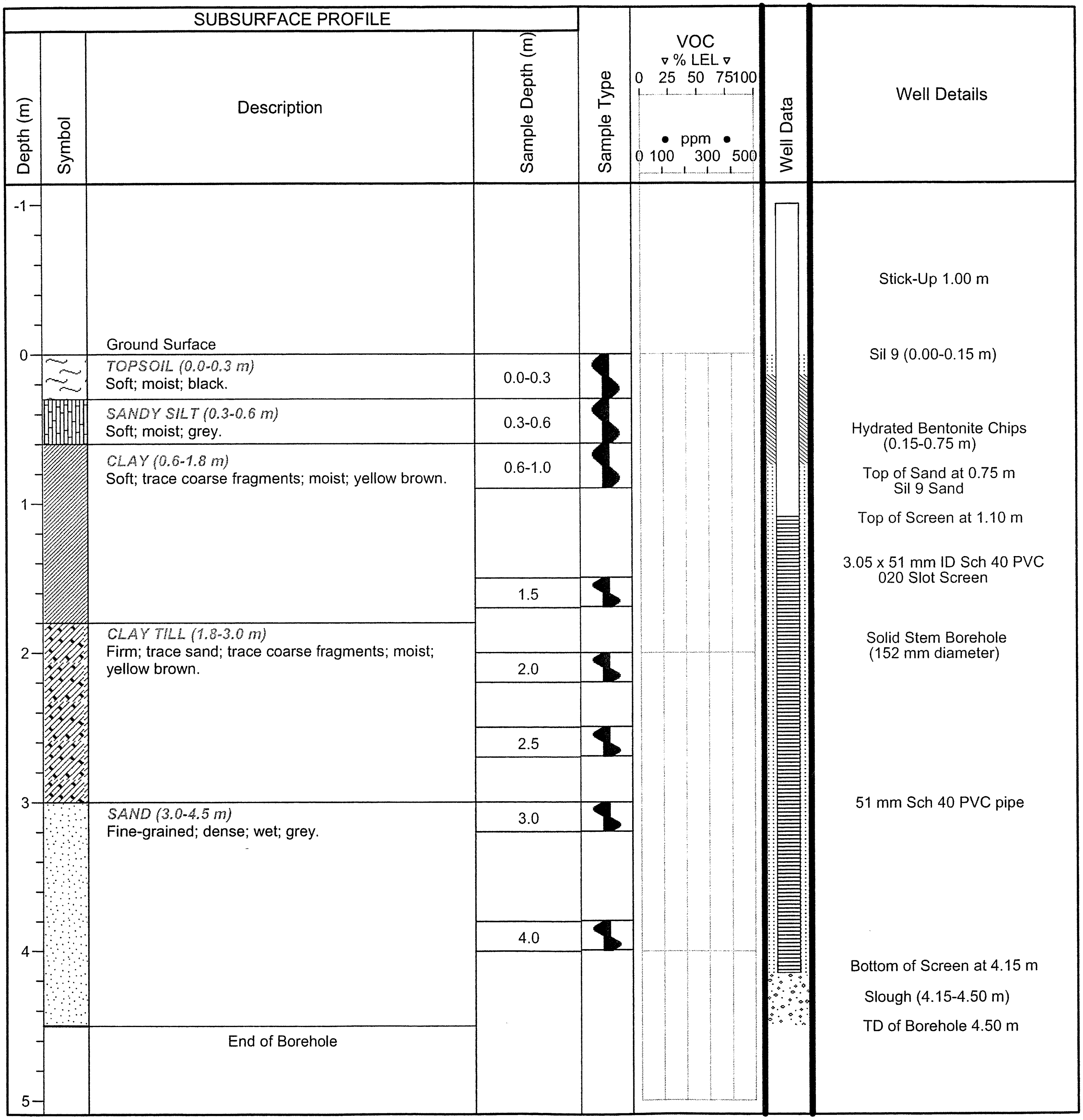
Northing:
Easting:
Elevation:

KOMEX INTERNATIONAL LTD.
ENVIRONMENT AND WATER RESOURCES

Borehole # 05-28

PROJECT # C62720000

SUBSURFACE PROFILE



Description	Sample Depth (m)
Ground Surface	
TOPSOIL (0.0-0.3 m) Soft; moist; black.	0.0-0.3
SANDY SILT (0.3-0.6 m) Soft; moist; grey.	0.3-0.6
CLAY (0.6-1.8 m) Soft; trace coarse fragments; moist; yellow brown.	0.6-1.0 1.5
CLAY TILL (1.8-3.0 m) Firm; trace sand; trace coarse fragments; moist; yellow brown.	2.0 2.5
SAND (3.0-4.5 m) Fine-grained; dense; wet; grey.	3.0 4.0
End of Borehole	

Well Details

Stick-Up 1.00 m
Sil 9 (0.00-0.15 m)
Hydrated Bentonite Chips (0.15-0.75 m)
Top of Sand at 0.75 m Sil 9 Sand
Top of Screen at 1.10 m
3.05 x 51 mm ID Sch 40 PVC 020 Slot Screen
Solid Stem Borehole (152 mm diameter)
51 mm Sch 40 PVC pipe
Bottom of Screen at 4.15 m
Slough (4.15-4.50 m)
TD of Borehole 4.50 m

File Path/Location: N:\62720000
Created by: LC
Date Created: Jan. 10/05

WPK-Piezo-50m-Geophys

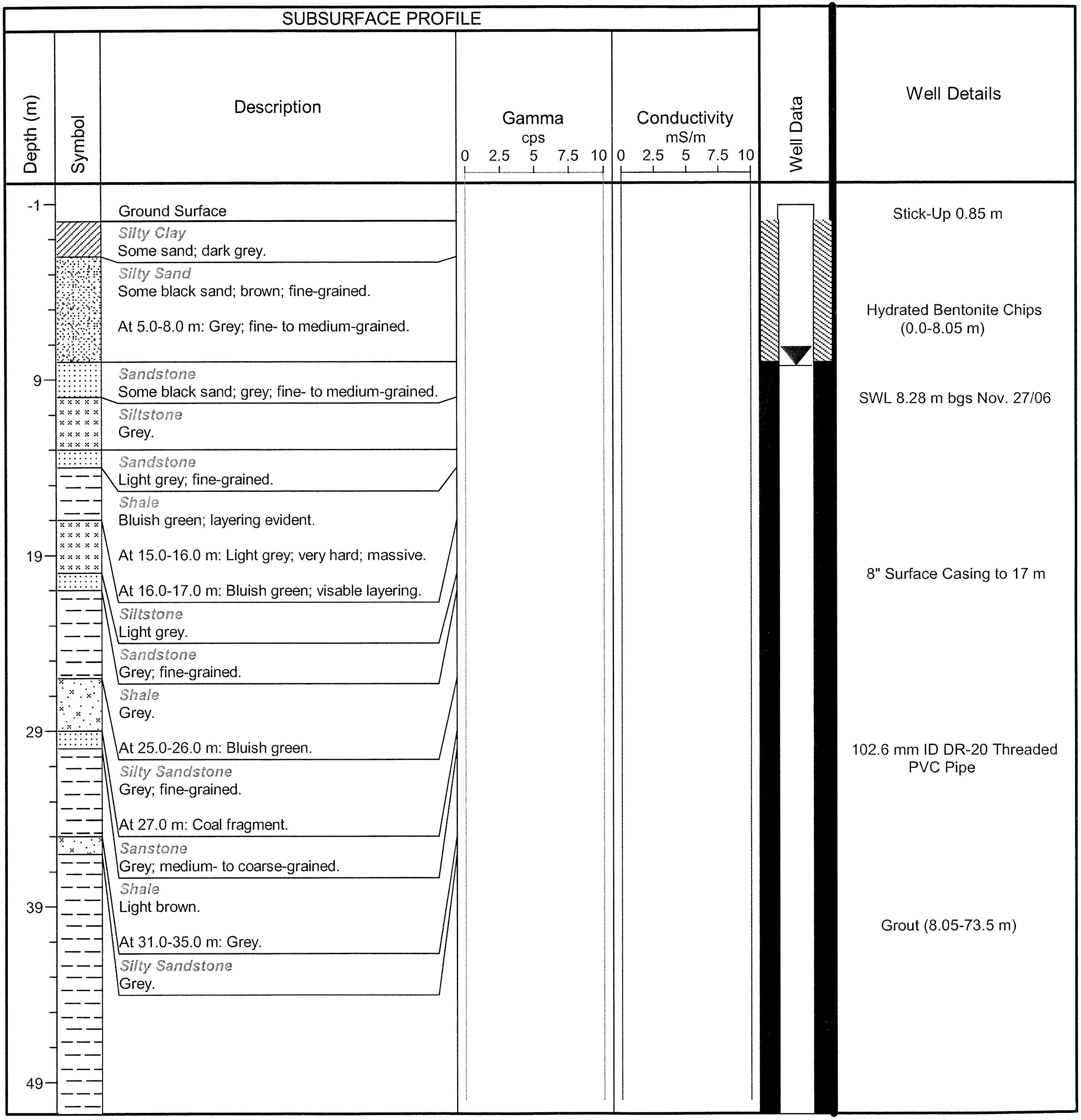
WorleyParsons Komex
resources & energy

Borehole # PW06-01

PROJECT # C62720105

Project Name: Proposed CCS Sulphur Facility
Client: Hazco Environmental Services Ltd.
Location: SW-35-55-20 W4M
Drilled by: Beck Drilling and Env. Services Ltd.
Drill Date: Nov.14/06
Compiled by: B. Abel

Northing: 5962155.6
Easting: 377123.7
Elevation: 0



Ground Surface

Silty Clay
Some sand; dark grey.

Silty Sand
Some black sand; brown; fine-grained.

At 5.0-8.0 m: Grey; fine- to medium-grained.

Sandstone
Some black sand; grey; fine- to medium-grained.

Siltstone
Grey.

Sandstone
Light grey; fine-grained.

Shale
Bluish green; layering evident.

At 15.0-16.0 m: Light grey; very hard; massive.

At 16.0-17.0 m: Bluish green; visable layering.

Siltstone
Light grey.

Sandstone
Grey; fine-grained.

Shale
Grey.

At 25.0-26.0 m: Bluish green.

Silty Sandstone
Grey; fine-grained.

At 27.0 m: Coal fragment.

Sanstone
Grey; medium- to coarse-grained.

Shale
Light brown.

At 31.0-35.0 m: Grey.

Silty Sandstone
Grey.

Stick-Up 0.85 m

Hydrated Bentonite Chips (0.0-8.05 m)

SWL 8.28 m bgs Nov. 27/06

8" Surface Casing to 17 m

102.6 mm ID DR-20 Threaded PVC Pipe

Grout (8.05-73.5 m)

WPK-Piezo-50m-Geophys

WorleyParsons Komex
resources & energy

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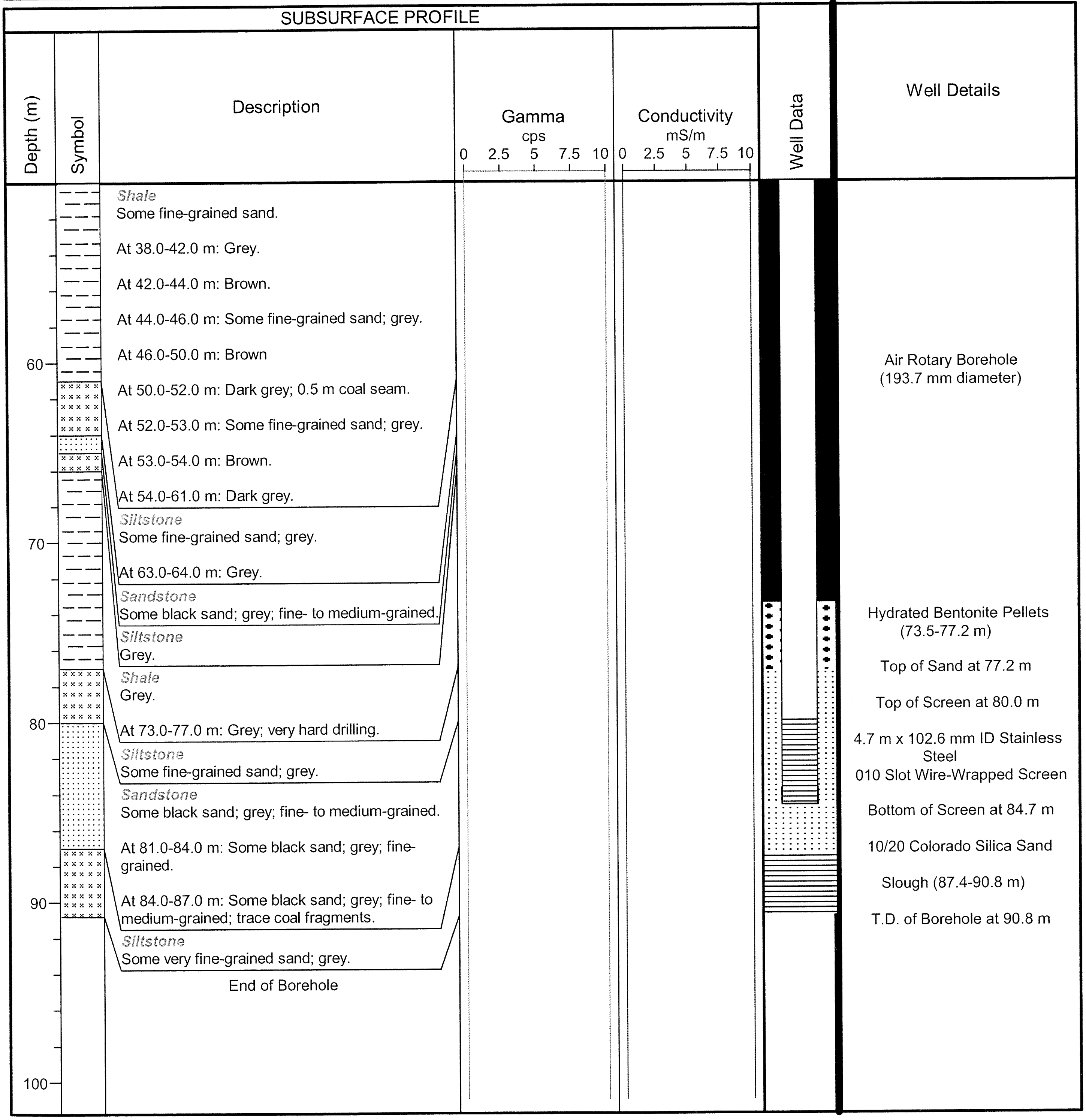

Shale
Some fine-grained sand.

At 38.0-42.0 m: Grey.

At 42.0-44.0 m: Brown.

At 44.0-46.0 m: Some fine-grained sand; grey.

At 46.0-50.0 m: Brown

At 50.0-52.0 m: Dark grey; 0.5 m coal seam.

At 52.0-53.0 m: Some fine-grained sand; grey.

At 53.0-54.0 m: Brown.

At 54.0-61.0 m: Dark grey.

Siltstone
Some fine-grained sand; grey.

At 63.0-64.0 m: Grey.

Sandstone
Some black sand; grey; fine- to medium-grained.

Siltstone
Grey.

Shale
Grey.

At 73.0-77.0 m: Grey; very hard drilling.

Siltstone
Some fine-grained sand; grey.

Sandstone
Some black sand; grey; fine- to medium-grained.

At 81.0-84.0 m: Some black sand; grey; fine-grained.

At 84.0-87.0 m: Some black sand; grey; fine- to medium-grained; trace coal fragments.

Siltstone
Some very fine-grained sand; grey.

End of Borehole

Air Rotary Borehole
(193.7 mm diameter)

Hydrated Bentonite Pellets
(73.5-77.2 m)

Top of Sand at 77.2 m

Top of Screen at 80.0 m

4.7 m x 102.6 mm ID Stainless Steel
010 Slot Wire-Wrapped Screen

Bottom of Screen at 84.7 m

10/20 Colorado Silica Sand

Slough (87.4-90.8 m)

T.D. of Borehole at 90.8 m

Volume IIB, Section 2: Groundwater Quantity and Quality

Appendix IV: Groundwater Monitoring and Water Quality Results

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Table IV-1: Monitoring Well Completion Details and Monitoring Details

Monitoring Well	Ground Elevation (masl)	Reference Casing Elevation (masl)	Stick-Up of PVC (m)	Total Depth of Monitoring Well (mbgs)	Depth Interval of Screen (mbgs)	Depth to Groundwater (mbtoc)	Depth To Groundwater (mbgs)	Date Measured (d-m-y)	Groundwater Surface Elevation (masl)	Hydraulic Conductivity (m/s)	Completion Lithology
Surficial Deposits											
05-03A	636.61	637.5	0.89	5.48	1.54-4.59	3.53	2.64	9-Jun-05	633.97	2.3E-08	clay
						3.62	2.73	9-Nov-05	633.88		
						3.71	2.82	14-Jun-06	633.79		
05-05A	636.1	636.84	0.74	5.02	1.23-4.28	3.21	2.47	9-Jun-05	633.63	4.2E-08	sand and clay
						3.12	2.38	9-Nov-05	633.72		
						3.20	2.46	14-Jun-06	633.64		
05-06A	636.39	637.3	0.91	5.59	1.63-4.68	1.94	1.03	9-Jun-05	635.36	1.4E-06	silty-sand
						1.76	0.85	22-Jun-05	635.54		
						2.30	1.39	9-Nov-05	635.00		
						2.13	1.22	14-Jun-06	635.17		
05-09A	634.02	634.85	0.83	8.51	4.63-7.68	0.97	0.14	9-Jun-05	633.88	8.0E-07	silty-sand
						1.13	0.30	9-Nov-05	633.72		
						1.04	0.21	14-Jun-06	633.81		
05-10A	637.39	638.14	0.75	5.48	1.68-4.73	2.92	2.17	9-Jun-05	635.22	3.0E-06	sand
						3.26	2.51	9-Nov-05	634.88		
						3.28	2.53	14-Jun-06	634.87		
05-11A	634.18	635.02	0.84	4.42	2.06-3.58	1.37	0.53	9-Jun-05	633.65	1.6E-06	silty-sand
						2.03	1.19	9-Nov-05	632.99		
						2.13	1.29	14-Jun-06	632.89		

Notes:
1 Negative numbers indicate water level above ground surface.
2 Monitoring well not surveyed; elevation determined from digital topographic information.
m – metres.
mbgs – metres below ground surface.
masl – metres above sea level.
mbtoc – metres below top of casing.
--- = not measured.
X – data point removed (anomalous).

Table IV-1: Monitoring Well Completion Details and Monitoring Details (Cont'd)

Monitoring Well	Ground Elevation	Reference Casing Elevation	Stick-Up of PVC	Total Depth of Monitoring Well	Depth Interval of Screen	Depth to Groundwater	Depth To Groundwater	Date Measured	Groundwater Surface Elevation	Hydraulic Conductivity	Completion Lithology
	(masl)	(masl)	(m)	(mbgs)	(mbgs)	(mbtoc)	(mbgs)	(d-m-y)	(masl)	(m/s)	
05-20	637.50[1]	638.40	0.90	5.00	1.95-5.00	3.20	2.30	14-Jun-06	635.20	---	clay
05-28	631.00[2]	632.00	1.00	4.50	1.10-4.15	0.92	-0.08[1]	14-Jun-06	631.08	---	sand and clay
Upper Bedrock											
05-01B	632.83	633.49	0.66	16.46	7.32-16.46	flowing	<-0.66[1]	9-Jun-05	> 633.49	6.6E-06	sandstone
						0.26	-0.40[1]	9-Nov-05	633.23		
						0.12	-0.54[1]	14-Jun-06	633.37		
05-03BI	636.69	637.51	0.82	7.86	6.28-7.04	3.47	2.65	9-Jun-05	634.04	3.9E-07	clay shale
						3.66	2.84	9-Nov-05	633.85		
						3.71	2.89	14-Jun-06	633.80		
05-03BII	636.73	637.56	0.83	7.96	5.52-7.12	3.53	2.70	9-Jun-05	634.03	4.5E-06	sandstone-clay shale
						3.71	2.88	9-Nov-05	633.85		
						3.77	2.94	14-Jun-06	633.79		
05-06B	636.41	637.36	0.95	10.18	7.71-9.23	X	X	9-Jun-05	X	1.7E-08	sandstone-clay shale
						1.90	0.95	22-Jun-05	635.46		
						2.35	1.40	9-Nov-05	635.01		
						2.27	1.32	14-Jun-06	635.09		

Notes:
1 Negative numbers indicate water level above ground surface.
2 Monitoring well not surveyed; elevation determined from digital topographic information.
m – metres.
mbgs – metres below ground surface.
masl – metres above sea level.
mbtoc – metres below top of casing.
--- = not measured.
X – data point removed (anomalous).

Table IV-1: Monitoring Well Completion Details and Monitoring Details (Cont'd)

Monitoring Well	Ground Elevation	Reference Casing Elevation	Stick-Up of PVC	Total Depth of Monitoring Well	Depth Interval of Screen	Depth to Groundwater	Depth To Groundwater	Date Measured	Groundwater Surface Elevation	Hydraulic Conductivity	Completion Lithology
	(masl)	(masl)	(m)	(mbgs)	(mbgs)	(mbtoc)	(mbgs)	(d-m-y)	(masl)	(m/s)	
05-09B	634.05	634.88	0.83	11.91	9.56-11.08	0.99	0.16	9-Jun-05	633.89	7.0E-08	clay shale
						1.27	0.44	9-Nov-05	633.61		
						1.08	0.25	14-Jun-06	633.80		
05-10B	637.41	638.23	0.82	8.63	6.29-7.81	3.03	2.21	9-Jun-05	635.20	2.1E-07	sandstone
						3.37	2.55	9-Nov-05	634.86		
						3.36	2.54	14-Jun-06	634.87		
Middle Bedrock											
05-01C	632.84	633.5	0.66	41.84	35.05-41.15	0.51	-0.15[1]	9-Jun-05	632.99	4.6E-09	clay shale
						0.59	-0.07[1]	9-Nov-05	632.91		
						1.02	0.36	14-Jun-06	632.48		
Lower Bedrock											
PW06-01	637.00[2]	637.85	0.85	90.80	80.0-84.7	8.28	7.43	27-Nov-06	629.57	---	sandstone

Notes:
1 Negative numbers indicate water level above ground surface.
2 Monitoring well not surveyed; elevation determined from digital topographic information.
m – metres.
mbgs – metres below ground surface.
masl – metres above sea level.
mbtoc – metres below top of casing.
--- = not measured.
X – data point removed (anomalous).

Table IV-2: Field Measured Parameters

Monitoring Well	Date Measured	Headspace Vapour Concentration (ppm)	Temperature (°C)	Electrical Conductivity (at 25°C) (µS/cm)	pH (-)
Surficial Deposits					
05-03A	9-Jun-05	<5	5.29	7,852	7.89
	9-Nov-05	560	7.15	3,121	7.91
	15-Jun-06	35	9.86	4,436	7.84
05-05A	10-Jun-05	120	6.58	5,484	7.37
	9-Nov-05	75	6.78	2,029	7.56
	15-Jun-06	<5	9.00	3,143	7.49
05-06A	10-Jun-05	5	7.49	2,165	7.30
	9-Nov-05	5	7.57	715	7.19
	15-Jun-06	10	11.50	1,114	7.24
05-09A	10-Jun-05	220	9.79	2,443	8.29
	9-Nov-05	10	5.93	763	8.17
	15-Jun-06	<5	11.80	1,208	8.13
05-10A	10-Jun-05	15	7.38	1,684	7.44
	9-Nov-05	20	7.03	559	7.18
	15-Jun-06	<5	13.49	847	7.15
05-11A	10-Jun-05	45	X	3,266	8.09
	9-Nov-05	<5	7.18	1,238	8.07
	15-Jun-06	<5	11.30	1,687	8.01
05-20	15-Jun-06	<5	10.95	4,543	7.43
05-28	15-Jun-06	<5	12.05	2,440	6.83
Upper Bedrock					
05-01B	28-May-05	---	6.60	1,109	8.14
	9-Nov-05	---	5.56	713	8.00
05-03BI	9-Jun-05	15	5.78	2,703	8.92
	9-Nov-05	10	6.18	872	8.17
05-03BII	9-Jun-05	15	5.45	2,902	7.82
	9-Nov-05	10	6.30	960	8.11
05-06B	10-Jun-05	150	6.02	2,224	7.13
	9-Nov-05	<5	6.60	739	7.52
05-09B	10-Jun-05	110	X	2,366	7.91
	9-Nov-05	15	4.63	807	8.53
05-10B	10-Jun-05	5	5.93	1,761	7.36
	9-Nov-05	5	6.37	576	7.25

Notes:
ppm – parts per million.
µS/cm – micro-Siemens/centimetre.
mg/L – milligrams/litre.
--- = not measured or analyzed.
X – data point removed (anomalous).

Table IV-2: Field Measured Parameters (Cont'd)

Monitoring Well	Date Measured	Headspace Vapour Concentration (ppm)	Temperature (°C)	Electrical Conductivity (at 25°C) (μS/cm)	pH (-)
Middle Bedrock					
05-01C	10-Jun-05	40	7.68	X	13.19
	21-Nov-05	5	6.91	1,389	11.73
	14-Jun-06	<5	7.45	2,382	12.28
Lower Bedrock					
PW06-01	6-Dec-06	---	6.30	4,350	8.98

Notes:
ppm – parts per million.
μS/cm – micro-Siemens/centimetre.
mg/L – milligrams/litre.
--- = not measured or analyzed.
X – data point removed (anomalous).

Table IV-3: Select Inorganic Indicator Data for Groundwater Samples

Monitoring Well	Date (d-m-y)	pH	TDS (mg/L)	Total Hardness as $CaCO_3$ (mg/L)	Carbonate (mg/L)	Bicarbonate (mg/L)	Chloride:D (mg/L)	Fluoride:D (mg/L)	Sulphate:D (mg/L)	NO_2+NO_3 as N (mg/L)	Calcium:D (mg/L)	Magnesium:D (mg/L)	Potassium:D (mg/L)	Sodium:D (mg/L)	Iron:D (mg/L)	Manganese:D (mg/L)	Ion Balance (%)	DOC (mg/L)	Hydrochemical Type
Aesthetic Objective (AO) [1]		---	*500*	---	---	---	*250*	---	*500*	---	---	---	---	*200*	*0.3*	*0.05*	---	---	---
Maximum Acceptable Concentration (MAC) [2]		---	---	---	---	---	---	*1.50*	---	*10.0*	---	---	---	---	---	---	---	---	---
Surficial Deposits																			
05-03A	10-Jun-05	8.4	**2,580**	94	24	1,410	6	0.57	**900**	0.6	20.4	10.4	2.5	**921**	0.012	0.032	98.00	17	Na-HCO_3-SO_4
	11-Nov-05	8.1	**3,110**	132	<5	1,510	9	0.73	**1,170**	<0.1	20.0	20.0	4.0	**1,140**	<0.06	**0.070**	106.00	---	
	15-Jun-06	8.5	**3,070**	126	33	1,480	8	0.74	**1,140**	<0.1	17.0	20.3	3.7	**1,120**	<0.005	**0.239**	104.00	24	
05-05A	10-Jun-05	8.0	**2,000**	63	<5	1,620	5	0.31	435	<0.1	12.0	8.0	2.9	**740**	0.009	**0.050**	93.80	9	Na-HCO_3-SO_4
	11-Nov-05	7.9	**1,970**	69	<5	1,570	3	0.40	368	<0.1	14.0	8.0	3.0	**799**	<0.06	**0.090**	108.00	---	
	15-Jun-06	8.1	**2,160**	83	<5	1,710	4	0.42	456	<0.1	15.4	10.8	2.6	**829**	<0.005	**0.102**	100.00	11	
05-06A	10-Jun-05	8.1	**686**	188	<5	571	5	0.05	148	0.2	56.9	11.2	4.8	178	<0.005	**0.071**	92.30	8	Na-HCO_3-SO_4
	11-Nov-05	7.6	**671**	195	<5	561	2	<0.05	132	<0.1	60.0	11.0	6.0	184	<0.06	**0.10**	100.00	---	
	15-Jun-06	8.0	**717**	221	<5	588	3	0.05	150	0.2	63.6	15.1	5.6	190	<0.005	**0.056**	99.70	8	
05-09A	10-Jun-05	8.6	**765**	21	27	682	4	0.10	98.6	<0.1	8.3	<0.2	1.4	**290**	<0.005	0.010	91.70	7	Na-HCO_3-SO_4
	11-Nov-05	8.3	**758**	15	5	697	3	0.07	94	0	5.0	1.0	2.0	**306**	<0.06	0.010	100.00	---	
	15-Jun-06	8.6	**757**	15	21	671	3	0.06	93.0	<0.1	4.9	0.7	2.1	**302**	<0.005	0.017	98.30	7	
05-10A	10-Jun-05	7.9	**531**	232	<5	543	3	0.14	57.4	0.8	68.4	14.8	4.8	112	<0.005	**0.057**	94.00	10	Na-Ca-Mg-HCO_3-SO_4
	11-Nov-05	7.7	**525**	228	<5	547	3	0.14	46	0	64.0	16.0	7.0	119	<0.06	**0.080**	98.80	---	
	15-Jun-06	8.0	**518**	233	<5	542	3	0.11	41.5	0.2	68.1	15.4	7.1	115	0.293	**0.172**	100.00	18	
05-11A	10-Jun-05	8.4	**1,040**	51	17	778	13	0.31	224	<0.1	17.9	1.6	1.7	**378**	0.008	0.031	95.40	13	Na-HCO_3-SO_4
	11-Nov-05	8.3	**1,170**	35	<5	864	6	0.32	269	<0.1	9.0	3.0	3.0	**457**	<0.06	**0.060**	104.00	---	
	15-Jun-06	8.5	**1,090**	32	23	827	5	0.29	218	<0.1	7.7	3.0	3.1	**425**	<0.005	0.019	101.00	11	
05-20	15-Jun-06	8.2	**3,310**	285	<5	1,490	4	0.76	**1,330**	0.7	58.9	33.4	7.3	**1,130**	<0.005	**0.190**	105.00	<1	Na-HCO_3-SO_4
05-28	15-Jun-06	7.8	**1,860**	1,120	<5	861	19	0.12	**787**	<0.1	269.0	109.0	19.2	229	0.011	**0.296**	106.00	29	Na-HCO_3-SO_4
Upper Bedrock																			
05-01B	28-May-05	8.4	**718**	40	12	660	3	0.19	87.0	<0.1	13.2	1.7	3.2	**274**	0.010	0.017	97.60	48	Na-HCO_3-SO_4
	11-Nov-05	8.1	**716**	41	<5	678	3	0.17	83	<0.1	13.0	2.0	4.0	**277**	<0.06	0.020	100.00	---	
05-03BI	10-Jun-05	8.5	**854**	16	23	846	2	0.34	68.1	<0.1	6.5	<0.2	1.4	**337**	0.012	0.012	93.30	10	Na-HCO_3
	11-Nov-05	8.3	**859**	19	<5	891	3	0.34	57.0	<0.1	6.0	1.0	3.0	**351**	<0.06	0.010	99.00	---	
05-03BII	10-Jun-05	8.4	**944**	32	19	835	3	0.34	140	<0.1	12.5	0.2	1.4	**358**	<0.005	0.024	93.80	11	Na-HCO_3-SO_4
	11-Nov-05	8.3	**926**	24	<5	869	3	0.33	115	<0.1	7.0	1.0	3.0	**369**	<0.06	0.040	99.30	---	
05-06B	10-Jun-05	8.1	**699**	171	<5	611	5	0.07	126	<0.1	53.6	9.0	6.0	199	<0.005	**0.151**	95.70	8	Na-HCO_3-SO_4
	11-Nov-05	7.8	**685**	153	<5	584	3	0.08	126	<0.1	49.0	8.0	6.0	**206**	<0.06	**0.170**	99.20	---	
05-09B	10-Jun-05	8.5	**754**	21	23	667	3	0.12	101	<0.1	8.4	<0.2	1.8	**289**	<0.005	0.014	93.90	8	Na-HCO_3-SO_4
	11-Nov-05	8.4	**779**	19	16	698	3	0.13	102	<0.1	6.0	1.0	2.0	**306**	<0.06	0.010	96.90	---	
05-10B	10-Jun-05	8.0	**537**	197	<5	572	2	0.11	47.4	<0.1	62.0	10.3	6.6	127	0.055	**0.094**	92.50	5	Na-Ca-HCO_3
	11-Nov-05	7.7	**549**	220	<5	561	3	0.13	53	0.0	69.0	12.0	7.0	128	<0.06	**0.220**	97.50	---	
Middle Bedrock																			
05-01C	10-Jun-05	12.6	**3,030**	335	212	<5	9	0.61	73.3	0.5	131.0	2.0	22.2	**1,100**	0.133	<0.001	95.20	6	
	24-Nov-05	12.2	**969**	35	107	<5	10	---	20.2	0.2	14.0	<0.1	4.2	**379**	0.109	<0.001	92.20	---	
Lower Bedrock																			
PW06-01	6-Dec-06	8.8	**3,240**	52	7	59	**1,980**	**2.94**	9.8	<0.1	16.8	2.4	5.9	**1,190**	<0.005	**2.4**	92.20	11	Na-Cl

Notes:

[1] Health Canada (2004) AO Guideline.

[2] Health Canada (2004) MAC Guideline.

--- denotes parameter not analysed or not applicable.

Bolded items indicate parameter concentration exceeds applicable guideline.

Table IV-4: Dissolved Metal Data for Groundwater Samples

Monitoring Well	Date	Aluminum:D	Barium:D	Beryllium:D	Boron:D	Cadmium:D	Chromium:D	Cobalt:D	Copper:D	Lead:D	Molybdenum:D	Nickel:D	Silicon:D	Silver:D	Strontium:D	Thallium:D	Tin:D	Titanium:D	Vanadium:D	Zinc:D
	(d-m-y)	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*	*(mg/L)*
Aesthetic Objective (AO) [1]		---	---	---	---	---	---	---	*1*	---	---	---	---	---	---	---	---	---	---	*5*
Maximum Acceptable Concentration (MAC) [2]		*0.1*	*1*	---	*5*	*0.005*	*0.05*	---	---	*0.01*	---	---	---	---	---	---	---	---	---	---
Surficial Deposits																				
05-03A	10-Jun-05	0.01	0.126	<0.001	0.30	<0.001	<0.005	<0.002	0.003	<0.005	0.023	0.005	4.4	<0.005	0.209	<0.05	<0.05	0.002	<0.001	0.007
	15-Jun-06	<0.01	0.065	<0.001	0.44	<0.001	0.007	0.003	0.007	<0.005	0.023	0.012	5.3	<0.005	0.309	<0.05	<0.05	0.001	<0.001	0.011
05-05A	10-Jun-05	<0.01	0.147	<0.001	0.35	<0.001	<0.005	<0.002	0.006	<0.005	<0.005	0.002	5.7	<0.005	0.194	<0.05	<0.05	0.001	<0.001	0.004
	15-Jun-06	<0.01	0.071	<0.001	0.48	<0.001	0.008	<0.002	0.005	<0.005	<0.005	0.004	7.7	<0.005	0.205	<0.05	<0.05	0.001	<0.001	0.006
05-06A	10-Jun-05	<0.01	0.152	<0.001	0.10	<0.001	0.014	<0.002	0.004	<0.005	<0.005	0.006	4.2	<0.005	0.331	<0.05	<0.05	<0.001	<0.001	0.006
	15-Jun-06	<0.01	0.114	<0.001	0.13	<0.001	<0.005	<0.002	0.006	<0.005	<0.005	0.005	6.3	<0.005	0.447	<0.05	<0.05	<0.001	<0.001	0.005
05-09A	10-Jun-05	<0.01	0.043	<0.001	0.25	<0.001	0.015	<0.002	0.003	<0.005	<0.005	<0.002	3.0	<0.005	0.077	<0.05	<0.05	<0.001	<0.001	0.003
	15-Jun-06	<0.01	0.030	<0.001	0.24	<0.001	<0.005	<0.002	0.045	<0.005	<0.005	<0.002	4.6	<0.005	0.066	<0.05	<0.05	<0.001	<0.001	0.010
05-10A	10-Jun-05	<0.01	0.086	<0.001	0.11	<0.001	0.013	<0.002	0.003	<0.005	<0.005	0.004	5.2	<0.005	0.512	<0.05	<0.05	<0.001	<0.001	0.005
	15-Jun-06	<0.01	0.088	<0.001	0.11	<0.001	<0.005	<0.002	0.014	<0.005	<0.005	0.004	5.9	<0.005	0.746	<0.05	<0.05	<0.001	<0.001	0.004
05-11A	10-Jun-05	0.01	0.041	<0.001	0.13	<0.001	<0.005	<0.002	0.008	<0.005	<0.005	0.003	2.9	<0.005	0.137	<0.05	<0.05	0.001	<0.001	0.005
	15-Jun-06	<0.01	0.026	<0.001	0.15	<0.001	<0.005	<0.002	0.021	<0.005	<0.005	0.003	3.9	<0.005	0.101	<0.05	<0.05	<0.001	0.001	0.004
05-20	15-Jun-06	<0.01	0.030	<0.001	0.11	<0.001	0.007	<0.002	0.009	<0.005	<0.005	0.011	5.7	<0.005	1.35	<0.05	<0.05	0.002	0.001	0.011
05-28	15-Jun-06	<0.01	0.075	<0.001	0.20	<0.001	0.005	<0.002	0.007	<0.005	<0.005	0.004	7.5	<0.005	1.91	<0.05	<0.05	0.001	<0.001	0.009
Upper Bedrock																				
05-01B	28-May-05	<0.01	0.029	<0.001	0.32	<0.001	<0.005	<0.002	<0.001	<0.005	<0.005	<0.002	4.2	<0.005	0.179	<0.05	<0.05	0.001	<0.001	0.035
05-03BI	10-Jun-05	0.01	0.036	<0.001	0.26	<0.001	<0.005	<0.002	<0.001	<0.005	<0.005	<0.002	4.1	<0.005	0.115	<0.05	<0.05	0.002	<0.001	0.006
05-03BII	10-Jun-05	<0.01	0.076	<0.001	0.20	<0.001	<0.005	<0.002	0.001	<0.005	<0.005	<0.002	3.6	<0.005	0.139	<0.05	<0.05	0.001	<0.001	0.004
05-06B	10-Jun-05	<0.01	0.038	<0.001	0.16	<0.001	0.015	<0.002	0.002	<0.005	<0.005	<0.002	4.9	<0.005	0.453	<0.05	<0.05	<0.001	<0.001	0.005
05-09B	10-Jun-05	<0.01	0.040	<0.001	0.24	<0.001	0.014	<0.002	0.003	<0.005	<0.005	<0.002	3.1	<0.005	0.091	<0.05	<0.05	<0.001	<0.001	0.004
05-10B	10-Jun-05	<0.01	0.089	<0.001	0.12	<0.001	0.013	<0.002	0.004	<0.005	<0.005	<0.002	5.7	<0.005	0.602	<0.05	<0.05	0.001	<0.001	0.009
Middle Bedrock																				
05-01C	10-Jun-05	**0.61**	0.311	<0.001	0.06	<0.001	0.023	<0.002	0.009	<0.005	0.061	<0.002	1.2	<0.005	2.880	<0.05	<0.05	<0.001	0.003	0.005
	24-Nov-05	**0.57**	0.070	<0.001	0.26	<0.001	<0.005	<0.002	0.005	<0.005	0.055	<0.002	---	<0.005	0.663	<0.05	<0.05	<0.001	0.012	0.008
Lower Bedrock																				
PW06-01	6-Dec-06	0.01	0.916	<0.001	0.31	<0.001	0.032	<0.002	0.014	<0.005	0.363	<0.002	0.7	<0.005	0.641	<0.05	<0.05	<0.001	0.010	0.025

Notes:
[1] Health Canada (2004) AO Guideline.
[2] Health Canada (2004) MAC Guideline.
--- denotes parameter not analysed or not applicable.
Bolded items indicate parameter concentration exceeds applicable guideline.

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Appendix V: AENV Water Well Database Search within 3 km Radius of the Site

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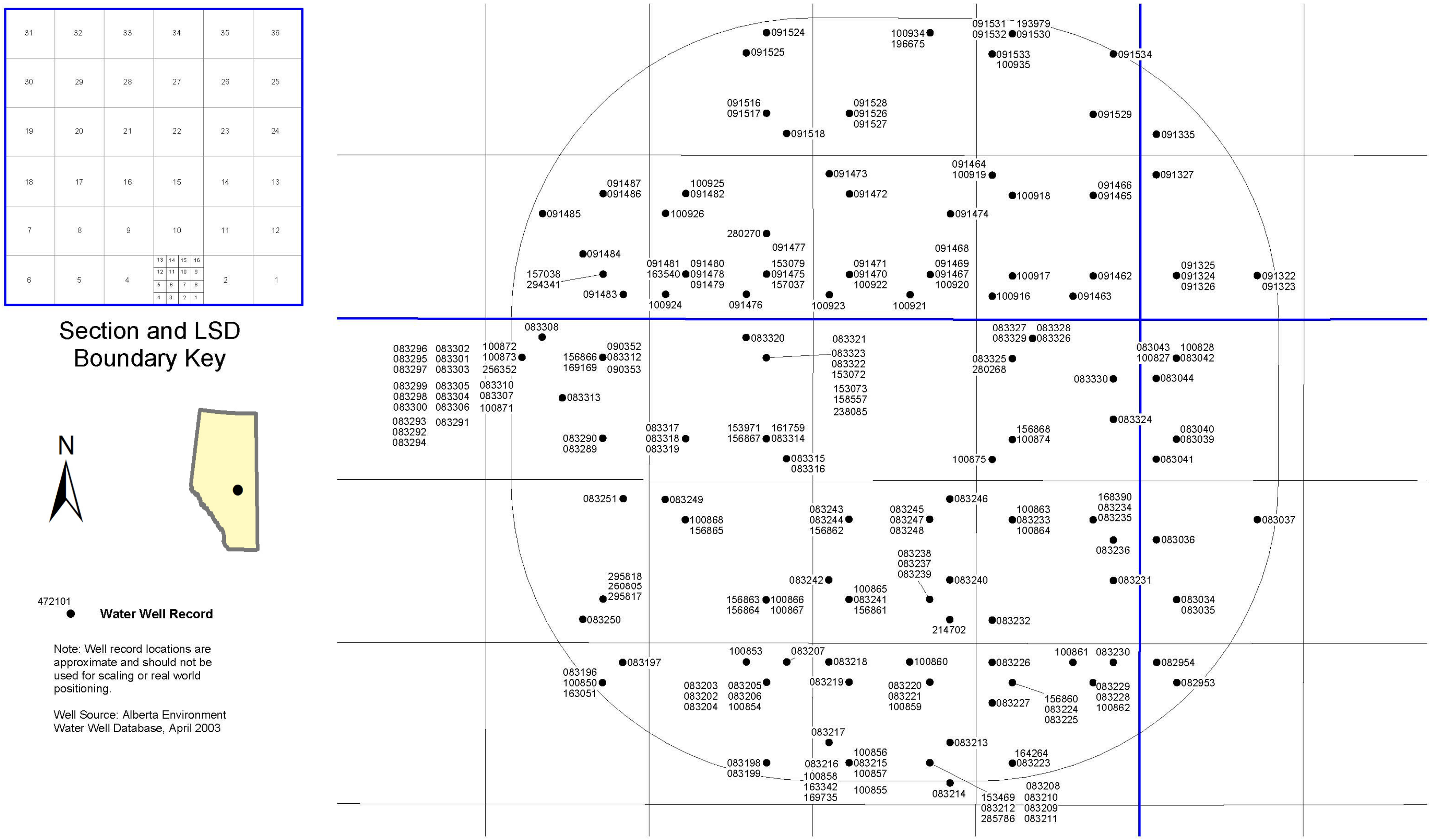

Note: Well record locations are approximate and should not be used for scaling or real world positioning.

Well Source: Alberta Environment Water Well Database, April 2003

Figure V–1: Water Well Records within a 3 km Radius of 35-55-20 W4M

Table V–1: Water Well Records within a 1 km radius of 35-55-20W4M

WELLID	LSD	SECTION	TOWNSHIP	RANGE	MERIDIAN	WELL_FINIS	WELLDEPTH_	PERFROM1_M	PERFTO1_M_	PERFROM2_M	PERFTO2_M_	PERFROM3_M	PERFTO3_M_	SCRNFROM1_	SCRNTO1_M_	SCRNFROM2_	SCRNTO2_M_	PROPOSED_U	TYPE_WORK	DRILL_METH	DATECOMPL	ABANDOND_D
083233	NW	25	055	20	4	Cribbed	12.50											Domestic & Stock	New Well	Bored	4/4/1989	
083240	08	26	055	20	4	Open hole	227.13											Industrial	Oil Exploratory	Rotary	3/2/1979	
083242	05	26	055	20	4	Casing/open hole	64.02											Domestic	New Well	Drilled	9/5/1964	
083243	NW	26	055	20	4	Unknown	14.33											Domestic	Chemistry	Unknown		
083244	NW	26	055	20	4	Cribbed	11.89											Domestic & Stock	Well Inventory	Bored		
083245	NE	26	055	20	4	Unknown	41.16											Stock	Well Inventory	Drilled		
083246	16	26	055	20	4	Unknown	9.15											Domestic & Stock	Federal Well Survey	Bored	1/1/1924	
083247	NE	26	055	20	4	Unknown	18.29											Domestic	Chemistry	Unknown		
083248	NE	26	055	20	4	Unknown	35.06											Domestic	Chemistry	Unknown		
083314	SE	34	055	20	4	Unknown	22.87											Domestic	Chemistry	Unknown		
083315	01	34	055	20	4	Unknown	33.54											Domestic & Stock	Federal Well Survey	Bored	1/1/1925	
083316	01	34	055	20	4	Unknown	9.15											Domestic	Chemistry	Hand Dug		
083320	15	34	055	20	4	Unknown	23.78											Domestic & Stock	Federal Well Survey	Bored	1/1/1914	
083321	NE	34	055	20	4	Unknown	12.20											Domestic	Chemistry	Unknown		
083322	NE	34	055	20	4	Unknown	12.20											Domestic	Chemistry	Unknown		
083323	NE	34	055	20	4	Unknown	9.15											Domestic	Chemistry	Unknown		
083324	08	36	055	20	4	Unknown	20.43											Domestic	Federal Well Survey	Bored		
083325	NW	36	055	20	4	Unknown	24.39											Domestic	Chemistry	Unknown		
083326	14	36	055	20	4	Open Hole	64.02											Stock	Dry Hole	Rotary	7/26/1979	
083327	14	36	055	20	4	Cribbed	25.30											Domestic	New Well	Bored	8/15/1979	
083328	14	36	055	20	4	Unknown	17.99											Domestic	Federal Well Survey	Bored	1/1/1917	
083329	14	36	055	20	4	Casing/open hole	62.80											Stock	New Well	Rotary	8/9/1966	
091463	02	01	056	20	4	Unknown	12.20											Domestic & Stock	Federal Well Survey	Hand Dug	1/1/1932	
091467	SE	02	056	20	4	Unknown	6.10											Stock	Well Inventory	Hand Dug		
091468	SE	02	056	20	4	Unknown												Domestic	Chemistry	Unknown		
091469	SE	02	056	20	4	Unknown	19.51											Domestic	Chemistry	Unknown		
091470	SW	02	056	20	4	Screen	30.49							24.38	30.48			Stock	New Well	Rotary	11/28/1987	
091471	SW	02	056	20	4	Unknown												Domestic	Chemistry	Drilled		
091475	SE	03	056	20	4	Cribbed	12.20											Domestic	Chemistry	Unknown		
091476	02	03	056	20	4	Unknown	4.88											Domestic	Federal Well Survey	Hand Dug		
091477	SE	03	056	20	4	Screen	18.29							14.63	18.29			Stock	New Well	Rotary	8/10/1989	
100863	NW	25	055	20	4	Unknown	58.54											Domestic	Chemistry	Unknown		
100864	NW	25	055	20	4	Casing/perforated liner	57.62	27.43	57.61									Domestic	New Well	Rotary	6/26/1975	
100874	SW	36	055	20	4	Unknown	18.29											Domestic	Chemistry	Unknown		
100875	04	36	055	20	4	Unknown	18.29											Domestic & Stock	Federal Well Survey	Bored		
100916	04	01	056	20	4	Unknown	11.59											Domestic & Stock	Federal Well Survey	Bored	1/1/1921	
100917	SW	01	056	20	4	Unknown	9.15											Domestic	Chemistry	Unknown		
100920	SE	02	056	20	4	Unknown	9.76											Domestic	Well Inventory	Bored		

Table V–2: Water Well Records within a 3 km radius of 35-55-20W4M (Cont'd)

WELLID	LSD	SECTION	TOWNSHIP	RANGE	MERIDIAN	WELL_FINIS	WELLDEPTH_	PERFROM1_M	PERFTO1_M_	PERFROM2_M	PERFTO2_M_	PERFROM3_M	PERFTO3_M_	SCRNFROM1_	SCRNTO1_M_	SCRNFROM2_	SCRNTO2_M_	PROPOSED_U	TYPE_WORK	DRILL_METH	DATECOMPL	ABANDOND_D
100921	02	02	056	20	4	Unknown	9.76											Domestic	Federal Well Survey	Bored	1/1/1926	
100922	SW	02	056	20	4	Unknown	9.76											Unknown	Chemistry	Unknown		
100923	04	02	056	20	4	Unknown	10.06											Domestic & Stock	Federal Well Survey	Bored	1/1/1900	
153072	NE	34	055	20	4	Perforated casing/liner	24.39											Stock	New Well	Bored	4/12/1983	
153073	NE	34	055	20	4	Casing/perforated liner	56.40											Domestic	New Well	Rotary	8/1/1966	
153079	SE	03	056	20	4	Casing/perforated liner	15.24											Stock	New Well	Cable Tool	11/16/1983	
153469	SE	23	055	20	4	Unknown	15.55	4.57	13.72									Domestic & Stock	New Well	Bored	7/12/1990	
153971	SE	34	055	20	4	Not applicable	21.65											Unknown	Old Well-Abandoned	Bored	6/1/1990	
156862	NW	26	055	20	4	Not applicable	24.39											Domestic	Chemistry	N/a		
156867	SE	34	055	20	4	Not applicable												Domestic	Chemistry	N/a		
156868	SW	36	055	20	4	Not applicable	16.77											Domestic	Chemistry	N/a		
157037	SE	03	056	20	4	Not applicable	24.39											Domestic	Chemistry	N/a		
158557	NE	34	055	20	4	Not applicable	22.87											Domestic	Chemistry	Rotary		
161759	SE	34	055	20	4	Not applicable	22.87											Domestic	Chemistry	N/a		
238085	NE	34	055	20	4	Perforated casing/liner	23.48	13.72	22.86									Domestic & Stock	New Well	Bored	6/11/1993	
280268	NW	36	055	20	4	Cribbed	17.38											Domestic	Chemistry	Bored		
280270	EH	03	056	20	4	Unknown	45.73											Domestic	Chemistry	Unknown		

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Appendix VI: Assessment Methods – Groundwater Quantity

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1. Assessment Methods – Groundwater Quantity

1.1 Background

The groundwater response to Project water withdrawals (pumping) in the upper bedrock sandstone aquifer was calculated based on the following three scenarios:

- Scenario 1: The upper bedrock aquifer behaves as confined (i.e., it is overlain by significant low permeability strata such as the till encountered at the Site) and will receive no recharge over the project lifetime. This is the most conservative scenario.
- Scenario 2: The upper bedrock aquifer is confined but is "leaky" and receives some inflows from groundwater recharge through the overlying till and/or areas where the till is absent. This is believed to be the most likely scenario for the Site.
- Scenario 3: The upper bedrock aquifer can be treated as unconfined (i.e., its response to pumping is dominated by windows in the till, such as the area of silty sand encountered near the plant site). This is the most optimistic scenario.

In confined (non-leaky) aquifers (Scenario 1), water is released from storage due to decompression of the aquifer, which leads to expansion of the fluid (water) and compression of the pore space (Freeze and Cherry 1979). These water release mechanisms are described by the aquifer storativity coefficient (S), while the rate at which water can flow towards the well is described by aquifer transmissivity (T). Higher values of T and S correspond to more productive aquifers and thus less drawdown for a given pumping rate at a certain distance from the well. Conversely, lower values of T and S result in greater drawdown for the same pumping rate and distance from the well.

Leaky confined aquifers (Scenario 2), behave similar to non-leaky confined aquifers, with the important difference that some inflows may be received from overlying geologic layers, as described by a leakage factor (Kruseman and de Ridder 1994). This leads to smaller drawdown in leaky confined aquifers compared to non-leaky confined aquifers that are of similar transmissivity and storativity.

In unconfined aquifers (Scenario 3), water is not only released from storage due to decompression of the aquifer (i.e., storativity) but also from drainage at the water table, as described by the aquifer specific yield (S_y). This more effective water release mechanism (S_y is typically several orders of magnitude greater than S) leads to smaller drawdown in unconfined aquifers compared to confined aquifers that are of similar transmissivity (Freeze and Cherry 1979).

Scenarios 1 and 3 were evaluated using the Theis (1935) analytical (type curve) solution for non-leaky confined aquifers while Scenario 2 was evaluated using the Hantush and Jacob (1955) solution for leaky confined aquifers. The Theis and Hantush-Jacob solutions are computational methods to assess the potential response of an aquifer to pumping at various distances from a production well and are described in detail in Kruseman and de Ridder (1994). Their main assumptions are also summarized below.

1.1.1 Solution Assumptions

The Theis solution was derived for simulating the response of confined non-leaky aquifers to pumping. The main assumptions of the Theis solution are:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- pumping well is fully penetrating
- flow to pumping well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- no recharge or leakage is occurring to the aquifer

The response of unconfined aquifers can also be described by the Theis solution after sufficiently long pumping periods (Kruseman and de Ridder 1994), with the important difference that the aquifer storativity coefficient should be replaced by specific yield.

The Hantush and Jacob (1955) type curve solution differs from the Theis solution in the final assumption of no recharge or leakage occurring to the aquifer, which is replaced by the following set of assumptions:

- aquifer is leaky
- confining bed(s) has infinite areal extent, uniform vertical hydraulic conductivity and uniform thickness
- confining bed(s) is overlain or underlain by an infinite constant-head plane source
- flow in the aquitard(s) is vertical

Compared to the Theis solution, the Hantush and Jacob solution for confined leaky aquifers requires as additional input, the specification of a leakage factor r/B, which depends on the distance between the pumping well and a point of observation and the parameter B, calculated as follows:

$$B = \sqrt{\frac{Tb'}{K'}}$$

in which b’ is the thickness of the overlying leaky aquitard and K’ is the hydraulic conductivity of the aquitard. As in the Theis solution, T represents aquifer transmissivity.

1.1.2 Input Parameters

1.1.2.1 Scenario 1

In using the Theis solution for representing Scenario 1, the following input parameters were required:

- aquifer saturated thickness (b): a value of b = 6 m was assumed for the upper bedrock sandstone aquifer, based on the results of the baseline geologic characterization conducted at the Site
- aquifer transmissivity (T): the value of T = 4.6 m^2/day (5.3 x 10^{-5} m^2/s) determined from the 2-hour pumping test conducted at well 05–01B was used in the calculations
- aquifer storativity (S): a value for aquifer storativity could not be determined from data for the 2-hour pumping test. Hence, a range of theoretical but realistic aquifer storativity values (e.g., Freeze and Cherry 1979) was considered in the calculations: S = 0.00005, 0.0005 and 0.005 (hereafter referred to as low S, mid S and high S cases).
- pumping well construction: it was assumed that the production well fully penetrates the aquifer. A casing radius and effective well radius of 0.075 m and 0.15 m were assumed, respectively.
- rate of water withdrawal at the pumping well: a constant pumping rate of 1.3 x 10^{-4} m^3/s was assumed to occur over a 25 year period

1.1.2.2 Scenario 2

In using the Hantush-Jacob solution for representing Scenario 2, required input parameters were identical to those for Scenario 2 with the following additional parameters required:

- till thickness (b’): a thickness of b’ = 5 m was assumed for the till, based on the results of the baseline geologic characterization conducted at the Site
- aquitard hydraulic conductivity (K’): because of the assumption of an infinite constant-head plane source atop the till aquitard, the Hantush-Jacob solution would tend to overestimate the amount of leakage to the upper sandstone aquifer if K’ were to be used directly. Actual leakage (i.e., groundwater recharge) is limited by seasonal water availability (i.e., precipitation and evapotranspiration). To accommodate this, the value of K’ was adjusted downward to reflect regional estimates of groundwater recharge rates (R) for areas characterized by till covers. A possible range of groundwater recharge rates corresponding to 1%, 3% and 5% of the annual precipitation of 460 mm was considered in the calculations, as based on regional estimates for till covered terrain (see Volume IIB, Section 2: Groundwater Quantity and Quality – Section 2.5.4). These percentages correspond to recharge rates of 5, 15 and 25 mm/y (hereafter referred to as low R, mid R and high R cases) and are believed to be reflective of potential long-term recharge rates to the upper bedrock sandstone aquifer over the bulk of the LSA. Higher recharge rates might be expected locally where the silty sand is exposed at surface (i.e., in the vicinity of 05–10A/B).

1.1.2.3 <u>Scenario 3</u>

In treating the aquifer as unconfined (Scenario 3), input parameters to the Theis solution were identical to those for Scenario 1, with the exception that aquifer storativity (S) was replaced by aquifer specific yield (Sy):

- a range of theoretical but realistic aquifer specific yield values (e.g., Freeze and Cherry 1979) was considered in the calculations: S = 0.05, 0.1 and 0.2 (hereafter referred to as low Sy, mid Sy and high Sy cases)

1.1.3 Results

With the above input parameters, the three analytical (type curve) solutions were used to calculate drawdown in the sandstone aquifer at various distances from the pumping well. The results from these calculations are summarized below and are identical to those presented in the groundwater quantity projects effects assessment (Volume IIB, Section 2: Groundwater Quantity and Quality).

Table VI– 1: Theoretical Drawdown in Upper Sandstone Bedrock Aquifer for Single 1.3 x 10^{-4} m^3/s Production Well after 25 years – Comparison by Scenario and Aquifer Parameters

Scenario (Analytical Solution)	**Input Parameters**				**Distance from pumping well (m) (Geographical Extent)**				
					0.5 (PW)	**100 (PDA)**	**1000 (LSA)**	**2000 (RSA)**	**3000 (RSA)**
		S (-)	**Sy (-)**	**R (mm/y)**	**Drawdown (m)**				
Confined aquifer (Theis)	Low S	0.00005	-	-	4.3	2.4	1.5	1.2	1.1
	Mid S	0.0005	-	-	4.0	1.9	1.0	0.8	0.6
	High S	0.005	-	-	3.7	1.5	0.6	0.4	0.2
Leaky aquifer (Hantush-Jacob)	Low R	0.0005	-	5	3.7	1.1	**0.2**	**0.07**	**0.03**
	Mid R	0.0005	-	15	3.7	0.9	**0.1**	**0.02**	**0.003**
	High R	0.0005	-	25	3.3	0.7	**0.1**	**0.007**	**0.001**
Unconfined aquifer (Theis)	Low Sy	0.0005	0.05	-	3.7	1.0	**0.2**	**0.03**	**0.0007**
	Mid Sy	0.0005	0.1	-	3.7	0.9	**0.1**	**0.007**	**0.0003**
	High Sy	0.0005	0.2	-	3.3	0.8	**0.03**	**0.0003**	**0.00003**

Notes:

PW – pumping well.

S – storativity, Sy – specific yield, R – recharge.

Bolded values reflect drawdown below natural (seasonal) variability in water levels of 0.2–0.5 m.

2. References

2.1 Literature Cited

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Volume IIB – Water and Aquatic Ecology

3. Surface Water Quantity

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Environment & Water Resources
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APPENDICES

Executive Summary

Alberta Sulphur Terminals Ltd. (AST), a division of HAZCO Environmental Services (HAZCO) which, in turn, is a division of CCS Income Trust (CCS), retained WorleyParsons Komex to complete a hydrological assessment of the proposed plant site for the Bruderheim Sulphur Forming and Shipping Facility (the Project) located on a portion of Section 35-55-20 W4M (the Site). The objectives of the surface water quantity assessment were as follows:

- satisfy the relevant section of the Terms of Reference (TOR) of the Environmental Impact Assessment (EIA) (AENV 2007)
- assess the hydrological suitability of the Site for the proposed Project
- provide initial hydrological design recommendations
- establish a hydrological monitoring program for the proposed Project

The surface water hydrology assessment confirmed that the Site was suitable for siting the proposed Project. The aspects of the TOR that are relevant to the surface water hydrology assessment and the respective conclusions of the assessment are summarized as follows.

Discuss baseline surface hydrology conditions. Identify components of the Project that will affect these conditions from a local and regional perspective. Discuss:

a) *existing drainage patterns, surface water bodies, and wetlands within local and regional Study Areas, and the seasonal flow/water level characteristics of these water bodies;*

   The Site is generally dry most of the year, with ephemeral drainages conveying surface runoff south to north during freshet and rainfall events. A small wetland is present in the northwest corner but dries up by late summer. Other small wetlands exist in the Site as a result of railways blocking natural flow pathways. A small seep is also present near the geographic centre of the property.

b) *Project-related temporary and permanent alterations to these drainage patterns, water bodies and wetlands;*

   There will be no significant Project-related or permanent alterations to drainage patterns, waterbodies or wetlands.

c) *possible water diversions from and return flows to these drainage channels, water bodies and wetlands under a variety of operating conditions and scenarios including, emergency conditions, low flow, or drought conditions;*

   There will be no direct water diversions from any drainage channels, waterbodies or wetlands.

d) *effects of site runoff management on flow/level characteristics and aquatic functions in these drainage channels, water bodies and wetlands;*

   The runoff from the immediate plant site will be contained in a pond and reused for non-contact cooling. The area of the immediate plant site is only 3.6% of the total drainage area, and thus, containment of this runoff is not expected to have a measurable affect on water levels or aquatic function of drainage channels, waterbodies or wetlands downstream. The pond is designed to contain runoff from the 25 year storm event. Runoff exceeding the capacity at the pond will be discharged into a nearby ephemeral drainage provided it meets approved discharge criteria.

e) *mitigation plans to minimize these effects;*

Mitigation is not required as measurable impacts are not anticipated.

f) *the relative contribution by the Project (after mitigation) to regional cumulative pressures on surface water resources; and*

The Project will not have a measurable impact to cumulative pressures on surface water resources.

g) *a monitoring program to assess hydrological impacts and assess performance of mitigation plans and water management systems.*

Water levels will be continuously monitored in the wetland in the northwest corner of the Site to validate the assessment made in the EIA.

All surface water that comes in contact with the sulphur handling and pastille storage areas will be collected and stored in a surface water runoff collection pond. This pond will be double-lined and equipped with leak detection monitoring to ensure that potentially acidic water is not released to the ground or to the surrounding watershed. Water contained within the lined pond will be used as cooling water in the sulphur forming process. Excess water will be neutralized and monitored prior to being released to the surrounding watershed. Design details for the surface water runoff pond and ditching are illustrated in Volume I: Project Description, Figure 3.5-1. The following design features were included to mitigate the risk of contaminating surface and groundwater as a result of operating the proposed facilities:

- areas surrounding the sulphur handling areas will be sloped away from the facility to prevent surface water run-on
- runoff from the sulphur forming and storage areas will be collected in a perimeter ditch lined with high density polyethylene (HDPE)
- the capacity of the surface water runoff pond exceeds the volume of runoff generated by the 1 in 25 years, 24 hour rainfall event. The pond is double-lined (60 mil HDPE liner over compacted clay soil) and includes a leak detection system to ensure that potentially impacted surface water is not released to the underlying aquifers
- capacity will 10,980 m^3, allowing for 300 mm of freeboard
- the pastille storage area will be lined with asphalt pavement and is underlain by compacted clay soil minimizing seepage of surface water into the surrounding ground
- water collected in the surface water runoff collection pond may be neutralized by adding free lime on a batch-basis, as needed

Freshwater consumption will be minimized by utilizing surface water in the process, and by recycling water used in the cooling process. The water diversions will be limited to the area of sulphur handling and will be temporary. All plans are consistent with standard design and operating practices for sulphur management facilities.

Monitoring of surface water quality will be implemented to preclude accidental release of acidic water from the surface water runoff collection pond. Grab samples will be collected immediately prior to release of any water to the environment. Any water that is potentially discharged from the Site will be sampled and tested to comply with the following generic criteria:

- no visible sheen
- $6<pH<9$

- chemical oxygen demand (COD) <50 mg/L
- chloride <500 mg/L
- total suspended solids (TSS) <50 mg/L

Samples will be collected and analyzed on a batch basis prior to releasing treated water to the environment. Discharge limits for specific contaminants (if and when suspected) will be determined in accordance with the Water Quality Based Effluent Limits Procedures Manual.

h) baseline surface water quality;

i) water quality of watercourses and water bodies in the Study Areas before and after Project development and operation. The description of water quality will consider all appropriate water quality parameters, (e.g., temperature, pH, conductivity, cations and anions, metals, dissolved oxygen, suspended sediment, dissolved solids, nutrients and other water contaminants) their seasonal variations and relationships to flow and other controlling factors, and a summary of existing water quality data including necessary surveys to characterize water quality of watercourses and water bodies in the Study Areas;

Seasonal baseline water quality data were collected in the Surface Water Quantity Local Study Area (LSA) and Regional Study Area (RSA). Parameters analyzed included temperature, pH, conductivity, dissolved oxygen, cations and anions, total and dissolved trace elements, suspended sediment, nutrients and hydrocarbons. In general, regional watercourses (Beaverhill Creek and Lamont Creek) demonstrate eutrophic or hypereutrophic trophic signatures, with water having high nutrient concentration. This is likely a consequence of municipal sewage discharge into Lamont Creek. Seasonality exerts a dominant influence on the water quality of Beaverhill Creek and Lamont Creek, with creek water being higher in salts and trace elements during the winter when flows consist predominantly of groundwater discharge. All water features (including the wetlands on the Site) were highly mineralized (total dissolved solids ranging from 283–1,380 mg/L) and are moderately to highly alkaline. Surface water within the LSA is of predominantly Na-HCO_3 hydrochemical type, similar to that of local groundwater chemistry.

In addition, snow quality sampling was conducted at six locations within the LSA to capture the influence of atmospheric deposition. Snow quality data indicate that, in general, snow quality is not influenced substantially by acid generating deposits.

Sediment samples were also collected and analyzed for trace elements and hydrocarbons. Metal concentrations in most sediment samples were generally below the Canadian Council of Ministers of the Environment (CCME) interim freshwater sediment quality guidelines (ISQGs; dry weight) and probable effect levels with some exceptions at a few sampling locations (cadmium, zinc, arsenic and copper).

j) the significant and potential impacts to surface water quality within the Study Areas resulting from the Project, including site runoff and Project-related wastewater discharges, that may indicate a potential adverse effect or exceedance of the Surface Water Quality Guidelines for Use in Alberta (November 1999) or Canadian Water Quality Guidelines;

In general, the Project is not expected to have any significant impacts to surface water quality within the study areas. Potentially, the impact of increased runoff during high rainfall events may in some circumstances have a negative direction, as sediment loading may increase. This is more of a concern during Project construction. Provided mitigation measures are implemented appropriately, the impacts to surface water quality within the LSA and RSA are in general considered to be low to moderate in magnitude, local in geographic extent (i.e., within property boundary), short term in duration and reversible.

k) *the potential Project related and cumulative impacts of acidifying and other air emissions on surface water quality;*

Baseline surface water and snow quality data collection indicates that regional acid deposition is not having any measurable impact to surface water quality. Assuming that all mitigation measures are implemented appropriately and given the high buffering capability and low sensitivity of waterbodies in the study areas to acid deposition, it is anticipated that impacts to surface water quality from acid deposition arising out of normal operational activities within the LSA and RSA will be low to moderate in magnitude, local in geographic extent (i.e., within property boundary), mid-term in duration and reversible.

l) *effects of site runoff on water quality in surface waterbodies within the Study Area;*

There will be no site run-off under all but extreme run-off conditions. Hence no impact to water quality in surface water ponding related to run-off is anticipated.

m) *the impacts to surface water quality within the Study Areas due to the change in groundwater movement, spills and contaminated groundwater resulting from spills;*

Groundwater pumping test analyses (see Volume IIB, Section 2: Groundwater Quantity and Quality) indicate that Project water withdrawals may lead to the reduction of groundwater inflows to the wetland area in the northwest quarter section of the Principal Development Area (PDA). However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total annual water balance inflows, the termination of baseflow to the wetland is considered to have a negligible impact on surface water quality. None of the other drainages on site are considered to be groundwater fed and lowering of groundwater levels will not impact surface water quality in these features.

The time required for groundwater to travel from the PDA to the north Site boundary, which is effectively the closest discharge point (wetland), is between 100 and 1,000 years. This long travel time allows for deployment of remediation technologies, and thus, potentially contaminated groundwater would not measurably impact surface water features. In addition, the aquifer is not considered to be vulnerable to contamination due to the presence of a protective surface till layer and the low risk of the Project activities.

n) *mitigation plans to minimize these effects during the construction, operation and reclamation phases of the Project;*

Several surface water management mitigation measures will be implemented to minimize possible changes to water level and flow, erosion potential and possible changes to basin sediment yield and loading to receiving watercourses. Measures include but are not limited to:

- using stormwater management facilities, such as berms, drainage ditches and collection pond to collect, convey and contain surface water runoff from the plant areas. These will be designed to provide full on-Project area storage of local runoff and excess plant process water. The capacity of the stormwater management pond will be approximately 11,000 m^3, which exceeds the run-off generated by the 1 in 25 year, 24 hour rainfall event. Surface water within the stormwater management pond will be stored and used as cooling water. In a flood situation where runoff exceeds the design criteria of the pond, the water would be tested for quality, treated (if required) and released to the environment provided that the water quality meets Surface Water Quality Guidelines for Use in Alberta (AENV 1999b). Water will be released in the natural grassed swale immediately east of the PDA where it will discharge into the wetland in the northwest quadrant of the Site. This wetland will provide additional natural filtration and impoundment before being discharged downstream to Beaverhill Creek.

- siting the facilities back at least 100 m from waterbodies where practicable, to minimize potential disturbances to riparian conditions and effects on local flow patterns. This will also provide an area for attenuation and dispersal of stormwater runoff before entering any natural waterbodies.

- providing culverts or bridges at defined watercourse crossings, ephemeral drainages and low points along road alignments. These will eliminate potential flow restrictions and maintain natural drainage patterns. Culverts will be provided as required to maintain local drainage with a typical maximum spacing of 300 m.

- etablishing a minimum culvert size of 500 mm in diameter; although larger than required for flood drainage in many cases, this will reduce potential blockage from ice, sediment and vegetation growth

- sizing culverts to convey the 1:25 year peak discharge at a water level not exceeding the crown of the culvert (no surcharging); this capacity should also accommodate partial blockage by vegetation or sediment where culverts are installed in wetland environments

- installing culverts, where required, at natural grade to prevent impoundment upstream of the inlet and to maintain equal water levels and natural flow patterns on both sides of the road. This will help control excessive ponding or drying of wetland areas.

- developing and implementing an erosion and sediment control plan for the site before construction. The natural low gradient terrain of the Project area means potential erosion concerns will be minimized. The use of best management practices will also minimize erosion and provide runoff control during construction of the plant, roads, railways and drainage ditches. These will include:

- appropriate sediment control planning to minimize sediment generation caused by surface water runoff from newly excavated areas
- scheduling and layout of works
- installing sediment and runoff retention structures, such as silt fences and incorporating biotechnical erosion control measures
- directing local road runoff away from any crossing locations into the adjacent vegetation
- maintaining buffers and minimizing disturbances
- minimizing the extent of surficial soil compaction during construction
- re-establishing a vegetative cover as soon as practicable after construction
- reclaiming impacted areas by grading and re-vegetating to restore natural drainage patterns as soon as practical following decommissioning. All culverts will be removed to facilitate restoration of natural drainage patterns and runoff conditions.

o) a plan and implementation program for the protection of surface water quality, addressing the following:

i) surface water monitoring program for early detection of potential contamination and assistance in remediation planning;

ii) surface water remediation options to be considered for implementation in the event that adverse effects are detected; and *iii) the relative contribution of the Project (after mitigation) to regional cumulative effects on surface water quality of watercourses and water bodies in the Study Areas (e.g., Project contributions to lake acidification).*

Surface water parameters will be monitored (particularly suspended sediments) during construction activities near surface waterbodies. This will be maintained throughout clearing and construction to ensure that water quality guidelines are not exceeded.

Clean runoff from landscaped and other hard surfaced areas outside the plant footprint will be diverted around the plant site to prevent commingling with localized acidifying compounds within the operations area.

During operation, grab samples will be collected immediately prior to release of any water to the surrounding environment. Any water that may be discharged from the run-off collection pond will be sampled and tested to comply with the following generic criteria:

- no visible sheen
- 6<pH<9
- COD <50 mg/L
- chloride <500 mg/L
- TSS <50 mg/L

Discharge limits for specific contaminants (if and when suspected) will be determined in accordance with the Water Quality Based Effluent Limits Procedures Manual (AEP 1995, as amended). The water quality monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local environment and the potential impact of the Project on it.

There are currently no other planned projects located within the RSA with the potential to affect water quality with respect to Project operations. Similarly, the effects of the Project on surface water quality are predicted to be low to moderate in magnitude and localized in geographical extent (within the LSA). The water quality of the receiving regional waterbodies, namely Beaverhill Creek, is generally poor and displays qualities of being in a hypereutrophic state. This is likely due to the discharge of treated effluent from municipal treatment facilities, perhaps compounded by agricultural runoff (e.g., fertilizers). The Project is not anticipated to contribute any eutrifying compounds to Beaverhill Creek, such as nutrients. The presence of the wetland in the northwest corner of the Site, which will act as a retention and natural treatment system, will further prevent any potentially deleterious compounds arising from surface disturbances or upset conditions reaching Beaverhill Creek.

The acid deposition and sensitivity analysis inherently considered cumulative effects and determined that cumulative impacts resulting from acidifying compounds are not considered to be detrimental to water quality. The Project is not anticipated to release other deleterious compounds into aquatic ecosystems, and therefore, no cumulative effects are anticipated.

Monitoring of surface water quality and quantity will be implemented in conjunction with the groundwater monitoring program.

3. Surface Water Quantity

3.1 Introduction

This section includes the baseline studies and effects assessments pertaining to surface water quantity for the sulphur forming and shipping facility (the Project) that has been proposed for the Bruderheim area by Alberta Sulphur Terminals Ltd. (AST). Field programs were conducted in 2006 and 2007 to assess the local and regional hydrological conditions at and near the Project (see Figure 3.2-1). The baseline portion of this document (Section 3.5) summarizes the findings of the field programs and characterizes the current hydrological conditions of surface waterbodies. The application portion of this document (Section 3.6) analyzes the potential effects of the Project on the existing hydrological regime, taking into account other existing, approved and planned projects and operations in the area.

3.2 Terms of Reference

The hydrological regime is an important element of ecosystems and interacts with other ecosystem components. Based on these considerations, Section 4.10.1 of the Final Terms of Reference (TOR) (AENV 2007) specifies that baseline surface hydrology conditions should be discussed and that the Project components which will affect surface hydrology conditions from a local and regional perspective should be identified. Components for discussion should include:

Discuss baseline surface hydrology conditions. Identify components of the Project that will affect these conditions from a local and regional perspective:

a) existing drainage patterns, surface water bodies, and wetlands within local and regional Study Areas, and the seasonal flow/water level characteristics of these water bodies;

b) Project-related temporary and permanent alterations to these drainage patterns, water bodies and wetlands;

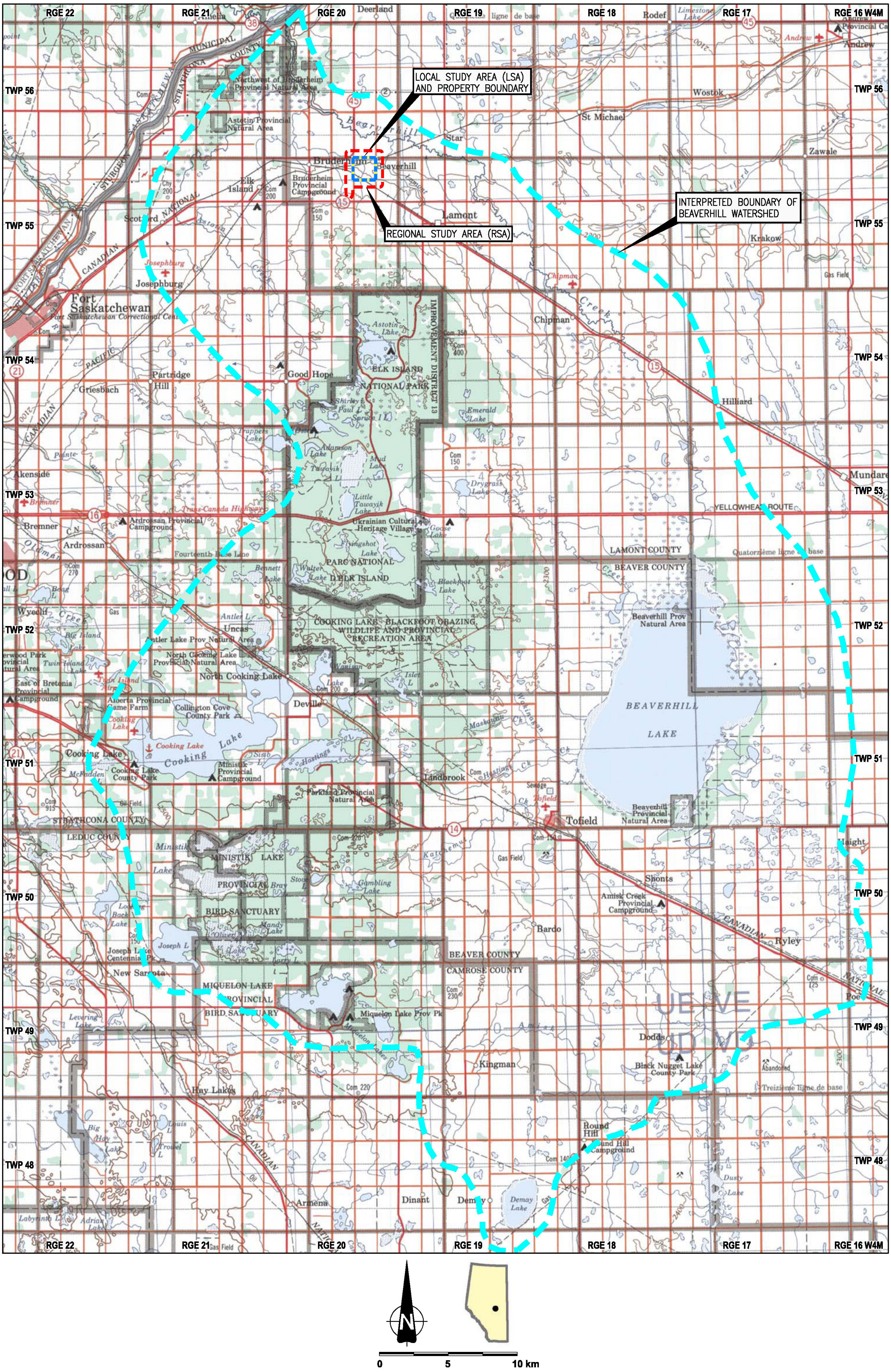
c) possible water diversions from and return flows to these drainage channels, water bodies and wetlands under a variety of operating conditions and scenarios including, emergency conditions, low flow, or drought conditions;

d) effects of site runoff management on flow/level characteristics and aquatic functions in these drainage channels, water bodies and wetlands;

e) mitigation plans to minimize these effects;

f) the relative contribution by the Project (after mitigation) to regional cumulative pressures on surface water resources; and

g) a monitoring program to assess hydrological impacts and assess performance of mitigation plans and water management systems.



MAP SOURCE: NTS MAP 083H
NAD 83 UTM Zone 12

Figure 3.2-1: Regional Setting

3.3 Issue Scoping

Construction and operation of the Project might affect the surface water flow regime in watercourses and waterbodies within the Project area. The following hydrologic issues, based on the project description provided in Volume I: Project Description, public and regulatory consultation, professional experience and issues from similar developments have been identified as having the potential to affect surface water resources around the Project:

- surface disturbances related to the construction and operation of infrastructure including railways, roads and the central sulphur forming facility, that have the potential to impact runoff (including peak flow and total runoff), geomorphic conditions, local water levels and sediment yields and concentrations within local streams and waterbodies
- groundwater abstraction that can potentially impact surface water systems

The potential impacts of these items are discussed and, where appropriate, analyzed in the context of the local and regional watersheds around the Project area.

3.4 Methods

3.4.1 Spatial and Temporal Boundaries

The baseline and impact assessments of the Project were conducted for the Surface Water Quantity Local Study Area (LSA) and Regional Study Area (RSA), and Section 35-55-20 W4M (the Site) which encompasses the Principal Development Area (PDA) (see Figure 3.2-1, Figure 3.4-1 and Figure 3.4-2). These areas are described in both spatial and temporal terms in the following sections.

3.4.1.1 Local Study Area

As regional and local hydrology is dominated by ephemeral streams, the area that will be potentially most affected by the Project is within the Site. The Surface Water Quantity LSA boundary is, therefore, the same as the Site boundary (Figure 3.4-1 and Figure 3.4-2). Predominant surface water features within the LSA include an ephemeral wetland in the northwest corner of the Site, a wetland system adjacent to the Canadian Pacific Railway (CPR) and an ephemeral drainage located near the middle of the north Site boundary.

3.4.1.2 Regional Study Area

The Surface Water Quantity RSA was established to assess regional effects beyond the local drainages contained within the Site. The property is surrounded by a topographically flat area with predominantly ephemeral streams and subterranean drainage. The RSA was set at 500 m beyond the Site boundary on the north and east sides (where there is no distinct watershed divide due to the flat topography) and follows the local watershed boundary on the south and west sides. The RSA measures approximately 7.35 km^2 and is shown in Figure 3.2-1 and Figure 3.4-1.

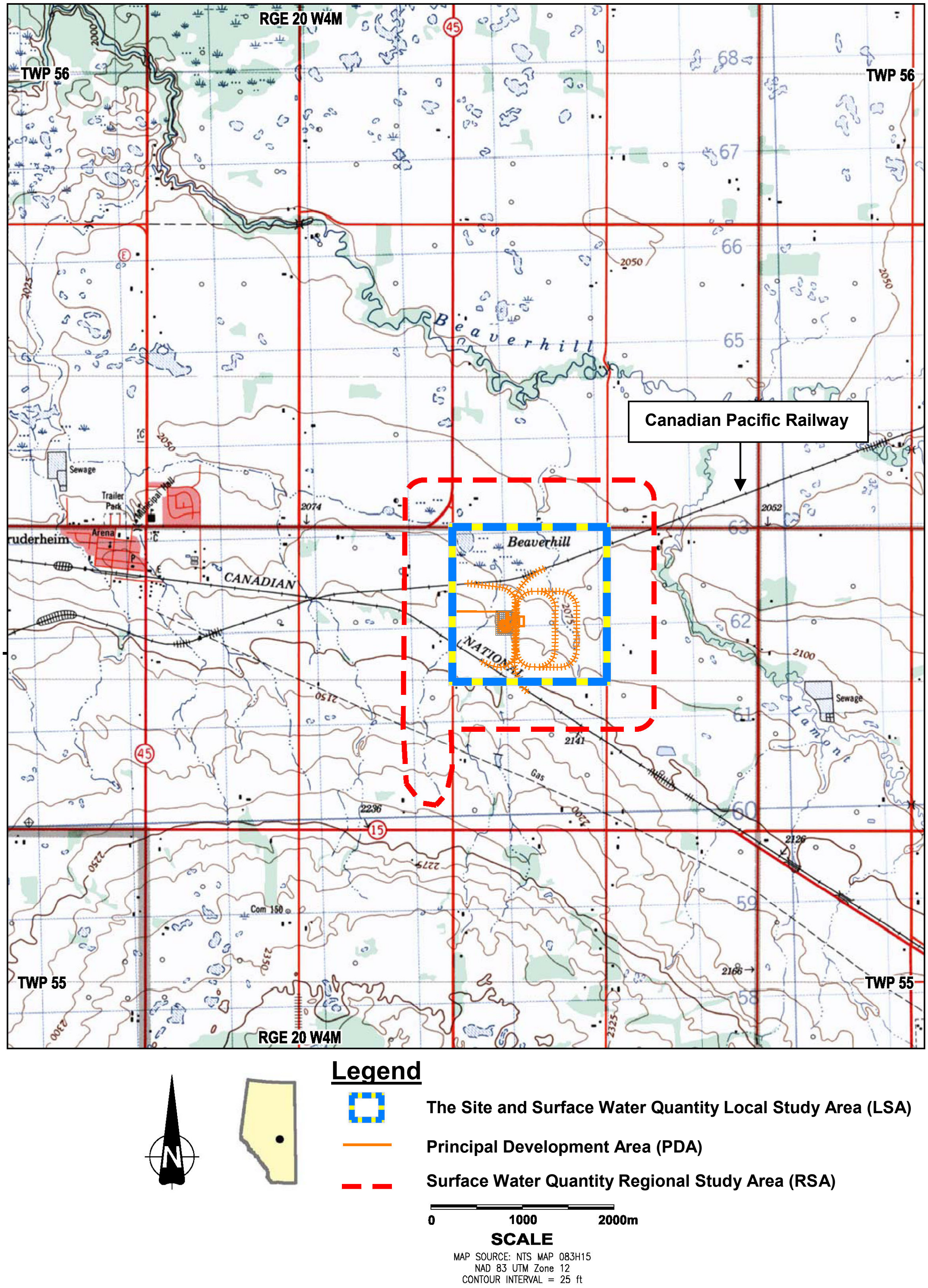
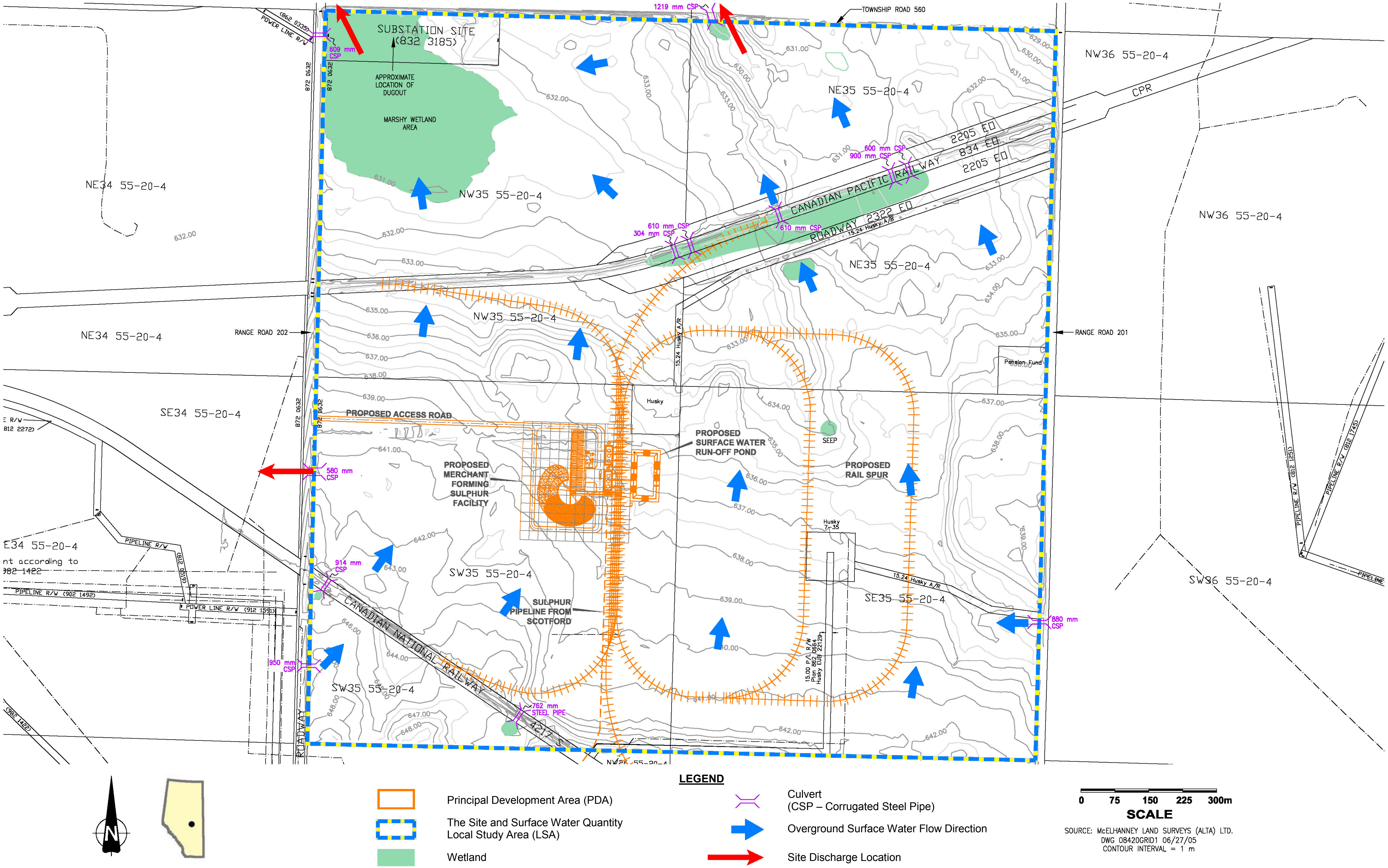


Figure 3.4-1: Surface Water Quantity LSA and RSA



SOURCE: McELHANNEY LAND SURVEYS (ALTA) LTD.
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CONTOUR INTERVAL = 1 m

Figure 3.4-2: Surface Water Quantity PDA, Local Topography and Likely Overland Surface Water Flow Directions

3.4.1.3 Principal Development Area

The PDA is located in a portion of the Site as illustrated in Figure 3.4-2. The PDA consists of the sulphur forming and shipping facility located in the west-central portion of the Site and rail transfer loop used to receive and ship sulphur connecting to the existing rail lines CPR and Canadian National Railway (CN).

3.4.1.4 Temporal Boundaries

The temporal boundaries for the surface water assessments were chosen to coincide with current conditions (baseline case), the anticipated lifespan of the Project (25 years) at maximum disturbance (application case) and closure. A full description of the schedule for construction, operation, decommissioning and reclamation can be found in Volume I: Project Description.

The maximum disturbance temporal boundary is important from a hydrological perspective and is used to determine the potential effect of the Project during its 25 years of operation on surface water resources. Closure is achieved when all facilities have been decommissioned and land reclamation has taken place. Any existing negative impacts to surface water levels should recover relatively rapidly following closure of the Project. The process of decommissioning and reclamation could have temporary negative impacts to the hydrological regime due to temporary water diversions. Thus, in the closure assessments the focus shifts to possible residual surface water quantity effects of the Project, if any.

3.4.2 Project Inclusion List

The project inclusion list in Table 3.4-1 shows the various anthropogenic disturbances in close proximity to the Project, which are included in each assessment case in order to effectively determine Project cumulative effects.

Table 3.4-1: Project Inclusion List

Project	Location	Operational Activities
ERCO Worldwide	Northwest section of 34-20-55 W4M (approximately 1.6 km west of northwest quadrant of the Project)	ERCO Worldwide, a sodium chlorate plant that has been in the area since 1990, is currently not in operation and is due to be shut down completely in 2007
Canexus Chemicals	Southeast quadrant of Section 34-20-55 W4M (immediately west of the southwest quadrant of the Project)	Canexus Chemicals is a sodium chlorate plant constructed in 1990/91 with operations beginning in 1991
Triton Fabrication	Northwest section of 26-20-55 W4M (immediately south of southwest quadrant of the Project)	Triton provides heavy-industrial general contracting, fabrication and maintenance services to resource and industrial clients throughout western Canada. Triton fabrication has been in the area since the summer of 2004.

3.4.3 Literature Review and Data Sources

The following data sources were reviewed to assess the regional and local watershed and basin characteristics, including climatic and hydrological conditions:

- climatic data including Canadian Monthly Climate Normals (1971–2000) from Meteorological Services of Canada (Environment Canada 2004, Internet site)
- evapotranspiration data (AENV 1999a)
- rainfall intensity-duration-frequency data (Environment Canada Atmospheric Environment Service 1990)
- median annual unit runoff (AENV 2005)
- regional archived hydrologic and hydrometric data (Environment Canada 2006, Internet site)
- Atlas of Alberta Lakes (University of Alberta 2004–2005)
- State of North Saskatchewan Watershed Report (NSWA 2005, Internet site)

3.4.4 Field Program

Five field monitoring visits were conducted to evaluate seasonal hydrological conditions within the LSA and RSA. A summer visit was undertaken in June 2006 and a fall visit was undertaken in October 2006. A brief site visit also occurred in August 2006 to install a water level monitoring apparatus. Field visits were made in February 2007 and during snowmelt in March 2007.

A reconnaissance walk-over survey was performed in June 2006 to identify and describe surface waterbodies within the Site and the vicinity. Surface water features were identified, catalogued, mapped and assessed. Overland flow patterns were visually assessed and photographed, but due to the lack of adequate flow at most monitoring locations, quantitative flow measurements could not be made. Another site inspection was conducted in March 2007 during snowmelt. All of the waterways in the LSA contained water during this time.

A water level pressure transducer, barometric pressure transducer and staff gauge were placed in the wetland in the northwest corner of the Site in August 2006 and removed during the October 2006 monitoring event. The pressure transducer recorded continuous water levels in the wetland over this time. Changes in water level were corrected using the barometric pressure data collected by the second transducer (barrologger).

3.4.5 Assessment Methodology

The surface water and climatic environmental setting was characterized by compiling existing long-term regional data, supplemented with short-term Project area-specific information regarding streams and waterbodies in the LSA. Comparisons between historical long-term regional data with Project area-specific data, where appropriate, provided the basis for characterizing the climate and hydrology in the study areas. Statistical analyses, summaries and comparisons were conducted to describe and predict the variability of climatic and hydrologic data in the study areas and to establish baseline trends and conditions within the study areas. Climatic and hydrological variables include temperature, precipitation, evaporation rates, runoff rates, local and regional stream flows and lake conditions. Other regional activities were reviewed to establish baseline trends and conditions within the LSA and RSA.

3.5 Baseline Case

3.5.1 Existing Development

The PDA is located in a portion of Section 35-55-20 W4M (the Site), approximately 2.2 km east of Bruderheim, Alberta. The Site is currently used for agricultural purposes (pasture and cropping) but is zoned for industrial use. It is generally flat and slopes gently to the north at less than 1°. Ground elevations decrease from 648 metres above sea level (masl) in the southern regions to 629 masl in the northern regions of the Site.

A CPR rail line runs west to northeast on the northern portion of the Site, while a Canadian National (CN) rail line runs west to southeast on the southwest quarter. A Husky Oil suspended well facility (pump jack and concrete pad still in place) is located close to the centre of the Site (06-35-55-20 W4M). The suspended well lease has a gravel access road. An abandoned Husky Oil well is also located approximately in the centre of the southeast quarter (07-35-22-20 W4M). The majority of the Site is grassed/pasture/cropland punctuated with discontinuous patches of small trees and brush.

A dugout is located in the northwest quarter section of the Site and is used for cattle watering. An ephemeral, marshy wetland area is also located in the northwest quarter section of the Site, which continues along the southeastern flanks of Highway 45. A second, smaller waterlogged marshy area is located along the southern edge of the CPR rail line, in the northeastern region of the Site. The lack of adequate drainage across the highway and the railway could lead to water backing up behind the features.

Two ephemeral drainages were encountered (see Volume IIB, Section 5: Aquatic Resources, Figure 5.3-1) and are shown in Figure 3.4-2. One drainage runs from the southwest Site boundary northwards towards the wetland in the northwest quarter section of the Site. The other drainage runs from south to north through the eastern half of the Site. This drainage collects runoff from areas south of the Site.

Adjacent to the wetland in the northwest quarter section is an electrical power metering station. Immediately to the north is Township Road 560 and agricultural and residential development. Range Road (R.R.) 201 is east of the Site, followed by agricultural and residential development. To the south is agricultural and residential development, and south of the southwest quarter section of the Site is the Triton Fabrication manufacturing facility. Highway 15 is located 1.5 km south of the Site boundary. R.R. 202 is west of the Site, followed by agricultural development. Canexus Chemicals is located west of the Site's southwest quarter section.

3.5.2 Regional Topography and Land Use

The Site is located within the eastern Alberta region of the interior plains. Regional topography is generally the result of glacial and post-glacial activity, both erosional and depositional. Regional elevations vary from 580–780 masl. The region is primarily a treed upland area consisting of rolling to hummocky terrain with knob and kettle topography that supports a high diversity of vegetation, waterfowl, mammals and birds (NSWA 2005, Internet site). Knobs range from 5–15 m in height and many of the kettles contain water without discharge pathways (University of Alberta 2004–2005, Internet site).

The Beaverhill Watershed (see Figure 3.2-1) drains into the North Saskatchewan River and lies in the Boreal Forest and Parkland Natural Regions (NSWA 2005). In general, ground surfaces slope gently from south to north, towards the North Saskatchewan River valley, which takes drainage from the entire region. The eastern and southern parts of the Beaverhill

Watershed drainage basin are a poorly drained ground moraine plain, with intermittent and permanent sloughs, lakes and boreal forests present throughout (NSWA 2005, Internet site).

The Beaver Hills (also known as the Cooking Lake Moraine) are located approximately 40 km south of the Site and include Elk Island National Park and the Cooking Lake-Blackfoot Recreation Area (see Figure 3.2-1). Beaverhill Lake was designated a Wetland of International Importance in 1987 by the RAMSAR Convention and the Cooking Lake Moraine area is one of four important areas identified by the Nature Conservancy of Canada for its mosaic of grasslands, woodlands and wetland habitats (NSWA 2005, Internet site).

With the exception of wetland depressions, very little of the landscape of the Central Parkland region surrounding the Beaver Hills retains native vegetation, with the vast majority of the watershed classified into land uses related to agricultural production, including grassland, cropland and forage (NSWA 2005, Internet site).

3.5.2.1 Temperature

Monthly average temperature data from 1971–2000 are summarized in Table 3.5-1 based on data collected at the Environment Canada climate station at Fort Saskatchewan (Environment Canada 2004, Internet site). The Fort Saskatchewan station is located approximately 23 km southwest of the Site at an elevation of 620 masl. Given the station's close proximity to the PDA and the similar elevations (between 629 and 644 masl), the temperature data are considered to be representative of the Site. The original dataset is provided in Appendix I.

Table 3.5-1: Monthly Average Temperatures at Fort Saskatchewan (1971–2000 Normals)

Month	**Mean Daily Maximum (^oC)**	**Mean Daily Minimum (^oC)**	**Mean Daily Temperature (^oC)**
January	-8.1	-18.8	-13.5
February	-4.6	-15.7	-10.2
March	1.5	-9.0	-3.8
April	10.9	-1.4	4.8
May	17.9	4.5	11.2
June	21.1	8.7	14.9
July	22.8	10.6	16.7
August	22.2	9.3	15.8
September	17	4.4	10.7
October	10.7	-1.3	4.7
November	-0.8	-10.3	-5.6
December	-6.4	-16.6	-11.5
Annual	**8.7**	**-3.0**	**2.9**

3.5.2.2 Precipitation

Monthly average precipitation data from 1971–2000 are summarized in Table 3.5-2 based on data collected at the Environment Canada climate station at Fort Saskatchewan (Environment Canada 2004, Internet site). The original dataset is provided in Appendix I.

Table 3.5-2: Monthly Average Precipitation at Fort Saskatchewan (1971–2000 Normals)

Month	Rainfall (mm)	Snowfall (cm)	Total Precipitation[1] (mm)
January	0.4	22.9	23.4
February	0.7	12.9	13.5
March	1.4	13.0	14.4
April	17.0	7.6	24.6
May	42.0	1.7	43.8
June	88.8	0.0	88.8
July	83.1	0.0	83.1
August	61.7	0.0	61.7
September	42.7	0.3	43.0
October	13.5	3.7	17.2
November	3.0	19.7	22.7
December	0.5	22.8	23.3
Annual	**354.8**	**104.6**	**459.4**
10-Year Drought[2]			360.0
20-Year Drought[2]			345.0

Note:

[1] Total precipitation is estimated by summing the rainfall and amount of water released by melting snowfall (assumed to be approximately 10% of cumulative snowfall depth).

[2] Calculated using the Weibull plotting position method.

Approximately 77% of the annual total precipitation at the Site is expected to occur as rain and the remaining 23% as snow. Approximately 60% of the total annual precipitation is expected to fall between May and August.

Rainfall intensity-duration-frequency data was obtained from Environment Canada Atmospheric Environment Service (1990) at Namao Airport, Edmonton, which is located approximately 40 km southwest of the Site, at an elevation of 685 masl. The original dataset is provided in Appendix I. A sample of rainfall intensities is provided in Table 3.5-3.

Table 3.5-3: Rainfall Intensity-duration-frequency Data

Return Period (yr)	Duration	Rainfall Amount (mm)
10	15 min	16.9
10	30 min	22.9
25	15 min	19.9
25	30 min	27.3
25	6 hr	34.5
10	24 hr	83.1
25	24 hr	99.2
100	30 min	33.8
100	24 hr	123.2

3.5.2.3 *Evapotranspiration*

Minimum, maximum, mean potential and areal evapotranspiration data over the monitoring period 1912–1996 are summarized in Table 3.5-4 based on data from Edmonton City Centre Airport (AENV 1999a). Edmonton City Centre Airport is located approximately 50 km, southwest of the Site at an elevation of approximately 670 masl. Given the airport's relatively close proximity to the PDA and that ground elevations within the Site are relatively similar (between 629 and 644 masl), the evapotranspiration data are considered to be representative of those at the Site. The original dataset is provided in Appendix I.

Table 3.5-4: Monthly Evapotranspiration

Month	Minimum PET[1] (mm)	Maximum PET[1] (mm)	Mean PET[1] (mm)	Minimum AET[2] (mm)	Maximum AET[2] (mm)	Mean AET[2] (mm)
January	-6	9	-1.1	-6	7	-1.1
February	-4	21	2.2	-4	11	1.9
March	0	58	26.1	0	25	15.3
April	24	152	96.7	13	62	31.4
May	93	214	157.0	29	92	55.2
June	102	219	162.7	33	115	80.1
July	112	219	173.7	70	133	99.2
August	91	202	143.1	32	111	69.9
September	41	134	82.5	6	44	19.6
October	12	47	29.1	6	19	12.5
November	-5	14	3.9	-5	6	1.9
December	-7	7	-1.3	-7	4	-1.4

Notes:
[1] PET – potential evapotranspiration: the evapotranspiration that would occur from a hypothetical moist surface with radiation absorption and vapour characteristics similar to those of the area and so small that the effects of the evapotranspiration on the overpassing air would be negligible.
[2] AET – areal evapotranspiration: the actual evapotranspiration from an area so large that the effects of upwind boundary transitions are negligible.
Source: AENV 1999a.

3.5.3 Regional Baseline Hydrology

3.5.3.1 *Regional Watersheds and Drainage Patterns*

The North Saskatchewan River Basin covers about 80,000 km^2 of the province of Alberta (AENV 2006). The basin begins in the ice fields of Banff and Jasper National Parks and flows over 1,000 km in a generally eastward direction to the Alberta–Saskatchewan border. The mean annual discharge from the basin in Alberta into Saskatchewan is over seven billion m^3 (AENV 2006, Internet site).

The Project is located within the Beaverhill Creek watershed which is illustrated in Figure 3.2-1. Drainage in the southern and western region of the watershed is predominantly towards Beaverhill Lake which has a drainage basin area of 1,970 km^2 (University of Alberta 2004–2005, Internet site). Numerous intermittent and permanent sloughs, wetlands and lakes are located within the knob and kettle terrain of the Cooking Lake Moraine, to the west of Beaverhill Lake. In the northern and western region of the watershed, Beaverhill Creek receives flow from several other ephemeral streams and creeks including Lamont and Astoria Creek, before eventually draining into the North Saskatchewan River. Most of the creeks draining into Beaverhill Lake flow intermittently and the outlet, Beaverhill Creek, is generally overgrown with cattails and flows only during periods of very high water (University of Alberta 2004–2005). During the site inspection in June 2006, Beaverhill Creek was not flowing near its mouth, even though there was a small amount of flow noted in the reach near the Site. The creek near the mouth appears to flow through a groundwater recharge zone. Beaver activity had caused numerous areas of ponded water between the reach and dry creek channel, but all water flow in the creek effectively infiltrates into this permeable zone.

3.5.3.2 Regional Streamflows and Basin Yields

Minimum, maximum and mean monthly discharge data were recorded at the mouth of Beaverhill Creek where it joins the North Saskatchewan River, for the monitoring period 1975–1986, between the ice-free periods from March–October. These seasonal archived hydrometric data from Canada's HYDAT database (Environment Canada 2006, Internet site) were reviewed and are summarized in Table 3.5-5. Original data are provided in Appendix II. A monthly hydrograph is also provided as Figure 3.5-1.

These data, although useful to characterize the regional hydrology, are not representative of the onsite surface water quantity for several reasons. First, the Beaverhill Creek drainage basin is very large (2,930 km^2) in comparison to the LSA. Second, much of the drainage basin contains areas that do not contribute to flows in Beaverhill Creek because these areas are isolated sloughs (such as kettle lakes), or drainage in these areas is via groundwater recharge.

Table 3.5-5: Monthly Discharge 1975–1986, Beaverhill Creek (05EB015)

Month	Mean Discharge (m^3/s)	Maximum Discharge (m^3/s)	Minimum Discharge (m^3/s)
January	n/m	n/m	n/m
February	n/m	n/m	n/m
March	0.939	3.39	0
April	1.78	5.38	0.255
May	0.358	1.95	0.011
June	0.408	3.9	0.002
July	1.13	6.02	0
August	0.083	0.29	0
September	0.152	1.71	0
October	0.034	0.134	0
November	n/m	n/m	n/m
December	n/m	n/m	n/m

Note:
n/m – not measured.

3.5.3.3 Regional Peak Flows

Peak daily discharges were recorded at the mouth of Beaverhill Creek where it joins the North Saskatchewan River, over the monitoring period 1975–1986 and between the months of March and October. These seasonal archived hydrometric data from Canada's HYDAT database (Environment Canada 2006, Internet site) were reviewed and are summarized in Table 3.5-6. Original data are provided in Appendix II.

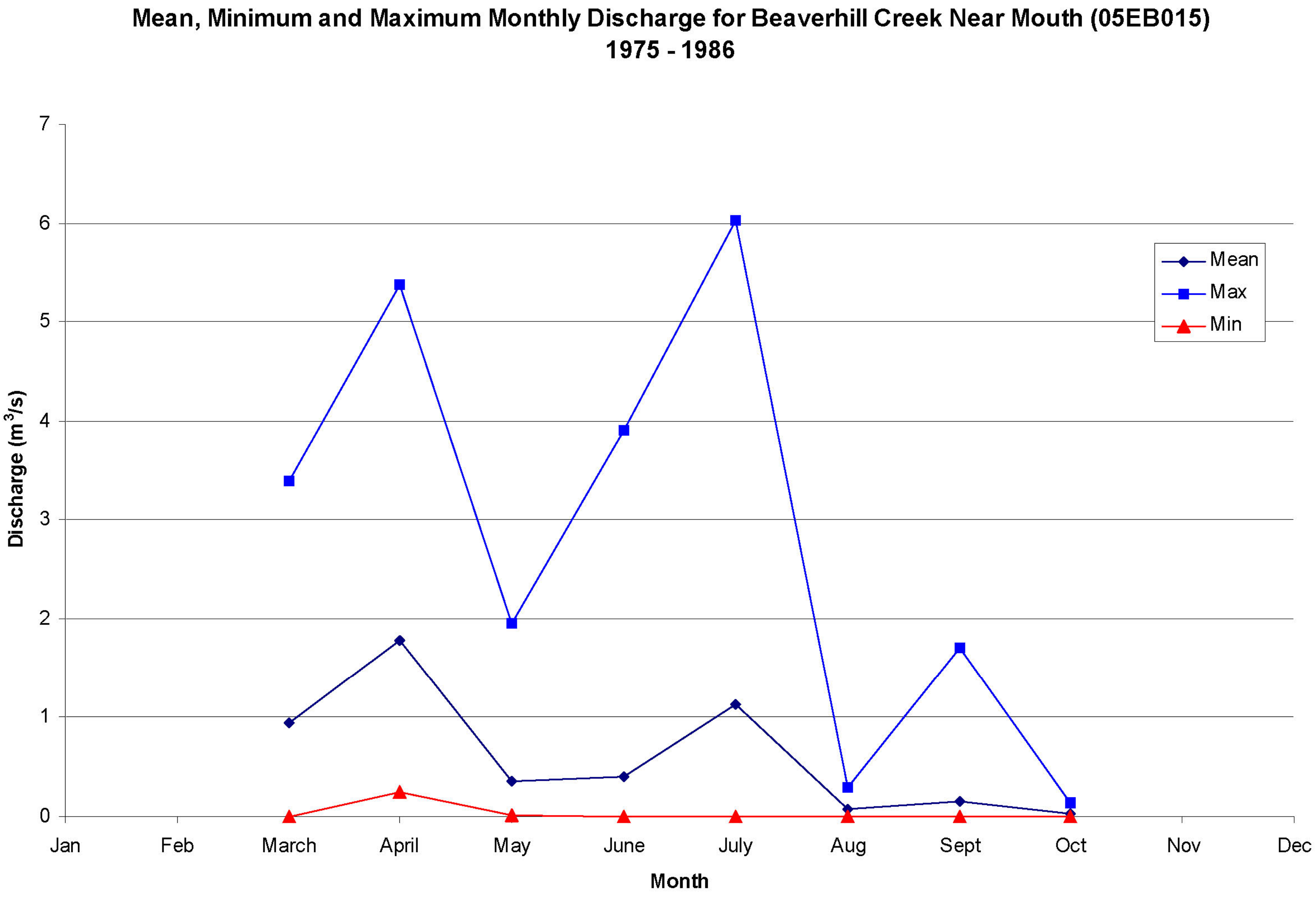


Figure 3.5-1: Monthly Hydrograph

Table 3.5-6: Maximum Daily Discharges 1975–1986, Beaverhill Creek near the Mouth (05EB015)

Year	Date	Maximum Daily Discharge (m^3/s)
1975	April 22	8.21
1976	April 05	1.48
1977	May 30	10.60
1978	September 20	4.79
1979	March 23	9.00
1980	April 14	13.00
1981	March 18	11.40
1982	April 27	24.60
1983	June 26	34.10
1984	March 29	4.02
1985	April 03	10.60
1986	July 20	48.60

The majority of peak flow discharges were recorded from mid-March to the end of April, coinciding with spring snow melts. Occasional peak flows were also recorded between May and September and are most likely associated with spring and summer storm events.

A frequency analysis was conducted using the statistical software package HYFRAN Version 1.1. HYFRAN is used to fit statistical distributions for the analysis of extreme events. The 3-parameter lognormal distribution was applied to the historical mean daily peak flow data record as it represented the observed data reasonably well. Results are presented in Table 3.5-7 and a graph showing this 3-parameter lognormal fit is provided in Appendix III. As these data are peak daily flow, the analysis is not intended to be used for design purposes - peak instantaneous data is required for any engineering design.

Table 3.5-7: Flood Frequency Analysis for Beaverhill Creek near the Mouth (05EB015)

Return Period (Years)	Maximum Mean Daily Flow (m^3/s)
200[1]	96.6[1]
100[1]	78.2[1]
50[1]	62.1[1]
20	43.9
10	32.2
5	22.0
3	15.4
2	10.6
1	3.23

Note:

[1] Confidence in flood prediction is substantially reduced for return periods greater than 20 years as the peak flow record of 12 years is not sufficient in length to provide dependable results.

3.5.4 Local Hydrology

3.5.4.1 Site Drainage

The Site drains from south to north via two ephemeral streams and two distinct sub-basins (see Figure 3.5-2 that illustrates the interpreted catchment area for the western sub-basin). Neither streams were flowing during the June and October 2006 site visits. Freshet (snowmelt) dominants the flow regime of this site, and both streams contained water from snowmelt runoff during the March 27, 2007 site inspection.

Drainage on the east half of the Site has been influenced by road construction and associated ditching. In general, flow preferentially runs along the roadside ditches until discharging via culverts. In addition, culverts installed on R.R. 201 were observed to cause ponding of water on the east side during snowmelt, which indicates that the inverts of the culverts have not likely been installed at an elevation that would resemble pre-development flow conditions.

The CPR line interferes with the natural drainage of this eastern-most, ephemeral creek. Although there are five culverts that convey water under the rail line ranging in size from 304–900 mm (see Volume IIB, Section 4: Surface Water Quality, Appendix III, Photo 4), the invert elevation of these culverts is not low enough to adequately drain the upgradient areas. This has resulted in the formation of a small wetland system on the south side of the tracks as shown on Figure 3.4-2. This small wetland supports an established community of riparian vegetation (e.g., cattails, sedges, grasses). A seep was observed discharging on the eastern central portion of the property (see Figure 3.4-2) and is visible from aerial photographs as shown in Figure 3.5-3. During the June and October site visits, the soil at this seep was moist, but open water was not evident.

The eastern half of the Site drains via a 1,219 mm diameter culvert under Township Road 560 (see Figure 3.4-2 and Volume IIB, Section 4: Surface Water Quality – Appendix III, Photo 3), which likely only flows during freshet or large storm events. This ephemeral stream eventually flows into Beaverhill Creek approximately 1.5 km to the north of the Site boundary.

The west side of the Site receives drainage from an area to the south of the site, encompassing a total drainage area of approximately 1.87 km^2. Two culverts (914 mm and 762 mm diameter) convey drainage under the CN rail line as shown on Figure 3.4-2. Drainage collects in a wetland area located in the northwest quarter section of the Site. Figure 3.5-2 shows the interpreted catchment area for this wetland. The open water area of the wetland during average annual flood conditions is estimated from aerial photos at 62,500 m^2. Analysis of results obtained from the water level and barometric pressure transducers placed in the wetland area between August and October 2006 indicate that the wetland area was almost completely dried out from mid-August 2006. Results are presented in Figure 3.5-4. There are three culverts that convey water under R.R. 202, which forms the western boundary.

An analysis of historical air photos was conducted to better understand the hydrology of this wetland complex. Figure 3.5-3 illustrates the development of the wetland between 1950 and 2001. In 1950, the area that now consists of wetland and riparian vegetation was substantially drier and was used for agricultural purposes. Ponded water is evident immediately northwest of the Site, but no riparian vegetation is evident on the property itself. Between 1962 and 2001, the wetland develops to a maximum area of approximately 160,000 m^2.

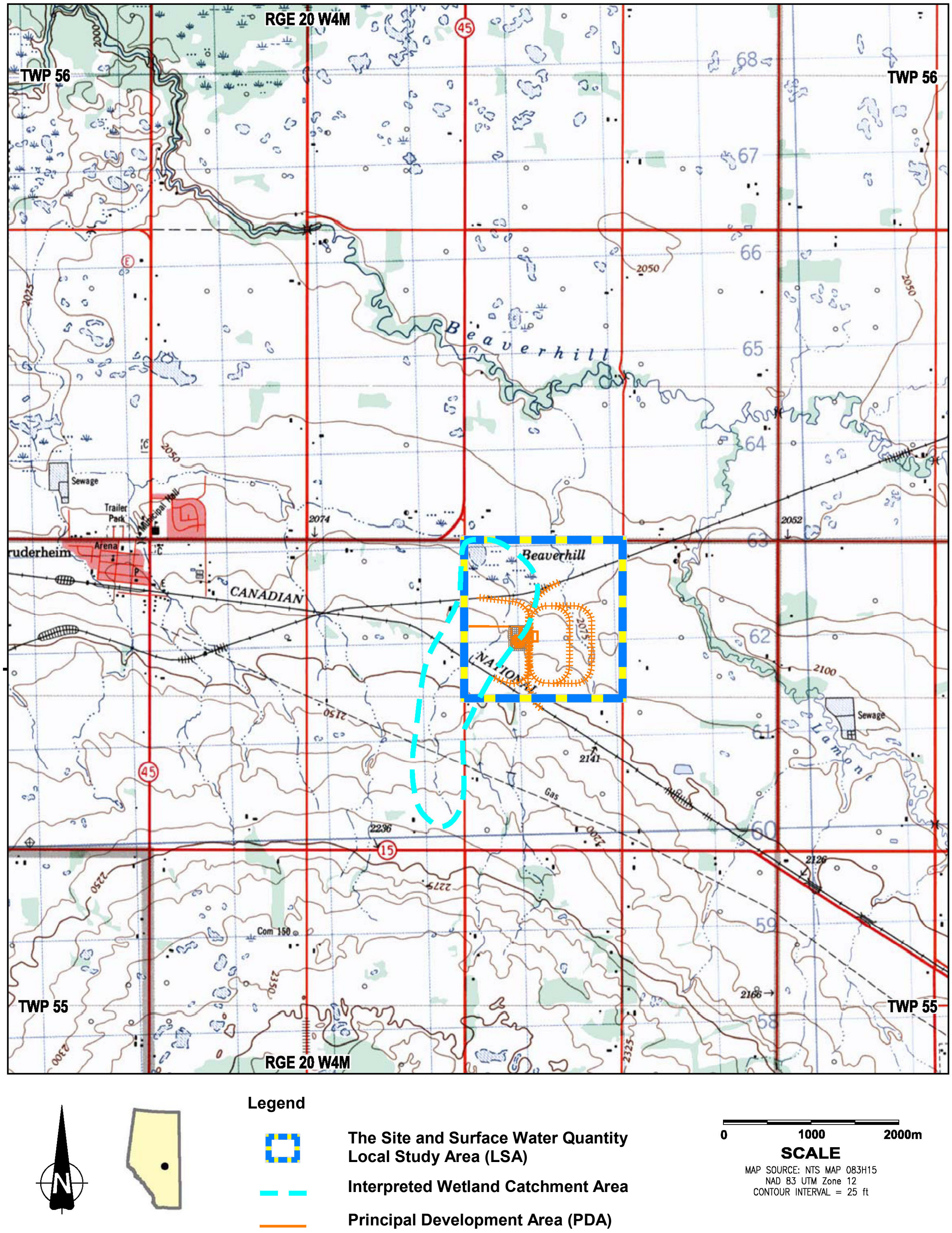
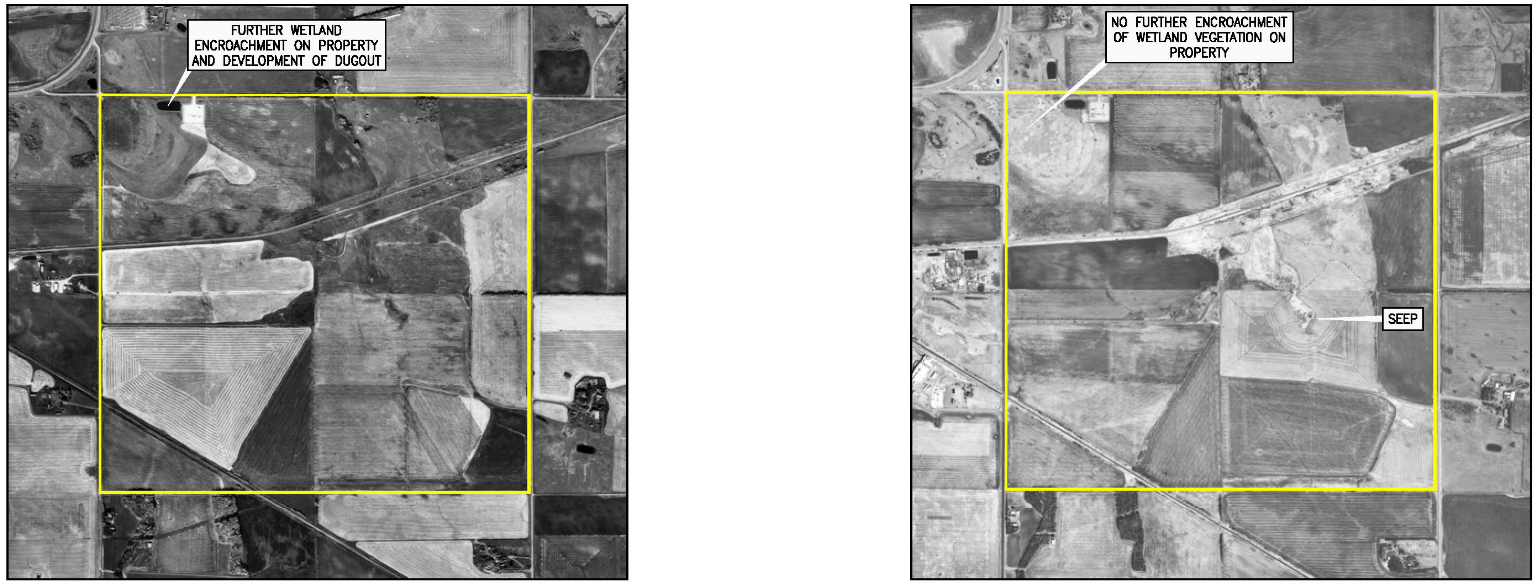


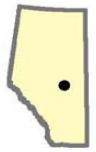
Figure 3.5-2: Interpreted Wetland Catchment Area

C:\PROJECTS\c62772\62772AerialChronology.dwg

SEPTEMBER 1950 **MAY 1962** **SEPTEMBER 1974**



SEPTEMBER 1986 **MAY 2001**



LEGEND

🟨 PROPERTY BOUNDARY

0 250 500 750 1000m

SCALE

AERIAL PHOTO SOURCE: ALBERTA GOVERNMENT – SUSTAINABLE RESOURCE DEVELOPMENT

Figure 3.5-3: Aerial Photo Chronology

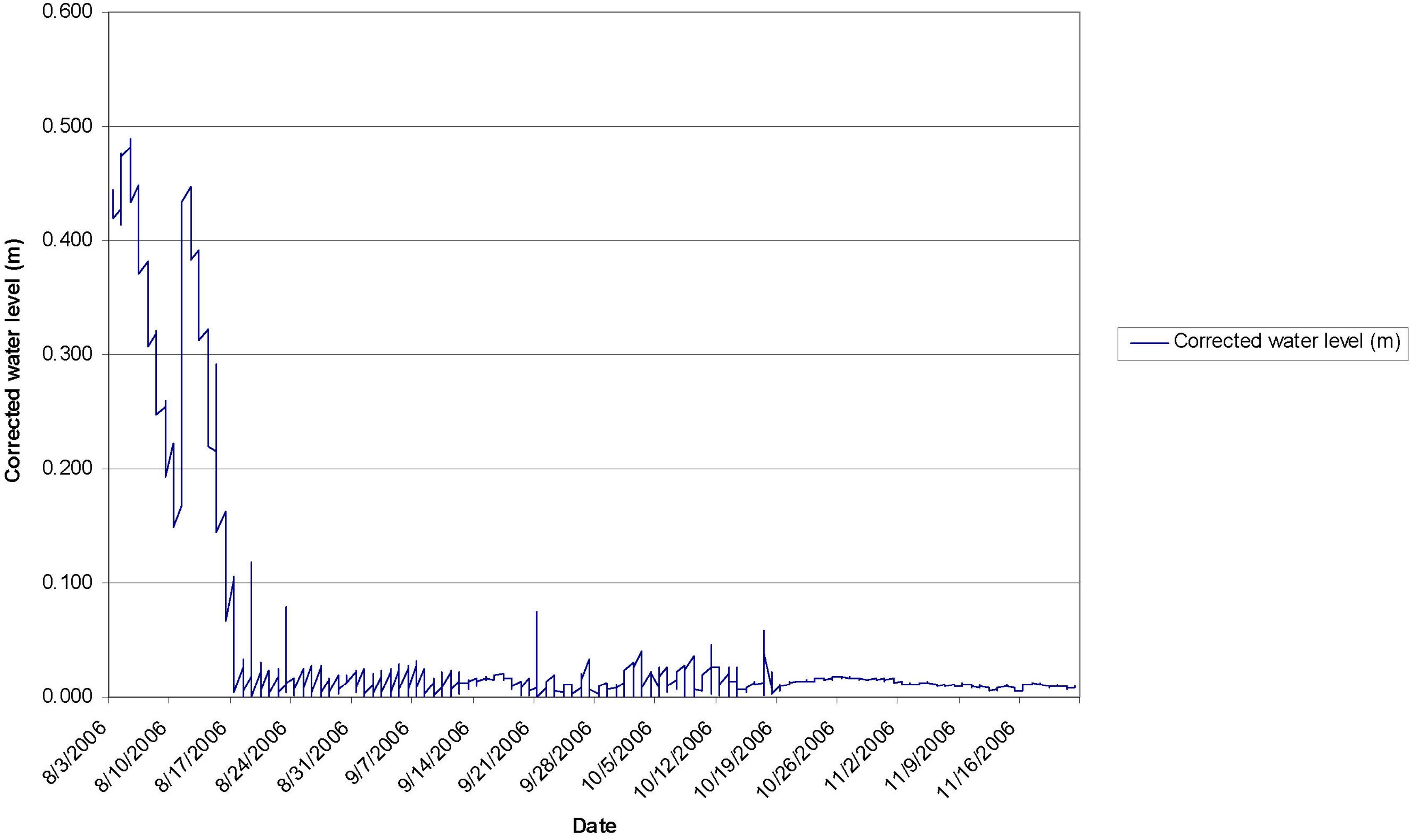


Figure 3.5-4: Water Level Fluctuations in Wetland

The aerial photographs indicate that road improvements to Highway 45 are likely to have been conducted at some point between 1962 and 1974. This suggests that the road improvements may have resulted in the net reduction of drainage under Highway 45. The silt-rich soils present in the local area do not drain quickly and thus water tends to pond over time, creating wetland habitat. It is not expected that the climate has contributed to the formation of this wetland, as the region has been getting warmer and drier since the shift in the Pacific decadal oscillation occurred in 1976 (Komex 2005). Thus, all of these changes to the hydrology of the area are likely a result of the reduction in the runoff conveyance under Highway 45 (likely due to an increase in the invert elevation of the culvert when improvements were made).

The time of concentration for the property was calculated as being approximately 45 minutes using the Kirpich formula (Maidment 1993) assuming a maximum basin length of 2,100 m and a slope of 0.008.

Local and regional waterbodies contained measurable flow only during the site visit conducted on March 27, 2007. Snowmelt runoff was observed entering the Site from areas south of Highway 15 via two culverts with diameters of 750 mm and 950 mm (see Figure 3.4-2). These culverts had a combined gauged discharge of 60 L/s. A portion of this runoff discharges eastward under R.R. 201 via a 600 mm culvert, located approximately 375 m south of the south Site boundary. Discharge was gauged at this culvert at 18 L/s. There is also an 880 mm culvert under R.R. 201 that diverts water onto the Site from the property immediately to the east (Figure 3.4-2). The discharge from this culvert was gauged at 147 L/s. All flow from the eastern half of the property exits via a 1,219 mm culvert under Township Road 560, which was gauged at 146 L/s. This culvert discharges into a cattle pasture north of Township Road 560 via a natural ephemeral stream, and eventually flows into Beaverhill Creek.

Drainage on the west side of the Site is influenced by R.R. 202 and associated ditching and culverts. Flow enters via a 950 mm culvert under R.R. 202 just south of the CN railway (see Figure 3.4-2), and was gauged at 24 L/s. Another culvert located approximately 100 m north of the CN railway conveys flow west under R.R. 202. This flow through this culvert was gauged at 39 L/s (see Figure 3.4-2). This flow continues north along the west side of R.R. 202 via a ditch and discharges in the wetland complex at the intersection of Township Road 560 and R.R. 202. The wetland drains northwest under R.R. 202 via a 609 mm diameter culvert, and then under Highway 45 via two 900 mm diameter culverts, which were not flowing on March 27, 2007, and a 1,300 mm x 660 mm box culvert, which was gauged at 72 L/s (see Figure 3.4-2). Drainage from the northern Site boundary follows an ephemeral route for almost 8 km across very flat fields, passing just north of Bruderheim 3.5 km to the west, where the stream turns north, eventually discharging in Beaverhill Creek approximately 4.5 km further downstream.

3.5.5 Water Balance

Average monthly water balance calculations were completed for the baseline case of the wetland complex. The purpose of these calculations was to characterize the baseline hydrology of the catchment where the proposed Project is located, which will form the basis of the impact assessment. Table 3.5-8 outlines the assumptions used in the calculations while the water balance results are discussed below. Original calculations are provided in Appendix IV.

Table 3.5-8: Assumptions of Water Balance Calculations

Parameter	Values used	Source
Precipitation	Average annual ranges (see Table 3.5-2)	Environment Canada 2004, Internet site. Namao Airport, Edmonton
Areal evapotranspiration	Mean annual ranges (see Table 3.5-4)	AENV 1999a; Edmonton City Centre Airport
Watershed area	1.87 km^2	Interpreted watershed area as shown in Figure 3.5-2. For application case, watershed area is minus plant and retention pond footprint area.
Runoff coefficient	0.06	AENV 2005. Regional median annual unit runoff estimates (based on Prairie Farm Rehabilitation Administration Hydrology Report #135, Feb 1994). Provided in Appendix I.
Open water area	62,500 m^2	Open area of the wetland estimated from ground survey and aerial photographs
Wetland storage	125,000 m^3	Open water area multiplied by depth of wetland estimated from field investigation
Cross sectional area of wetland through which groundwater might flow	500 m^2	Determined by taking the width of the slough along its southeast perimeter (250 m) and assuming a seasonally average depth of about 2 m
Average hydraulic conductivity of shallow soils	4.1×10^{-7} m/s	Volume IIB, Section 2: Groundwater Quantity and Quality – Section 2.5.7
Average hydraulic gradient of shallow groundwater	0.008	Volume IIB, Section 2: Groundwater Quantity and Quality – Section 2.5.7

Average baseline conditions indicate total annual inputs (runoff, direct rainfall and groundwater) of 80,200 m^3/y. Average groundwater contributions are very minor and are estimated at approximately 50 m^3/y or less than 0.1% annually. Total average baseline outputs (evapotranspiration and drainage out of open water) are estimated at 80,000 m^3/y. Assumptions for calculating baseline outputs assume that between 15 and 25% (representing flow rates of between 4.3 and 7.7 L/s) of annual inputs occur as runoff from the wetland area between the months of April, May, June and July only. In reality, it is expected that much of the runoff will occur as a small number of short term, high flow freshet events resulting from the melt of late snowfall events. However, flow rates have been assumed in model calculations to be continuous lower level flow conditions through the months of April–July.

Sensitivity analyses were undertaken for the baseline case by inputting a range of runoff coefficient values and a range of hydraulic conductivity values. Increasing the runoff coefficient to 0.1 increases annual inputs to the system by almost 35,000 m^3. Increasing hydraulic conductivity values to 3×10^{-6} m/s increases overall groundwater contributions to just under 380 m^3/day. Sensitivity analysis results are provided in Appendix IV.

3.5.6 Peak Instantaneous Flows

Peak flows were estimated for the western drainage basin using the Rational Method:

$$q = F\ C\ i\ A$$

where q is peak discharge in m^3/s, F is a unit conversion factor (0.278 for metric conversion), C is the runoff coefficient (0.06), i is the rainfall intensity in mm/hr and A is the drainage basin area (1.87 km^2). The rainfall intensity was estimated from data collected at Edmonton Namao Airport and is 22.9 mm, 27.3 mm and 33.8 mm over 30 minutes for the 10 year, 25 year and 100 year return periods, respectively. The time period estimated for rainfall intensity is 30 minutes, which is similar to the estimated time of concentration of 45 minutes (see Section 3.5.2). A conversion factor of 2 was used to transform the 30 minutes rainfall depths to millimetres per hour.

Peak flows for the site for the 10 year, 25 year and 100 year events are 1.43 m^3/s, 1.70 m^3/s and 2.11 m^3/s respectively.

3.5.7 Erosion and Sediment Transport

In general, erosion and sediment transport is not currently an issue at any of the water features located within the LSA. This is attributed to several factors, including:

- very low gradient slopes of the watershed
- vegetated ditches and vegetated, natural draws that filter runoff
- settling and filtering provided by the wetlands located upstream of the railways and in the northwest corner of the Site

Evidence of erosion, such as rills, undercut banks, or depositional features were not observed in any of the water features in the LSA.

3.5.8 Surface Water/Groundwater interactions

The interaction between surface water and groundwater was assessed using both physical and chemical techniques. A localized groundwater recharge area was identified in the southern central section of the PDA (near 05–10 shown in Volume IIB, Section 2: Groundwater Quantity and Quality – Figure 2.5-7) during groundwater investigations. The presence of silty sand and lower total dissolved solids (TDS) concentrations in this area are likely reflective of the influence of surface water mixing and suggests that some connections between groundwater and surface water exist in this area of the PDA. A seep area (potential groundwater discharge zone) was further identified approximately 300 m northeast of 05–10 both on aerial photos and on the ground during surface water investigations (see Figure 3.4-2 and Figure 3.5-3) and suggests that further connections between groundwater and surface water exist in this localized area of the PDA.

Other than these isolated zones of connection, predominant near-neutral vertical hydraulic gradients are inferred for the PDA. Geologic cross-section A-A' (see Volume IIB, Section 2: Groundwater Quantity and Quality – Figure 2.5–3) illustrates that if a groundwater connection exists between the recharge zone and the wetland and dugout area located in the northwest quarter section of the Project, it may involve a groundwater flow pathway through the upper sandstone interval because the silty sand pinches out north of the PDA. Nonetheless, hydraulic connectivity between the sandstone interval and surface water is likely limited or eliminated by the presence of the overlying till.

Possible groundwater contributions to the water balance of the wetland area were calculated assuming lateral inflow through the surficial deposits (see Volume IIB, Section 2: Groundwater Quantity and Quality). Annual contribution values ranged between 3 and 380 m^3/y depending on the range of hydraulic conductivity values used (see Volume IIB, Section 2: Groundwater Quantity and Quality). Based on these calculations, groundwater contribution to the total annual inputs to the wetland area (80,000 m^3/y) are therefore very minor and were estimated to be less than 0.5% on an annual basis. This further emphasizes that the dug-out and wetland area in the northwest portion of the LSA represent an area of poor drainage with only a minor groundwater influence on the surface water balance.

Water quality analysis indicates that the predominant hydrochemical type of both surface water (in the wetland) and groundwater is Na-HCO_3. Surface water exhibits more dilute concentrations and lower TDS values, as would be expected through the processes of mixing and dilution. This suggests that some groundwater is likely discharging into the wetland, but that the primary input is surface water. Given the low permeability nature of the shallow soils, the interaction between groundwater and surface water at the site is considered minimal. The seep in the southeast quarter of the section was observed in June and October 2006 as being very minor and does not contribute to a sizable riparian habitat.

3.6 Application Case

3.6.1 PDA Development and Infrastructure

The primary development and infrastructure components of the proposed sulphur forming and shipping facility are:

- rail and road access for receiving and shipping sulphur
- molten sulphur unloading and transfer facilities
- sulphur forming facilities to produce sulphur pastilles
- loading and shipping facilities for formed sulphur
- sulphur pastilles temporary storage area

The entire PDA sits within the western drainage basin of the Site, which has a total area of 1.87 km^2. The typical hydrologic effect of surface disturbances, particularly the construction of impermeable areas, is a decrease in evaporation and infiltration resulting in increases in runoff (both total volume and peak flow). However, the PDA (totalling 0.066 km^2 or approximately 3.5% of the drainage basin) will have an essentially closed circuit drainage system. Railway spurs and access roads make up an additional 0.02 km^2 of impacted area. Table 3.6-1 outlines the total percentage of the watershed area that will be developed.

Existing site conditions, including existing structures (abandoned Husky oil wells, etc.) are considered to represent baseline conditions. The wetland area in the northwest corner of the Site is the surface water feature which is most likely to be impacted by on-site development.

Table 3.6-1: Percent of Total Watershed Affected from Baseline Conditions

Proposed Infrastructure/ Development Type	**Development/disturbance Area (m^2)**	**Total Watershed Area (%)**
Sulphur forming plant footprint (including storage, forming and handling areas)	59,000	3.16
Stormwater management pond	6,800	0.36
Railway spur and access road	20,500	1.10
Total	**86,300 (0.086 km^2)**	**4.60**

This table indicates that overall impacts of the hard surface development area are unlikely to be significant, with just 4.6% of the total watershed area likely to be affected. Estimated hydrologic effects on the local and regional hydrology were predicted and assessed. The following sections discuss specific hydrologic effects of the various surface activities and potential groundwater abstraction.

3.6.2 Water Balance for the Application Case

The water balance assumptions used to calculate the baseline case were adjusted to represent the application case, with the primary influence being the introduction of the closed circuit drainage area. Average annual runoff from the developed plant site closed circuit drainage area (including the stormwater management pond) is estimated at approximately 22,650 m^3. This assumes a runoff coefficient of 72% for the plant site, and 100% for the pond area, and annual precipitation of 459.5 mm. The 10-year and 20-year drought annual runoff volumes from the plant site are 17,700 m^3 and 17,000 m^3 assuming annual precipitation of 360 mm and 345 mm respectively.

The impacts discussed in the following sections are on the land outside the closed circuit drainage area. No substantial changes to the water balance are predicted under average application conditions. Total annual inputs (runoff, direct rainfall and groundwater) decrease slightly to 78,400 m^3/y or by 2.3%, with total average baseline outputs (evapotranspiration and drainage out of open water) reduced slightly to 78,100 m^3/y. Groundwater contributions remain very minor and are estimated at just over 50 m^3/y. Based on this analysis, it was determined that neither more advanced modelling nor dry season modelling would be required to assess impacts to the water balance as the overall effects of the Project are very minor.

3.6.3 Peak Flows for the Application Case

The peak flow assumptions used to calculate the baseline case were adjusted to represent the application case, with the primary influence being the introduction of the closed circuit drainage area. No substantial changes to the peak flow were identified. Peak flows decrease by approximately 3.5% for the 10 year, 25 year and 100 year storm events as a result of the construction of the closed circuit drainage area. Based on this analysis, it was determined that more advanced numerical modelling would not be required to assess impacts to event-based flows as the overall effects of the Project are very minor.

3.6.4 Water Use for the Application Case

The sulphur forming process has a water use requirement of 12 USGPM (US gallons per minute) or 0.76 L/s (litres per second). Groundwater investigations were undertaken to assess the ability of the underlying aquifers to support the water use requirements for the life of the Project (see Volume IIB, Section 2: Groundwater Quantity and Quality). The upper bedrock aquifer has been identified as a potentially viable groundwater supply source; however, the potential response of the upper bedrock aquifer to long-term water withdrawals is subject to some uncertainty. Where the upper aquifer proves viable and is utilized, it appears that multiple wells will be necessary to meet the required yield. In addition, surface water runoff contained within the stormwater management pond will be used as the primary cooling water supply.

In the case that the multi-well option is unrealistic, an alternate water supply source (e.g., from a regional reservoir) will need to be secured for the Project. This could include an off-site source or increasing the capacity of the surface runoff collection pond.

3.6.5 Summary of Potential Impacts to Hydrology from Surface Activities

Surface activities and disturbances might occur during the construction and operation phases of the Project. These activities may give rise to potential changes in surface hydrology including:

- changes in land use due to land clearing and construction of facilities, the run-off collection pond and associated infrastructure (e.g., roads, railway spurs), increasing the potential for erosion and sediment run-off
- changes in land use due to land clearing and construction of facilities, run-off collection pond and associated infrastructure (e.g., roads, railway spurs) potentially altering existing flow patterns and existing basin sediment yield
- construction activity at and close to watercourse crossings giving rise to changes in flow patterns/conveyance capacity of streams, downstream geomorphology and sediment loading resulting from erosion during construction and operations

A number of ephemeral watercourses are present on site where crossings will take place. Although these features may appear small and insignificant at certain times of the year when flow is low, the *Alberta Water Act* definition of a waterbody is ‘any location where water flows or is present, whether or not the flow or the presence of water is continuous, intermittent or occurs only during a flood and includes but is not limited to wetlands and aquifers’. Any defined crossings of watercourses will therefore be installed in accordance with Alberta Environment’s Code of Practice under the *Water Act* (AENV 2001).

3.6.6 Mitigation of Potential Impacts to Hydrology from Surface Activities

Several surface water management mitigation measures will be implemented to minimize possible changes to water level and flow, erosion potential and possible changes to basin sediment yield and loading to receiving watercourses. Measures include but are not limited to:

- using stormwater management facilities, such as berms, drainage ditches and collection pond, to collect, convey and contain surface water runoff from the plant areas. These will be designed to provide full on-Project area storage of local runoff and excess plant process water. The capacity of the stormwater management pond will be approximately 11,000 m^3, which exceeds the run-off generated by the 1 in 25 year, 24 hour rainfall event. Surface water within the stormwater management pond will be stored and used as cooling water. In a flood situation where runoff exceeds the design criteria of the pond, the water would be tested for quality, treated (if required) and released to the environment provided that the water quality meets Surface Water Quality Guidelines for Use in Alberta (AENV 1999b). Water will be released in the natural grassed swale immediately east of the PDA where it will discharge into the wetland in the northwest quadrant of the Site. This wetland will provide additional natural filtration and impoundment before being discharged downstream to Beaverhill Creek.
- siting the facilities back at least 100 m from waterbodies where practicable, to minimize potential disturbances to riparian conditions and effects on local flow patterns. This will also provide an area for attenuation and dispersal of stormwater runoff before entering any natural waterbodies.

- providing culverts or bridges at defined watercourse crossings, ephemeral drainages and low points along road alignments. These will eliminate potential flow restrictions and maintain natural drainage patterns. Culverts will be provided as required to maintain local drainage with a typical maximum spacing of 300 m.
- establishing a minimum culvert size of 500 mm in diameter. Although larger than required for flood drainage in many cases, this will reduce the potential blockage from ice, sediment and vegetation growth.
- sizing culverts to convey the 1:25 year peak discharge at a water level not exceeding the crown of the culvert (no surcharging). This capacity should also accommodate partial blockage by vegetation or sediment where culverts are installed in wetland environments.
- installing culverts, where required, at natural grade to prevent impoundment upstream of the inlet and to maintain equal water levels and natural flow patterns on both sides of the road. This will help control excessive ponding or drying of wetland areas.
- developing and implementing an erosion and sediment control plan for the site before construction. The natural low gradient terrain means potential erosion concerns will be minimized. The use of best management practices will also minimize erosion and provide runoff control during construction of the plant, roads, railways and drainage ditches. These will include:
  - appropriate sediment control planning to minimize sediment generation caused by surface water runoff from newly excavated areas
  - scheduling and layout of works
  - installing sediment and runoff retention structures, such as silt fences and incorporating biotechnical erosion control measures
  - directing local road runoff away from any crossing locations into the adjacent vegetation
  - maintaining buffers and minimizing disturbances
  - minimizing the extent of surficial soil compaction during construction
  - re-establishing a vegetative cover as soon as practicable after construction
  - reclaiming impacted areas by grading and re-vegetating to restore natural drainage patterns as soon as practical following decommissioning. All culverts will be removed to facilitate restoration of natural drainage patterns and runoff conditions.

3.6.7 Classification of Residual Impacts to Hydrology from Surface Activities

3.6.7.1 Residual Impacts to Flow, Water Levels and Drainage Patterns

3.6.7.1.1 Construction and Operation

The increase in runoff from disturbed areas during wet periods may in some circumstances have a negative effect, as higher flows may contribute to flooding. However, the diversion of runoff from all plant areas to the collection pond and reuse of stormwater for process purposes will reduce the overall annual inputs (including runoff, direct rainfall and groundwater contributions) by 2.3%, compared to the baseline case. Peak flows for the 10 year, 25 year and 100 year return period frequencies are also predicted to decrease by approximately 3.5% for the drainage area outside the closed-circuit plant area. Changes in drainage patterns are expected to be neutral in direction provided as the above management practices will be employed for all stream crossings, which will maintain natural drainage patterns.

The magnitudes of the expected effects to flow and water level are therefore considered low to moderate, local in geographic extent, mid term in duration and are considered reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 3.

3.6.7.1.2 Project Closure

With reclamation of the facilities and restoration of the drainage patterns, although slightly reduced infiltration rates might be expected in some locations because of increased soil compaction at depth, runoff rates are expected to be comparable to pre-development baseline conditions. Effects following Project completion are therefore predicted to be neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

3.6.7.2 Residual Impacts to Channel Regime and Channel Alterations

3.6.7.2.1 Construction and Operation

Changes to the channel regime in a negative direction can result from periodic increases in runoff or alteration of channel morphology/hydraulics. As runoff rates are not anticipated to change substantially (approximately 2.3% reduction outside the plant, closed-circuit drainage area), these impacts are predicted to be low in magnitude, local in geographic extent, mid-term in duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 3.

3.6.7.2.2 Project Closure

With reclamation of the facilities and restoration of the drainage patterns, runoff rates are expected to be comparable to baseline conditions. Effects following Project completion are therefore neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

3.6.7.3 Residual Impacts to Sediment Yield

3.6.7.3.1 Construction and Operation

Sediment concentrations and erosion rates are expected to locally increase for short-term periods during construction. Despite best management practices, incidents or disturbances from construction activities are to be expected. Temporary effects may be negative in direction, but low in magnitude as these effects will be localized and readily mitigated by the low gradient and ephemeral receiving streams and/or natural buffer areas and will not extend past the wetland located on the northwest corner of the Site. Overall impacts are predicted to be negligible to low in magnitude, local in geographic extent, short-term in duration and reversible. Confidence for these residual impact assessments is moderate and the final impact rating is Class 3.

3.6.7.3.2 Project Closure

Project closure will result in the elimination of sediment impacts on receiving waterbodies. Effects following Project completion are therefore neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

3.6.8 Summary of Potential Impacts to Hydrology from Groundwater Abstraction

Volume IIB, Section 2: Groundwater Quantity and Quality discusses the potential impacts of groundwater abstraction on surface water in detail. Results indicate that Project water withdrawals may lead to the cessation of groundwater inflows to the wetland area in the northwest quarter section of the PDA. However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total annual water balance inflows, the termination of baseflow to the wetland is predicted to have a negligible impact.

Where installation of multiple wells in the upper bedrock aquifer proves unfeasible, an alternate water supply source (e.g., from a regional reservoir) will need to be secured for the Project and potential impacts to surface water from groundwater abstraction will be eliminated.

3.6.9 Mitigation of Potential Impacts to Hydrology from Groundwater Abstraction

Water levels in the wetland in the northeast corner of the Site will be monitored monthly throughout the ice-free season to evaluate potential impacts to water levels. Volume IIB, Section 2: Groundwater Quantity and Quality further outline the groundwater monitoring program which will be put in place to evaluate potential impacts to groundwater levels.

3.6.10 Residual Impacts to Hydrology from Groundwater Abstraction

3.6.10.1 Construction and Operation

The overall impacts to surface water-groundwater interactions during the Project lifetime are predicted to be negative in direction, local in geographic extent, negligible in magnitude, mid-term in duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 3.

3.6.10.2 Project Closure

After closure and reclamation of the Project, water withdrawals will no longer be required and local and regional groundwater levels and flows are anticipated to recover relatively rapidly within a time frame of a few years. Effects following Project completion are therefore predicted to be neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

3.6.11 Cumulative Watershed Hydrologic Effects

The assessments conducted in this section of the Environmental Impact Assessment (EIA) suggest that Project effects on hydrology will largely be limited to the LSA. Drainage on the

Site has already been impacted by the construction of roads and railways such that runoff to Beaverhill Creek has been reduced due to the improper placement of culvert inverts. In addition, natural drainage has been impacted by deforestation of the region, which has substantial effects on the water balance, primarily increased evaporation due to exposure of the soil to wind and solar radiation (Komex 2005). Provided that BMPs are implemented over the life of the Project, additional impacts to local hydrology are expected to be negligible.

Other drainage impacts in the vicinity of the Project include development-related impacts from Canexus, ERCO and Triton, all located within the regional drainage area of the Project. These developments have likely caused minor increases in runoff yield and peak flow due to the increase in impervious surfaces. However, all four developed areas make up a small fraction of the undeveloped lands in the local area and all development is buffered by vegetated ditches and green space, which combine to promote infiltration, thereby mitigating the effects of increased impermeable areas. Therefore, it is likely that the cumulative effect of the existing and proposed industrial developments on peak flows or total yield will be neutral in direction. Confidence for these residual impact assessments is moderate and the final impact rating is Class 3.

3.7 Management and Monitoring

The following hydrological monitoring will be performed by AST and/or HAZCO Environmental Services (HAZCO) during construction and operation activities to ensure potential impacts are mitigated:

- water levels in the wetland in the northeast corner of the Site will continue to be monitored monthly throughout the ice-free season for a period of at least one year
- the water quality of the waterbodies within the LSA will continue to be monitored before, during and after construction, including total suspended solids. Monitoring results will be compared to baseline levels to validate EIA assessment. In addition, Best Management Practices (BMPs) will be employed during construction. This is discussed in more detail in the Surface Water Quality portion of this EIA.

3.8 Summary

The hydrological impact assessment has concluded that potential adverse effects from development of the Project will be largely of local geographical extent, of low to moderate magnitude, of short to mid-term duration and will be reversible in nature. Confidence for these residual impact assessments is generally moderate to high. The final impact ratings for the construction and operation phases of the Project are Class 3 (see Table 3.8-1) and after Project closure are Class 4.

To minimize erosion potential and to maintain baseline drainage patterns, these impact classifications require that the appropriate Best Management Practices are effectively implemented. An impact assessment summary table is provided below.

Table 3.8-1: Final Impact Assessment Summary Table

Issue	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Confidence	Final Impact Rating	
							Construction and Operation	Closure
Potential Impact from Surface Activities								
Changes to flow, water level and drainage patterns	Negative	Low to Moderate	Local	Mid-term	Reversible	High	Class 3	Class 4
Impact to channel regime and channel alterations	Negative	Low to Moderate	Local	Mid-term	Reversible	High	Class 3	Class 4
Impact to sediment yield	Negative	Negligible to Low	Local	Short-term	Reversible	Moderate	Class 3	Class 4
Potential Impact from Groundwater Abstraction								
Changes to water level and drainage patterns	Negative	Negligible	Local	Mid-term	Reversible	High	Class 3	Class 4

3.9 References

3.9.1 Literature Cited

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Volume IIB, Section 3: Surface Water Quantity

Appendix I: Temperature, Precipitation, Rainfall IDF, Evapotranspiration and Runoff Data

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LIST OF ATTACHMENTS

Temperature and Precipitation Data

Source: Environment Canada, 2004. Meteorological Services of Canada station data and Canadian Monthly Climate Normals. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

Environment Canada Environnement Canada

[français] [Back]

Canadian Climate Normals 1971-2000

The minimum number of years used to calculate these Normals is indicated by a code for each element. A "+" beside an extreme date indicates that this date is the first occurrence of the extreme value. Values and dates in bold indicate all-time extremes for the location.

NOTE!! *Data used in the calculation of these Normals may be subject to further quality assurance checks. This may result in minor changes to some values presented here.*

FORT SASKATCHEWAN
ALBERTA

Latitude: 53° 43' N **Longitude:** 113° 10' W **Elevation:** 620.00 m

Climate ID: 3012710 **WMO ID:** **TC ID:**

Temperature:	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Code**
Daily Average (°C)	-13.5	-10.2	-3.8	4.8	11.2	14.9	16.7	15.8	10.7	4.7	-5.6	-11.5	2.9	A
Standard Deviation	4.6	5.1	3.2	2.1	1.5	1	1	1.7	1.8	1.5	3.8	4.7	3.6	A
Daily Maximum (°C)	-8.1	-4.6	1.5	10.9	17.9	21.1	22.8	22.2	17	10.7	-0.8	-6.4	8.7	A
Daily Minimum (°C)	-18.8	-15.7	-9	-1.4	4.5	8.7	10.6	9.3	4.4	-1.3	-10.3	-16.6	-3	A
Extreme Maximum (°C)	10	15	18.9	31.1	33.5	34.4	35.6	**36**	33.3	29.5	18.9	12.5		
Date (yyyy/dd)	1993/29+	1988/26	1959/26	1977/26	1993/12	1961/04+	1961/14	**1997/06**	1967/01	1987/02	1975/03	1999/28		
Extreme Minimum (°C)	-45	-41.5	**-45.6**	-28	-9.5	-3.3	2.2	-1	-10	-24.5	-36	-43.9		
Date (yyyy/dd)	1982/21	1994/07	**1962/01**	1982/03	1987/20	1969/12	1966/22	1992/25	1974/30	1984/31	1985/26	1977/09		
Precipitation:														
Rainfall (mm)	0.4	0.7	1.4	17	42	88.8	83.1	61.7	42.7	13.5	3	0.5		A
Snowfall (cm)	22.9	12.9	13	7.6	1.7	0	0	0	0.3	3.7	19.7	22.8		A
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3		A
Average Snow Depth (cm)					0	0	0	0	0					C
Median Snow Depth (cm)					0	0	0	0	0					C
Snow Depth at Month-end (cm)				0	0	0	0	0	0					C
Extreme Daily Rainfall (mm)	6.9	12	10.2	15.7	48.4	**77.7**	62	47	76.5	15.2	11	6.4		
Date (yyyy/dd)	1962/05	1991/12	1975/29	1973/27	1991/13	**1965/26**	1990/02	1975/28	1958/13	1960/08	1978/07	1958/02		
Extreme Daily Snowfall (cm)	33	25.4	18	**35**	23.5	0	0	0	6.4	18.5	25.4	23.4		
Date (yyyy/dd)	1994/04	1961/15	2000/06	**1985/21**	1997/20	1958/01+	1958/01+	1958/01+	1974/29	1991/16	1996/10	1976/08		

Extreme Daily Precipitation (mm)	33	25.4	18	36.6	48.4	**77.7**	62	47	76.5	22.5	25.4	23.4		
Date (yyyy/dd)	1994/04	1961/15	2000/06	1991/06	1991/13	**1965/26**	1990/02	1975/28	1958/13	1991/16	1996/10	1976/08		
Extreme Snow Depth (cm)	**15**	2	15	3	0	0	0	0	0	2	0	8		
Date (yyyy/dd)	**1998/31**	2001/01+	2002/15	1999/05	1981/01+	1981/01+	1981/01+	1982/01+	1982/01+	2001/22	1981/01+	2000/31		
Days with Maximum Temperature:														
<= 0 °C	24.1	18	11.7	1.8	0	0	0	0	0.08	1.9	14.4	23.3	95.3	A
> 0 °C	6.9	10.2	19.3	28.3	31	30	31	31	29.9	29.1	15.6	7.7	270	A
> 10 °C	0	0.24	2.6	16.5	28.1	29.8	31	30.8	25.3	17.3	1.2	0.07	183.1	A
> 20 °C	0	0	0	1.9	9.9	17.9	23.2	20.5	9.4	2	0	0	84.6	A
> 30 °C	0	0	0	0.04	0.42	0.32	0.7	1	0.12	0	0	0	2.6	A
> 35 °C	0	0	0	0	0	0	0	0.04	0	0	0	0	0.04	A
Days with Minimum Temperature:														
> 0 °C	0.12	0.29	1.3	11	26.2	29.9	31	30.6	25.2	11.1	0.82	0.31		A
<= 2 °C	30.9	28.2	30.8	24	9.3	0.48	0	1	8.1	24.5	29.7	31		A
<= 0 °C	30.9	28	29.8	19	4.8	0.1	0	0.37	4.8	19.9	29.2	30.7		A
< -2 °C	30.6	27	25.5	11.3	1.7	0	0	0	2	11.8	27	30.1		A
< -10 °C	24.7	19.3	11.9	1.6	0	0	0	0	0	1	12.6	22.4		A
< -20 °C	12.6	8.6	2.9	0.11	0	0	0	0	0	0.2	3.1	9.6		A
< - 30 °C	4.2	2.2	0.18	0	0	0	0	0	0	0	0.21	2.8		A
Days with Rainfall:														
>= 0.2 mm	0.14	0.21	0.66	5.1	10.1	13.3	14.2	13.5	10.2	6	1.5	0.18	75	A
>= 5 mm	0.03	0.03	0.07	0.96	2.5	5.1	4.6	3.5	2.6	0.76	0.07	0.04	20.4	A
>= 10 mm	0	0.03	0.03	0.59	1.2	2.8	2.7	1.7	1.2	0.24	0.07	0	10.5	A
>= 25 mm	0	0	0	0	0.15	0.79	0.54	0.36	0.22	0	0	0	2.1	A
Days With Snowfall:														
>= 0.2 cm	6.5	4.8	3.7	1.5	0.35	0	0	0	0.07	1	4.9	5.8		A
>= 5 cm	1.5	0.83	0.86	0.46	0.12	0	0	0	0.04	0.21	1.3	1.6		A
>= 10 cm	0.5	0.1	0.41	0.18	0.04	0	0	0	0	0.08	0.44	0.52		A
>= 25 cm	0.08	0	0	0.04	0	0	0	0	0	0	0.04	0		A
Days with Precipitation:														
>= 0.2 mm	6.6	5	4.3	6.3	10.2	13.3	14.2	13.5	10.2	6.8	6.4	5.9		A
>= 5 mm	1.5	0.83	0.97	1.4	2.7	5.1	4.6	3.5	2.6	1.1	1.4	1.6		A
>= 10 mm	0.5	0.14	0.45	0.78	1.3	2.8	2.7	1.7	1.2	0.38	0.52	0.5		A
>= 25 mm	0.08	0	0	0.07	0.19	0.79	0.54	0.36	0.22	0	0.04	0		A
Days with Snow Depth:														
>= 1 cm					0	0	0	0	0					C
>= 5 cm					0	0	0	0	0					C
>= 10					0	0	0	0	0					C
>= 20					0	0	[illegible]	0	0					C
Degree Days:														

▲

Important Notices

Created : 2002-06-21
Modified : 2004-02-25
Reviewed : 2004-02-25
Url of this page : http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html

The Green Lane™,
Environment Canada's World Wide Web Site.

Rainfall Intensity Duration Frequency Data

Source: Environment Canada, 1990. Atmospheric Environment Service. Rainfall intensity-duration-frequency data.

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                    ATMOSPHERIC ENVIRONMENT SERVICE
                SERVICE DE L"ENVIRONNEMENT ATMOSPHERIQUE

                RAINFALL INTENSITY-DURATION FREQUENCY VALUES
                  INTENSITE, DUREE ET FREQUENCE DES PLUIES

                        DATA INTEGRATION DIVISION
                   LA DIVISION DU TRAITEMENT DES DONNEES

          GUMBEL - METHOD OF MOMENTS/METHODE DES MOMENTS - 1990

*****************************************************************************
**

         TABLE 1         EDMONTON NAMAO AIRPORT  ALTA                3012210

         LATITUDE 5340       LONGITUDE 11328      ELEVATION/ALTITUDE  685  M
*****************************************************************************
**
          YEAR   5 MIN 10 MIN 15 MIN 30 MIN   1 H    2 H    6 H   12 H   24 H
         ANNEE

          1965     3.6    4.8    6.1    9.7   12.2   19.0   46.5   70.4   94.7
          1966     4.6    5.6    6.3    6.3    9.9   11.4   22.4   31.2   35.1
          1967     3.3    5.8    7.4   10.4   11.4   13.2   18.5   28.2   28.2
          1968     7.9    8.9    9.1    9.1   10.2   10.2   14.0   19.8   30.0
          1969     3.0    5.6    6.3    9.1    9.4   13.2   23.6   35.6   60.7
          1970     5.8    9.7   10.4   10.7   10.7   11.7   21.1   28.2   47.8
          1971     7.4    9.1   10.2   11.9   13.7   16.3   19.6   23.4   35.1
          1972     6.9   11.7   14.7   16.8   17.0   17.0   17.5   21.1   24.1
          1973     6.6   10.2   15.5   25.4   30.0   31.0   31.5   34.0   64.3
          1974     7.9   15.0   17.8   18.3   18.3   23.4   53.3   76.5   83.6
          1975     6.9   12.7   15.7   18.0   20.6   22.4   31.0   39.6   49.3
          1976     4.6    8.6   10.9   18.0   19.8   23.1   36.3   37.1   38.4
          1977     3.0    4.3    5.8    6.1    6.3   10.9   19.6   27.2   33.3
          1978     4.2    6.3    8.8   15.8   19.5   19.6   27.5   35.0   59.8
          1979     6.1   10.1   14.1   23.7   24.6   24.6   29.1   38.1   44.0
          1980     8.7   14.4   16.8   19.9   22.0   22.4   29.4   36.2   39.6
          1981     5.5   10.2   15.3   16.7   16.7   27.7   40.8   47.3   54.7
          1982     8.1   11.9   15.5   19.0   19.3   19.3   33.1   44.2   67.5
          1983   -99.9  -99.9  -99.9  -99.9   15.8   24.7   36.0   41.1   74.5
          1984     3.8    4.4    5.5   10.1   11.7   13.8   29.9   42.7   59.3
          1985     3.7    7.3    8.9   13.2   13.5   26.1   36.0   36.0   36.0
          1986     8.6   12.0   12.9   12.9   12.9   18.2   31.1   42.2   54.0
          1987    13.7   15.5   16.8   27.7   32.3   46.9   57.2   60.2   60.2
          1988     7.1    8.2    9.3   11.3   20.2   29.6   37.2   63.8   96.4
          1989     9.2   12.0   14.7   15.5   15.8   15.8   27.8   33.3   42.4
          1990    10.7   12.5   14.9   23.9   31.0   31.7   47.1   77.8  103.6
          NOTE:-99.9 INDICATES MSG DATA
                     DONNEES MANQUANTES

         # YRS.    25     25     25     25     26     26     26     26     26
         ANNEES
           MEAN    6.4    9.5   11.6   15.2   17.1   20.9   31.4   41.2   54.5
        MOYENNE
```

```
     STD. DEV.   2.6     3.4     4.1     5.9     6.8     8.3    11.0    16.0    21.9
    ECART-TYPE
          SKEW   0.79    0.06   -0.10    0.44    0.78    1.19    0.66    1.09
0.79
   DISSYMETRIE
      KURTOSIS   4.11    2.33    1.83    2.73    3.40    5.57    3.35    3.75
3.17
      KURTOSIS


         NOTE: -99.9 INDICATES LESS THAN 10 YEARS OF DATA AVAILABLE
               INDIQUE MOINS DE 10 ANNEES DE DONNEES DISPONIBLES
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         TABLE 2         EDMONTON NAMAO AIRPORT  ALTA                 3012210

         LATITUDE 5340       LONGITUDE 11328       ELEVATION/ALTITUDE  685  M
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                                RETURN PERIOD RAINFALL AMOUNTS (MM)
                            PERIODE DE RETOUR QUANTITIES DE PLUIE (MM)

        DURATION    2        5        10       25       50       100   # YEARS
         DUREE    YR/ANS   YR/ANS   YR/ANS   YR/ANS   YR/ANS   YR/ANS   ANNEES
         5 MIN     6.0      8.3      9.9     11.8     13.3     14.7       25
        10 MIN     8.9     11.9     13.9     16.3     18.2     20.0       25
        15 MIN    10.9     14.5     16.9     19.9     22.1     24.3       25
        30 MIN    14.2     19.5     22.9     27.3     30.6     33.8       25
           1 H    16.0     22.0     26.0     31.0     34.8     38.5       26
           2 H    19.5     26.9     31.7     37.9     42.4     46.9       26
           6 H    29.6     39.4     45.8     54.0     60.0     66.0       26
          12 H    38.5     52.7     62.1     74.0     82.8     91.5       26
          24 H    50.9     70.2     83.1     99.2    111.2    123.2       26

                RETURN PERIOD RAINFALL RATES (MM/HR)-95% CONFIDENCE' LIMITS
  INTENSITE DE LA PLUIE PAR PERIODE DE RETOUR (MM/H)-LIMITES DE CONFIANCE DE
95%

        DURATION  2 YR/ANS  5 YR/ANS 10 YR/ANS 25 YR/ANS 50 YR/ANS 100 YR/ANS
         DUREE
          5 MIN       72.1      99.9     118.5     141.8     159.1      176.3
                 +/- 11.4  +/- 19.1  +/- 25.9  +/- 34.9  +/- 41.7  +/- 48.6

         10 MIN       53.5      71.3      83.2      98.1     109.1      120.1
                 +/-  7.3  +/- 12.2  +/- 16.5  +/- 22.3  +/- 26.6  +/- 31.0

         15 MIN       43.7      58.0      67.6      79.6      88.5       97.4
                 +/-  5.9  +/-  9.9  +/- 13.3  +/- 18.0  +/- 21.5  +/- 25.0

         30 MIN       28.4      38.9      45.9      54.6      61.2       67.6
                 +/-  4.3  +/-  7.2  +/-  9.7  +/- 13.1  +/- 15.7  +/- 18.3

            1 H       16.0      22.0      26.0      31.0      34.8       38.5
                 +/-  2.4  +/-  4.0  +/-  5.5  +/-  7.4  +/-  8.8  +/- 10.3

            2 H        9.8      13.4      15.9      18.9      21.2       23.5
                 +/-  1.5  +/-  2.5  +/-  3.3  +/-  4.5  +/-  5.4  +/-  6.3

            6 H        4.9       6.6       7.6       9.0      10.0       11.0
                 +/-  0.6  +/-  1.1  +/-  1.5  +/-  2.0  +/-  2.4  +/-  2.8

           12 H        3.2       4.4       5.2       6.2       6.9        7.6
                 +/-  0.5  +/-  0.8  +/-  1.1  +/-  1.4  +/-  1.7  +/-  2.0

           24 H        2.1       2.9       3.5       4.1       4.6        5.1
                 +/-  0.3  +/-  0.5  +/-  0.7  +/-  1.0  +/-  1.2  +/-  1.4
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         TABLE 3         EDMONTON NAMAO AIRPORT  ALTA                    3012210

         LATITUDE 5340       LONGITUDE 11328       ELEVATION/ALTITUDE  685  M
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         INTERPOLATION EQUATION / EQUATION D"INTERPOLATION: R = A * T ** B
                 R = RAINFALL RATE / INTENSITE DE LA PLUIE (MM /HR)
                 T = TIME IN HOURS / TEMPS EN HEURES

            STATISTICS                 2 YR   5 YR  10 YR  25 YR  50 YR 100 YR
           STATISTIQUES                ANS    ANS    ANS    ANS    ANS    ANS


           MEAN OF  R                  25.9   35.2   41.4   49.2   55.0   60.7
           MOYENNE DE R


           STD. DEV. R                 25.2   34.4   40.5   48.3   54.0   59.7
           ECART-TYPE


           STD. ERROR                   4.0    4.5    4.9    5.4    5.7    6.1
           ERREUR STANDARD


           COEFF. (A)                  16.2   22.1   26.0   30.9   34.5   38.1
           COEFFICIENT (A)


           EXPONENT (B)              -0.648 -0.647 -0.646 -0.646 -0.646 -0.645
           EXPOSANT (B)


           MEAN % ERROR                 5.4    4.9    4.7    4.7    4.7    4.8
           % D'ERREUR
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Evapotranspiration Data

Source: Alberta Environmental Protection (AENV), 1999a. Evaporation and Evapotranspiration in Alberta: Report 1912-1985, Data 1912-1996. Water Sciences Branch, Water Management Division, Alberta Environmental Protection. January, 1999.

EDMONTON CITY CENTRE AIRPORT
POTENTIAL EVAPOTRANSPIRATION - MM

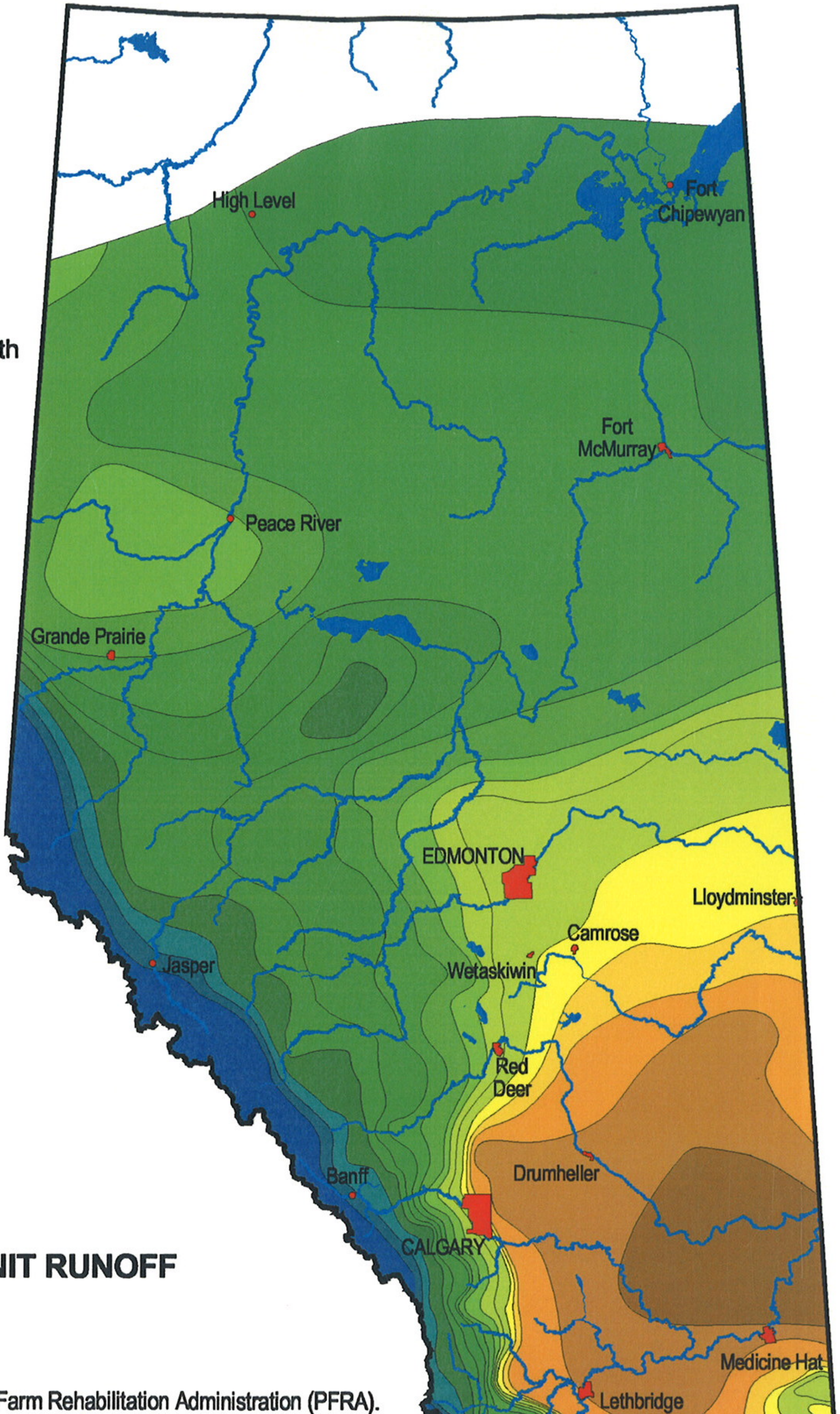
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	%	TOTAL
1912	-4.	-3.	2.	76.	141.	176.	112.	108.	73.	24.	7.	3.	82.	715.
1913	2.	6.	27.	100.	128.	128.	136.	104.	78.	20.	5.	1.	85.	735.
1914	-1.	1.	33.	104.	162.	117.	153.	133.	53.	20.	2.	-2.	89.	775.
1915	-2.	-4.	27.	111.	116.	107.	117.	138.	83.	26.	3.	-2.	83.	720.
1916	-1.	-1.	28.	95.	121.	146.	136.	112.	69.	23.	6.	0.	84.	734.
1917	1.	1.	30.	62.	129.	158.	181.	132.	81.	20.	10.	0.	93.	805.
1918	0.	2.	38.	110.	124.	145.	155.	123.	83.	27.	3.	-2.	93.	808.
1919	-1.	0.	5.	95.	135.	160.	153.	137.	74.	12.	0.	-1.	88.	769.
1920	-2.	3.	7.	36.	126.	138.	187.	124.	67.	23.	1.	-1.	82.	709.
1921	0.	7.	25.	92.	147.	167.	162.	120.	83.	33.	1.	0.	96.	837.
1922	0.	0.	24.	76.	145.	144.	174.	126.	92.	26.	5.	-1.	93.	811.
1923	0.	4.	21.	111.	152.	145.	154.	123.	90.	38.	7.	-1.	97.	844.
1924	-1.	4.	13.	80.	148.	153.	163.	112.	77.	25.	-1.	-3.	89.	770.
1925	-3.	-2.	21.	90.	166.	152.	168.	118.	59.	16.	3.	1.	91.	789.
1926	1.	4.	44.	106.	139.	145.	189.	105.	46.	18.	1.	-1.	92.	797.
1927	-1.	0.	34.	77.	118.	149.	148.	135.	69.	21.	0.	-1.	86.	749.
1928	-1.	7.	28.	62.	172.	115.	151.	116.	98.	22.	4.	7.	90.	781.
1929	-1.	0.	43.	71.	144.	177.	202.	158.	74.	43.	12.	-1.	106.	922.
1930	-1.	6.	49.	90.	117.	111.	176.	151.	68.	18.	6.	-1.	91.	790.
1931	-2.	12.	30.	126.	173.	-	167.	163.	77.	35.	9.	2.	-	-
1932	2.	-1.	6.	67.	153.	171.	191.	202.	109.	23.	5.	-2.	106.	926.
1933	0.	-	-	101.	143.	160.	175.	175.	81.	26.	10.	-1.	-	-
1934	4.	14.	36.	145.	178.	132.	167.	171.	62.	42.	7.	-2.	110.	956.
1935	-2.	10.	13.	55.	113.	142.	177.	126.	98.	28.	0.	-4.	87.	756.
1936	-1.	0.	19.	73.	159.	148.	214.	165.	79.	33.	12.	2.	104.	903.
1937	1.	2.	37.	97.	161.	169.	163.	129.	41.	27.	4.	0.	95.	831.
1938	-1.	0.	37.	101.	156.	164.	182.	134.	123.	31.	4.	-1.	107.	930.
1939	-1.	0.	14.	105.	130.	102.	170.	170.	68.	16.	3.	-	-	-
1940	0.	0.	23.	70.	128.	134.	120.	134.	93.	26.	0.	-3.	83.	725.
1941	0.	5.	40.	114.	-	146.	178.	122.	60.	24.	6.	2.	-	-
1942	-2.	1.	44.	97.	156.	135.	156.	136.	43.	30.	-3.	-6.	90.	787.
1943	-2.	-3.	7.	113.	144.	133.	166.	116.	110.	25.	8.	0.	94.	817.
1944	-5.	-4.	12.	123.	140.	132.	157.	135.	74.	43.	-3.	-7.	92.	797.
1945	-3.	-3.	33.	68.	153.	164.	192.	141.	70.	29.	-5.	-6.	96.	833.
1946	-6.	-3.	37.	112.	144.	134.	180.	138.	70.	27.	-3.	-6.	95.	824.
1947	-2.	-3.	4.	75.	159.	130.	191.	108.	66.	29.	-3.	-5.	86.	749.
1948	-3.	-4.	1.	24.	141.	190.	176.	134.	85.	37.	2.	-6.	89.	777.
1949	-3.	-2.	29.	124.	164.	181.	167.	152.	101.	24.	11.	-6.	108.	942.
1950	4.	-3.	2.	79.	161.	205.	190.	140.	106.	16.	-5.	-7.	102.	888.
1951	-5.	-4.	0.	80.	146.	171.	144.	121.	78.	16.	-5.	-6.	85.	736.
1952	-5.	-4.	1.	129.	172.	148.	163.	144.	88.	39.	6.	-5.	101.	876.
1953	-6.	0.	7.	77.	148.	138.	155.	128.	93.	39.	8.	2.	91.	789.
1954	-1.	8.	26.	56.	119.	130.	172.	91.	75.	38.	10.	1.	83.	725.
1955	-3.	1.	7.	70.	157.	202.	153.	168.	76.	28.	-2.	-2.	98.	855.
1956	-2.	-2.	12.	84.	200.	162.	173.	149.	79.	30.	12.	-1.	103.	896.
1957	-4.	-2.	14.	94.	165.	211.	196.	131.	106.	26.	4.	-2.	108.	939.
1958	-2.	0.	10.	90.	199.	171.	196.	178.	87.	37.	7.	-1.	112.	972.
1959	-1.	2.	52.	116.	157.	153.	209.	120.	81.	19.	5.	1.	105.	914.
1960	-4.	-1.	17.	117.	145.	153.	200.	136.	98.	30.	4.	-6.	102.	889.
1961	-3.	1.	33.	103.	164.	217.	185.	186.	86.	24.	5.	-3.	115.	998.
1962	-1.	-3.	3.	96.	149.	176.	156.	136.	96.	35.	5.	-2.	97.	846.
1963	-2.	-1.	29.	98.	151.	180.	190.	166.	107.	39.	3.	0.	110.	960.
1964	-3.	8.	15.	114.	156.	188.	201.	149.	60.	37.	0.	-1.	106.	924.
1965	-1.	1.	14.	77.	154.	164.	189.	157.	60.	47.	-1.	-3.	99.	858.
1966	-2.	-2.	33.	80.	194.	176.	183.	129.	103.	30.	0.	-3.	106.	921.
1967	-2.	0.	4.	64.	174.	180.	203.	201.	134.	31.	5.	-1.	114.	993.
1968	-3.	5.	42.	107.	195.	175.	200.	138.	75.	28.	6.	-3.	111.	965.
1969	-3.	-2.	30.	104.	176.	209.	189.	179.	66.	24.	6.	-4.	112.	974.
1970	-3.	7.	13.	109.	173.	200.	170.	179.	97.	27.	-3.	-4.	111.	965.
1971	-3.	-2.	16.	109.	212.	142.	172.	189.	78.	35.	4.	-2.	109.	950.
1972	-2.	0.	28.	100.	186.	184.	158.	166.	53.	32.	2.	-1.	104.	906.
1973	-2.	2.	41.	91.	196.	191.	200.	144.	85.	26.	-2.	0.	112.	972.
1974	1.	7.	12.	103.	154.	219.	208.	141.	81.	42.	12.	4.	113.	984.
1975	9.	4.	27.	77.	158.	172.	206.	131.	106.	28.	9.	0.	106.	927.
1976	1.	7.	31.	126.	193.	166.	202.	178.	96.	32.	14.	3.	120.	1049.
1977	1.	21.	44.	151.	153.	214.	167.	137.	72.	44.	13.	0.	117.	1017.
1978	-2.	1.	38.	91.	156.	199.	191.	142.	63.	40.	5.	-1.	106.	923.
1979	-2.	0.	46.	77.	157.	170.	169.	145.	100.	29.	9.	-2.	103.	898.
1980	-2.	2.	33.	145.	188.	145.	176.	115.	60.	32.	11.	0.	104.	905.
1981	-4.	8.	50.	119.	164.	174.	170.	195.	99.	29.	8.	-2.	116.	1010.
1982	-1.	-2.	11.	98.	186.	208.	163.	131.	97.	35.	0.	-1.	106.	925.
1983	-2.	1.	5.	111.	173.	155.	160.	182.	74.	31.	-1.	-1.	102.	888.
1984	3.	13.	39.	136.	124.	170.	213.	180.	61.	23.	-3.	-1.	110.	958.
1985	-1.	1.	44.	110.	196.	189.	219.	145.	62.	28.	0.	0.	114.	993.
1986	2.	1.	41.	99.	174.	199.	131.	185.	63.	33.	1.	0.	107.	929.
1987	-1.	6.	20.	128.	184.	202.	172.	109.	118.	39.	9.	1.	113.	987.
1988	0.	10.	50.	152.	214.	168.	188.	150.	93.	38.	4.	1.	123.	1068.
1989	1.	1.	24.	130.	164.	164.	175.	112.	96.	31.	6.	1.	104.	905.
1990	1.	5.	53.	94.	164.	173.	186.	157.	125.	29.	4.	0.	114.	991.
1991	2.	11.	35.	121.	162.	140.	215.	175.	91.	23.	-1.	0.	112.	974.
1992	2.	3.	52.	100.	150.	199.	181.	177.	73.	33.	3.	-1.	112.	972.
1993	-2.	5.	39.	84.	182.	174.	154.	138.	98.	34.	6.	2.	105.	914.
1994	0.	1.	58.	130.	168.	147.	175.	133.	112.	32.	4.	-5.	110.	955.
1995	-1.	6.	43.	77.	161.	164.	146.	107.	118.	26.	2.	-1.	97.	848.
1996	0.	7.	30.	81.	93.	134.	147.	151.	64.	23.	0.	-1.	84.	729.
MIN	-6.0	-4.0	0.0	24.0	93.0	102.0	112.0	91.0	41.0	12.0	-5.0	-7.0		
MAX	9.0	21.0	58.0	152.0	214.0	219.0	219.0	202.0	134.0	47.0	14.0	7.0		
MEAN	-1.1	2.2	26.1	96.7	157.0	162.7	173.7	143.1	82.5	29.1	3.9	-1.3	100.	875.

EDMONTON CITY CENTRE AIRPORT
AREAL EVAPOTRANSPIRATION - MM

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	%	TOTAL
1912	-4.	-3.	2.	36.	67.	106.	80.	70.	27.	15.	5.	3.	106.	404.
1913	2.	6.	19.	37.	71.	90.	107.	85.	31.	17.	4.	1.	123.	470.
1914	-1.	1.	16.	19.	54.	88.	126.	91.	34.	19.	2.	-2.	117.	447.
1915	-2.	-4.	25.	38.	66.	99.	113.	111.	44.	14.	3.	-2.	132.	505.
1916	-1.	-1.	21.	32.	62.	89.	97.	76.	28.	13.	5.	0.	110.	421.
1917	1.	1.	20.	43.	59.	103.	120.	96.	28.	15.	0.	0.	127.	486.
1918	0.	2.	20.	41.	61.	95.	117.	86.	33.	15.	3.	-2.	123.	471.
1919	-1.	0.	5.	38.	75.	105.	103.	79.	28.	12.	0.	-1.	116.	443.
1920	-2.	3.	7.	36.	63.	93.	131.	86.	26.	16.	1.	-1.	120.	459.
1921	0.	7.	20.	43.	68.	102.	112.	76.	17.	11.	1.	0.	120.	457.
1922	0.	0.	21.	37.	62.	76.	108.	76.	18.	13.	4.	-1.	108.	414.
1923	0.	4.	19.	37.	61.	87.	99.	94.	39.	15.	4.	-1.	120.	458.
1924	-1.	4.	13.	39.	68.	105.	108.	81.	33.	17.	-1.	-3.	121.	463.
1925	-3.	-2.	20.	41.	73.	110.	114.	79.	24.	16.	3.	1.	125.	476.
1926	1.	4.	19.	50.	82.	94.	117.	69.	35.	17.	1.	-1.	128.	488.
1927	-1.	0.	20.	49.	63.	100.	120.	86.	28.	16.	0.	-1.	126.	480.
1928	-1.	7.	21.	42.	92.	90.	133.	92.	30.	18.	4.	4.	139.	532.
1929	-1.	0.	19.	39.	54.	64.	95.	60.	19.	9.	0.	-1.	94.	357.
1930	-1.	6.	22.	32.	56.	56.	111.	90.	29.	18.	4.	-1.	111.	422.
1931	-2.	11.	17.	15.	38.	-	90.	55.	13.	12.	6.	2.	-	-
1932	2.	-1.	6.	43.	73.	67.	73.	32.	11.	13.	5.	-2.	84.	322.
1933	0.	-	-	34.	48.	59.	105.	61.	15.	14.	6.	-1.	-	-
1934	4.	10.	13.	17.	58.	51.	96.	51.	8.	7.	6.	-2.	84.	319.
1935	-2.	10.	13.	55.	84.	78.	97.	74.	16.	12.	0.	-4.	113.	433.
1936	-1.	0.	19.	44.	65.	90.	96.	46.	16.	9.	0.	2.	101.	386.
1937	1.	2.	17.	29.	67.	89.	98.	73.	6.	9.	4.	0.	104.	395.
1938	-1.	0.	17.	20.	56.	81.	104.	58.	13.	13.	4.	-1.	95.	364.
1939	-1.	0.	14.	38.	72.	88.	124.	73.	21.	16.	3.	-	-	-
1940	0.	0.	20.	62.	88.	113.	114.	96.	28.	13.	0.	-3.	139.	531.
1941	0.	5.	19.	42.	-	115.	129.	85.	20.	16.	3.	2.	-	-
1942	-2.	1.	15.	21.	47.	83.	107.	72.	43.	12.	-3.	-6.	102.	390.
1943	-2.	-3.	7.	41.	49.	68.	109.	79.	19.	14.	4.	0.	101.	385.
1944	-5.	-4.	12.	28.	54.	95.	97.	75.	18.	9.	-3.	-7.	97.	369.
1945	-3.	-3.	19.	30.	40.	70.	86.	69.	18.	14.	-5.	-6.	86.	329.
1946	-6.	-3.	20.	28.	50.	79.	101.	77.	20.	16.	-3.	-6.	98.	373.
1947	-2.	-3.	4.	28.	54.	60.	113.	53.	19.	12.	-3.	-5.	87.	330.
1948	-3.	-4.	1.	24.	63.	86.	85.	63.	17.	10.	2.	-6.	89.	338.
1949	-3.	-2.	24.	16.	46.	59.	75.	88.	16.	14.	0.	-6.	86.	327.
1950	4.	-3.	2.	33.	50.	73.	87.	66.	13.	16.	-5.	-7.	86.	329.
1951	-5.	-4.	0.	36.	58.	82.	98.	74.	19.	16.	-5.	-6.	95.	363.
1952	-5.	-4.	1.	22.	57.	83.	102.	80.	17.	11.	3.	-5.	95.	362.
1953	-6.	0.	7.	41.	49.	76.	102.	81.	18.	10.	4.	2.	101.	384.
1954	-1.	8.	21.	30.	53.	65.	96.	69.	22.	11.	2.	1.	99.	377.
1955	-3.	1.	7.	33.	64.	93.	97.	81.	18.	12.	-2.	-2.	105.	399.
1956	-2.	-2.	12.	42.	62.	68.	106.	75.	18.	13.	1.	-1.	103.	392.
1957	-4.	-2.	14.	38.	61.	33.	91.	59.	16.	16.	4.	-2.	85.	324.
1958	-2.	0.	10.	28.	52.	80.	99.	57.	17.	11.	6.	-1.	94.	357.
1959	-1.	2.	18.	29.	53.	79.	100.	56.	19.	14.	5.	1.	98.	375.
1960	-4.	-1.	17.	25.	48.	73.	104.	64.	16.	12.	4.	-6.	92.	352.
1961	-3.	1.	21.	26.	49.	77.	101.	63.	17.	12.	5.	-3.	96.	366.
1962	-1.	-3.	3.	33.	59.	89.	97.	64.	17.	11.	4.	-2.	97.	371.
1963	-2.	-1.	20.	39.	49.	71.	87.	67.	16.	10.	3.	0.	94.	359.
1964	-3.	8.	15.	17.	38.	61.	86.	53.	18.	10.	0.	-1.	79.	302.
1965	-1.	1.	14.	41.	54.	76.	96.	61.	18.	7.	-1.	-3.	95.	363.
1966	-2.	-2.	22.	35.	52.	80.	94.	62.	14.	9.	0.	-3.	95.	361.
1967	-2.	0.	4.	49.	40.	72.	77.	59.	7.	10.	5.	-1.	84.	320.
1968	-3.	5.	17.	27.	53.	63.	92.	63.	17.	11.	4.	-3.	91.	346.
1969	-3.	-2.	23.	29.	61.	76.	99.	74.	20.	17.	4.	-4.	103.	394.
1970	-3.	7.	13.	33.	45.	62.	87.	65.	13.	12.	-3.	-4.	86.	327.
1971	-3.	-2.	16.	41.	36.	70.	101.	60.	13.	10.	4.	-2.	90.	344.
1972	-2.	0.	21.	30.	52.	68.	80.	77.	16.	9.	2.	-1.	92.	352.
1973	-2.	2.	16.	25.	45.	67.	90.	71.	16.	12.	-2.	0.	89.	340.
1974	1.	7.	12.	29.	38.	57.	70.	58.	15.	6.	0.	4.	78.	297.
1975	7.	4.	20.	24.	43.	64.	85.	59.	16.	11.	4.	0.	88.	337.
1976	1.	7.	17.	24.	29.	81.	89.	47.	9.	10.	0.	3.	83.	317.
1977	1.	7.	15.	13.	53.	80.	82.	56.	15.	7.	3.	0.	87.	332.
1978	-2.	1.	17.	16.	50.	84.	93.	66.	20.	9.	5.	-1.	94.	358.
1979	-2.	0.	18.	30.	53.	80.	113.	83.	23.	11.	3.	-2.	107.	410.
1980	-2.	2.	22.	15.	36.	85.	102.	70.	26.	12.	3.	0.	97.	371.
1981	-4.	8.	18.	23.	45.	93.	98.	67.	14.	14.	5.	-2.	99.	379.
1982	-1.	-2.	11.	39.	53.	63.	100.	68.	16.	12.	0.	-1.	94.	358.
1983	-2.	1.	5.	27.	40.	69.	106.	66.	17.	11.	-1.	-1.	89.	338.
1984	3.	9.	19.	17.	40.	86.	85.	52.	18.	14.	-3.	-1.	89.	339.
1985	-1.	1.	17.	25.	51.	91.	102.	66.	17.	11.	0.	0.	100.	380.
1986	2.	1.	17.	22.	45.	77.	85.	69.	17.	13.	1.	0.	92.	349.
1987	-1.	6.	20.	23.	64.	87.	88.	61.	15.	9.	4.	1.	99.	377.
1988	0.	10.	13.	14.	32.	87.	92.	66.	16.	11.	4.	1.	91.	346.
1989	1.	1.	21.	29.	46.	93.	115.	68.	21.	13.	6.	1.	109.	415.
1990	1.	5.	19.	27.	63.	81.	95.	54.	14.	12.	4.	0.	98.	375.
1991	2.	7.	21.	23.	67.	73.	100.	64.	15.	14.	-1.	0.	101.	385.
1992	2.	3.	16.	21.	43.	75.	91.	49.	14.	11.	3.	-1.	86.	327.
1993	-2.	5.	16.	27.	51.	65.	87.	70.	16.	12.	6.	2.	93.	355.
1994	0.	1.	14.	16.	49.	81.	104.	68.	16.	13.	4.	-5.	95.	361.
1995	-1.	6.	18.	25.	55.	79.	77.	64.	17.	12.	2.	-1.	93.	353.
1996	0.	7.	20.	38.	38.	77.	95.	86.	20.	14.	0.	-1.	103.	394.
MIN	-6.0	-4.0	0.0	13.0	29.0	33.0	70.0	32.0	6.0	6.0	-5.0	-7.0		
MAX	7.0	11.0	25.0	62.0	92.0	115.0	133.0	111.0	44.0	19.0	6.0	4.0		
MEAN	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	100.	383.

Mean Annual Unit Runoff Data

Source: Alberta Environmental Protection (AENV) 2005. Regional median annual unit runoff estimates (based on Prairie Farm Rehabilitation Administration Hydrology Report #135, Feb 1994).



Alberta
Environment

MEDIAN ANNUAL UNIT RUNOFF
(mm per year)

Data coverage provided by Prairie Farm Rehabilitation Administration (PFRA).
Based on PFRA Hydrology Report #135 (February 1994).

September 9, 2005

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Appendix II: Archived Hydrometric Data

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BEAVERHILL CREEK NEAR THE MOUTH (05EB015)

Monthly Mean Discharge (m^3/s)

Archived hydrometric data from Canada's HYDAT database.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean+
1975	-	-	0.003	2.40	0.444	0.061	0.188	0.171	0.049	0.005	-	-	0.410
1976	-	-	0.019	0.255	0.011	0.010	0.008	0	0	0	-	-	0.037
1977	-	-	0.032	1.22	1.95	0.302	0.184	0.030	0.005	0.006	-	-	0.467
1978	-	-	0.266	1.75	0.091	0.057	0	0.020	1.71	0.134	-	-	0.496
1979	-	-	2.61	3.18	0.387	0.026	0.103	0.003	0	0.011	-	-	0.788
1980	-	-	0.003	2.78	0.018	0.009	0	0.152	0.023	0.024	-	-	0.369
1981	-	-	3.39	0.933	0.053	0.053	0.051	0.002	0	0.003	-	-	0.564
1982	-	-	0	5.38	1.10	0.011	3.04	0.290	0.019	0.019	-	-	1.23
1983	-	-	0.028	0.329	0.032	3.90	6.02	0.138	0.005	0.045	-	-	1.31
1984	-	-	0.804	0.296	0.032	0.032	0.018	0	0.014	0.030	-	-	0.154
1985	-	-	1.17	2.47	0.139	0.437	0.124	0.001	0	0.003	-	-	0.538
1986	-	-	2.94	0.397	0.033	0.002	3.79	0.194	0.004	0.007	-	-	0.930
Mean	-	-	0.939	1.78	0.358	0.408	1.13	0.083	0.152	0.024	-	-	0.607
Max	-	-	3.39	5.38	1.95	3.90	6.02	0.290	1.71	0.134	-	-	1.31
Min	-	-	0.000	0.255	0.011	0.002	0.000*	0.000*	0.000*	0.000	-	-	0.037

+ Mean for the period of March to October.

* Asterisk - occurs more than once.

This report was produced on February 08, 2007 using the Archived Hydrometric Data application located at http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

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Canada

BEAVERHILL CREEK NEAR THE MOUTH (05EB015)

Peak Discharges (m^3/s)

Archived hydrometric data from Canada's HYDAT database.

Year	Maximum Instantaneous Discharge (m^3/s)	Maximum Daily Discharge (m^3/s)	Minimum Daily Discharge (m^3/s)	Total Discharge (dam^3)$^+$
1975	----	8.21B on Apr 22	0.000 on Jun 13	8 690
1976	----	1.48B on Apr 05	0.000 on May 07	787
1977	----	10.6 on May 30	0.000 on Jun 21	9 880
1978	----	4.79 on Sep 20	0.000 on Jun 26	10 500
1979	----	9.00B on Mar 23	0.000E on Aug 14	16 700
1980	15.7B at 00:25 MST on Apr 14	13.0B on Apr 14	0.000B on Feb 27	7 800
1981	12.2 at 10:00 MST on Mar 18	11.4B on Mar 18	0.000 on Jun 25	11 900
1982	26.1 at 07:10 MST on Apr 27	24.6 on Apr 27	0.000B on Mar 01	26 000
1983	78.7 at 01:10 MST on Jun 26	34.1 on Jun 26	0.000 on May 26	27 800
1984	4.88 at 13:30 MST on Mar 29	4.02B on Mar 29	0.000 on Jul 03	3 250
1985	12.1B at 23:40 MST on Apr 03	10.6B on Apr 03	0.000 on Aug 05	11 400
1986	60.5 at 07:16 MST on Jul 20	48.6 on Jul 20	0.000 on Jun 21	19 700
Mean				12 900

$^+$ Total discharge for the period of March to October.

This report was produced on February 08, 2007 using the Archived Hydrometric Data application located at http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

Environment Canada Environnement Canada Canada

BEAVERHILL CREEK NEAR THE MOUTH (05EB015)

1986 Daily Discharge (m^3/s)

Archived hydrometric data from Canada's HYDAT database.

1986	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	-	-	5.00 B	3.62 B	0.032	0.003	0	2.20	0.006	0.005	-	-
2	-	-	4.90 B	2.47 B	0.023	0.003	0	1.25	0.005	0.005	-	-
3	-	-	4.60 B	1.93 B	0.014	0.002	0	0.727	0.004	0.005	-	-
4	-	-	4.20 B	1.10 B	0.017	0.003	0	0.477	0.003	0.006	-	-
5	-	-	3.80 B	0.530 B	0.016	0.003	0	0.293	0.003	0.011	-	-
6	-	-	2.60 B	0.329 B	0.014	0.005	0	0.162	0.003	0.009	-	-
7	-	-	1.33 B	0.340 B	0.011	0.006	0	0.098	0.003	0.008	-	-
8	-	-	1.20 B	0.137 B	0.011	0.008	0	0.086	0.003	0.014	-	-
9	-	-	1.15 B	0.088 B	0.019	0.004	0	0.074	0.003	0.014	-	-
10	-	-	1.00 B	0.078 B	0.018	0.002	0	0.062	0.003	0.011	-	-
11	-	-	0.750 B	0.084 B	0.017	0.001	0	0.059	0.003	0.008	-	-
12	-	-	0.514 B	0.087	0.016	0.001	0	0.055	0.003	0.010	-	-
13	-	-	0.333 B	0.087	0.015	0.001	0	0.052	0.004	0.010	-	-
14	-	-	0.276 B	0.085	0.014	0.001	0	0.048	0.004	0.009	-	-
15	-	-	0.367 B	0.073	0.031	0.001	0	0.045	0.004	0.009	-	-
16	-	-	0.336 B	0.068	0.045	0.001	0.066	0.042	0.004	0.008	-	-
17	-	-	0.517 B	0.068	0.045	0.001	0.127	0.038	0.004	0.008	-	-
18	-	-	1.12 B	0.067	0.085	0.001	0.876	0.035	0.004	0.007	-	-
19	-	-	2.12 B	0.064	0.090	0.001	19.8	0.031	0.004	0.007	-	-
20	-	-	6.08 B	0.056	0.070	0.001	48.6	0.028	0.004	0.006	-	-
21	-	-	10.1 B	0.051	0.058	0	8.07	0.026	0.004	0.006	-	-
22	-	-	8.89 B	0.050	0.051	0	4.97	0.023	0.004	0.005	-	-
23	-	-	5.75 B	0.054	0.039	0	4.64	0.020	0.004	0.005	-	-
24	-	-	3.43 B	0.070	0.123	0	4.50	0.017	0.004	0.005	-	-
25	-	-	1.71 B	0.071	0.062	0	4.11	0.015	0.004	0.004	-	-
26	-	-	2.92 B	0.063	0.043	0	3.47	0.014	0.005	0.004	-	-
27	-	-	2.91 B	0.058	0.020	0	3.03	0.013	0.005	0.003	-	-
28	-	-	2.43 B	0.050	0.014	0	2.64	0.011	0.005	0.003	-	-
29	-		3.37 B	0.045	0.008	0	2.27	0.009	0.005	0.003	-	-
30	-		3.50 B	0.041	0.003	0	5.58	0.008	0.005	0.003 A	-	-
31	-		4.01 B		0.003		4.64	0.007		0.003 E		-
Mean			2.94	0.397	0.033	0.002	3.79	0.194	0.004	0.007		
Max			10.1 B	3.62 B	0.123	0.008	48.6	2.20	0.006	0.014		
Min			0.276 B	0.041	0.003	0.000	0.000	0.007	0.003	0.003		
Total			91.213	11.914	1.027	0.049	117.389	6.025	0.119	0.214		
Total Dam^3			7880	1030	88.7	4.23	10100	521	10.3	18.5		

Overall Mean	Maximum Daily	Minimum Daily	Total Discharge	Total Discharge in dam^3
	-	-		

Maximum Instantaneous : 60.5 on Jul 20 at 07:16 MST

A - Partial Day
D - Dry
R - Revised within the last two years
* - Asterik-occurs more than once
P - Partially Dry

B - Ice Conditions
E - Estimated
\- no symbol
d - Complete and Some Dry

This report was produced on February 08, 2007 using the Archived Hydrometric Data application located at http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

Min ☑ Lower quartile ☐ Normal ●
Mean ☐ Median ☐ Year 1986

Archived Hydrometric Data Report:

Report Type: MONTHLY [Obtain Report]
Report Output Type: IN CURRENT BROWSER (NUMERICAL)

Station Information: BEAVERHILL CREEK NEAR THE MOUTH (05EB015)

Active or discontinued	Discontinued	**Province/Territory**	Alberta
Latitude	53°53'21" N	**Longitude**	112°56'57" W
Gross drainage area	2930 km^2		
Record length	12 years	**Period of record**	1975 - 1986
Regulation type	Natural		

Period of record	Hydrometric measurement type	Operational schedule	Gauge type
1974 - 1978	Flow	Seasonal	Manual
1979 - 1986	Flow	Seasonal (Mar-Oct)	Recorder

Real-time data available	No	**Sediment data available**	No
Type of water body	River	**RHBN**	No
EC regional office	CALGARY		
Datum of published data	ASSUMED DATUM		

***Note:** **If n<10, percentiles are not calculated. Click here for further information.**

Created: 2003-12-22
Modified: 2006-06-02
Reviewed: 2006-06-02

Important Notices

URL of this page:
http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?
cname=graph.cfm

Canada

The Green Lane^{TM},
Environment Canada's World Wide Web Site

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Appendix III: Flood Frequency Analysis

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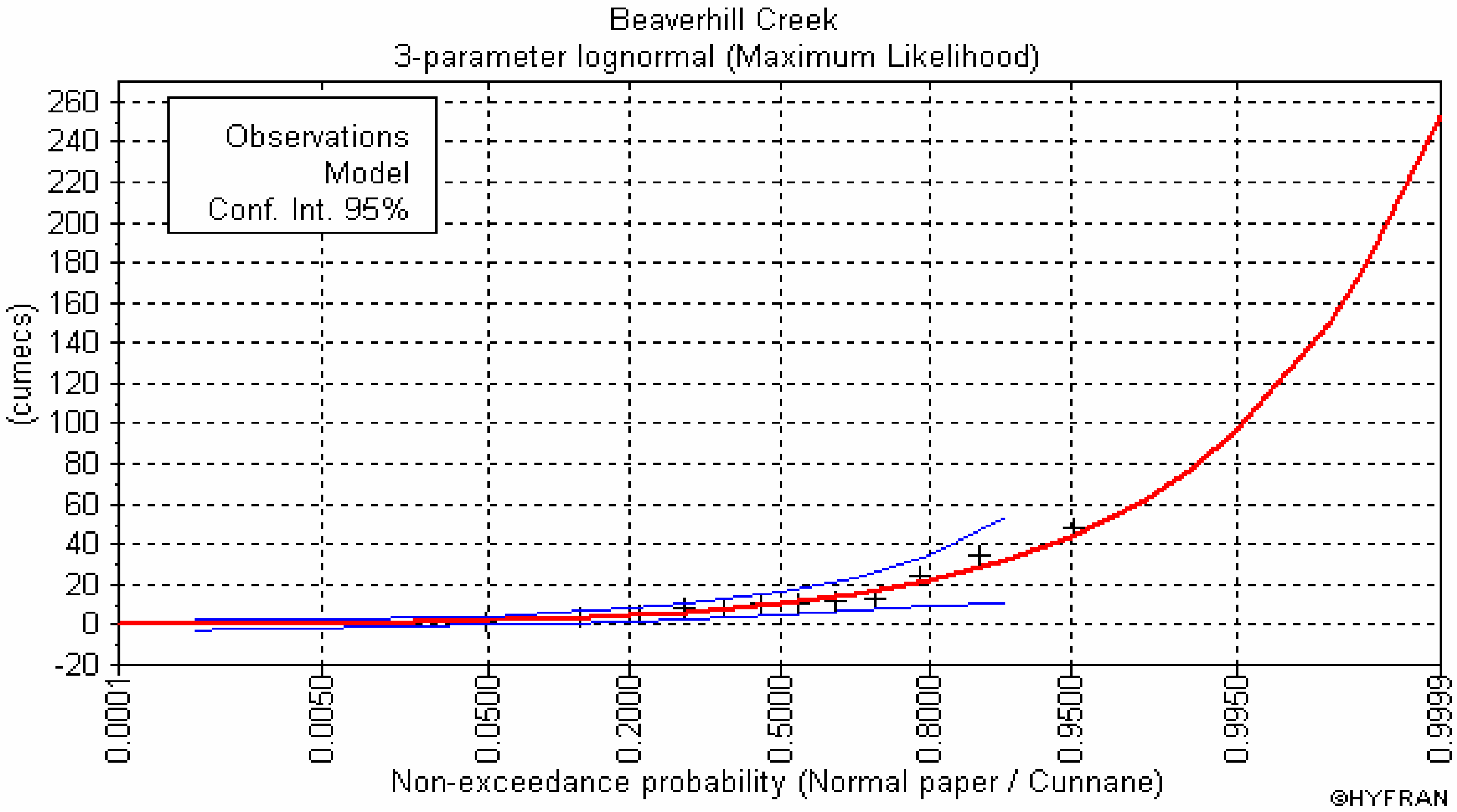
Flood Frequency Analysis



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Appendix IV: Water Balance Calculations and Sensitivity Analysis

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Table IV-1: Average Monthly Water Balance - Baseline Case

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)	1,866,952													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,621	1512	1613	2,756	4,906	9,947	9,309	6,911	4,817	1,927	2,543	2,610	51,472	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	80,242
Outputs													Actual runoff	(44,758)
Aerial ET from Open Water (mm)				1962.5	3,450	5,006.25	6,200						Total groundwater contrib.	51.71904
Runoff (mm)				12,036.35	20,060.58	20,060.58	11,233.93							
			M^3/d	401.212	668.686	668.686	374.464						Total outputs	80,010.20
			l/s	4.643653685	7.73942281	7.73942281	4.3340768							
Storage (m^3) i.e., inputs – outputs or actual runoff	4,084	2,356	2,513	-9,701	-15,862	-9,565	-2,927	10,768	7,504	3,002	3,962	4,066		
Cumulative storage	4,084	6,440	8,953	-749	-16,611	-26,177	-29,104	-18,336	-10,832	-7,830	-3,869	198		

Notes:

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Runoff coefficient is from AENV 2005.

Table IV-2: Average Monthly Water Balance - Application Case

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)[1]	1,801,397													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,529	1,459	1,556	2,659	4,734	9,598	8,982	6,669	4,648	1,859	2,454	2,518	49,665	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	78,396
Outputs													Actual runoff	(46,604)
Aerial ET from Open Water (mm)				1,962.5	3,450	5,006.25	6,200						Total groundwater contrib.	51.71904
Runoff (mm)				11,759.43	19,599.05	19,599.05	10,583.49							
		flow rate	m^3/d	391.98	653.30	653.30	352.78						Total outputs	78,159.76
		flow rate	l/s	4.54	7.56	7.56	4.08							
Storage (m^3) i.e., inputs – outputs or actual runoff	3,992	2,303	2,456	-9,526	-15,573	-9,453	-2,604	10,525	7,335	2,934	3,872	3,975		
Cumulative storage	3,992	6,295	8,751	-775	-16,348	-25,801	-28,405	-17,880	-10,544	-7,610	-3,738	236		

Notes:

[1] Watershed area assumes closed circuit drainage for footprint area = total watershed area - plant footprint - pond footprint.

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated)

Runoff coefficient is from AENV 2005.

Table IV-3: Baseline Sensitivity Analysis: Runoff Coefficient 0.1

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)	1,866,952													
Runoff Coefficient	0.1													
Open Water Area (m^2)	62,500													
Storage (m^3)	125,000													
GW K	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	4,369	2,520	2,688	4,593	8,177	16,579	15,514	11,519	8,028	3,211	4,238	4,350	85,786	
Direct Rainfall	1,462.5	843.75	900.00	1,537.50	2,737.50	5,550.00	5,193.75	3,856.25	2,687.50	1,075.00	1,418.75	1,456.25	28,719	
Groundwater	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	114,557
													Actual runoff	(10,443)
Outputs													Total GW contrib	51.71904
ET from Open Water				1,962.5	3,450	5,006.25	6,200							
Runoff/outflows				17,183.54	28,639.23	28,639.23	16,037.97						Total outputs	107,118.71
			m^3/d	572.785	954.641	954.641	534.599							
Flow rate from pond			l/s	6.629451009	11.049085	11.049085	6.1874876							
Storage/overall balance (m^3)	5,831	3,364	3,588	-13,012	-21,170	-11,513	-1,526	15,375	10,715	4,286	5,657	5,806		
	5,831	9,195	12,784	-228	-21,398	-32,911	-34,436	-19,061	-8,345	-4,059	1,597	7,404		

Notes:

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Table IV-4: Baseline Sensitivity Analysis: Runoff Coefficient 0.15

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)	1,866,952													
Runoff Coefficient	0.15													
Open Water Area (m^2)	62,500													
Storage (m^3)	125,000													
GW K	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	6,553	3,781	4,033	6,889	12,266	24,868	23,272	17,279	12,042	4,817	6,357	6,525	128,680	
Direct Rainfall	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	157,450
													Actual runoff	32,450
Outputs													Total GW contrib	51.71904
ET from Open Water				1,962.5	3,450	5,006.3	6,200							
Runoff/outflows				23,617.52	39,362.53	39,362.53	22,043.02						Total outputs	141,004.36
			m^3/d	787.251	1312.084	1312.084	734.767							
Flow rate from pond			l/s	9.111697664	15.1861628	15.1861628	8.5042512							
Storage/overall balance (m^3)	8,016	4,624	4,933	-17,149	-27,805	-13,947	227	21,135	14,729	5,892	7,776	7,981		
	8,016	12,640	17,572	423	-27,382	-41,328	-41,102	-19,967	-5,237	654	8,430	16,411		

Notes:

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Table IV-5: Baseline Sensitivity Analysis: Hydraulic Conductivity 3 x 10^{-6} m/s

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)	1,866,952													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Storage (m^3)	125,000													
GW K	0.000003													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,621	1,512	1,613	2,756	4,906	9,947	9,309	6,911	4,817	1,927	2,543	2,610	51,472	
Direct Rainfall	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater	4.30992	4.30992	4.30992	4.30992	31.536	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	80,270
													Actual runoff	(44,730)
Outputs													Total GW contrib	78.94512
ET from Open Water				1,962.5	3,450	5,006.25	6,200							
Runoff/outflows				12,040.43	20,067.39	20,067.39	12,040.43						Total outputs	80,834.40
			m^3/d	401.348	668.913	668.913	401.348							
Flow rate from pond			l/s	4.645229269	7.74204878	7.74204878	4.6452293							
Storage/overall balance (m^3)	4,084	2,356	2,513	-9,706	-15,842	-9,572	-3,734	10,768	7,504	3,002	3,962	4,066		
	4,084	6,440	8,953	-753	-16,595	-26,167	-29,901	-19,133	-11,629	-8,627	-4,666	-599		

Notes:
Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.
Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).
Open water area is considered only the ponded area in the NW corner of the property (non-vegetated)

Table IV-6: Baseline Sensitivity Analysis: Hydraulic Conductivity 2.3 x 10^{-8} m/s

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)	1,866,952													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Storage (m^3)	125,000													
GW K	0.000000023													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,621	1,512	1,613	2,756	4,906	9,947	9,309	6,911	4,817	1,927	2,543	2,610	51,472	
Direct Rainfall	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater	4.30992	4.30992	4.30992	4.30992	0.241776	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	80,238
													Actual runoff	(44,762)
Outputs													Total GW contrib	47.650896
ET from Open Water				1962.5	3,450	5006.25	6200							
Runoff/outflows				12,035.74	20,059.57	20,059.57	11,233.36						Total outputs	80,006.98
			m^3/d	401.191	668.652	668.652	374.445							
Flow rate from pond			l/s	4.64341826	7.73903043	7.73903043	4.333857							
Storage/overall balance (m^3)	4,084	2,356	2,513	-9,701	-15,865	-9,564	-2,927	10,768	7,504	3,002	3,962	4,066		
	4,084	6,440	8,953	-748	-16,614	-26,178	-29,105	-18,337	-10,833	-7,831	-3,869	197		

Notes:

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Table IV-7: Application Sensitivity Analysis: Runoff Coefficient 0.1

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)[1]	1,801,397													
Runoff Coefficient	0.1													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	4,215	2,432	2,594	4,431	7,890	15,996	14,970	11,115	7,746	3,098	4,089	4,197	82,774	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	111,506
Outputs													Actual runoff	(13,494)
Aerial ET from Open Water (mm)				1,962.5	3,450	5,006.25	6,200						Total groundwater contrib.	51.71904
Runoff (mm)				16,725.88	27,876.47	27,876.47	15,053.29							
		flow rate	m^3/d	557.53	929.22	929.22	501.78						Total outputs	104,150.86
		flow rate	l/s	6.45	10.75	10.75	5.81							
Storage (m^3) i.e., inputs – outputs or actual runoff	5,678	3,276	3,494	-12,719	-20,695	-11,332	-1,086	14,971	10,434	4,173	5,508	5,654		
Cumulative storage	5,678	8,953	12,447	-272	-20,967	-32,299	-33,384	-18,413	-7,980	-3,806	1,702	7,355		

Notes:

[1] Watershed area assumes closed circuit drainage for footprint area = total watershed area – plant footprint – pond footprint.

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Runoff coefficient is from AENV 2005.

Table IV-8: Application Sensitivity Analysis: Runoff Coefficient 0.15

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)[1]	1,801,397													
Runoff Coefficient	0.15													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	0.00000041													
Average hydraulic gradient (i)	0.008													
Inputs	January	February	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec		
Runoff (m^3)	6,323	3,648	3,891	6,647	11,835	23,995	22,454	16,672	11,619	4,648	6,134	6,296	124,161	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	152,893
Outputs													Actual runoff	27,893
Aerial ET from Open Water (mm)				1,962.5	3,450	5,006.25	6,200						Total groundwater contrib.	51.71904
Runoff (mm)				22,933.95	38,223.24	38,223.24	20,640.55							
		flow rate	m^3/d	764.46	1,274.11	1,274.11	688.02						Total outputs	136,639.73
		flow rate	l/s	8.85	14.75	14.75	7.96							
Storage (m^3) i.e., inputs – outputs or actual runoff	7,785	4,492	4,791	-16,712	-27,096	-13,681	812	20,528	14,307	5,723	7,553	7,752		
Cumulative storage	7,785	12,277	17,068	356	-26,740	-40,421	-39,609	-19,081	-4,774	949	8,501	16,253		

Notes:

[1] Watershed area assumes closed circuit drainage for footprint area = total watershed area – plant footprint – pond footprint.

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Runoff coefficient is from AENV, 2005.

Table IV-9: Application Sensitivity Analysis: Hydraulic Conductivity 3 x 10^{-6} m/s

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Aerial Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)[1]	1,801,397													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	0.000003													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,529	1,459	1,556	2,659	4,734	9,598	8,982	6,669	4,648	1,859	2,454	2,518	49,665	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	31.536	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	78,423
Outputs													Actual runoff	(46,577)
Aerial ET from Open Water (mm)				1,962.5	3,450	5,006.25	6200						Total groundwater contrib.	78.94512
Runoff (mm)				11,763.51	19,605.86	19,605.86	10,587.16							
		flow rate	m^3/d	392.12	653.53	653.53	352.91						Total outputs	78,181.14
		flow rate	l/s	4.54	7.56	7.56	4.08							
Storage (m^3) i.e., inputs – outputs or actual runoff	3,992	2,303	2,456	-9,530	-15,553	-9,460	-2,607	10,525	7,335	2,934	3,872	3,975		
Cumulative storage	3,992	6,295	8,751	-779	-16,331	-25,791	-28,399	-17,874	-10,539	-7,605	-3,732	242		

Notes:

[1] Watershed area assumes closed circuit drainage for footprint area = total watershed area – plant footprint – pond footprint.

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Aerial ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Table IV-10: Application Sensitivity Analysis: Hydraulic Conductivity 2.3 x 10^{-8} m/s

Assumptions	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**	
Precipitation (mm)	23.4	13.5	14.4	24.6	43.8	88.8	83.1	61.7	43	17.2	22.7	23.3	459.5	
Areal Evapotranspiration: ET (mm)	-1.1	1.9	15.3	31.4	55.2	80.1	99.2	69.9	19.6	12.5	1.9	-1.4	384.5	
Watershed Area (m^2)[1]	1,801,397													
Runoff Coefficient	0.06													
Open Water Area (m^2)	62,500													
Wetland storage (m^3)	125,000													
Shallow groundwater hydraulic conductivity (k)	2.3E-08													
Average hydraulic gradient (i)	0.008													
Inputs	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Runoff (m^3)	2,529	1,459	1,556	2,659	4,734	9,598	8,982	6,669	4,648	1,859	2,454	2,518	49,665	
Direct Rainfall (mm)	1,462.5	843.75	900	1,537.5	2,737.5	5,550	5,193.75	3,856.25	2,687.5	1,075	1,418.75	1,456.25	28,719	
Groundwater flow rate: Q=KiA (m^3)	4.30992	4.30992	4.30992	4.30992	0.241776	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	4.30992	Total inputs	78,392
Outputs													Actual runoff	(46,608)
Areal ET from Open Water (mm)				1,962.5	3,450	5,006.25	6,200						Total groundwater contrib.	47.650896
Runoff (mm)				11,758.82	19,598.03	19,598.03	10,582.94							
		flow rate	m^3/d	391.96	653.27	653.27	352.76						Total outputs	78,156.57
		flow rate	l/s	4.54	7.56	7.56	4.08							
Storage (m^3) i.e., inputs – outputs or actual runoff	3,992	2,303	2,456	-9,525	-15,576	-9,452	-2,603	10,525	7,335	2,934	3,872	3,975		
Cumulative storage	3,992	6,295	8,751	-774	-16,350	-25,802	-28,405	-17,880	-10,545	-7,611	-3,739	236		

Notes:

[1] Watershed area assumes closed circuit drainage for footprint area = total watershed area - plant footprint - pond footprint.

Precipitation data from Environment Canada, 2004. Namao Airport, Edmonton.

Areal ET data is from Edmonton City Centre Airport (AENV 1999a).

Open water area is considered only the ponded area in the NW corner of the property (non-vegetated).

Runoff coefficient is from AENV, 2005.

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Alberta Sulphur Terminals Ltd.
Bruderheim Sulphur Forming and Shipping Facility

Volume IIB – Water and Aquatic Ecology

4. Surface Water Quality

Project Number 62720000
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Refer to Volume IIB, Section 3: Surface Water Quantity for the Executive Summary for Surface Water Quantity and Surface Water Quality.

4. Surface Water Quality

4.1 Introduction

This report includes the baseline studies and effects assessment pertaining to surface water quality for the proposed Bruderheim Sulphur Forming and Shipping Facility (the Project) (see Figure 4.1-1). Field programs were conducted in 2006 to assess baseline surface water and sediment quality at and near the Project. The baseline portion of this document (see Section 4.5) summarizes field program results and characterizes the current condition of surface waterbodies at, and near, the Project. The application case portion of this document (see Section 4.6) analyzes the potential effects of the Project on the existing quality of surface water, taking into account other existing, approved and planned operations and projects in the area.

The Project includes the construction and operation of facilities for receiving liquid sulphur, sulphur forming, sulphur pastille storage and shipment for export. Information about the properties of the sulphur that will be handled and processed and issues relating to safe handling and storage as well as chemical reactions that can potentially occur are provided in Volume I: Project Description.

A summary of sulphur handling and storage issues that may create potential surface water quality and environmental concerns are provided below. Possible chemical reactions that might occur are also summarized.

4.1.1 Transport and Handling of Liquid and Solid Elemental Sulphur

Elemental sulphur, like all elements, is in what is known as its zero oxidation state. When reduced, it becomes hydrogen sulphide; when oxidized in the presence of water, it becomes sulphuric acid or some other acidic oxidized species. Such acidification is an important phenomenon associated with the handling and transportation of solid elemental sulphur.

4.1.1.1 *Acidity Development*

Elemental sulphur that is exposed to sunlight and oxygen will slowly oxidize to sulphur dioxide (SO_2) and other oxy-sulphur species. A bacterial oxidation process further results in the direct formation of sulphuric acid from elemental sulphur and/or SO_2 (Stanley et al. 1989), involving the following bacteria:

- *Thiobacillus ferrooxidans* (also referred to as *Ferrobacillus sulfooxidans* or *Ferrobacillus ferrooxidans*) are capable of oxidizing ferrous iron, thiosulfate, sulphur and metallic sulphides
- *Thiobacillus thiooxidans* has very similar characteristics but cannot oxidize iron or metallic sulphides, other than sodium sulphide. This reaction may also occur abiotically; however, typically this would be at a much slower rate.

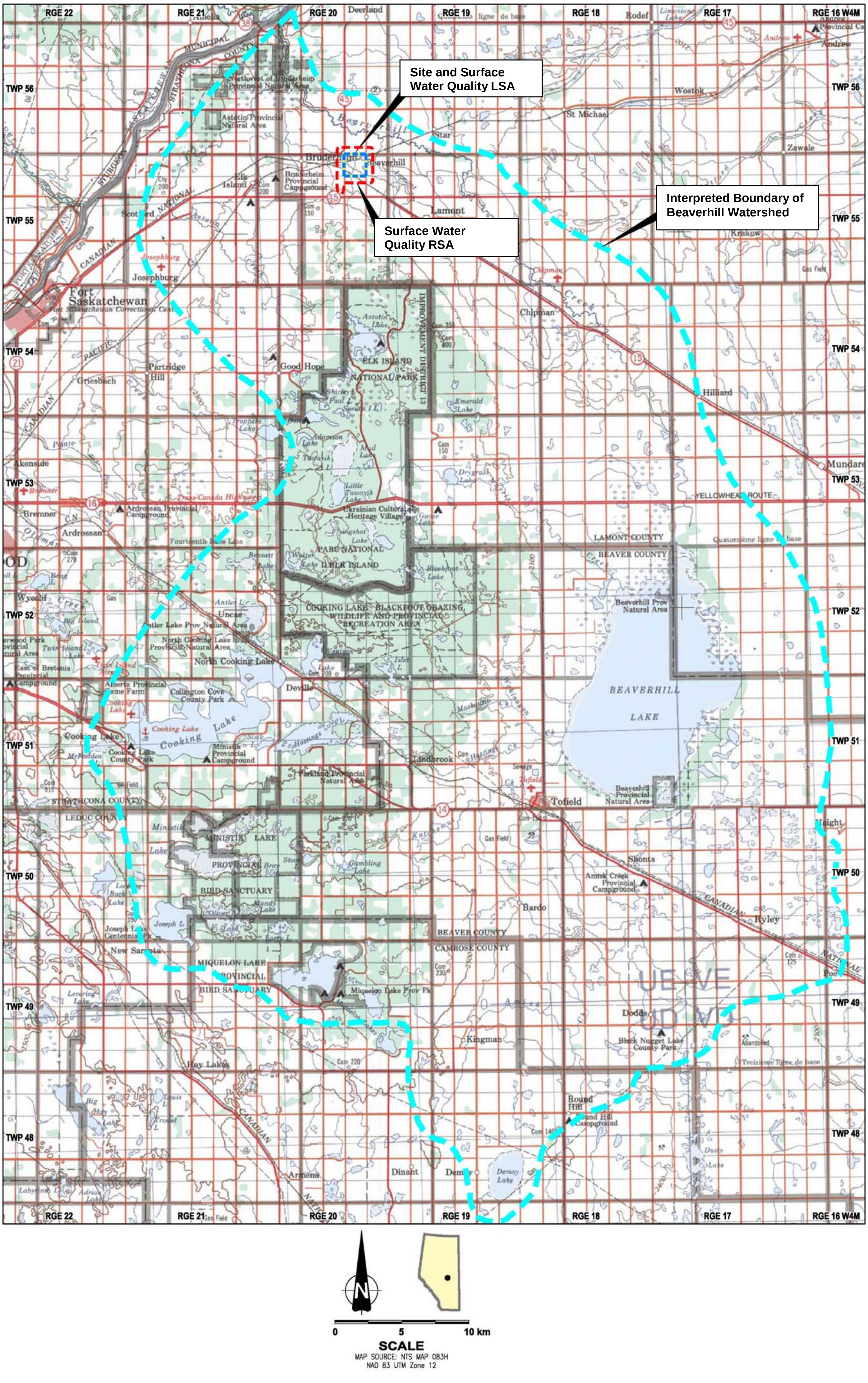


Figure 4.1-1: Regional Setting

Elemental sulphur is also biologically oxidized to sulphate, which produces protons (H^+) by the following reaction:

$$S^0 + \frac{3}{2}O_2 + H_2O \rightarrow SO_4{}^{2-} + 2H^+$$

This reaction shows that sulphur, oxygen and water are each required for formation of acid. The acid is potentially toxic if released to the environment and can further mobilize other metals that, in turn, results in increased bioavailability of these metals.

4.1.1.2 Hydrogen Sulphide Generation and Corrosion

Elemental sulphur also has the potential of being reduced to H_2S or a metal sulphide, again through bacterial transformation. Reduction of sulphate and elemental sulphur is possible when these compounds are present in saturated, anaerobic conditions (i.e. under water). Changes in the storage temperature and pressure of liquid sulphur, as well as agitation, have been observed to promote release of H_2S from liquid sulphur (Clark 2006, Internet site). In the presence of only water and elemental sulphur, reduction would form hydrogen sulphide through the following reaction:

$$2S^0 + 2H_2O \rightarrow 2H_2S + O_2$$

H_2S is highly toxic and even low concentrations in air can be fatal. Leakages can also create an odour nuisance. Hydrogen sulphide is also highly flammable and can form explosive mixtures in air.

In the presence of dissolved metals such as iron, the sulphide will bind to form a metal sulphide. Corrosion may then occur as a result of deposition of solidified sulphur coatings on metal surfaces and ingress of moisture. Corrosive attack by wet elemental sulphur on structural materials and containment vessels is a common feature of liquid and solid sulphur handling and transportation systems (Hyne 1996, Internet site). The moisture film between the elemental sulphur and the structural material or containment vessel is an essential dielectric medium for the ionic reactions – without contact between the two mediums, little or no corrosion occurs. In the case of solid sulphur, the drier the sulphur, the better it is for mitigating corrosion. Also, preventing contact between the solid sulphur and steel stops the corrosive attack.

Note that sulphuric compounds cause failure of reinforced concrete and spalling of the concrete surface.

In the absence of available metals, the H_2S will stay in solution until the interstitial water becomes saturated with H_2S. At this point, the H_2S will become liberated as a gas and migrate to the atmosphere. In the presence of oxygen, H_2S quickly converts to SO_2 and SO_4. Given that the proposed sulphur forming and shipping facilities are above ground and in an open environment, the possibility of developing anaerobic reducing conditions and H_2S during operational activities is considered to be remote.

4.1.1.3 Water

Water spraying has commonly been used to control dust generated during the handling and transportation of bulk elemental sulphur. However, water reacts with elemental sulphur to form oxy sulphur acids such as sulphurous and sulphuric acid, giving rise to acid water runoff and potential corrosion damage. The use of fogs and foams instead of water has become more commonplace as they have much lower moisture contents and equal or better dust control properties (Hyne 1996, Internet site).

The reactions between water and elemental sulphur are markedly dependent on the particle size of the solid elemental sulphur. Thus, as the particle size decreases and the surface area per unit weight increases, so too does the rate of acid production (Hyne 1996). This means that the finer the material generated in handling formed sulphur, the greater will be the potential for acidity to build up.

4.1.2 Acid Buffering

Acid buffering in water and soil is provided by an equilibrium relationship involving carbonate alkalinity. The following equation illustrates this relationship.

$$2H_2O + CO_2 \Leftrightarrow H^+ + OH^- + H_2CO_3 \Leftrightarrow 2H^+ + OH^- + HCO_3 - \Leftrightarrow 3H^+ + OH^- + CO_3^{2-}$$

This reaction indicates that the addition of acidity, or hydrogen ions, will be resisted, in accordance with Le Chatelier’s Principle, by conversion of CO_3^{2-} to HCO_3- and HCO_3- to H_2CO_3 and ultimately evolution of CO_2 gas from solution. Similarly, addition of calcium carbonate ($CaCO_3$), a source of CO_3^{2-}, will drive the reaction to the left, consuming hydrogen ions as long as excess CO_3^{2-} is present. Once buffered, the sulphuric acid generally combines with calcium to form gypsum, which precipitates out of solution, thus mitigating potential adverse environmental affects. Accordingly, it is advantageous to site sulphur forming and shipping facilities in a location where local groundwater, surface water, soils and bedrock have natural buffering properties.

4.2 Terms of Reference

Surface water quality is an important ecosystem component that interacts with other ecosystem components. Based on these considerations, the Final Terms of Reference (TOR) (AENV 2007) specifies that baseline surface water quality should be discussed and that Project components that will affect surface water quality conditions should be identified. Components for discussion should include:

h) baseline surface water quality;

i) water quality of watercourses and water bodies in the Study Areas before and after Project development and operation. The description of water quality will consider all appropriate water quality parameters, (e.g., temperature, pH, conductivity, cations and anions, metals, dissolved oxygen, suspended sediment, dissolved solids, nutrients and other water contaminants) their seasonal variations and relationships to flow and other controlling factors, and a summary of existing water quality data including necessary surveys to characterize water quality of watercourses and water bodies in the Study Areas;

j) the significant and potential impacts to surface water quality within the Study Areas resulting from the Project, including site runoff and Project-related wastewater discharges, that may indicate a potential adverse effect or exceedance of the Surface Water Quality Guidelines for Use in Alberta (November 1999) or Canadian Water Quality Guidelines;

k) the potential Project related and cumulative impacts of acidifying and other air emissions on surface water quality;

l) effects of site runoff on water quality in surface waterbodies within the Study Area;

m) the impacts to surface water quality within the Study Areas due to the change in groundwater movement, spills and contaminated groundwater resulting from spills;

n) mitigation plans to minimize these effects during the construction, operation and reclamation phases of the Project;

o) a plan and implementation program for the protection of surface water quality, addressing the following:

  i) surface water monitoring program for early detection of potential contamination and assistance in remediation planning;

  ii) surface water remediation options to be considered for implementation in the event that adverse effects are detected; and

  iii) the relative contribution of the Project (after mitigation) to regional cumulative effects on surface water quality of watercourses and water bodies in the Study Areas (e.g., Project contributions to lake acidification).

4.3 Issue Scoping

The Project's construction, operation and reclamation activities have the potential to affect surface water quality in watercourses and waterbodies within the Surface Water Quality Local Study Area (LSA) and Regional Study Area (RSA) as follows:

- surface disturbances related to the construction and operation of infrastructure including plant facilities, roads, railways and ponds
- aerial deposition of acidifying compounds on waterbodies within the RSA throughout the Project operations
- runoff from plant areas that are subject to the aerial deposition of acidifying compounds and spillage of elemental sulphur
- upset conditions, including:
  - chemical spills around the plant area
  - breach of the surface water runoff collection system, including collection pond

4.4 Methods

4.4.1 Spatial and Temporal Boundaries

The baseline and impact assessments of the Project were conducted for the LSA and RSA, and the Principal Development Area (PDA) (see Figure 4.1-1, Figure 4.4-1 and Figure 4.4-2). These are described in both spatial and temporal terms in the following sections.

4.4.1.1 Principal Development Area

The PDA is located in a portion of the HAZCO property, Section 35-55-20 W4M (the Site) (see Figure 4.4-2). The PDA consists of rail and road access for receiving molten sulphur, molten sulphur unloading and transfer facilities, sulphur forming facilities to produce sulphur pastilles, loading and shipping facilities for formed sulphur, and a sulphur pastille temporary storage area.

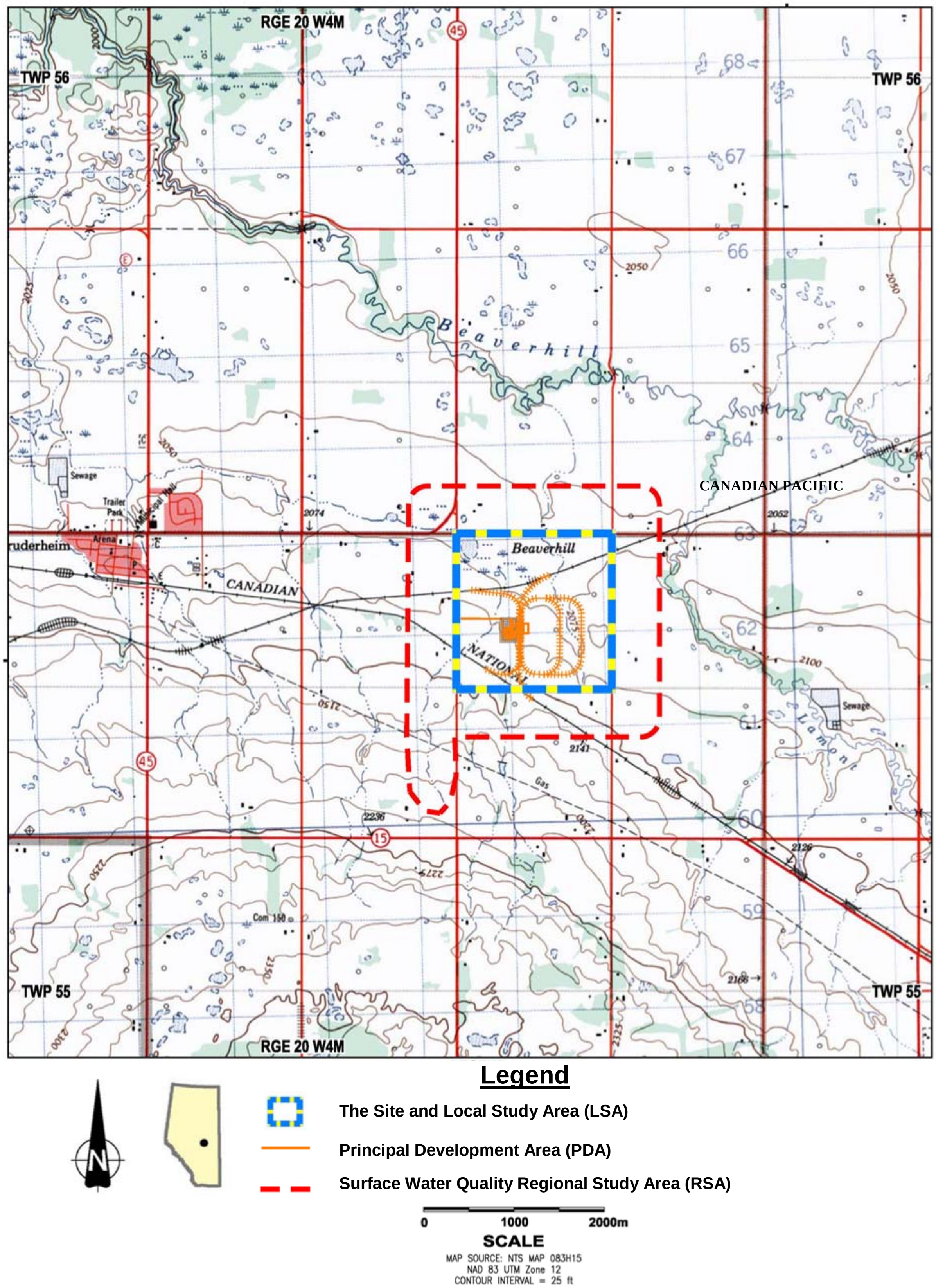


Figure 4.4-1: Surface Water Quality LSA and RSA

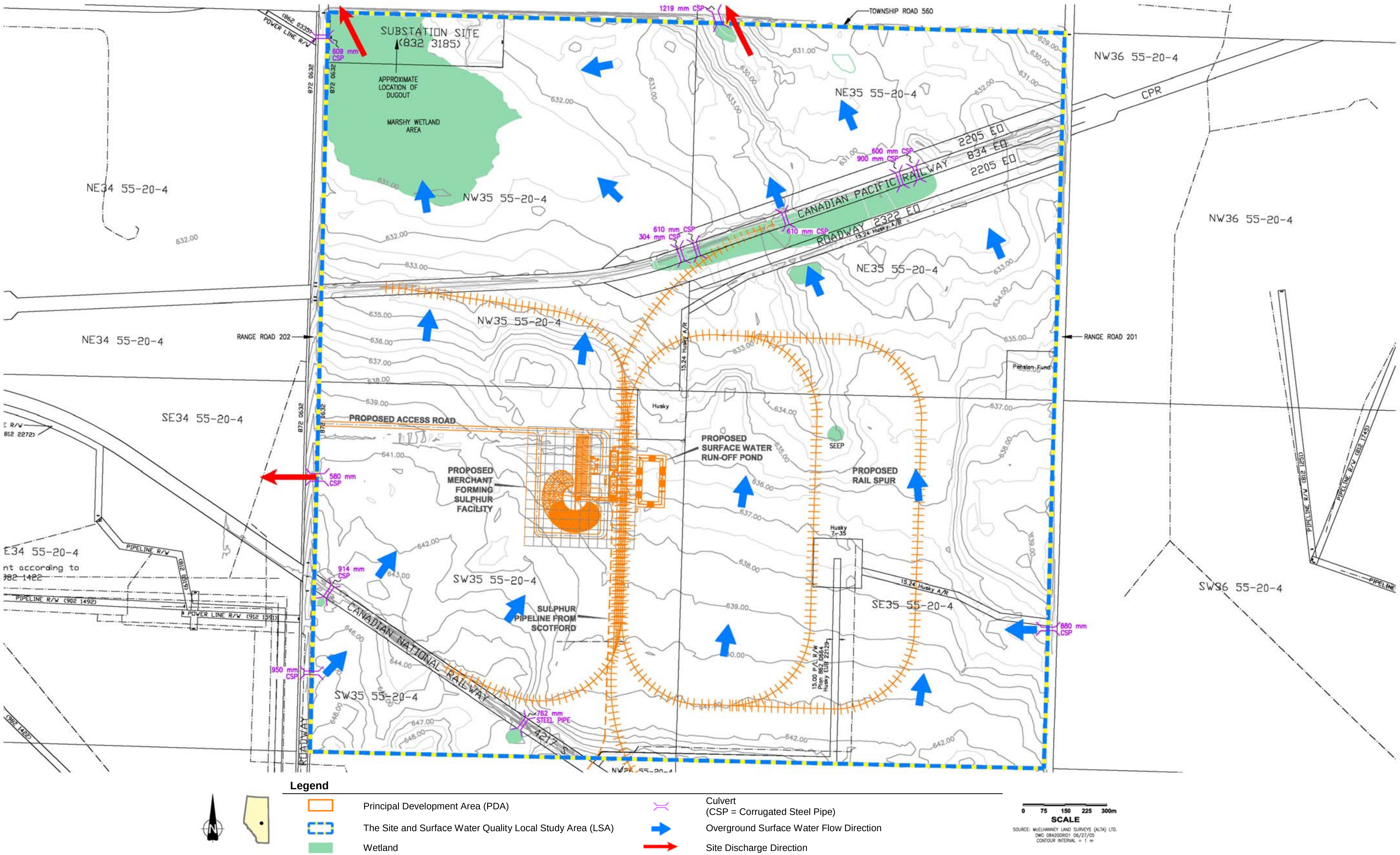


Figure 4.4-2: Surface Water Quality PDA and Local Topography

4.4.1.2 Local Study Area

The LSA includes the areas that can reasonably expect to be affected by water discharges and air emissions associated with the Project. These areas are contained within the Site and significant features include a wetland in the northwest corner of the property, a wetland system adjacent to the Canadian Pacific Railway (CPR) and an ephemeral drainage located near the middle of the north property boundary. The LSA boundary is, therefore, the same as the Site boundary (see Figure 4.1-1 and Figure 4.4-1).

4.4.1.3 Regional Study Area

The RSA was established to assess regional effects beyond the local drainages contained by the Project. As the Project is surrounded by a topographically flat area with predominantly ephemeral streams and subterranean drainage, the RSA was set at 500 m beyond the Site on the north and east sides (where there is no distinct watershed divide due to the flat topography) and follows the local watershed boundary on the south and west sides. The RSA measures approximately 7.35 km^2 and is shown in Figure 4.1-1 and Figure 4.4-1.

4.4.1.4 Temporal Boundaries

The temporal boundaries for the surface water assessments were chosen to coincide with current conditions (baseline case), the lifespan of the Project (estimated at 25 years) at maximum disturbance (application case) and closure. A full description of the schedule for construction, operation, decommissioning and reclamation of the Project can be found in Volume I: Project Description.

The maximum disturbance temporal boundary is important from a surface water quality perspective and is used to determine the potential effects of the Project during its 25 year lifespan. Closure is considered when all project facilities have been decommissioned and reclamation has taken place. Any existing negative impacts on surface water quality would tend to recover relatively rapidly following cessation of the operational activities and water use by the Project. Thus, in the closure assessments, the focus shifts to possible residual surface water quality effects of the Project (if any).

4.4.2 Project Inclusion List

The Project Inclusion List considers the various anthropogenic disturbances that must be included in each assessment case in order to effectively determine Project effects and cumulative effects.

Table 4.4-1 provides the list of projects and operations in close proximity to the Project.

Table 4.4-1: Project Inclusion List

Project	Location	Operational Activities
ERCO Worldwide	Northwest section of 34-20-55 W4M (approximately 1.6 km west of northwest quadrant of Project)	Sodium chlorate plant established in 1990; no longer in operation and due to be shut down completely in 2007
Canexus Chemicals	Southeast quadrant of Section 34-20-55 W4M (immediately west of the southwest quadrant of the Project)	Canexus Chemicals is a sodium chlorate plant constructed in 1990–91 with operations beginning in 1991
Triton Fabrication	Northwest section of 26-20-55 W4M (immediately south of southwest quadrant of the Project)	Established 2004; provides heavy-industrial general contracting, fabrication and maintenance services to resource and industrial clients throughout western Canada
Lamont wastewater treatment plant	North central section of 30-19-55 W4M (approximately 2.5 km east of southeast quadrant of the Project)	Sewerage and wastewater treatment
Bruderheim wastewater treatment plant	South central section of 05-20-56 W4M (approximately 3.75 km west of northwest quadrant of the Project)	Sewerage and wastewater treatment

4.4.3 Literature Review and Data Sources

The following data sources were reviewed to assess watershed and basin characteristics, including surface water quality

- Atlas of Alberta Lakes (University of Alberta 2004–2005, Internet site)
- State of North Saskatchewan Watershed Report (NSWA 2005, Internet site)
- Alberta Environment Surface Water Quality Website (AENV 2007, Internet site)

4.4.4 Field Program

Three field monitoring and sampling investigations were conducted to evaluate seasonal surface water quality conditions within, and beyond, the LSA and RSA. A summer visit was undertaken in June 2006, a fall visit was undertaken in October 2006 and a winter sampling event was undertaken in February 2007. The winter sampling event included snow sampling at six locations within the property boundary. A visit was undertaken in March 2007 to observe snowmelt (freshet) conditions.

Surface water and sediment quality monitoring was undertaken at thirteen different locations within the property boundary, the LSA, the RSA and beyond. Surface water quality data were collected at nine sites as illustrated in Figure 4.4-3. Sediment quality data were collected at ten sites as illustrated on Figure 4.4-4. Within the LSA, monitoring and sampling was undertaken within surface water features such as natural drainage features, railway culverts, a wetland area and a dugout (SW1, SW2, SW4, SW6, SW7 and SW9).

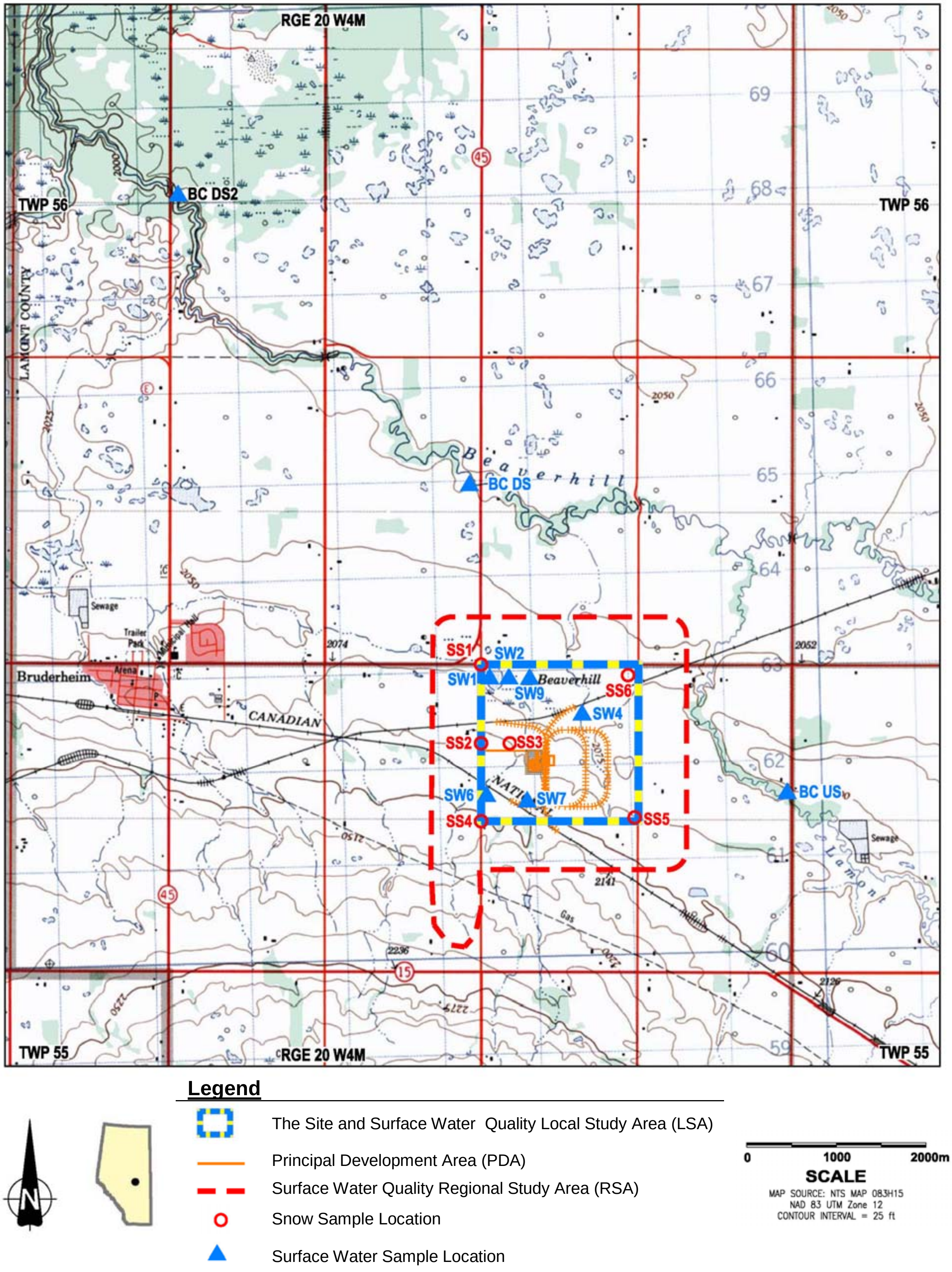


Figure 4.4-3: Surface Water Monitoring and Sampling Locations

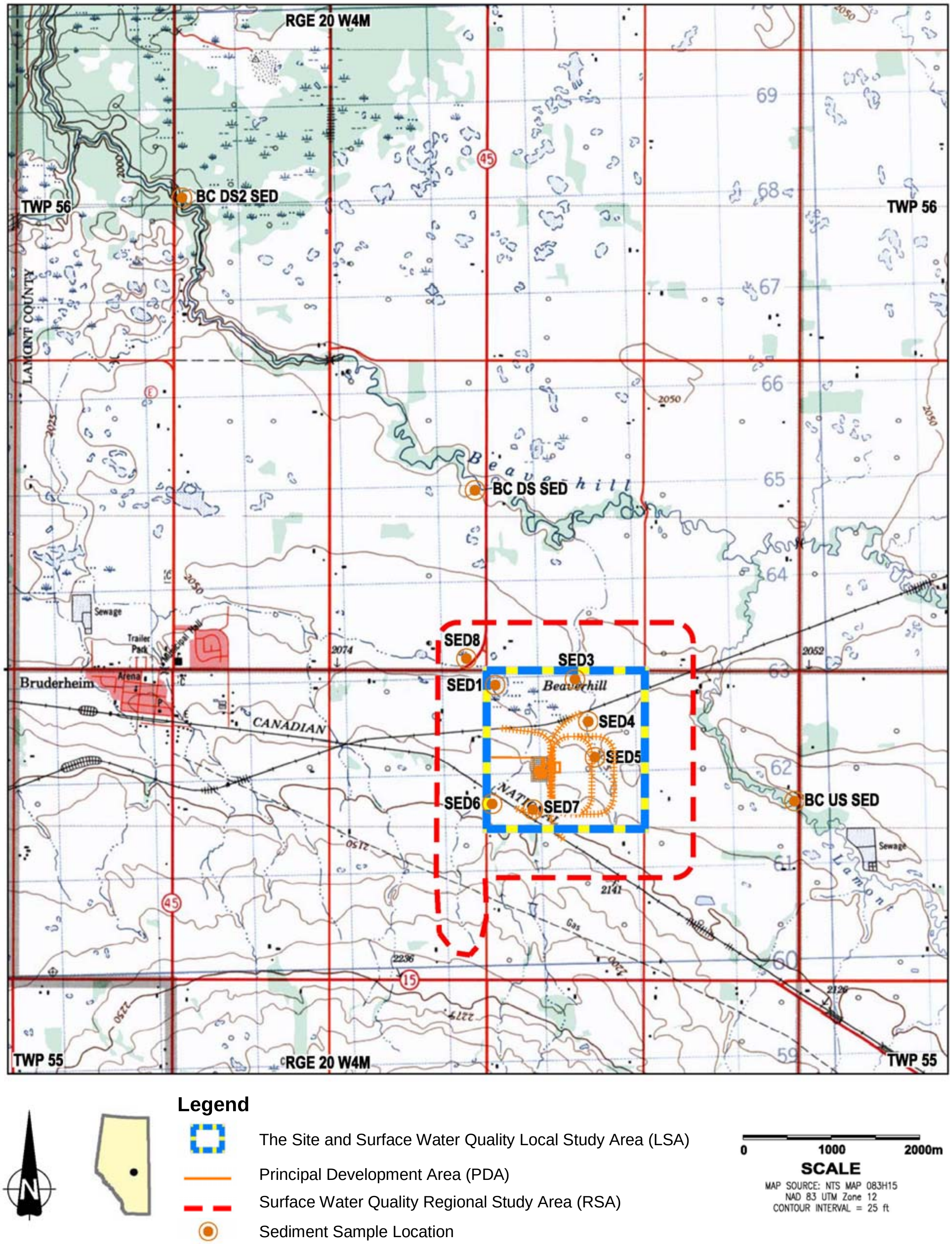


Figure 4.4-4: Sediment Sampling Locations

Within the RSA and beyond, water sampling was undertaken within Lamont Creek, upstream of the Site (BC US) and downstream of the Site within Beaverhill Creek (BC DS and BC DS2). Water quality and sediment quality data are presented in Appendix I. A number of surface water features within the LSA and RSA are ephemeral and were dry during the June 2006, October 2006 and February 2007 sampling events. Sediment samples were however taken at most sampling locations (SED1, SED3, SED4, SED5, SED6, SED7, SED8, SED BC US, SED BCDS and SED BC DS2).

Each site visit included collecting field data and taking water samples for laboratory analysis, as outlined below:

- field parameters (i.e., water temperature, electrical conductivity (EC), pH and dissolved oxygen (dissolved oxygen meter not working during June 2006 sampling event)) to characterize in-situ chemical and physical indicators of the water
- routine parameters to characterize general water chemistry
- nitrite–nitrate–nitrogen (NO_2–NO_3–N) and dissolved and total phosphorus (TP) to determine nutrient loading
- total suspended solids (TSS) and turbidity to measure the amount of sediment in the water column
- filtered and unfiltered samples for dissolved and total trace metals, as indicators for aquatic life parameters
- oils and grease, total petroleum hydrocarbons (TPH) C3-C10, total extractable hydrocarbons (TEH) C11-C30 and benzene, toluene, ethylbenzene, xylene (BTEX) to determine the presence of hydrocarbons

Sediment samples were also collected for the following laboratory analyses:

- full metals suite as indicators for aquatic life
- BTEX and TPH (C3-C10) to determine the presence of hydrocarbons

Snow samples were collected in February 2007 for the following laboratory analyses in order to characterize the impact of atmospheric deposition on snowpack quality:

- total nitrogen
- total sulphur
- sulphate
- alkalinity
- pH
- total solids

Field measured parameters are presented in Section 4.5.1.

4.4.5 Assessment Methodology

The water quality data was compared against Alberta surface water quality guidelines (AENV 2007). Professional judgement, based on results from the baseline case surface water assessments, was used to assess potential surface water quality effects related to the Project (e.g., as a result of surface disturbances, deposition of acidifying compounds and upset conditions) and provide recommendations for mitigation and emergency response planning.

4.4.6 Assessment Criteria

The purpose of the Environmental Impact Assessment (EIA) is to assess and report on the potential impacts associated with the construction and operation of the Project. This includes impacts to existing water and sediment quality in a local and regional context. The EIA also includes preventative, mitigative and compensatory actions to reduce impacts of the Project.

Impact assessments are based upon measured, predicted or reasonably expected changes in attributes of a water or sediment quality indicator. Assessment of residual effects was based on a combination of objective (measurable) and subjective (deduced) evaluations concerning the key water and sediment quality characteristics. Objective, quantitative evaluations were used where practicable. However, under some circumstances, subjective evaluation was the only feasible alternative. The criteria selection process for surface water/sediment quality took into account the presence or absence of a guideline protective of aquatic life (see Section 4.4.7).

4.4.6.1 Final Impact Rating

For each individual impact assessment, a qualitative, final evaluation rating is used where specific guidelines do not exist. This rating is a combination of quantitative analysis and subjective professional judgment that takes into account the various descriptors for each attribute (direction, magnitude, geographic extent, duration, confidence and reversibility) and the potential effects of the specific impact. Impact classification does not always relate directly to standard descriptors used to explain the impact occurring; this is often seen where a relative change of high magnitude is occurring yet the impact is classified as Class 3 because the overall effect (e.g., impacts to one small stream within a watershed) is not substantial.

The final impact rating is an aggregated, relative, numerical ranking determined by both the analysis of impact and the level of action recommended by the professional report author, as necessary to address the impact. This ranking is applied to both the Project-specific impacts and cumulative effects residual impacts. See Volume IIB, Section 1: Introduction.

4.4.7 Applicable Surface Water and Sediment Quality Guidelines

Several regulatory guidelines are relevant to an assessment of surface water and sediment quality and are included in the tables and figures where relevant:

- Alberta Surface Water Quality (ASWQ) Guidelines for the Protection of Freshwater Aquatic Life (AENV 1999)
- Canadian Water Quality (CWQ) guidelines (CCME 2006) for the protection of freshwater aquatic life are referenced when no applicable ASWQ guideline exists
- Canadian Sediment Quality (CSQ) guidelines (CCME 2002) for the protection of freshwater aquatic life are referenced when no applicable ASWQ guideline exists

4.4.8 Quality Assurance and Quality Control

Quality assurance and quality control (QA and QC) procedures were followed during the field and laboratory analysis portions of the baseline study. Baseline hydrological data were used both to establish the conceptual hydrological framework and baseline surface water chemistry of the Project and provide data for the effects assessments.

The major areas of QA and QC relied on for the assessments were:

- baseline surface water and sediment chemistry field data
- baseline surface water chemistry laboratory data
- assessment methodologies (computation methods)
- reporting of results

4.4.8.1 Baseline Field Data Quality Assurance and Quality Control

Industry standards for surface water and sediment sampling procedures were followed to ensure the collection of representative samples. Field sampling QA and QC procedures included appropriate calibration of all field measuring equipment.

Water samples were collected in accordance with established surface water grab sampling protocols. Bottles were rinsed three times using in-situ water. Within streams, water samples were taken as close to the thalweg as practicable. Within standing water, samples were taken approximately 1 m from shore, at a depth of approximately 20 cm. A duplicate sample and trip blank were also analyzed for every 10 samples taken as part of the QA/QC program. The trip blank sample consisted of high-grade ultrapure water provided by the laboratory. The trip blank provided a check on potential contamination during field activities and transportation to the laboratory. The field duplicate sample was taken by filling an extra set of water samples at one site, which was labelled with a different site number, not known by the laboratory. The field duplicate was used to check for laboratory analysis accuracy.

Snow samples were collected from snow drifts within the property boundary. A snow pit was excavated using an aluminum snow shovel. The side of the snow pit was cleared by scraping the snow horizontally, so as not to commingle the layers. The side of the snow pit being sampled was sheltered against direct sunlight. The layer of snow demonstrating the longest exposure to the atmosphere (e.g., the dirtiest layer) was targeted for sampling. Snow was collected and placed into sterile plastic bags using a trowel and then double-bagged to protect against leakage. Additional snow was collected and melted on site, which was used to collect field parameters (pH and electrical conductivity).

All samples were immediately packed on ice in a cooler and taken directly to the lab within 8 hours of sampling. The coolers were sealed with tape to prevent tampering. Chain of custody forms were filled out by the field personnel and submitted to the lab with the samples.

4.4.8.2 Laboratory Quality Assurance and Quality Control

Laboratory QA and QC methods included:

- proper receipt, storage and preparation of samples for analysis
- assessment of ion balance – calculated difference between the sum of the cations and sum of the anions in solution

- analysis of method blanks – samples of distilled water prepared in the laboratory and analyzed immediately after field samples to check for carry-over effects in the analytical process or equipment
- laboratory duplicates – replicates of field samples prepared in the laboratory and analyzed to check for sample preparation errors
- matrix spikes – laboratory prepared samples where a known amount of analyte is added to the sample and samples are analyzed to measure extraction and digestion efficacy
- analysis of surrogate recoveries – laboratory duplicates to which a known amount of a substance is added before extraction and analysis. Surrogate recoveries are used to track analyte recovery through the analytical process.
- laboratory control sampled – substances of known composition that are analyzed to test the accuracy of laboratory analytical methods

4.4.8.3 Assessment Methodologies (Computational Methods)

Project effects assessment QA and QC relied on the selection of computational methods that are accepted by industry and regulators. It was ensured that data used in the computational methods were appropriate to the surface water conditions within the Site, LSA and RSA. Sensitivity analyses were used to quantify the degree of uncertainty in the output of the computation methods and strengthen confidence in results.

4.4.8.4 Reporting Quality Assurance and Quality Control

Reporting QA and QC methods included multi-stage report review processes consisting of:

- technical review conducted by scientists familiar with the Project
- administrative review conducted by a scientific technical editor
- senior technical review conducted by peer professionals

4.5 Baseline Case

4.5.1 Existing Baseline Water Quality

The characterization of baseline conditions is primarily based on data collected during summer and fall 2006 sampling events undertaken within the Site, LSA and RSA boundary. Surface water samples were collected up gradient of the Site within both Lamont Creek to the east (BC US) and Beaverhill Creek to the north (BC DS) to assess background surface water quality. Sampling location BC US is located approximately 0.5 km downstream of the Lamont wastewater treatment facility and sampling location BC DS2 is located approximately 5 km downstream of the Bruderheim wastewater treatment facility. The northwestern corner of the Site is located immediately adjacent to Highway 45. No other significant sources of potential surface water contamination are known to exist within the LSA.

The characterization of baseline conditions is also based on historical data obtained from Alberta Environment (AENV) which were collected from a monitoring station at the mouth of Beaverhill Creek on the North Saskatchewan River between 1975 and 1990. The monitoring station (AB05EB0900) is located approximately 11 km northwest and downgradient of the Site. Appendix I, Table I-4 presents analytical data for AENV surface water samples.

4.5.1.1 *Field Measured Water Quality*

Results of field measured water quality parameters and sampling regime are provided in Table 4.5-1. Locations of surface water and sediment samples are shown in Figure 4.4-3 and Figure 4.4-4. Photos of each sampling location are presented in Appendix III, Photos 1–12.

Field measured water quality results taken in June and October 2006 indicate alkaline conditions at all locations, with pH ranging between 7.15 and 8.89, within ASWQ guidelines. Electrical conductivity (EC) values range from 470–962 µS/cm, with all values apart from one (SW6) measuring greater than 700 µS/cm. Dissolved oxygen measurements within Lamont Creek indicate that the Creek is generally well-oxygenated, with dissolved oxygen concentrations above 7.0 mg/L. Dissolved oxygen measurements within Beaverhill Creek range between 1.86–2.26 mg/L, which are significantly lower than the ASWQ acute and chronic guidelines of 5.0 mg/L and 6.5 mg/L respectively.

Field parameter measurements taken in February 2007 display lower pH, ranging from 6.46–7.31, and much higher EC, ranging from 1,193–2,158 µS/cm. These measurements indicate a flow-dependent relationship and are more representative of groundwater hydrochemical signatures. The pH measurement of 6.46 taken at BC-DS is below the minimum range of the ASWG of 6.5. Dissolved oxygen measurements indicate anoxic conditions in Beaverhill Creek, ranging from 0.03–0.73 mg/L.

4.5.1.2 *Routine Parameters*

In general, major ion and routine parameter concentrations were within ASWQ guidelines and all ion concentrations were low, including the historic AENV samples taken from the mouth of Beaverhill Creek. Total dissolved solids (TDS) concentrations ranged from 170–1,490 mg/L. Water samples exhibited significant seasonal variability in major ion concentrations, with marked increases during the winter season. The sample collected in the dugout at the northwest corner of the property (SW9) showed a TDS concentration increase from 517 mg/L in October to 1,490 mg/L in February. This is likely the result of ice formation on the dugout, which tends to concentrate dissolved constituents in the remaining liquid. Sodium, calcium, bicarbonate and chloride increased at every sample location in the winter months.

AENV historic samples also exhibit seasonal variations in TDS and chloride concentrations, with lowest concentrations recorded in the low flow summer months (July, August) and highest concentrations recorded in higher flow early winter and spring months (November–March).

In normal surface water, natural background concentrations of chloride are generally no more than a few mg/L. Up to 5% of aquatic life will be affected by concentrations of around 210 mg/L and 10% of aquatic life will be affected by concentrations of around 240 mg/L (Environment Canada and Health Canada 2001, Internet site). At several locations (BC DS, BC DS2, BC US, SW1, SW2, SW7 and SW9) slightly elevated (ranging between 33 and 129 mg/L) chloride concentrations were detected, with highest concentrations recorded during the winter season. Lower chloride concentrations (between 2 and 19 mg/L) were consistently recorded in groundwater samples taken on site (see Volume IIB, Section 2: Groundwater Quantity and Quality – Appendix IV, Table IV-3).

Table 4.5-1: Surface Water Field Measured Parameters and Samples Taken

Sample Location and Name	Date	pH	EC (µS/cm)	Temp. (°C)	Dissolved oxygen (mg/L)	Waterbody Type	Photo Number	Flow Conditions	Sample Taken
SW1 and SED1	13-Jun-06	7.25	932	3.5	n/m	Wetland	III-1	Stagnant	W and S
	18-Oct-06	Dry	Dry	Dry	Dry			Dry	dry
SW2	13-Jun-06	7.8	777	12.1	n/m	Wetland	III-2	Stagnant	W
	18-Oct-06	Dry	Dry	Dry	Dry			Dry	dry
SED3	13-Jun-06	Dry	Dry	Dry	Dry	Ephemeral drainage	III-3	Dry	S
SW4 and SED4	13-Jun-06	7.61	938	13.4	n/m	Wetland	III-4	Stagnant	W and S
	18-Oct-06	Dry	Dry	Dry	Dry			Dry	
SED5	13-Jun-06	Dry	Dry	Dry	Dry	Seep	III-5	Dry	S
SW6 and SED6	13-Jun-06	7.22	470	7.3	n/m	Wetland	III-6	Trickle	W and S
	18-Oct-06	Dry	Dry	Dry	Dry			Dry	
SW7 and SED7	13-Jun-06	7.15	724	7.3	n/m	Wetland	III-7	Stagnant	W and S
	18-Oct-06	Dry	Dry	Dry	dry			Dry	
SED8	18-Oct-06	Dry	Dry	Dry	n/m	Ephemeral drainage	III-8	Dry	S
SW9	18-Oct-06	8.89	743	2.6	n/m	Dugout	III-9	Stagnant	W
	16-Feb-07	7.31	2158	0.0	3.32				W
BC-DS and SEDBC-DS	13-Jun-06	7.61	943	9.4	n/m	Creek (Beaverhill)	III-10	10 L/s (est.)	W and S
	18-Oct-06	8.14	853	2.9	1.86			10 L/s (est.)	W
	16-Feb-07	6.98	1193	0.1	0.03			<10 L/s	W
BC-DS2 and SEDBC-DS2	18-Oct-06	8.38	962	3.4	2.26	Creek (Beaverhill)	III-11	Stagnant	W and S
	16-Feb-07	6.46	1209	1.2	0.73				W
BC-US and SEDBC-US	13-Jun-06	7.43	956	14	n/m	Creek (Lamont)	III-12	10 L/s (est.)	W and S
	18-Oct-06	8.87	958	3.7	7.06			10 L/s (est.)	W
	16-Feb-07	6.91	1690	0.2	0.24			<10 L/s	W

Notes:

n/m - not monitored.

S – sediment.

W – water.

Dry - not enough water available to take water sample.

est. - estimated flow rate.

Although the origin of higher chloride concentrations in surface water could be the result of evaporation, the source is also potentially of anthropogenic origin. Possible anthropogenic sources contributing to chloride concentrations in surface water within the RSA include local roadways such as Highway 45 located immediately northwest of the Site and the Lamont and Bruderheim wastewater treatment plants located to the southeast and northwest of the Site.

Road salts enter the environment through their storage and use, from disposal of and runoff from snow cleared from roadways, and through air dispersal as wind-borne powder by splashing and spray from vehicles (Environment Canada and Health Canada 2001, Internet site). Concentrations of up to 18,000 mg/L can be recorded in runoff from roadways in Canada. Field measurements have also shown that roadway applications in rural areas can result in increased chloride concentrations in lakes and waterbodies located a few hundred metres from roadways (Environment Canada and Health Canada 2001).

Calcium chloride is often used for dust control on gravel roads in rural municipalities and elevated chloride concentrations are also commonly found in wastewater effluent. The chloride concentration measured at downstream locations will, however, depend of the level of effluent treatment undertaken at the wastewater treatment plant and the nature of dilution that takes place within the receiving waterbody. It is likely that both road salt runoff and wastewater discharges contributed to the slightly elevated chloride concentrations recorded in the surface water samples. However, results of historic surface water sampling undertaken in Beaverhill Creek by AENV between 1975 and 1990 (see Appendix I; Table I-4) shows significant seasonal fluctuations in chloride concentrations between winter and spring (12–78 mg/L) and summer sampling rounds (3–6 mg/L). This suggests that the use of road salt in winter and subsequent spring snow melt is likely the most significant contributing factor to elevated chloride concentrations in surface water.

Turbidity results for samples generally ranged from 3.9–14 NTU (nephelometric turbity unit), with one elevated value of 130 NTU recorded in the dugout (SW9). TSS results for all samples taken in October ranged between 493 and 640 mg/L with a value recorded in the dugout (SW9) of 517 mg/L. The concentration of TSS substantially decreased at all sites measured during the winter season.

AENV historic samples were also analyzed for phenolic materials and during almost every sampling event the ASWG guideline for total phenols (0.005 mg/L) was exceeded.

Appendix I; Table I-1 shows routine parameter data for recent surface water samples and Appendix I; Table I-4 shows routine parameter data for historic AENV surface water samples.

4.5.1.3 <u>Metals</u>

Most metals were below ASWQ/Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of freshwater aquatic life. Dissolved metal concentrations were only analyzed during the June 2006 sampling event. Total and dissolved metal concentrations were analyzed during the October 2006 sampling round. Typically ASWQ and CCME metal guidelines refer to total concentration in an unfiltered sample. As a conservative measure, both dissolved and total baseline metal results are compared to the total guidelines and are discussed below.

Dissolved iron concentrations exceeded the CCME guideline (0.3 mg/L) at one location (SW1) during the June sampling round. The total iron concentrations exceeded the CCME guideline at three locations (SW9, BC DS and BC DS2) during the October sampling round and were substantially higher in winter at all three sampling locations (BC US, BC DS and BC DS2) on Beaverhill Creek (1.36–23.1 mg/L). Total iron concentration in SW9 was lower in February as compared to October, but still exceeded the guideline at 0.48 mg/L.

Total aluminum, cadmium, copper, iron and zinc concentrations also exceeded CCME guidelines in the dugout (SW9) during the October sampling round. In February, only total arsenic and total iron slightly exceeded ASWG in the dugout (SW9). It is likely that the presence of even minor amounts of suspended solids in the dugout in October gave rise to elevated metal concentrations in these samples.

Total aluminum concentrations exceeded the ASWG of 0.1 mg/L during the October sampling event in BC DS2 (0.129 mg/L) and during the February sampling event at BC DS (0.331 mg/L), BC DS2 (0.138 mg/L) and BC US (0.25 mg/L). Dissolved aluminum concentrations were below the ASWG.

Dissolved phosphorus concentrations exceeded the ASWG guideline (0.05 mg/L) at three locations (SW1, BC US and BC DS) during the June sampling round. Both dissolved and total phosphorus concentrations exceeded the ASWG guideline at all four locations (BC US, BC DS, BC DS2 and SW9) during the October sampling round, indicating that Beaverhill Creek and Lamont Creek are in hypereutrophic states. Total and dissolved phosphorus exceeded the ASWG at BC DS, BC DS2 and BC US for samples collected in February, ranging from 1.3–3.1 mg/L and were substantially higher as compared to June and October sampling events. These values are high for surface waterbodies and are likely the result of treated municipal wastewater discharge.

Dissolved cadmium concentrations exceeded the CCME guideline for aquatic life (0.000017 mg/L) in one sample only during the June sampling round and in two samples during the October sampling round. One of the elevated concentrations was recorded in a duplicate sample (THETA) but was not recorded in the original sample (BC DS2). Samples were reanalyzed in the laboratory to determine if an analytical error had occurred, however original sample results were confirmed. Total cadmium exceeded the CCME guideline in one sample (SW9) only during the October sampling round. This was also the case in the winter duplicate sample for BC DS, which indicated that dissolved cadmium exceeded the ASWQ guideline of 0.000017 mg/L. However, dissolved cadmium was below the detection limit in the original sample and thus this value is discredited as being unreliable.

Dissolved arsenic concentrations exceeded the CCME guideline (0.005 mg/L) at six sampling locations during the June sampling round (BC US, BC DS, SW1, SW4, SW6 and SW7). However, an elevated dissolved arsenic concentration was also recorded in the June trip blank sample, therefore, these results are not considered representative and have been discredited. Elevated dissolved arsenic concentrations were not detected in any samples during the October sampling round. Total arsenic concentrations exceeded the CCME guidelines for freshwater aquatic life at BC DS and BC DS2 during the February sampling event. Dissolved arsenic concentrations slightly exceeded the CCME guideline in the duplicate BC DS sample, but were below the guideline in the original sample.

Historic AENV samples from the mouth of Beaverhill Creek recorded total iron concentrations in excess of CCME guidelines during almost all sampling events and total phosphorus concentrations in excess of ASWG guidelines during every sampling event. Total cadmium and total copper concentrations in excess of CCME guidelines were also recorded during a number of sampling events, although seasonal trends were not discernable.

Appendix I; Table I-2 shows metal parameter data for recent surface water samples and Appendix I; Table I-4 shows metal parameter data for historic AENV surface water samples.

4.5.1.4 Hydrocarbons

Samples taken in June and October, 2006 and February, 2007 were analyzed for BTEX, oil and grease and TPH/TEH). BTEX results were below the limits of detection for June and

October samples, however, samples taken from BC DS and BC DS2 in February were above the CCME Freshwater Aquatic Life guidelines for toluene. All samples were analyzed for oil and grease (O&G) and barely detectable concentrations were measured at two locations (SW1 and BC DS) during the June and October sampling rounds. O&G was also detected in the June field blank sample (BETA) therefore the June results have been discredited. October samples were also analyzed for TPH (C3–C10) and TEH (C11–C30) and all concentrations were below detection limits.

Appendix I – Table I-3 shows hydrocarbon parameter data for surface water samples.

4.5.1.5 Relationship between Surface Water and Groundwater Quality

An expanded Durov diagram characterizing recent surface water major ion chemistry is presented in Figure 4.5-1 with the associated legend shown in Figure 4.5-2. The results of the plot illustrate that the surface water chemistry in the LSA and RSA is predominantly Na-HCO_3 type, with a number of locations (SW2 and SW7) exhibiting Na-HCO_3 type water and SW6 exhibiting Ca-HCO_3 type water.

To compare the relationship between surface water and groundwater major ion chemistry, an expanded Durov diagram was prepared and is presented in Figure 4.5-3. The results of the plot illustrate that the predominant chemical type of both surface water and groundwater is Na-HCO_3 type, with surface water exhibiting slightly dilute concentrations and lower TDS values, as would be expected through the processes of mixing and dilution.

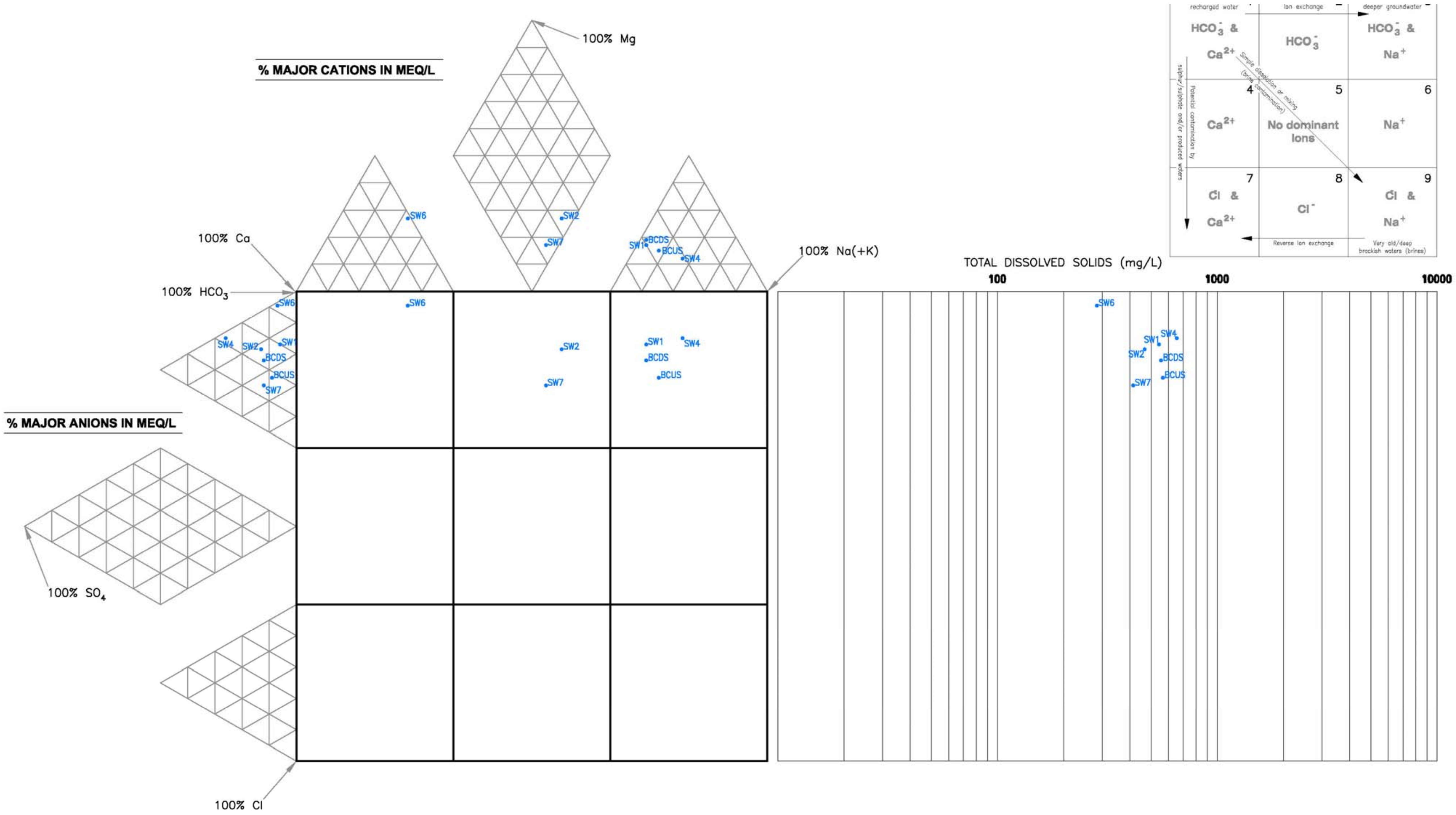
4.5.1.6 Snow Sampling

Snow samples were collected on February 16, 2007 from six locations within the property boundary (see Figure 4.4-3). The purpose of the snow sampling was to characterize the effect of atmospheric deposition on snow quality.

Total solids for all snow samples ranged from 32–3,320 mg/L, which indicates that snow samples generally had been exposed to atmospheric deposition. In general, all samples were generally alkaline, with total alkalinity ranging from 3–40 mg/L, and most values being between 12–16 mg/L. All laboratory-measured pH values were above 7, with the exception of SS3, which displayed a laboratory pH of 6.7. Total nitrogen ranged from <1–2 mg/L. Total sulphur ranged from 0.7–2.9 mg/L. These data indicate that, in general, snow quality is not influenced substantially by acid generating deposits.

4.5.1.7 Summary of Existing Baseline Surface Water Quality

In general, seasonality exerts a dominant influence on the water quality of Beaverhill Creek and Lamont Creek, with creek water being higher in salts and trace elements during the winter when flows consist predominantly of groundwater discharge. Moderate-to-high alkaline conditions were generally encountered at all sampling locations during summer and fall sampling periods, however, pH decreased in all samples during the winter sampling event. EC values recorded during the summer and fall sampling periods are indicative of fresh to marginal surface water quality, with highest EC values recorded in Lamont Creek (upstream of the Project) and Beaverhill Creek (downstream of the Project). Winter EC values substantially increased in Beaverhill and Lamont Creeks and the dugout (SW9), indicating a groundwater signature and/or concentration of salts and trace elements due to ice formation.



NOTES:

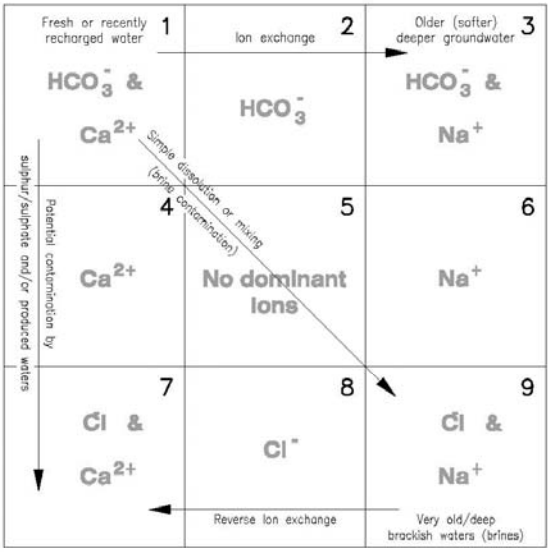
SW1 – SURFACE WATER SAMPLE

"HCO_3^- & Na^+" INDICATES ION DOMINANT FIELDS

Source: Lloyd, J.W. and J.A. Heathcote 1985

Natural Inorganic Chemistry in Relation to Groundwater. Clarendon Press, Oxford.

Figure 4.5-1: Surface Water Chemistry: Main Ion Characterization (Expanded Durov Diagram)



Field 1: HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters (or "fresh" groundwater) in many aquifers.

Field 2: HCO_3^- dominant and cation indiscriminant, with Mg^{2+} often being the dominant cation. However, those samples in which Ca^{2+} and Na^+ are significant, an important partial ion exchange is presumed.

Field 3: HCO_3^- and Na^+ are dominant, indicating ion exchanged water.

Field 4: Ca^{2+} dominant and anion indiscriminant or SO_4^{2-} dominant. Frequently indicates a mixed water or water exhibiting simple dissolution.

Field 5: No dominant anion or cation, indicating water exhibiting simple dissolution or mixing.

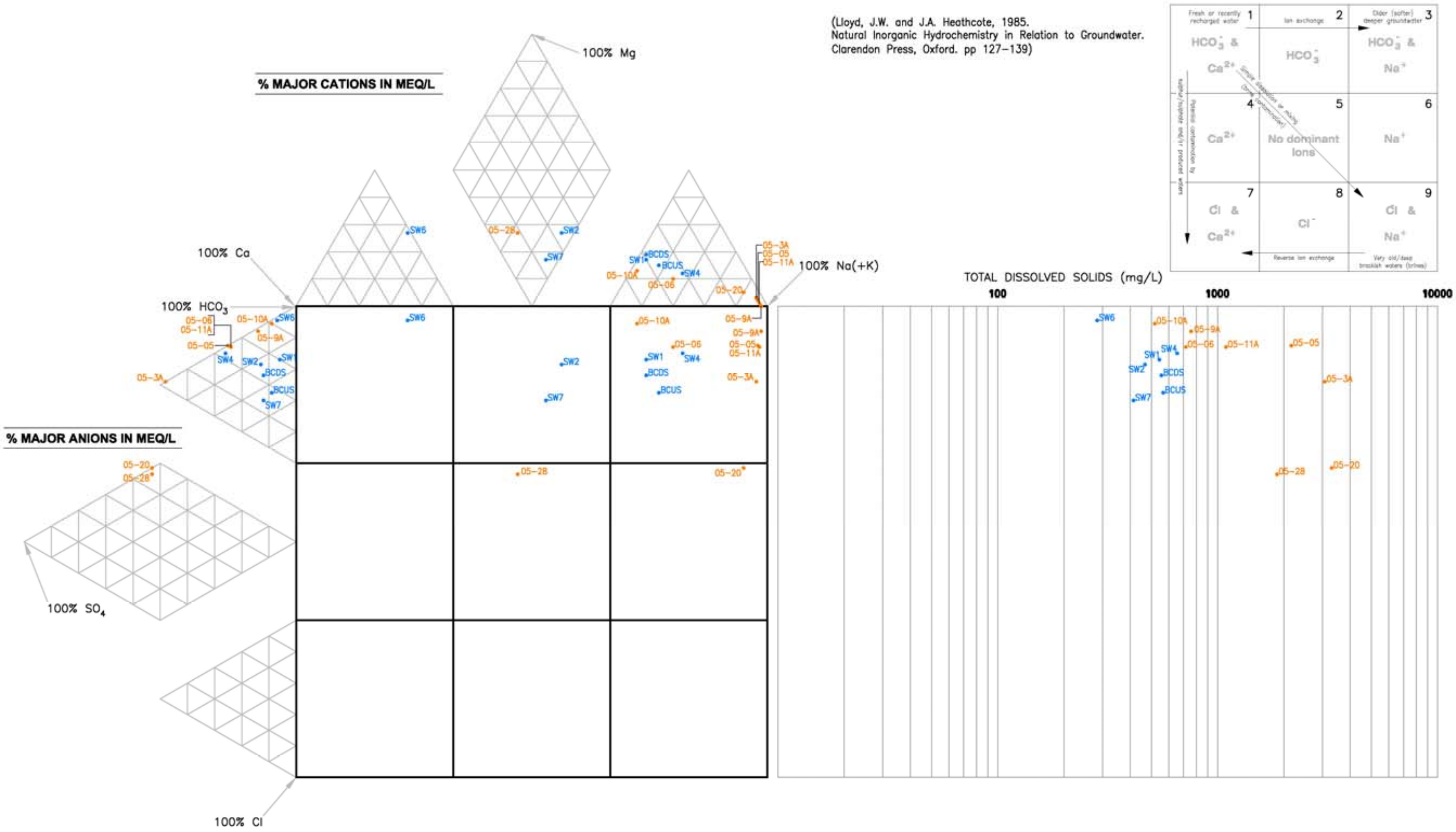
Field 6: Na^+ dominant and anion indiscriminant or SO_4^{2-} dominant. This is a water type that is not frequently encountered and indicates probable mixing influences.

Field 7: Cl^- and Ca^{2+} dominant is frequently encountered, the water may result from reverse ion exchange of Na–Cl waters.

Field 8: Cl^- dominant anion and no dominant cation, indicate that the groundwater is related to reverse ion exchange of Na–Cl waters.

Field 9: Cl^- and Na^+ dominant frequently indicate end–point waters (i.e., brackish–type water).

Figure 4.5-2: Legend for Surface Water Chemistry: Main Ion Characterization (Expanded Durov Diagram)



(Lloyd, J.W. and J.A. Heathcote, 1985.
Natural Inorganic Hydrochemistry in Relation to Groundwater.
Clarendon Press, Oxford. pp 127–139)

NOTES:

SW1 – SURFACE WATER SAMPLE
05–05 – GROUNDWATER SAMPLE (SURFICIAL DEPOSITS)

"HCO_3^- & Na^+" INDICATES ION DOMINANT FIELDS

FOR LEGEND SEE FIGURE 6B.

Figure 4.5-3: Groundwater and Surface Water Chemistry: Main Ion Characterization (Expanded Durov Diagram)

Dissolved oxygen measurements taken during the summer and fall events within Lamont Creek indicate that the creek is generally well oxygenated. Dissolved oxygen concentrations recorded within Beaverhill Creek during the summer and fall sampling events indicate that the Creek is poorly oxygenated and that aquatic life will be under severe stress within this section of the Creek between the upstream and downstream sampling points. Dissolved oxygen measurements taken in the winter indicate that Beaverhill Creek and Lamont Creek are anoxic. Beaverhill Creek exhibits characteristics typical of a hypereutrophic waterbody; whereas Lamont Creek ranges between eutrophic to hypereutrophic. TSS ranged between 11 and 640 mg/L, with lower TSS concentrations recorded in the winter.

Major ion and routine parameter concentrations were generally within ASWQ guidelines. TDS concentrations in surface waters ranged from 283–1,380 mg/L. Slightly elevated chloride concentrations were detected in surface water samples where they were not detected in groundwater at similar locations within the LSA. Seasonal concentration fluctuations were also recorded, suggesting that the source of chloride is most likely related to road salt use. Surface water within the LSA is of predominantly $Na\text{-}HCO_3$ hydrochemical type. Groundwater chemistry within the LSA is also predominantly $Na\text{-}HCO_3$ hydrochemical type.

Minor exceedances of metal concentrations (iron, phosphorus, cadmium) were recorded in a number of samples during both the June and October 2006 sampling rounds. Winter baseline results indicate generally higher concentrations of trace elements, with marked increases in total and dissolved iron and total and dissolved phosphorous; several exceedances of applicable guidelines were noted for these parameters in Lamont Creek (BC US) and Beaverhill Creek (BC DS and BC DS2).

Exceedances of metal concentrations (iron, phosphorus, copper and cadmium) and phenolic materials were also recorded in numerous AENV samples taken from Beaverhill Creek between 1975 and 1990.

Hydrocarbons (BTEX, TPH and TEH) were not detected in surface water within the LSA. However, the concentration of toluene exceeded the CCME freshwater aquatic life guideline in February for BC DS and BC DS2.

Snow quality data indicate that in general, snow quality is not influenced substantially by acid generating deposits.

4.5.2 Existing Baseline Sediment Quality

4.5.2.1 *Metals*

Metal concentrations in most sediment samples were below CCME Interim freshwater sediment quality guidelines (ISQGs; dry weight) and probable effect levels (PELs). Exceptions were at sampling location SW3 where cadmium and zinc concentrations exceeded relevant ISQGs and at SW1 where zinc concentrations exceeded its ISQG. At sampling location SW4, arsenic and copper concentrations exceeded both of their respective ISQGs and PELs.

Appendix I – Table I-5 shows metal parameter data for sediment samples.

4.5.2.2 *Hydrocarbons*

All sediment samples were analyzed for BTEX and two samples were analyzed for TPH. At all locations concentrations were below method detection limits.

Appendix I – Table I-6 shows hydrocarbon parameter data for sediment samples.

4.6 Application Case

Potential changes to surface water quality can produce adverse effects to other components of the ecosystem including aquatic resources (fisheries and benthic invertebrates) and human health. The potential impacts to surface water quality from the construction, operation and reclamation phases of the Project are related to:

- surface disturbances
- aerial deposition of acidifying compounds
- upset conditions

The potential impacts to surface water quality and general mitigation methods are discussed in the following sections. Impact assessment criteria as described in Section 4.4.6 were used to determine the final impact rating of each potential change to surface water quality within the LSA and RSA. Evaluations of surface water quality impacts and their dependent effects are presented in Sections 4.6.1–4.6.9.

4.6.1 Potential Impacts to Surface Water Quality from Surface Disturbances

Surface disturbances and potential changes to surface water quality during the construction phase of the Project could result from:

- construction activity close to waterbodies causing disturbances to streambeds and banks and increasing the potential for erosion and sediment runoff
- changes in land use due to land clearing and construction of facilities and associated infrastructure (e.g., roads, railway spurs), increasing the potential for erosion and sediment runoff
- changes in land use during construction and operational phases, potentially altering existing runoff patterns and existing basin sediment yield

During the operational phase of the Project, runoff from the majority of facilities and structures as well as recycled process and cooling water will be collected in a runoff collection pond. Surface disturbances and potential changes to surface water quality during the operational phase of the Project could result where:

- an increase in runoff from paved/hard packed areas such as the access road and additional railway spurs occurs, which potentially contains deleterious substances
- groundwater pumping is required for water supply and where the pumping causes a reduction in aquifer supplied base flow and impacts surface water quality in local waterbodies. Where the upper aquifer proves viable and groundwater is utilized for the Project, it appears that multiple wells will be necessary to meet the required yield (see Volume IIB, Section 2: Groundwater Quantity and Quality). In the case that the multi-well option is unrealistic, an alternate water supply source (e.g., from a regional reservoir) will need to be secured for the Project and potential impacts to surface water quality from groundwater abstraction will be eliminated.

Domestic wastewater generated at the Site will be collected in a septic tank and hauled off site for disposal at an approved sewage treatment facility

4.6.2 Mitigation from Surface Disturbances

Measures to mitigate potential adverse effects to surface water quality during Project construction and operations are aimed at preventing the release of silt and sediments to local waterbodies, in line with the Alberta Code of Practice for watercourse crossings (AENV 2001). During construction, such measures include:

- minimizing disturbances near streambanks
- creating minimum setback distances from watercourses and waterbodies, where practicable
- clearing streambanks in an environmentally responsible manner
- installing erosion control measures on slopes and streambanks
- limiting earth disturbance activities during high surface runoff events
- reclaiming excavated areas as soon as practicable
- developing and implementing site-specific erosion and sediment control plans
- developing a storm water management plan to handle runoff
- diverting potentially impacted runoff to the wetland located in the northwest corner of the property boundary (see Figure 4.4-2). The wetland would naturally improve the water quality through the processes of retention, settling, filtration, polishing and natural biodegradation, and runoff could also be actively treated if required prior to discharge to the Beaverhill Creek. The wetland has a point source discharge in the form of a culvert under R.R. 202 (see Figure 4.4-2) that could be controlled to prevent uncontrolled discharge to Beaverhill Creek.

Mitigation measures during operation include:

- diverting potentially impacted runoff to the wetland located in the northwest corner of the property boundary (see Figure 4.4-2) as discussed above
- only pumping groundwater to maintain the minimum required water level within the runoff collection pond for process requirements and firefighting purposes: 12 USGPM (US gallon per minute) or 0.76 L/s (litres per second). Groundwater pumping test analyses (see Volume IIB, Section 2: Groundwater Quantity and Quality) indicate that Project water withdrawals may lead to the cessation of groundwater inflows to the wetland area in the northwestern quarter section of the PDA. However, given that baseline groundwater inflows were determined to comprise less than 0.5% of total annual water balance inflows, the termination of baseflow to the wetland is predicted to have a negligible impact on surface water quality. None of the other drainages on site are considered to be groundwater fed and lowering of groundwater levels will not impact surface water quality in these features.

4.6.3 Classification of Residual Impacts to Surface Water Quality from Surface Disturbances

4.6.3.1 Construction and Operation

The impact of increased runoff during high rainfall events may in some circumstances have a negative effect, as sediment loading may increase. Reduction of groundwater baseflow to the wetland area is predicted to have a negligible impact on surface water quality and have a neutral direction. The time of travel of groundwater from the plant site to the wetland is more than 100 years, and thus there is sufficient time to mitigate potentially impacted groundwater. Provided mitigation measures are implemented appropriately, the impacts to surface water quality within the LSA and RSA are in general predicted to be low to moderate in magnitude, local in geographic extent (i.e., within property boundary), short term in duration and reversible. Confidence for these residual impact assessments is moderate to high and the final impact rating is Class 3.

4.6.3.2 ***Project Closure***

Project closure activities related to surface disturbances include road and rail line spur deactivation, facility and floor slab removal, watercourse crossing removal, reclamation and re-vegetation. After closure and reclamation of the Project, removing facilities and re-vegetation will eliminate the potential for surface disturbance related water quality impacts. Effects following Project completion are therefore, predicted to be neutral in direction, negligible in magnitude over the long-term and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

4.6.4 Potential Impacts from Deposition of Acidifying Compounds on Waterbodies

Many industrial activities result in the emission of compounds containing sulphur and nitrogen which, when deposited in terrestrial and aquatic systems, may result in acidification. Acid deposition related to the Project consists primarily of nitrogen and sulphur oxide emissions associated with stack emissions from the sulphur forming plant and windborne emissions from sulphur pastille storage and handling processes. Where natural buffering capacity is low, acid deposition can reduce ambient pH levels and increase the mobility of some trace elements in surface waterbodies to the point where the aquatic system is adversely affected.

Volume IIA, Section 2: Climate and Air Quality indicates that emissions of acidifying substances including NO_x and SO_2 could potentially contribute to wet acid deposition. Fine particles (assumed to be mainly elemental sulphur) with diameters less than 2.5 µm ($PM_{2.5}$), could contribute to dry acid deposition. These parameters have concentrations only slightly above current ambient concentrations and below regulatory emissions guidelines. Further, air dispersion modelling indicates that for $PM_{2.5}$ the deposition will occur only within the property boundary of the Site.

Surface waterbodies vary in their level of sensitivity to acid deposition, depending on a variety of factors within their drainage basins. The most important of these factors include soils, surficial geology, topography, hydrology, vegetation and climate.

Published regional receptor sensitivity data (which includes soil and surface water) to acidifying input is available for the region and includes the RSA and LSA (CASA and AENV 1999). The study assumes the intersection of the 1° longitude x 1° latitude grid cells represent the centre of the grid. Based on this, the region receptors are classified as being within a high sensitivity grid cell. Since the preparation of the 1999 document, AENV has updated their 1° longitude x 1° latitude modelling using 1° longitude x 1° latitude grid cells that have been shifted by a half degree (from Cheng 2006, as discussed in Sturgeon Upgrader EIA, Petro-Canada Oil Sands Inc. 2006). The 1° longitude x 1° latitude grid cells now represent the corners of the grid. Based on this, the region is now placed within a low sensitivity grid cell. The grid cell sensitivity data is intended to provide a regional overview and the data may not be directly applicable to relatively small areas (i.e., the RSA and LSA) within a grid cell.

Site specific soil acidification sensitivity ratings were also determined for the LSA and RSA in Volume IIC, Section 2: Soil. Results indicate overall acid sensitivity for soils in the RSA and LSA to be low to moderate.

For water, acid sensitivity is usually evaluated by analyzing samples of surface water for chemical constituents, the most important of which is alkalinity. Acid sensitivity can be evaluated by comparing alkalinity measured in a lake (hereafter, the term lake is also used to refer to the wetland/open waterbody within the LSA) with a generally accepted scale of acid sensitivity, such as the one provided below.

4.6.4.1 Lake Acid Sensitivity

Acid sensitive lakes share the following characteristics, as summarized by Sullivan (2000):

- concentrations of all major ions are low and conductivity is less than 25 µS/cm (microSiemens per centimetre)
- alkalinity and acid-neutralizing capacity (ANC) are less than 10 mg/L as $CaCO_3$ or 0.2 meq/L (milliequivalents per litre) ANC
- concentrations of base cations ($Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}$) in pristine areas are generally less than 0.1 meq/L
- concentrations of dissolved organic carbon (DOC) are generally less than 5 mg/L
- pH is generally below 6.5

Physical characteristics are as follows:

- moderate to high elevation
- high topographical relief in the contributing watershed
- severe short-term changes in hydrology, such as flash flooding
- minimal contact between drainage waters and soils or geologic material that may contribute weathering products to solution
- small drainage basins that derive much of their hydrologic input as direct precipitation to the lake surface

Saffran and Trew (1996) present a scale of lake sensitivity to acidification (see Table 4.6-1) based on alkalinity and a sensitivity map of Alberta lakes using available data for 1,156 lakes.

Table 4.6-1: Lake Sensitivity to Acidification Based on Alkalinity

Acid Sensitivity	**Alkalinity (mg/L as $CaCO_3$)**
High	0–10
Moderate	11–20
Low	21–40
Least	>40

The wetland area within the LSA does not have the typical characteristics of acid sensitive lakes, with the exception that it has a small drainage basin, which in itself is not an indication of acid sensitivity. Using the lake classification system of Saffran and Trew (1996) above, alkalinity data for the wetland area (260 mg/L) suggests that it has a very high buffering capacity, and therefore, has negligible sensitivity to acidification.

4.6.4.2 *Stream Acid Sensitivity*

The primary concern regarding acidification of streams is episodic acidification, which is a decrease in pH that occurs during hydrological events such as spring snowmelt or rainfall. This episodic acidification, also referred to as a spring acid pulse, is a widespread natural phenomenon in surface waters (Sullivan 2000). However, acidic deposition from industrial sources can also contribute to episodic acidification and can cause a more severe depression of pH and a longer recovery period.

The sensitivity of streams to spring acid pulse depends on a number of factors related to runoff and basin characteristics. Streams that are the most sensitive have the following characteristics (Sullivan 2000):

- small channel, flows and watersheds
- high elevations
- steep topography of the contributing watershed
- extensive areas of exposed bedrock
- deep snowpack
- thin soils with low alkalinity

As in lakes, the primary indicator of acid sensitivity in streams is the acid neutralizing capacity. The generally accepted categories of acid sensitivity (see Table 4.6-2) are based on Boward et al. (1999).

Table 4.6-2: Acid Sensitivity of Streams based on ANC

Acid Sensitivity	ANC (µeq/L)
Acidic	<0
Highly sensitive	0–50
Sensitive	>50–200
Not sensitive	>200

SOURCE: Boward et al. (1999).

Apart from the streams and creeks draining the LSA being small and shallow, watershed characteristics in this area are generally inconsistent with those of acid sensitive streams. Alkalinity measurements in small streams and creeks within the local area range between 200–300 mg/L as $CaCO_3$, or between 3,996–5,994 µeq/L and show little seasonal variation. Seasonal variations in pH are not significant either. Using the stream acid sensitivity classification system of Boward et al. (1999) above, ANC data for the streams and creeks in the area suggests that they have negligible sensitivity to acidification, either from spring acid pulses or industrial sources.

4.6.4.3 *Approach to Assessment and Evaluation of Potential Effects from Acid Deposition*

The assessment of possible baseline and future effects from acid deposition relied on the comparison of calculated critical loads of acidity, to the most recent levels of Potential Acid Input (PAI) in Alberta as estimated by CASA and AENV (1999) and estimated future PAI levels as calculated in Volume IIC, Section 2: Soil. Estimated future PAI levels take into consideration PAI loadings from other existing and proposed operations in the local area. As such, the estimated future PAI level is a worst case cumulative assessment. The assessment also involved comparison of calculated critical loads with the critical loads accepted for application by Alberta for protection of low to high sensitivity soil and aquatic systems (Target Loading SubGroup 1996).

The definition of critical load of acidity that has been accepted for use in Alberta (Target Loading Subgroup 1996) is the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems. A critical load of acidity (CL) ranging between 3.5–4.1 keq H^+/(ha•y) was calculated for the wetland area located in the northwestern corner of the Project, based on the steady-state water chemistry model described by Henriksen and Posch (2001). The model used is based on the input of acid neutralizing chemicals from the wetland's catchment area and a conservative acid neutralizing capacity required to protect aquatic ecosystems. Details of the model parameters and calculations are provided in Appendix II and a summary of the data is provided in Table 4.6-3 below.

Three critical loads were accepted for application in Alberta (Target Loading SubGroup 1996) for sensitive soils (0.25 keq H^+/(ha•y)), for moderately sensitive soils (0.50 keq H^+/(ha•y)) and for soils of low sensitivity (1.00 keq H^+/(ha•y)). An additional scientific review of the sensitivity of aquatic systems to acid input concluded that these critical loads would be protective of wetlands.

PAI in Alberta was estimated in grid cells measuring 1° latitude and 1° longitude, using the Regional Lagrangian Acid Deposition (RELAD) model (CASA/AENV 1999). The grid cell which the LSA and RSA falls in is between 53° and 54° latitude and 112° and 113° longitude. Current levels of acid input (PAI) for this cell range between <0.05–0.1 keq H^+/(ha•y), well below the Alberta critical load of 0.25 keq H^+/(ha•y) for aquatic systems that are highly sensitive to acid input. PAI values were also calculated for the baseline (0.13 keq H^+/(ha•y)), application (0.17 keq H^+/(ha•y)) and cumulative effects assessment (CEA) (0.22 keq H^+/(ha•y)) cases for the study site in Volume IIA, Section 2: Climate and Air Quality.

Table 4.6-3: Summary of Parameters used in Critical Load of Acidity Calculation Compared to PAI

Sample ID	pH	Ca^{2+} (µeq/L)	Mg^{2+} (µeq/L)	K^+ (µeq/L)	Na^+ (µeq/L)	CL^- (keq H^+/(ha•y))	BaselinePAI[1] (keq H^+/(ha•y))	Baseline PAI[2] (keq H^+/(ha•y))	Application PAI[2] (keq H^+/(ha•y))	CEA PAI[2] (keq H^+/(ha•y))
SW1 – wetland	7.9	3,139	2,040	1,002	4,481	4.1	<0.05–0.1	0.13	0.17	0.22
SW2 – wetland	8.4	2,515	2,501	586	3,567	3.5	<0.05–0.1	0.13	0.17	0.22

Notes:
[1] Baseline estimate value from CASA/AENV 1999.
[2] PAI estimate value as calculated in Volume IIA, Section 2: Climate and Air Quality.

Comparison of the calculated critical load for the Project and baseline, application and CEA PAI values indicates that potential acid input rates are significantly lower than the critical load and that the wetland area is not sensitive to acid deposition.

Comparison to Alberta's recommended critical loads also indicates that the critical load calculated for the wetland area is significantly higher than that required to be protective of aquatic systems of low sensitivity (1.00 keq H^+/(ha•y)).

Snowmelt plays a role in acid deposition in that dry acidifying compounds will accumulate in the snowpack over the course of the winter and be discharged over a relatively short period of time during freshet. Snowmelt hydrology for the Project area is documented in Volume IIB, Section 3: Surface Water Quantity. The impact of the deposition of dry acidifying compounds on snow and subsequent melting are not expected to impact the local or regional study areas for two reasons:

- calculated PAI values for the application (0.17 keq H^+/(ha•y)) and cumulative effects assessment (CEA) (0.22 keq H^+/(ha•y)) cases for the study site (Volume IIA, Section 2: Climate and Air Quality) are below the Alberta critical load of 0.25 keq H+/(ha•y) for aquatic systems that are highly sensitive to acid input
- acid-forming bacteriological oxidation processes have an optimal temperature range of between 30°C and 35°C (e.g. *Thiobacillus ferrooxidans)* and will be retarded in a snowpack environment and it is anticipated that dry sulphur deposited on snow will remain in its benign elemental state until temperatures reach >10°C, at which point bacteriological process commence (Stanley et al. 1989). Snowmelt from the LSA will have reached the North Saskatchewan River before temperatures reach the minimum required for bacterial oxidation. Further, once in the aquatic anaerobic environment, bacterial oxidation will not occur.

4.6.5 Mitigation of Impacts from Deposition of Acidifying Compounds on Waterbodies

An environmental management system will be implemented to ensure that SO_2 emissions from on site activities will be minimized at all times. These measures will include, but will not necessarily be limited to:

- establishment of an air quality monitoring program measuring SO_2 and particulate sulphur (see Volume IIA, Section 2: Climate and Air Quality)
- inclusion of surface water monitoring in the groundwater monitoring program
- implementation of safe operational procedures to reduce potential for accidental or uncontrolled releases on site during the operational phase
- development of an Emergency Response Plan detailing response procedures for potential unplanned events

4.6.6 Classification of Residual Impacts from Deposition of Acidifying Compounds on Waterbodies

4.6.6.1 Operation

Assuming that all mitigation measures are implemented appropriately and given the high buffering capability and low sensitivity of waterbodies in the local area to acid deposition, it is anticipated that impacts to surface water quality from acid deposition arising out of normal operational activities within the LSA and RSA will be low to moderate in magnitude, local in geographic extent (i.e., within property boundary), mid-term in duration and reversible. Confidence for these residual impact assessments is moderate to high and the final impact rating is Class 3.

4.6.6.2 *Project Closure*

After closure and reclamation of the Project, facilities will no longer be operational and the potential for acid deposition to occur will be eliminated. Local acid impacts within the PDA will naturally attenuate within months of closure. The residual impacts of acid deposition to surface water will then be neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

4.6.7 Potential Impacts to Surface Water Quality from Upset Conditions

Upset conditions might occur during the construction and operational phases of the Project. These conditions are generally the result of unplanned events and could result in a temporary negative impact to receiving surface water quality.

Upset conditions and potential changes to surface water quality during the construction and operation phase of the Project could result from:

- accidental release/spillage of process affected water or other chemicals such as dust suppression agents (Dustbind S5) and proprietary sulphur release aid (IPAC SRB Plus). Material Safety Data Sheets which include a description of the nature of chemicals to be used on site are provided in Volume 1: Project Description – Appendix IV: Health and Safety Plan
- emissions and accidental release of elemental sulphur
- uncontrolled release from the runoff collection pond taking place prior to neutralization, testing and sampling

4.6.8 Mitigation of Impacts to Surface Water Quality from Upset Conditions

An environmental management system will be implemented to minimize the potential for upsets that may directly or indirectly affect surface waters and to control the potential impacts should they occur. These measures will include, but not necessarily be limited to:

- implementation of safe construction and operational work procedures to reduce potential for accidental spillages/collisions/emissions on site during the construction and operational phase. This will be developed in line with the AENV (1994) guidance document on Best Management Practices and Spill Response
- development of an Emergency Response Plan detailing response procedures for potential accidental/catastrophic events
- liquid and solid chemicals required for processing being managed and applied in enclosed systems to minimize opportunity for accidental release to the environment
- runoff from the sulphur forming and storage areas being collected in a perimeter ditch lined with high density polyethylene (HDPE) that feeds into the surface water runoff pond
- ensuring the capacity of the surface water runoff pond exceeds the volume of runoff generated by the 1 in 25 years, 24 hour rainfall event to prevent accidental release/breakthrough, including recycling and reusing runoff collection water where possible to minimize the potential for controlled releases from the pond
- the pond being double-lined (60mil HDPE liner over compacted clay soil) and including a leak detection system

- monitoring, sampling, testing and neutralization (if required) of the runoff collection water prior to release, where a controlled release is required
- the initial sulphur load-out and transfer tank comprising an in-ground concrete tank surrounded by a permeable leak detection system and secondary compacted clay soil liner
- the liquid sulphur storage tanks including leak detection systems
- the asphalt storage pad for sulphur pastilles including primary asphalt containment, a secondary clay soil liner, runoff and run-on controls and a leak detection system

Controlled releases from the runoff collection pond and runoff from other areas outside of the plant footprint (e.g., landscaped areas, pavements and roadways, etc.) will be diverted via a natural swale to the ephemeral wetland located in the northwest corner of the property boundary (both features shown on Figure 4.4-2). The wetland has a high ANC and typically it dries up by the end of summer and, therefore, has the ability to completely contain runoff for most of the year. The estimated volumetric capacity of the wetland is approximately 125,000 m^3. Average annual runoff from the plant site is estimated at approximately 30,000 m^3. Thus, it is anticipated that the wetland would likely be able to completely contain an unplanned release from the runoff pond at the plant site without discharging from the property boundary. The wetland will naturally improve the water quality through the processes of retention, filtration and natural biodegradation and could also be actively neutralized/treated if required prior to discharge to the Beaverhill Creek. The wetland has a point source discharge in the form of a 609 mm culvert under R.R. 202 (see Figure 4.4-2) which could further be controlled to prevent breakthrough to Beaverhill Creek, should an unplanned release occur.

4.6.9 Classification of Residual Impacts to Surface Water Quality from Upset Conditions

4.6.9.1 Construction and Operation

The impact of upset conditions on water quality may at times have a negative direction and the geographical extent of these impacts is likely to be local (within the LSA). However, provided mitigation measures are implemented appropriately, the impacts to surface water quality within the LSA and RSA are predicted to be low to moderate in magnitude, local in geographic extent, short term in duration and reversible. Confidence for these residual impact assessments is moderate to high and the final impact rating is Class 3.

4.6.9.2 Project Closure

After closure and reclamation of the Project, facilities will no longer be operational and the potential for upset conditions to occur will be eliminated. Effects following Project closure are, therefore, predicted to be neutral in direction, negligible in magnitude over the long term duration and reversible. Confidence for these residual impact assessments is high and the final impact rating is Class 4.

4.6.10 Cumulative Effects Assessment

There are currently no other planned projects located within the RSA with the potential to affect surface water quality with respect to Project operations. Similarly, the effects of the Project on surface water quality are predicted to be low to moderate in magnitude and localized in geographical extent (within the LSA). The water quality of the receiving regional waterbodies, namely Beaverhill Creek, is generally poor and displays qualities of being in a hypereutrophic state. This is likely due to the discharge of treated effluent from municipal treatment facilities, perhaps compounded by agricultural runoff (e.g., fertilizers). The Project is not anticipated to contribute any eutrifying compounds to Beaverhill Creek, such as nutrients. The presence of the wetland in the northwestern corner of the property, which will act as a retention and natural treatment system, will further prevent any potentially deleterious compounds arising from surface disturbances or upset conditions from reaching Beaverhill Creek.

The acid deposition and sensitivity analysis inherently considered cumulative effects and determined that cumulative impacts resulting from acidifying compounds are not considered to be detrimental to water quality. The Project is not anticipated to release other deleterious compounds into aquatic ecosystems and, therefore, no cumulative effects are anticipated.

4.7 Management and Monitoring

The following surface water quality monitoring will be performed by Alberta Sulphur Terminals Ltd. (AST) and/or HAZCO Environmental Services (HAZCO) during construction and operation activities to ensure potential impacts are mitigated:

- best management practices will be employed during construction to minimize impacts to runoff quality
- monitoring of surface water quality in the wetland will be conducted at a reasonable frequency, consistent with groundwater monitoring. Water quality will be monitored in the on site wetland before and after groundwater withdrawals commence to assess potential impacts. Grab samples will be collected immediately prior to release of any water to the surrounding environment. Any water that may be discharged from the runoff collection pond will be sampled and tested to comply with the following generic criteria:
    - no visible sheen
    - 6<pH<9
    - chemical oxygen demand <50 mg/L
    - chloride <500 mg/L
    - TSS <50 mg/L
- discharge limits for specific contaminants (if and when suspected) will be determined in accordance with the Water Quality Based Effluent Limits Procedures Manual (AENV 1995)
- the water quality monitoring program will be adaptively managed to ensure that it adequately reflects understanding of the local environment and the potential impact of the Project on it
- an air quality monitoring program will be established to measure SO_2 and particulate sulphur during operation as described in Volume IIA, Section 2: Climate and Air Quality

4.8 Summary

The water quality impact assessment has concluded that potential adverse effects from development of the Project will be largely of local geographical extent, low-to-moderate magnitude, short to mid-term duration and reversible in nature. Confidence for these residual impact assessments are considered moderate to high and the final impact ratings are Class 3.

For sediment mobilization potential and in the case of unplanned events, these impact classifications require that the appropriate Best Management Practices are effectively implemented to ensure minimal impact. A final impact assessment summary is provided in Table 4.8-1.

Table 4.8-1: Final Impact Assessment Summary Table

Issue	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Confidence	Final Impact Rating	
							Construction and Operation	Closure
Potential Impact from Surface Disturbances								
Increased erosion and basin sediment yield and altered runoff patterns	Negative	Low to moderate	Local	Short-term	Reversible	Moderate to high	Class 3	Class 4
Impact of groundwater withdrawal on local water quality	Negative	Negligible	Local	Mid-term	Reversible	High	Class 3	Class 4
Potential Impact from the Deposition of Acidifying Compounds on Waterbodies								
Project contribution to acid deposition on local waterbodies (including snowmelt)	Negative	Low to moderate	Local	Mid-term	Reversible	Moderate to high	Class 3	Class 4
Potential impact from Upset Conditions								
Accidental spillages or leaks	Negative	Low to moderate	Local	Short-term	Reversible	Moderate to high	Class 3	Class 4
Uncontrolled release from runoff collection pond	Negative	Low to moderate	Local	Short-term	Reversible	Moderate to high	Class 3	Class 4

4.9 References

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Volume IIB: Surface Water Quality

Appendix I: Surface Water and Sediment Quality Analytical Tables

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Table I–1: Water Quality Analytical Results: Routine Indicator Parameters

		PHYSICAL					INDICATORS	ION BALANCE	Nutrients									
Monitoring Station	Date	pH	Turbidity	Total Suspended Solids	Total Dissolved Solids	Electrical Conductivity	TDS-Calculated	Ion Balance	Total Nitrogen	Nitrite NO_2 as N	Nitrate NO_3 as N	Nitrate plus Nitrite NO_2+NO_3 as N	Total Alk. as $CaCO_3$	PP Alk. as $CaCO_3$	Bicarbonate	Carbonate	Tot Hardness as $CaCO_3$	Hydroxide
	(d-m-y)	(units)	(NTU)	(mg/L)	(mg/L)	(µS/cm)	(mg/L)	(balance)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
CCME Freshwater Sediment (1999)		6.5 - 8.5	---	---		---	---	---		---	---	---		---	---	---	---	---
CCME Freshwater Sediment (PEL), 99		6.5 - 9	---	---		---	---	---		0.06	13	---		---	---	---	---	---
BC DS	14-Jun-06	8.1	---	---	---	928	556	1.02	---	<0.06	<0.2	<0.2	366	<1	447	<1	240	<1
D L (Duplicate of BC DS)	14-Jun-06	8.1	---	---	---	922	564	1.06	1	<0.06	<0.2	<0.2	345	<1	421	<1	230	<1
	18-Oct-06	8.13	14	493	---	905	493	0.9	---	0.004	0.003	0.007	410	<0.5	500	<0.5	220	<0.5
THETA (Duplicate of BC DS2)	18-Oct-06	8.18	5.4	640	---	1,060	640	0.91	---	<0.003	<0.003	<0.003	474	<0.5	579	<0.5	300	<0.5
	16-Feb-07	7.5	---	46	720	1,190	698	0.98	---	<0.06	<0.2	<0.2	560	<1	683	<1	320	<1
(Duplicate)	16-Feb-07	8	---	50	712	1180	698	1.02	---	<0.06	<0.2	<0.2	557	<1	680	<1	330	<1
BCDS2	18-Oct-06	8.19	7.5	640	---	1,070	640	0.9	---	<0.003	0.004	0.004	475	<0.5	580	<0.5	290	<0.5
	16-Feb-07	7.6	---	11	772	1,250	744	0.96	---	<0.06	<0.2	<0.2	628	<1	766	<1	370	<1
BC US	14-Jun-06	8.1	---	---	---	925	566	1.06	---	<0.06	<0.2	<0.2	348	<1	425	<1	230	<1
	18-Oct-06	8.37	3.9	571	---	967	571	0.9	---	0.027	0.124	0.151	283	3.7	336	4.5	200	<0.5
	16-Feb-07	7.3	---	80	988	1,640	987	0.94	---	<0.06	<0.2	<0.2	731	<1	892	<1	420	<1
SW1	14-Jun-06	7.9	---	---	---	887	544	1.09	---	<0.06	<0.2	<0.2	---	<1	478	<1	260	<1
SW2	14-Jun-06	8.4	---	---	---	734	467	1.08	---	<0.06	<0.2	<0.2	---	<1	388	<1	250	<1
SW4	14-Jun-06	8.3	---	---	---	953	654	1.08	---	<0.06	0.3	0.3	---	<1	498	<1	200	<1
SW6	14-Jun-06	7.9	---	---	---	492	283	1.02	---	<0.06	<0.2	<0.2	---	<1	312	<1	220	<1
SW7	14-Jun-06	8	---	---	---	687	414	1.08	---	<0.06	<0.2	<0.2	---	<1	284	<1	210	<1
SW9	18-Oct-06	8.32	130	517	---	896	517	0.93	---	0.005	0.023	0.028	362	2.6	435	3.1	220	<0.5
(Duplicate)	16-Feb-07	8.1	---	17	1480	2200	1400	0.99	---	<0.06	<0.2	<0.2	994	<1	1210	<1	660	<1
SNOW SAMPLES					---													
SS1	16-Feb-07	8.2	---	3,320	84	---	84	---	2	---	---	---	40	<1	49	<1	---	<1
SS1 Lab-Dup	16-Feb-07	---	---	---	---	---	---	---	2	---	---	---	---	---	---			
SS2	16-Feb-07	7.5	---	510	48	---	48	---	2	---	---	---	16	<1	19	<1	---	<1
SS3	16-Feb-07	6.7	---	32	<20	---	<20	---	1	---	---	---	3	<1	3	<1	---	<1
SS4	16-Feb-07	7.3	---	598	40	---	40	---	<1	---	---	---	12	<1	15	<1	---	<1
SS5	16-Feb-07	7.6	---	242	36	---	36	---	1	---	---	---	14	<1	17	<1	---	<1
SS6	16-Feb-07	7.4	---	328	36	---	36	---	1	---	---	---	13	<1	16	<1	---	<1
BETA (TRIP BLANK)	14-Jun-06	**5.7**[1 2]	---	---	---	1	<10	---	---	<0.06	<0.2	<0.2	<1	<1	<1	<1	<0.5	<1
TRIP BLANK	18-Oct-06	**5.7**[1 2]	0.1	<10	---	1	<10	---	---	<0.003	<0.003	<0.003	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table I–1: Water Quality Analytical Results: Routine Indicator Parameters (Cont'd)

Notes:

[1] Denotes values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999).

[2] Denotes values exceeding CCME Freshwater Aquatic Life, 2006 (Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates).

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Bolded indicates parameters above applied guideline/criteria

pH

Not to be altered by more than 0.5 pH units from background values.

Cadmium: (CCME guidelines)

0.000017 mg/L, 10 {0.86[log(hardness)]-3.2}.

Aluminum: (CCME guidelines)

0.005 mg/L pH<6.5; [Ca2+]<4.0 mg/L; DOC<2.0 mg/L.
0.1 mg/L ph>6.5; [Ca2+]>4.0 mg/L; DOC>2.0 mg/L.

Copper:D (ASWG guidelines)

See guideline tables for further calculations regarding copper concentrations.
0.0017 mg/L Hardness(CaCO3) = 10 mg/L.
0.0081 mg/L Hardness(CaCO3) = 50 mg/L.
0.016 mg/L Hardness(CaCO3) = 100 mg/L
Chronic - 0.007 mg/L Hardness(CaCO3) = >50 mg/L. Applies to acid-extractable copper concentrations.

Copper: (CCME guidelines)

0.0002 mg/L Hardness(CaCO3) = 0-120 mg/L.
0.003 mg/L Hardness(CaCO3) = 120-180 mg/L.
0.004 mg/L Hardness(CaCO3) = >180 mg/L

Table I–2: Water Quality – Dissolved Metals and Trace Elements

		DISSOLVED METALS AND TRACE ELEMENTS																																					
Monitoring Station	Date	Aluminum:D	Antimony:D	Arsenic:D	Barium:D	Beryllium:D	Bismuth:D	Boron:D	Cadmium:D	Calcium:D	Chloride:D	Chromium:D	Cobalt:D	Copper:D	Fluoride:D	Iron:D	Lead:D	Lithium:D	Magnesium:D	Manganese:D	Mercury:D	Molybdenum:D	Nickel:D	Phosphorus:D	Potassium:D	Selenium:D	Silicon:D	Silver:D	Sodium:D	Strontium:D	Sulphate:D	Sulphur:D	Thallium:D	Tin:D	Titanium:D	Uranium:D	Vanadium:D	Zinc:D	Zirconium:D
	(d-m-y)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Alberta Surface Water Guidelines		---	---	---	---	---	---	---	---	---	---	---	---	0.007	---	---	---	---	---	---	0.000005	---	---	0.05	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CCME Freshwater Aquatic Life, 2006		0.1	---	0.005	---	---	---	---	0.000017	---	---	0.0089	---	0.004	---	0.3	0.007	---	---	---	0.000026	0.073	0.15	---	---	0.001	---	0.0001	---	---	---	---	0.0008	---	---	---	---	0.03	---
BC DS	14-Jun-06	0.005	<0.001	**0.01**[2]	0.053	<0.001	<0.2	0.12	<0.00001	62.6	60	<0.007	<0.005	<0.002	0.6	0.157	<0.001	0.02	21.1	0.446	<0.00005[3]	<0.006	0.014	**0.4**[1]	14.6	<0.001	1.69	<0.0001	119	0.43	58	19.4	<0.0008	<0.04	<0.006	0.001	<0.05	<0.005	<0.005
	18-Oct-06	0.007	<0.0002	0.0015	0.04	<0.001	---	<0.02	<0.00001	56.4	61.2	0.001	0.0006	0.0008	0.54	**0.34**[2]	<0.0002	0.02	19.5	0.094	---	<0.0002	0.0043	**0.3**[1]	12.2	<0.0002	1.8	<0.0001	96.7	0.37	<0.5	1.8	<0.0002	<0.001	0.003	0.0002	<0.001	0.009	---
	16-Feb-07	0.005	<0.0002	0.004	0.13	<0.001	---	<0.02	<0.00001	79.1	82	<0.001	0.0023	0.0008	---	**6.10**[2]	<0.0002	0.22	28.5	1.52	<0.00005	<0.0002	0.0032	**1.3**	18.2	0.001	4.1	<0.0001	145	0.56	1	1.4	<0.0002	<0.001	0.001	<0.0001	0.001	0.011	---
(Duplicate)	16-Feb-07	0.012	<0.0002	**0.007**	0.13	<0.001	---	<0.02	0.00014	82.3	78	**0.019**	0.0023	0.0005	---	5.93	<0.0002	0.22	30.3	1.5	<0.00005	<0.0002	0.0044	1.1	18.2	<0.001	4.2	<0.0001	145	0.56	2	0.9	<0.0002	<0.001	0.001	0.0004	0.007	0.017	---
BCDS2	18-Oct-06	0.005	<0.0002	0.0018	0.06	<0.001	---	0.11	0.00001	74.8	33	<0.001	<0.0003	0.0008	0.21	0.09	<0.0002	0.08	26	0.031	---	0.0004	0.004	**0.2**[1]	7.5	<0.0002	2.6	<0.0001	118	0.56	95.5	26.3	<0.0002	<0.001	0.003	0.0009	<0.001	0.009	---
	16-Feb-07	0.005	<0.0002	0.005	0.12	<0.001	---	0.14	<0.00001	92.3	57	<0.001	0.0004	0.0008	---	**1.36**[2]	<0.0002	0.16	34.1	1.35	<0.00005	<0.0002	0.0028	**1.6**	12.5	<0.001	6.2	<0.0001	144	0.79	25	8.3	<0.0002	<0.001	0.002	0.0003	0.002	0.013	---
BC US	14-Jun-06	0.024	<0.001	**0.011**[2]	0.062	<0.001	<0.2	0.09	<0.00001	59	83	<0.007	<0.005	<0.002	0.4	0.15	<0.001	0.03	19.9	0.638	<0.00005[3]	<0.006	0.014	**0.6**[1]	12	<0.001	2.8	<0.0001	137	0.43	45	15.7	<0.0008	<0.04	<0.006	0.001	<0.05	<0.005	<0.005
	18-Oct-06	0.013	<0.0002	0.0015	0.02	<0.001	---	0.21	<0.00001	54	63	<0.001	0.0009	0.0017	0.93	<0.06	<0.0002	<0.02	17	0.12	---	0.0071	0.0054	**0.8**[1]	11.4	<0.0002	4.4	<0.0001	114	0.41	141	40.9	<0.0002	<0.001	0.004	0.0013	0.002	0.009	---
	16-Feb-07	0.007	<0.0002	0.002	0.21	<0.001	---	0.06	<0.00001	110	117	<0.001	0.0023	0.0010	---	**23.1**[2]	<0.0002	0.07	35.1	3.66	<0.00005	<0.0002	0.0032	**3.1**[1]	10.9	<0.001	8.6	<0.0001	194	0.89	54	16.3	<0.0002	<0.001	0.001	0.0001	0.002	0.003	---
SW1	14-Jun-06	<0.005	<0.001	**0.01**[2]	0.045	<0.001	<0.2	0.06	**0.00002**[2]	62.9	50	<0.007	<0.005	<0.002	0.3	**0.446**[2]	<0.001	0.04	24.8	1.09	<0.00005[3]	<0.006	<0.008	**0.3**[1]	39.2	<0.001	5.38	<0.0001	103	0.47	27	10.8	<0.0008	<0.04	<0.006	<0.001	<0.05	<0.005	<0.005
SW2	14-Jun-06	---	---	---	---	---	---	---	---	50.4	36	---	---	---	0.3	0.078	---	---	30.4	0.002	---	---	---	---	22.9	---	---	---	82	---	54	---	---	---	---	---	---	---	---
SW4	14-Jun-06	<0.005	<0.001	**0.011**[2]	0.062	<0.001	<0.2	0.07	0.00001	50.7	7	<0.007	<0.005	0.003	0.3	0.135	<0.001	0.03	17.4	0.173	<0.00005[3]	<0.006	0.016	<0.1[3]	10.2	<0.001	2.92	<0.0001	183	0.37	139	46.4	<0.0008	<0.04	<0.006	0.004	<0.05	<0.005	<0.005
SW6	14-Jun-06	0.008	<0.001	**0.011**[2]	0.119	<0.001	<0.2	0.06	<0.00001	58.4	2	<0.007	<0.005	<0.002	0.3	0.045	<0.001	<0.02	18.4	0.042	<0.00005[3]	<0.006	<0.008	<0.1[3]	10	<0.001	4.23	<0.0001	22.5	0.46	18	6.2	<0.0008	<0.04	<0.006	0.002	<0.05	<0.005	<0.005
SW7	14-Jun-06	0.006	<0.001	**0.01**[2]	0.155	<0.001	<0.2	<0.05	<0.00001	58.6	64	<0.007	<0.005	0.003	0.2	0.035	<0.001	<0.02	16.6	0.006	<0.00005[3]	<0.006	0.01	<0.1[3]	14.8	<0.001	3.62	<0.0001	75.7	0.48	44	16.3	<0.0008	<0.04	<0.006	0.003	<0.05	0.007	<0.005
SW9	18-Oct-06	0.008	0.0003	0.0008	0.13	<0.001	---	0.11	**0.00004**[2]	40.6	46.1	<0.001	0.0003	0.0007	0.39	0.13	<0.0002	0.06	29.8	0.027	---	0.0028	0.0041	**0.1**[1]	21	<0.0002	4.7	<0.0001	97.1	0.57	64.7	19.3	<0.0002	<0.001	0.004	0.0042	0.002	0.012	---
	16-Feb-07	0.008	<0.0002	0.004	0.31	<0.001		0.23	<0.00001	108	129	<0.001	0.0016	0.0030		0.07	<0.0002	0.16	85.1	0.550	<0.00005	0.0033	0.0105	**0.2**[1]	44.5	<0.001	9.1	<0.0001	261	1.59	155	45.2	<0.0002	<0.001	0.003	0.0055	0.002	0.018	---
(Duplicate)	16-Feb-07	0.011	<0.0002	0.004	0.31	<0.001	---	0.23	<0.00001	112	123	**0.016**	0.0008	0.0033	---	0.11	0.0004	0.17	92.3	0.545	<0.00005	0.0043	0.0114	**0.1**[1]	46.4	**0.002**	9.5	<0.0001	275	1.59	152	48.4	<0.0002	<0.001	0.004	0.0068	0.006	0.035	---
SNOW SAMPLES																																							
SS1	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	6	---	---	---	---	---	---	---	---
SS2	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4	---	---	---	---	---	---	---	---
SS3	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2	---	---	---	---	---	---	---	---
SS4	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3	---	---	---	---	---	---	---	---
SS5	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3	---	---	---	---	---	---	---	---
SS6	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4	---	---	---	---	---	---	---	---
D L (Duplicate of BC DS)	14-Jun-06	0.018	<0.001	**0.012**[2]	0.062	<0.001	<0.2	0.09	0.00001	58.7	83	<0.007	<0.005	<0.002	0.4	0.157	<0.001	0.03	19.8	0.635	<0.00005[3]	<0.006	0.015	**0.6**[1]	11.9	<0.001	2.79	<0.0001	137	0.43	45	15.7	<0.0008	<0.04	<0.006	0.001	<0.05	<0.005	<0.005
BC DS (Lab Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
THETA (Duplicate of BC DS2)	18-Oct-06	0.028	0.0005	0.0018	0.06	<0.001	---	0.11	**0.00007**[2]	76.1	32.7	<0.001	0.0004	0.0009	0.21	0.13	<0.0002	0.08	26.1	0.074	---	0.0006	0.0046	**0.2**[1]	7.5	<0.0002	2.7	<0.0001	117	0.57	95.3	26.5	<0.0002	<0.001	0.003	0.001	<0.001	<0.003	---
BETA (TRIP BLANK)	14-Jun-06	<0.005	<0.001	**0.013**[2]	<0.003	<0.001	<0.2	<0.05	<0.00001	<0.05	<1	<0.007	<0.005	<0.002	<0.1	<0.006	<0.001	<0.02	<0.05	<0.001	<0.00005[3]	<0.006	<0.008	<0.1[3]	<0.2	<0.001	<0.05	<0.0001	<0.05	<0.01	<1	<0.2	<0.0008	<0.04	<0.006	<0.001	<0.05	<0.005	<0.005
TRIP BLANK	18-Oct-06	0.004	<0.0002	<0.0002	<0.01	<0.001	---	<0.02	<0.00001	<0.3	<0.5	<0.001	<0.0003	0.0006	<0.05	<0.06	<0.0002	<0.02	<0.2	<0.004	---	<0.0002	<0.0005	<0.1[3]	<0.3	<0.0002	<0.1	<0.0001	<0.5	<0.02	<0.5	<0.2	<0.0002	<0.001	<0.001	<0.0001	<0.001	0.008	---

Notes:

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Yellow highlighted text indicates paramaters above applied guideline/criteria

[1] *values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999.)*

[2] *values exceeding CCME Freshwater Aquatic Life, 2006 (Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates)*

[3] *Method Detection Limits exceed one or more guideline*

- *Aluminum: (CCME guidelines)*
  - *0.005 mg/L pH<6.5; [Ca2+]<4.0 mg/L; DOC<2.0 mg/L.*
  - *0.1 mg/L ph>6.5; [Ca2+]>4.0 mg/L; DOC>2.0 mg/L.*
- *Cadmium: (CCME guidelines)*
  - *0.000017 mg/L, 10 {0.86[log(hardness)]-3.2}.*
- *Chromium:(CCME guidelines)*
  - *Limit is for Trivalent Chromium.*
- *Copper:D (ASWG guidelines)*
  - *See guideline tables for further calculations regarding copper concentrations.*
  - *0.0017 mg/L Hardness(CaCO3) = 10 mg/L.*
  - *0.0081 mg/L Hardness(CaCO3) = 50 mg/L.*
  - *0.016 mg/L Hardness(CaCO3) = 100 mg/L*
  - *Chronic - 0.007 mg/L Hardness(CaCO3) = >50 mg/L. Applies to acid-extractable copper concentrations.*
- *Copper: (CCME guidelines)*
  - *0.0002 mg/L Hardness(CaCO3) = 0-120 mg/L.*
  - *0.003 mg/L Hardness(CaCO3) = 120-180 mg/L.*
  - *0.004 mg/L Hardness(CaCO3) = >180 mg/L*
- *Lead:(CCME guidelines)*
  - *0.001 mg/L Hardness(CaCO3) = 0-60 mg/L*
  - *0.002 mg/L Hardness(CaCO3) = 60-120 mg/L*
  - *0.004 mg/L Hardness(CaCO3) = 120-180 mg/L*
  - *0.007 mg/L Hardness(CaCO3) = >180 mg/L*
- *Mercury: (ASWG guidelines)*
  - *Alberta guidelines for Mercury are draft.*
  - *Chronic - 0.005 ug/L.*
- *Nickel: (CCME guidelines)*
  - *0.025 mg/L Hardness(CaCO3) = 0-60 mg/L*
  - *0.065 mg/L Hardness(CaCO3) = 60-120 mg/L*
  - *0.110 mg/L Hardness(CaCO3) = 120-180 mg/L*
  - *0.150 mg/L Hardness(CaCO3) = >180 mg/L*
- *Phosphorus: (ASWG guidelines)*
  - *Chronic guideline for Phophorus as P (total inorganic and organic).*

Table I–2: Water Quality – Dissolved Metals and Trace Elements (Cont'd)

				TOTAL METALS AND TRACE ELEMENTS																																
Monitoring Station	Date	Monitoring Station	Date	Aluminum:T	Antimony:T	Arsenic:T	Barium:T	Beryllium:T	Boron:T	Cadmium:T	Calcium:T	Chromium:T	Cobalt:T	Copper:T	Iron:T	Lead:T	Lithium:T	Magnesium:T	Manganese:T	Mercury:T	Molybdenum:T	Nickel:T	Phosphorus:T	Potassium:T	Selenium:T	Silicon:T	Silver:T	Sodium:T	Strontium:T	Sulphur:T	Thallium:T	Tin:T	Titanium:T	Uranium:T	Vanadium:T	Zinc:T
	(d-m-y)		(d-m-y)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Alberta Surface Water Guidelines		Alberta Surface Water Guidelines		---	---	---	---	---	---	---	---	---	---	0.007	---	---	---	---	---		---	---	0.05	---	---	---	---	---	---		---	---	---	---	---	---
CCME Freshwater Aquatic Life, 2006		CCME Freshwater Aquatic Life, 2006		0.1	---	0.005	---	---	---	0.000017	---	0.0089	---	0.004	0.3	0.007	---	---	---		0.073	0.15	---	---	0.001	---	0.0001	---	---		0.0008	---	---	---	---	0.03
BC DS	14-Jun-06	BC DS	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
	18-Oct-06		18-Oct-06	0.081	<0.0002	0.0039	0.06	<0.001	<0.02	<0.00001	56.5	<0.001	0.0012	0.0007	**1.63**^{2}	0.0004	0.02	20	0.698		<0.0002	0.005	**0.5**^{1}	12.7	0.0002	2	<0.0001	98.2	0.36		<0.0002	<0.001	0.005	0.0003	<0.001	0.012
	16-Feb-07		16-Feb-07	**0.331**^{2}	0.0007	**0.007**^{2}	0.14	<0.001	<0.02	<0.00001	87.0	0.005	0.0037	0.0016	**7.64**^{2}	0.0005	0.03	30.0	1.56	<0.00005	0.0004	0.0061	**1.3**^{1}	17.9	<0.001	5.0	0.0001	143	0.56	1.1	<0.0002	<0.001	0.011	0.0006	0.004	<0.003
(Duplicate)	16-Feb-07	(Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	<0.00005	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BCDS2	18-Oct-06	BCDS2	18-Oct-06	**0.129**^{2}	<0.0002	0.0039	0.07	<0.001	0.11	0.00001	74.9	<0.001	0.0006	0.0019	**0.41**^{2}	0.0003	0.08	26.5	0.142		0.0004	0.005	**0.2**^{1}	7.8	0.0002	2.9	<0.0001	117	0.54		<0.0002	<0.001	0.005	0.001	<0.001	0.015
	16-Feb-07		16-Feb-07	**0.138**^{2}	0.0009	**0.006**^{2}	0.15	<0.001	0.13	<0.00001	98.6	0.003	0.0006	0.0012	**2.98**^{2}	0.0005	0.08	34.6	1.36	<0.00005	0.0005	0.0038	**1.6**^{1}	12.0	<0.001	6.7	**0.0002**^{2}	137	0.77	7.9	<0.0002	<0.001	0.007	0.0007	0.003	0.020
BC US	14-Jun-06	BC US	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
	18-Oct-06		18-Oct-06	0.084	<0.0002	0.0032	0.02	<0.001	0.21	<0.00001	52.6	<0.001	0.0011	0.0018	0.19	<0.0002	<0.02	16.9	0.145		0.0077	0.0059	**0.7**^{1}	11.7	0.0002	4.5	<0.0001	114	0.4		<0.0002	<0.001	0.006	0.0014	0.002	0.011
	16-Feb-07		16-Feb-07	0.250^{2}	0.0004	0.002	0.23	<0.001	0.07	<0.00001	130	0.004	0.0027	0.0024	**25.9**^{2}	0.0003	0.07	39.7	3.97	<0.00005	0.0003	0.0045	**2.9**^{1}	11.8	<0.001	10.2	<0.0001	210	0.94	18.1	<0.0002	<0.001	0.010	0.0006	0.003	0.006
SW1	14-Jun-06	SW1	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
SW2	14-Jun-06	SW2	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
SW4	14-Jun-06	SW4	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
SW6	14-Jun-06	SW6	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
SW7	14-Jun-06	SW7	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
SW9	18-Oct-06	SW9	18-Oct-06	**2.71**^{2}	0.0007	0.0031	0.17	<0.001	0.12	**0.00004**^{2}	46.3	0.004	0.0019	**0.0049**^{2}	**2.88**^{2}	0.0018	0.07	32.7	0.164		0.0029	0.0084	**0.3**^{1}	22.7	0.0003	8.3	<0.0001	101	0.62		<0.0002	<0.001	0.051	0.0048	0.009	**0.031**^{2}
	16-Feb-07		16-Feb-07	0.064	0.0005	**0.007**^{2}	0.32	<0.001	0.23	<0.00001	116	0.005	0.0018	**0.004**	**0.48**^{2}	0.0005	0.16	91.0	0.568	<0.00005	0.0058	0.0127	**0.4**^{1}	46.4	<0.001	10.0	<0.0001	273	1.59	50.0	<0.0002	<0.001	0.005	0.0089	0.003	0.014
(Duplicate)	16-Feb-07	(Duplicate)	16-Feb-07	0.078	<0.0002	0.008	0.33	<0.001	0.23	<0.00001	109	0.004	0.0018	**0.005**	**0.46**^{2}	0.0009	0.17	95	0.551	<0.00005	0.0059	0.0145	**0.5**^{1}	48.5	0.002	9.8	<0.0001	284	1.63		<0.0002	<0.001	0.006	0.0088	0.003	0.015
SNOW SAMPLES		SNOW SAMPLES																																		
SS1	16-Feb-07	SS1	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.9	---	---	---	---	---	---
SS2	16-Feb-07	SS2	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.8	---	---	---	---	---	---
SS3	16-Feb-07	SS3	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.7	---	---	---	---	---	---
SS4	16-Feb-07	SS4	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.3	---	---	---	---	---	---
SS5	16-Feb-07	SS5	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.1	---	---	---	---	---	---
SS6	16-Feb-07	SS6	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.5	---	---	---	---	---	---
D L (Duplicate of BC DS)	14-Jun-06	D L (Duplicate of BC D	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
BC DS (Lab Duplicate)	16-Feb-07	BC DS (Lab Duplicate)	16-Feb-07	**0.404**^{2}	0.0006	0.008	0.14	<0.001	<0.02	**<0.01**^{2}	86.7	0.005	0.004	0.0018	**7.6**^{2}	0.0007	0.03	29.8	1.56	---	0.0005	0.0072	**1.3**^{1}	17.9	<0.001	5.0	<0.0001	142	0.56	1.1	<0.0002	<0.001	0.012	0.0006	0.004	0.005
THETA (Duplicate of BC DS2)	18-Oct-06	THETA (Duplicate of B	18-Oct-06	0.091	0.0011	0.0038	0.07	<0.001	0.11	<0.00001	74.8	<0.001	0.0013	0.0058^{2}	**0.34**^{2}	0.0008	0.08	26.4	0.189		0.0004	0.0051	**0.2**^{1}	7.6	0.0002	2.8	<0.0001	117	0.54		<0.0002	0.003	0.005	0.0004	<0.001	0.011
BETA (TRIP BLANK)	14-Jun-06	BETA (TRIP BLANK)	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---	---	---	---	---	---	---	---	---		---	---	---	---	---	---
TRIP BLANK	18-Oct-06	TRIP BLANK	18-Oct-06	0.006	0.0004	<0.0002	<0.01	<0.001	<0.02	<0.00001	<0.3	<0.001	<0.0003	0.0012	<0.06	0.0003	<0.02	<0.2	<0.004		<0.0002	<0.0005	<0.1^{3}	<0.3	<0.0002	<0.1	<0.0001	<0.5	<0.02		<0.0002	0.152	0.002	<0.0001	<0.001	0.006

Notes:

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Yellow highlighted text indicates paramaters above applied guideline/criteria

[1] *values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999.)*

[2] *values exceeding CCME Freshwater Aquatic Life, 2006 (Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates)*

[3] *Method Detection Limits exceed one or more guideline*

- *Aluminum: (CCME guidelines)*
  - *0.005 mg/L pH<6.5; [Ca2+]<4.0 mg/L; DOC<2.0 mg/L.*
  - *0.1 mg/L ph>6.5; [Ca2+]>4.0 mg/L; DOC>2.0 mg/L.*
- *Cadmium: (CCME guidelines)*
  - *0.000017 mg/L, 10 {0.86[log(hardness)]-3.2}.*
- *Chromium:(CCME guidelines)*
  - *Limit is for Trivalent Chromium.*
- *Copper:D (ASWG guidelines)*
  - *See guideline tables for further calculations regarding copper concentrations.*
  - *0.0017 mg/L Hardness(CaCO3) = 10 mg/L.*
  - *0.0081 mg/L Hardness(CaCO3) = 50 mg/L.*
  - *0.016 mg/L Hardness(CaCO3) = 100 mg/L*
  - *Chronic - 0.007 mg/L Hardness(CaCO3) = >50 mg/L. Applies to acid-extractable copper concentrations.*
- *Copper: (CCME guidelines)*
  - *0.0002 mg/L Hardness(CaCO3) = 0-120 mg/L.*
  - *0.003 mg/L Hardness(CaCO3) = 120-180 mg/L.*
  - *0.004 mg/L Hardness(CaCO3) = >180 mg/L*
- *Lead:(CCME guidelines)*
  - *0.001 mg/L Hardness(CaCO3) = 0-60 mg/L*
  - *0.002 mg/L Hardness(CaCO3) = 60-120 mg/L*
  - *0.004 mg/L Hardness(CaCO3) = 120-180 mg/L*
  - *0.007 mg/L Hardness(CaCO3) = >180 mg/L*
- *Mercury: (ASWG guidelines)*
  - *Alberta guidelines for Mercury are draft.*
  - *Chronic - 0.005 ug/L.*
- *Nickel: (CCME guidelines)*
  - *0.025 mg/L Hardness(CaCO3) = 0-60 mg/L*
  - *0.065 mg/L Hardness(CaCO3) = 60-120 mg/L*
  - *0.110 mg/L Hardness(CaCO3) = 120-180 mg/L*
  - *0.150 mg/L Hardness(CaCO3) = >180 mg/L*
- *Phosphorus: (ASWG guidelines)*
  - *Chronic guideline for Phophorus as P (total inorganic and organic).*

Table I–3: Water Quality: Hydrocarbons

		BTEX						SELECT HYDROCARBONS					C1-C60
Monitoring Station	Date	Benzene	Toluene	Ethylbenzene	Xylenes-total	Xylene-m&p	Xylene-o	LH (C5-C10)	Total Hydrocarbons C5-C30	TPH (C3-C10)	TEH (C11-C30)	Oils & Greases	Total Extractables C10 to C30
	(d-m-y)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)		(mg/L)	(mg/L)	(mg/L)	(mg/L)
CCME Freshwater Aquatic Life, 2006		**0.37**	**0.002**	**0.09**	---	---	---			---	---	---	
Alberta Surface Water Guidelines		---	---	---	---	---	---			---	---	---	
BC DS	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	<0.2	---	---	<2	<0.2
D L (Duplicate of BC DS)	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	<0.2	---	---	<2	<0.2
	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	2	---
	16-Feb-07	<0.0004	**0.0153**[1]	<0.0004	<0.0008	<0.0004	<0.0012	<0.1	<0.2	<0.2	0.2	<2	0.6
(Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---
BCDS2	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	<2	---
THETA (Duplicate of BC DS2)	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	<4	---
	16-Feb-07	<0.0004	**0.0024**[1]	<0.0004	<0.0008	<0.0004	<0.0012	<0.1	0.6	0.6	0.6	<2	<0.2
BC US	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	<0.2	---	---	<2	0.2
	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	<4	---
	16-Feb-07	<0.0004	0.0010	<0.0004	<0.0008	<0.0004	<0.0012	<0.1	<0.2	<0.2	<0.1	<2	<0.2
BETA	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	<0.2	---	---	4	<0.2
SW1	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	---	---	---	3	---
SW4	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	---	---	---	<2	---
SW6	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	---	---	---	<2	---
SW7	14-Jun-06	<0.0005	<0.0005	<0.0005	<0.001	<0.001	<0.0005	<0.1	---	---	---	<2	---
SW9	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	<2	---
	16-Feb-07	<0.0004	<0.0004	<0.0004	<0.0008	<0.0004	<0.0012	<0.1	<0.2	<0.2	<0.1	<2	<0.2
(Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---
BCDS2 Lab-Dup	16-Feb-07	---	---	---	---	---	---	<0.1	---	---	---	---	---
TRIP BLANK	18-Oct-06	<0.0004	<0.0004	<0.0004	<0.0008	<0.0008	<0.0004	---	---	<0.1	<0.51	<2	---

		C1-C60																			
Monitoring Station	Date	C11 Undecanes	C12 Dodecanes	C13 Triadecanes	C14 Tetradecanes	C15 Pentadecanes	C16 Hexadecanes	C17 Heptadecanes	C18 Octadecanes	C19 Nonadecanes	C20 Eicosanes	C21 Heneicosanes	C22 Docosane	C23 Triacosanes	C24 Tetracosanes	C25 Pentacosanes	C26 Hexacosanes	C27 Heptacosanes	C28 Octacosanes	C29 Nonacosanes	C30 Triacontanes
	(d-m-y)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
CCME Freshwater Aquatic Life, 2006		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Alberta Surface Water Guidelines		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BC DS	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
D L (Duplicate of BC DS)	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BCDS2	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
THETA (Duplicate of BC DS2)	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BC US	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BETA	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SW1	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SW4	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SW6	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SW7	14-Jun-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SW9	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
(Duplicate)	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
BCDS2 Lab-Dup	16-Feb-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
TRIP BLANK	18-Oct-06	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026

Notes:

[1] values exceeding CCME Freshwater Aquatic Life, 2006 (Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates).

[2] values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999.)

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Bolded text indicates parameters above applied guideline/criteria

Notes:

[1] values exceeding CCME Freshwater Aquatic Life, 2006 (Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates).

[2] values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999.)

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Bolded text indicates parameters above applied guideline/criteria

Table I–4: AENV Water Quality Analytical Results: Indicator Parameters

		PHYSICAL			INDICATORS				TOTAL METALS							MAJOR IONS, NUTRIENTS AND CARBONATES									
Monitoring Station: Beaverhill Creek Station Number: AB05EB0900	Date	pH (Lab)	Turbidity	Specific Conductance (Lab)	TDS-calculated	Biological Oxygen Demand (BOD	Chemical Oxygen Demand (COD)	Phenolic Material	Manganese: T	Iron:T	Phosphorus:T	Arsenic:T	Cadmium:T	Chromium:T	Copper:T	Calcium:D	Sodium:D	Potassium:D	Magnesium:D	Chloride:D	Sulphate:D	Total Kjedahl Nitrogen (TKN)	NO2+NO3 as N	Total Alkalinity as $CaCO_3$	Tot Hard as $CaCO_3$
	(d-m-y)	(units)	(NTU)	(µS/cm)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Alberta Surface Water Guidelines		**6.5 - 8.5**	**---**	**---**	**---**	**---**	**---**	**0.005**	**---**	**---**	**0.05**	**---**	**---**	**---**	**0.007**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**
CCME Freshwater Aquatic Life, 2005		**6.5 - 9**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**0.3**	**---**	**5**	**0.000017**	**8.9**	**0.004**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**
75AB000775	26-Nov-75	8.2	8	700	501	2.8	---	0.01[1]	0.036	0.6[2]	0.2[1]	---	<0.001	0.002	0.003	---	46	6.6	26	44	45	---	<0.1	394	347
75AB000776	17-Dec-75	7.9	3	620	452	1.6	---	0.008[1]	0.13	0.5[2]	0.2[1]	---	<0.001	0.002	0.002	---	33	5.1	25	28	40	---	<0.1	365	359
76AB003753	29-Jan-76	7.8	8	780	525	2.4	---	0.011[1]	0.5	0.2	0.065[1]	---	<0.001	<0.001	0.006[2]	---	53	5.9	27	24	37	1	<0.1	422	422
76AB003754	26-Feb-76	8	---	740	468	4.7	---	0.012[1]	0.88	0.3	0.163[1]	---	<0.001	0.005	0.002	---	41	5.4	32	32	40	1.5	0.468	383	350
76AB003755	24-Mar-76	8	---	520	346	6.7	---	0.037[1]	0.78	1.9[2]	1.107[1]	---	0.01[2]	<0.001	0.003	---	64	13.2	13	20	31	3	0.55	261	167
77AB003377	10-Jun-77		---		---	10.8	---	0.02[1]	---	---	0.72[1]	---	---	---	---	---						2.78	0.582	---	---
83AB007002	29-Jun-83	7.5	---	313	170	6.7	121.2	0.02[1]	0.284	7.32[2]	0.3[1]	0.0035	<0.001	0.008	0.016[1,2]	23	26	5.7	7	3	45	3.1	0.15	99	---
83AB007003	14-Jul-83	8	---	410	241	---	75.8	0.015[1]	0.091	2.61[2]	0.33[1]	---	<0.001	0.005	0.007[1,2]	43	29	7.2	11	3	45	0.84	0.17	169	---
83AB007004	04-Aug-83	8.2	---	510	286	---	70.8	0.017[1]	0.104	2.06[2]	0.28[1]	---	0.002	0.005	0.005[2]	48	32	8.2	15	5	42	2	0.25	224	---
83AB007005	24-Aug-83	8.1	---	390	211	1.8	26.7	0.005	0.042	0.21	0.108[1]	0.0012	<0.001	0.003	0.002	46	11	2.8	14	3	37	0.74	0.15	162	---
83AB007006	21-Sep-83	8	---	415	220	1.1	21.9	0.003	0.062	0.32[2]	0.152[1]	0.0008	<0.001	0.003	<0.001	46	13	2	14	6	40	1.4	0.38	162	---
83AB007007	16-Nov-83	8.2	---	806	473	2.1	38.3	0.012[1]	0.205	0.88[2]	0.082[1]	0.0017	<0.001	0.003	0.019[1,2]	92	49	6.2	26	12	98	1.02	<0.05	317	---
89AB005038	06-Mar-89	8.06	62	1320	---	3.16	---	0.012[1]		8.1[2]	0.765[1]	---	---	0.001	---	142	97	12	36	78	117	6.4	0.009	520	503.18
90AB003425	10-Jul-90	8.04	77	414	242	---	---	0.021[1]	0.108	---	0.44[1]	0.0035	0.001[2]	0.007	0.007[1,2]	33	39	6.4	12	7.7	50	2.55	0.31	153	132

NOTES:

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Highlighting indicates paramaters above applied guideline/criteria

[1] values exceeding Alberta Surface Water Guidelines (Alberta Environment Surface Water Quality Guidelines, Nov. 1999.

[2] values exceeding CCME Freshwater Aquatic Life, 2006(Canadian Environmental Quality Guidelines for Freshwater Aquatic Life (CCME, 1999 and updates).

pH
Not to be altered by more than 0.5 pH units from background values.
Cadmium: (CCME guidelines)
0.000017 mg/L, 10 {0.86[log(hardness)]-3.2}.
Copper:D (ASWG guidelines)
See guideline tables for further calculations regarding copper concentrations.
0.0017 mg/L Hardness(CaCO3) = 10 mg/L.
0.0081 mg/L Hardness(CaCO3) = 50 mg/L.
0.016 mg/L Hardness(CaCO3) = 100 mg/L
Chronic - 0.007 mg/L Hardness(CaCO3) = >50 mg/L. Applies to acid-extractable copper concentrations.
Copper: (CCME guidelines)
0.0002 mg/L Hardness(CaCO3) = 0-120 mg/L.
0.003 mg/L Hardness(CaCO3) = 120-180 mg/L.
0.004 mg/L Hardness(CaCO3) = >180 mg/L

Table I–5: Soil Analytical Results

		Metals																																	
Sampling Location	Date	Aluminum:T	Antimony:T	Arsenic:T	Barium:T	Beryllium:T	Bismuth:T	Boron:T	Cadmium:T	Calcium:T	Chromium:T	Cobalt:T	Copper:T	Iron:T	Lead:T	Lithium:T	Magnesium:T	Manganese:T	Mercury:T	Molybdenum:T	Nickel:T	Phosphorus:T	Potassium:T	Selenium:T	Silver:T	Sodium:T	Strontium:T	Thallium:T	Tin:T	Titanium:T	Uranium:T	Vanadium:T	Zinc:T	Zirconium:T	Hex Chromium
	(d-m-y)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
CCME Freshwater Sediment (ISQG, 1999)		**---**	**---**	**5.9**	**---**	**---**	**---**	**---**	**0.6**	**---**	**37.3**	**---**	**35.7**	**---**	**35**	**---**	**---**	**---**	**0.17**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**123**	**---**	**---**
CCME Freshwater Sediment (PEL, 1999)		**---**	**---**	**17**	**---**	**---**	**---**	**---**	**3.5**	**---**	**90**	**---**	**197**	**---**	**91.3**	**---**	**---**	**---**	**0.486**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**---**	**315**	**---**	**---**
BC DS SED	14-Jun-06	8,460	<2	3	137	0.5	<10	2.7	<0.2	9,040	13	7.1	16	14,400	<10	10.8	5,270	226	<0.05	<0.5	22	758	1,280	<0.5	<1	312	41.9	<1	<2	67.4	1	23	58	2	<0.3
BC DS2 SED	18-Oct-06	---	<1	5	128	<0.4	---	1.9	0.4	---	12	7	14	---	7	---	---	---	<0.05	<0.4	17	---	---	<0.5	<1	---	---	<0.3	<1	---	---	19	43	---	<0.2
BC US SED	14-Jun-06	8,060	<2	3	130	0.4	<10	3.1	<0.2	6,170	13	6.8	15	12,300	<10	8.8	3,130	238	<0.05	0.7	19	901	1,160	<0.5	<1	485	48.9	<1	<2	72.8	1.1	21	66	2	<0.3
SED1	14-Jun-06	11,800	<2	3	146	0.7	<10	2.1	0.3	10,300	18	4.7	22	17,100	12	15.1	6,020	250	0.07	0.7	21	1,030	2,650	<0.5	<1	503	59.9	<1	<2	76	2.4	29	300[1]	3	<0.3
SED3	14-Jun-06	8,300	<2	3	193	0.5	<10	2.9	1[1]	15,500	12	6.6	20	15,200	<10	9.9	3,790	343	0.07	0.9	22	1,390	2,060	<0.5	<1	314	101	<1	<2	66.2	7.8	23	201[1]	3	<0.3
SED4	14-Jun-06	6,350	<2	10[1]	148	0.3	<10	1.4	<0.2	9,340	19	6.8	202[1,2]	49,700	20	8.9	2,830	402	<0.05	24.3	45	961	976	<0.5	<1	463	39.4	<1	8	55.8	1.2	20	<2	2	<0.3
SED5	14-Jun-06	12,800	<2	4	221	0.7	<10	3	0.5	7,960	17	8.8	21	17,000	<10	14.4	3,510	294	0.05	1.7	26	1,330	2,280	0.6	<1	1,000	51.4	<1	<2	78.9	4.8	30	88	3	<0.3
SED6	14-Jun-06	11,100	<2	4	171	0.6	<10	1.5	0.4	6,640	12	17.9	14	13,700	<10	11	2,940	477	<0.05	<0.5	23	575	1,280	<0.5	<1	108	58.6	<1	<2	52.1	1.6	24	51	4	<0.3
SED7	14-Jun-06	9,040	<2	3	103	0.4	<10	0.4	<0.2	2,770	10	3.4	8	9,020	<10	9.2	2,040	85.5	<0.05	<0.5	11	247	1,070	<0.5	<1	145	28.3	<1	<2	64.3	0.6	18	40	3	<0.3
SED8	18-Oct-06	---	<1	4	150	<0.4	---	2.9	0.4	---	12	7	13	---	8	---	---	---	<0.05	<0.4	18	---	---	<0.5	<1	---	---	<0.3	<1	---	---	19	64	---	<0.2
BETA	14-Jun-06	7,330	<2	2	26.3	0.1	<10	0.2	<0.2	2,670	11	3.6	12	12,000	<10	6.1	4,650	198	<0.05	<0.5	14	384	394	<0.5	<1	193	13.9	<1	<2	273	<0.2	26	26	1	<0.3
D L (Duplicate of BC DS SED)	14-Jun-06	7,870	<2	3	158	0.5	<10	3.1	<0.2	8,130	12	7.7	17	15,700	<10	9.3	3,590	335	<0.05	0.5	19	1,430	1,260	<0.5	<1	589	59.9	<1	<2	62.9	1.1	22	67	2	<0.3

NOTES:

[1] values exceeding CCME Freshwater Sediment ISQG (Canadian Environmental Quality Guidelines for Freshwater Sediment (ISQGs), (CCME, 1999).)

[2] values exceeding CCME Freshwater Sediment PEL(Canadian Environmental Quality Guidelines for Freshwater Sediment (PEL), (CCME, 1999).)

--- in guideline row(s) denotes no criteria for that parameter.

--- in detail data row(s) denotes parameter not analyzed.

Highlighting indicates paramaters above applied guideline/criteria

In original sediment analytical results (Appendix X), sample annotations SW1 to SW8 relate to SED1 to SED8 and sample annotations BC DS, BC DS2 and BC US relate to BC DS SED, BC DS2 SED and BC US SED.

Table I–6: Soil Analytical Results: Hydrocarbons

		Hydrocarbons						
Sampling Location	**Date**	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylenes-total**	**Xylene-m&p**	**Xylene-o**	**TPH (C_3-C_{10})**
	(d-m-y)	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
CCME Freshwater Sediment (1999)		---	---	---	---	---	---	---
CCME Freshwater Sediment (PEL), 99		---	---	---	---	---	---	---
BC DS SED	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
BC DS2 SED	18-Oct-06	<0.010	<0.040	<0.020	<0.090	<0.080	<0.040	<1.0
BC US SED	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED1	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED3	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED4	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED5	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED6	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED7	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
SED8	18-Oct-06	<0.0083	<0.033	<0.017	<0.074	<0.066	<0.033	<0.83
BETA	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---
D L	14-Jun-06	<0.04	<0.1	<0.1	<0.1	<0.1	<0.1	---

Notes:
[1] values exceeding Alberta Surface Water Guidelines(Alberta Environment Surface Water Quality Guidelines, Nov. 1999.)
[2] values exceeding CCME Freshwater Aquatic Life, 2005(Canadian Environmental Quality Guidelines for the Protection of Aquatic Life (CCME, 2005).)
--- in guideline row(s) denotes no criteria for that parameter.
--- in detail data row(s) denotes parameter not analyzed.
Highlighting indicates parameters above applied guideline/criteria
In original sediment analytical results (Appendix X), sample annotations SW1 to SW8 relate to SED1 to SED8
and sample annotations BC DS, BC DS2 and BC US relate to BC DS SED, BC DS2 SED and BC US SED.

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Appendix II: Critical Load of Acidity Calculations

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Table II-1: Critical Load of Acidity Calculations Critical Load Calculations Using ANClim=100

Waterbody	Catchment Size (km^2)	Wetland area (km^2)	Annual Water Yield (mm/yr)	Annual Precipitation Minus Evaporation (mm/yr)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	K^+ (mg/L)	Na^+ (mg/L)	Ca^{+2} (µeq/L)	Mg^{+2} (µeq/L)	K^+ (µeq/L)	Na^+ (µeq/L)	Sum of Base Cations (µeq/L)	Annual Water Yield (m^3/s)	Lake Evap. (m^3/s)	Net Annual Yield (m^3/sec)	Critical Load (keq/ha/yr)
Wetland (Sample SW1)	1.87	0.0625	42.9	75	62.9	24.8	39.2	103	3,139	2,040	1,002	4,481	10,662	0.002459415	0.000149	0.002311	4.116
Wetland (Sample SW2)	1.87	0.0625	42.9	75	50.4	30.4	22.9	82.00	2,515	2,501	586	3,567	9,168	0.002459415	0.000149	0.002311	3.534

Table II-2: Background Data

Annual Water Inputs to Wetland (m^3/yr)	Wetland Catchment Size (km^2)	Annual Catchment Water Yield (mm/yr)	Evaporation (mm/yr)	Precipitation (mm/yr)
80,242	1.87	42.91	384.5	459.5

Table II-3: Sensitivity Analysis

ANClim (µeq/L)	CL SWI (keq/ha/yr)	CL SW2 (keq/ha/yr)
ANClim: 20	4.147	3.565
ANClim: 50	4.135	3.553
ANClim: 75	4.126	3.544

1. Background to Critical Load of Acidity Calculations

Model used is from Henricksen and Posch 2001:

$$\mathbf{CL = (BC_0^* - ANClim) * Q}$$

where

CL = critical load (keq/ha/yr)

BC_0^* = pre-industrial non-marine base cation (BC) concentration (keq/L) assumed to correspond to the current values in Alberta lakes, because they are considered unaffected by acidification at the present

ANClim = critical limit for acid neutralizing capacity (µeq/L) beyond which the probability of damage to fish populations reduces.

Q = mean annual runoff to the wetland (mm/year).

1.1 Background

ANClim of 100 µeq/L was chosen as a conservative measure based on the high pH, higher CL and the potentially less sensitive ecosystem in the local area and hence potentially higher biological diversity. Setting a higher ANClim should keep that higher diversity intact where present (Henricksen and Posch 2001). As a comparison, ANClim of 75 µeq/L is commonly used in north eastern Alberta lakes which are considered much more sensitive to acid deposition, with surface water pHs commonly in the order of 6 (CEMA 2004).

Sensitivity analysis for this study show that using a much lower value of ANClim = 20 µeq/L changes the critical load value by less than 1% and shows that the ANClim choice has a small influence on the overall critical load value.

While Henriksen and Posch (2001) converted the present-day base cation flux (i.e., the [BC_0^*] term in the critical load equation) to a pre-acidification flux for European lakes and Ontario lakes, the procedure applied here assumed that the current conditions are representative of the preindustrial conditions. Anthropogenic lake acidification has not been observed in Alberta (CEMA 2004), as demonstrated by data collected by the Acid Sensitive Lakes component of the oil sands Regional Aquatic Monitoring Program (RAMP 2004). Therefore, use of recent lake water quality data was considered appropriate for calculating critical loads for this study, without adjusting the base cation term.

2. References

CEMA (Cumulative Environmental Management Association). 2004. Recommendations for the Acid Deposition Management Framework for the Oil Sands Region of North-Eastern Alberta. Final Approval – February 25, 2004.

Henriksen and Posch. 2001. Steady-State Models for Calculating Critical Loads of Acidity for Surface Waters. Water, Air and Soil Pollution: Focus 1: 375-398.

RAMP (RAMP 2003 Implementation Team). 2004. Regional Aquatics Monitoring Program (RAMP) 2003 Annual Report. Prepared for: RAMP Steering Committee. Submitted by the RAMP 2003 Implementation Team consisting of: Hatfield Consultants Ltd., Jacques Whitford Environment Ltd., Mack, Slack & Associates Inc., and Western Resource Solution. March 2004.

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Appendix III: Photos

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Photo III–2: **Surface Water Monitoring Location SW2 (Wetland) Looking Southeast (June 14, 2006)**

Photo III–3: **Sediment Sampling Location SED3 Looking South (June 14, 2006). Conveyance under Township Road 560 is via a 1,219 mm Corrugated Steel Culvert. No Free Water, only Sediment was Sampled at this Location**

Photo III–4: **Surface water monitoring location SW4 looking south (June 14, 2006). Conveyance under the CPR Railway is via a 304 mm Corrugated Steel Culvert (shown) and a 610 mm Corrugated Steel Culvert (immediate left of photo)**

Photo III–5: Sediment Sampling Location SED5 (June 14, 2006). This Area is a Groundwater Seep that did not have any Free Water, although the Soils were Damp Relative to the Ambient Conditions nearby. Only Sediment was Sampled at this Location

Photo III–6: **Surface Water Quality Monitoring Location SW6 looking North (June 14, 2006). Conveyance under the CN Railway is via a 762 mm Steel Pipe**

Photo III–7: **Surface Water Quality Monitoring Location SW7 looking North (June 14, 2006). Conveyance under the CN Railway is via a 914 mm Corrugated Steel Culvert**

Photo III–8: Sediment Sampling Location SED8 (October 18, 2006). No Free Water, only Sediment was Sampled at this Location. Conveyance under Highway 45 is via two 760 mm Concrete Pipes mitred to Bank

Photo III–9: **Surface Water Monitoring Location SW9 (Dugout) looking East (October 18, 2006)**

Photo III–10: Surface Water Monitoring Location BC-DS looking East (June 14, 2006)

Photo III–11: Surface Water Monitoring Location BC-DS2 looking West (October 18, 2006)

Photo III–12: **Surface Water Monitoring Location BC-US looking East (June 14, 2006)**

WorleyParsons Komex
resources & energy

Alberta Sulphur Terminals Ltd.
Bruderheim Sulphur Forming and Shipping Facility

Volume IIB – Water and Aquatic Ecology

5. Aquatic Resources

Project Number 62720000
June 2007

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Executive Summary

Alberta Sulphur Terminals Ltd. (AST), a division of HAZCO Environmental Services (HAZCO) which, in turn, is a division of CCS Income Trust (CCS), retained WorleyParsons Komex to complete an aquatic resources assessment for the proposed Bruderheim Sulphur Forming and Shipping Facility (the Project) located on a portion of Section 35-55-20 W4M (the Site). The objectives of the aquatic resources assessment were as follows:

- inventory baseline aquatic resource conditions within the study area
- identify and assess potential impacts to aquatic resources that may result from the proposed Project
- recommend mitigation strategies to minimize impacts to aquatic resources
- recommend monitoring initiatives for the Project relating to aquatic resources

The aquatic resources assessment confirmed the proposed Project is not likely to result in adverse impacts to aquatic resources when mitigation strategies are applied. The aspects of the Terms of Reference (AENV 2007) that are relevant to the aquatic resources assessment, and the respective conclusions of the assessment, are summarized as follows.

Identify components of the Project that will affect baseline conditions from a local and regional perspective. Discuss:

a) *baseline aquatic resource conditions, including fish and benthic invertebrate habitat capability and their characteristics in water bodies within the Study Area. Conduct the necessary surveys to characterize the aquatic resources in the PDA and any potential changes that could occur in this component of the aquatic ecosystem in the Study Area(s) as a result of the Project;*

   Two aquatic resource features were identified within the Aquatic Resources Local Study Area (LSA) – Wetland 01 and Wetland 02. Within the Aquatic Resources Regional Study Area (RSA), one additional aquatic resource feature was identified – Lamont Creek. Wetland 01 and Lamont Creek were found to contain two species of fish, fathead minnow and brook stickleback. These aquatic environments were characterized as shallow with poor water quality and severe oxygen depletion. Lamont Creek was also found to have multiple beaver dams which are potential fish migration barriers. Wetland 02 was observed to be completely dry in the fall and had no connectivity with any other waterbody at other times of the year; therefore, it would not be considered fish habitat. Wetland 01 and Lamont Creek are considered low value fish habitat. All three aquatic resource features provide a filtering function for surface water runoff as well as habitat for birds, mammals, amphibians and invertebrates.

b) *components of the Project that will potentially affect aquatic resources within the Study Area, potential impacts of these components and their significance;*

   The impact assessment identified potential sources of impact that could occur at each of the three phases of the Project: siting the facility, construction and operation. The aquatic resource indicators used in the assessment include water quality and water quantity. Siting and construction could result in potential surface disturbance impacts. Surface disturbance has a Class 4 rating at application and a Class 4 rating at closure. Operation of the facility could result in impacts from dust deposition, air emissions, stormwater discharge, groundwater drawdown and contaminant spills. Operational impacts all have a Class 3 rating at application and a Class 4 rating at closure.

c) *cumulative effects of the impacts that already exist and potential project-related impacts on the aquatic resources in relevant water bodies;*

Industrial disturbances to the landscape that have occurred within the RSA include Canexus sodium chlorate plant, Triton fabrication facility and AltaLink electrical substation. Other anthropogenic disturbances within the RSA include agriculture, road construction and rural residential development.

Cumulative effects were only assessed when an impact (Section 5.5) was classified as Class 1, 2 or 3. Impacts of such classes were identified for dust deposition, air emissions, stormwater discharge, groundwater drawdown and contaminant spills. The impacts of stormwater discharge, groundwater drawdown and contaminant spills are not addressed on a regional scale because these impacts are unlikely to extend beyond the Site. Surface disturbance was classified as a Class 4 impact and is not of regional significance. Surface disturbances from road construction (drainage impedance) and construction of the dugout within Wetland 01 (pool creation) likely resulted in the creation of a new waterbody that retains sufficient water year round to support fish.

d) mitigation plans to minimize these effects;

Mitigation plans to minimize potential Project impacts include:

1. Surface disturbance
    a) appropriate siting of the facility to avoid loss of aquatic habitats
    b) implementation of appropriate sediment control techniques during construction is recommended
2. Dust deposition
    a) protect sulphur storage piles from wind erosion with a wind screen
    b) application of a dust suppression agent and release aid
3. Air emissions
    a) no mitigation measures are planned due to the low levels predicted
4. Wastewater and stormwater discharge
    a) Wastewater
        i) domestic wastewater will be stored and routinely transported off site
    b) Stormwater
        i) surface water will be collected, stored and recycled on site
        ii) the storage pond will be double lined and equipped with leak detection monitoring
        iii) areas surrounding sulphur handling will be sloped away from the facility to prevent surface water run-on
        iv) storage areas will be lined with asphalt and underlain by compacted clay soil to minimize surface water seepage into the ground
        v) neutralization of water discharged from the storage pond will be achieved by adding free lime as needed
5. Groundwater drawdown
    a) minimize groundwater diversion requirements through the collection, storage and recycling of surface water that falls on the storage areas

6. Contaminant spills
   a) liquid products will be stored in steel tanks that include double-containment with leak detection
   b) the storage pad will consist of asphalt over a clay soil liner with surface water runoff and run-on controls and leak detection

e) an assessment of the relative contribution of the Project (after mitigation) to regional cumulative effects on aquatic resources (e.g., Project contributions to lake acidification);

A potential cumulative effect on aquatic resources was identified relating to dust deposition and air emissions interacting with sodium chlorate. Sulphur emissions have the potential to acidify surface waters in the vicinity of the Canexus sodium chlorate plant. Sodium chlorate forms chlorine dioxide, a disinfectant, in acid aqueous reaction. Chlorine dioxide is a gas that absorbs readily into water but is unstable and typically converts to chlorite. Chlorine dioxide has been found to be moderately toxic to fish (0.21 mg/l) but chlorite has been found to be only slightly toxic to fish (3.3 mg/l). This impact is predicted to be unlikely to occur given the buffering capacity of the soils and because both operating facilities are unlikely to release these substances into the environment.

f) the potential for contamination of fish by wastewater discharges relative to fish consumption guidelines; and

Wetland 01 and Lamont Creek were found to contain two species of fish, fathead minnow and brook stickleback. These fish are considered forage fish and would not be consumed by people due to their small size.

g) programs to monitor aquatic habitat quality and the effectiveness of mitigation strategies.

Planned monitoring activities with respect to surface water and groundwater include:

1. monitoring water that is potentially discharged from the Site immediately prior to discharge for:
   - visible sheen
   - 6<pH<9
   - chemical oxygen demand<50 mg/L
   - chloride<500 mg/l
   - total suspended solids<50 mg/L
2. Monitoring groundwater twice annually for water table level, temperature, pH, electrical conductivity and potability

   In addition to the planned monitoring activities, it is recommended that:
   - surface water in Wetland 01 be monitored for turbidity during construction
   - surface water in Wetland 01 be sampled twice annually for temperature, pH and dissolved oxygen during operations

5. Aquatic Resources

5.1 Introduction

This section presents the results of baseline studies and the impact assessment for aquatic resources as part of the Environmental Impact Assessment (EIA) for the proposed Bruderheim Sulphur Forming and Shipping Facility Project (the Project). The objectives were to satisfy the Terms of Reference (TOR) for the Project (AENV 2007) as follows:

Identify components of the Project that will affect baseline conditions from a local and regional perspective. Discuss:

a) baseline aquatic resource conditions, including fish and benthic invertebrate habitat capability and their characteristics in water bodies within the Study Area. Conduct the necessary surveys to characterize the aquatic resources in the PDA and any potential changes that could occur in this component of the aquatic ecosystem in the Study Area(s) as a result of the Project;

b) components of the Project that will potentially affect aquatic resources within the Study Area, potential impacts of these components and their significance;

c) cumulative effects of the impacts that already exist and potential Project-related impacts on the aquatic resources in relevant water bodies;

d) mitigation plans to minimize these effects;

e) an assessment of the relative contribution of the Project (after mitigation) to regional cumulative effects on aquatic resources (e.g., Project contributions to lake acidification);

f) the potential for contamination of fish by wastewater discharges relative to fish consumption guidelines; and

g) programs to monitor aquatic habitat quality and the effectiveness of mitigation strategies.

5.2 Regulatory Framework

The provincial *Water Act* supports and promotes conservation and management of water in Alberta and governs activities that cause, may cause, or may become capable of causing effects on the aquatic environment. Review of activities may also be required under the provincial *Environmental Protection and Enhancement Act* (EPEA) which supports and promotes protection, enhancement and wise use of the environment. The EPEA specifically addresses the manufacturing or processing of sulphur products.

The Federal Government, through the Department of Fisheries and Oceans Canada (DFO), has jurisdiction over aquatic habitat that may be affected temporarily or permanently by construction and operation of a facility through the *Fisheries Act*. The Act prohibits the destruction of fish, harmful alteration, disruption or destruction of fish habitat (HADD) and deposition of deleterious substances into water frequented by fish, or into places that may result in the deposition of deleterious substances into other water frequented by fish (Sections 32, 35 and 36 of the Act, respectively). DFO determines whether the *Fisheries Act* has been, or could be, contravened. It is the proponent’s responsibility to provide sufficient data and information with respect to aquatic habitat so that DFO can issue a Letter of Advice stating whether violation of the Act is likely given the works proposed. If violation of the Act is likely, the proponent must obtain Ministerial approval before proceeding with the work and remain in compliance with the Act. Part of this approval process requires that any HADD be mitigated through enhancement or improvement of that already existing, to satisfy the No Net Loss guiding principle (DFO 1998).

5.3 Spatial and Temporal Boundaries

5.3.1 Principal Development Area

The proposed Project will be developed in the Principle Development Area (PDA), a portion of Section 35-55-20 W4M (the Site), which comprises the area of disturbance and development. The PDA is equal to the Project footprint, which includes the direct footprint of the proposed facility and associated infrastructure, and is 24.8 ha. All infrastructure and activities will be confined to the Site. The PDA, shown in Figure 5.3–1, contains the liquid sulphur unloading and transfer facility and the pastille forming and shipping facility, located in the west-central portion of the Site and a rail transfer loop used to receive and ship sulphur.

5.3.2 Local Study Area

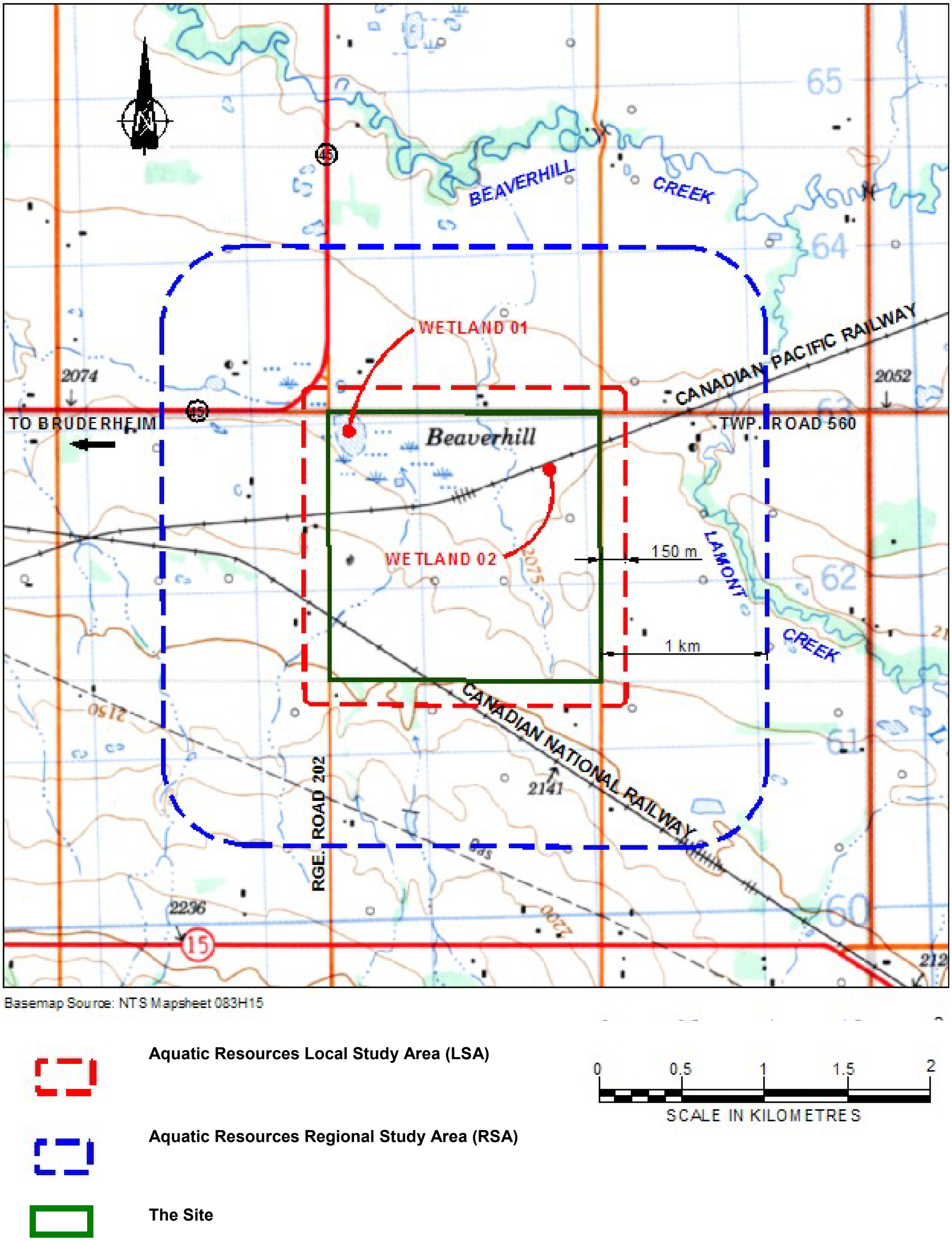
As regional and local hydrology is dominated by ephemeral streams and there are no significant discharges from the Site, the area that will be potentially most affected by the Project is within the Site. The Aquatic Resources Local Study Area (LSA) includes the Site plus a buffer 200 m beyond the perimeter of the Site (see Figure 5.3-1). The 200 m buffer was included to contain the predicted emissions from the Project within the LSA (see Volume IIA, Section 2: Climate and Air Quality).

The LSA is located in the Central Parkland Natural Subregion of Alberta. This subregion consists of rolling to hummocky terrain that is mostly cultivated with a mosaic of aspen and prairie vegetation on remnant native parkland areas. It lies between the cold, snowy northern forests and the warm, dry southern prairies, sharing the climatic and vegetation characteristics of both. In southern and eastern parts of the subregion, plains rough fescue prairie is the dominant vegetation, with clumps of aspen present but restricted to moist sites. In northern and western parts, aspen forest is dominant and grasslands are restricted to drier areas (NRC 2006).

The LSA lies in the Beaverhill sub-watershed of the North Saskatchewan watershed (NSWA 2005). The main named drainages within the Beaverhill sub-watershed in the vicinity of the Project include Beaverhill Creek and its tributary Lamont Creek. The LSA is located in the Lamont County Industrial Heartland, which forms the eastern portion of the Alberta Industrial Heartland.

5.3.3 Regional Study Area

The Aquatic Resources Regional Study Area (RSA) was established to assess regional effects beyond the local drainages contained within the Project. The RSA is defined as the Site plus a 1,000 m buffer zone (Figure 5.3-1). The RSA was delineated based on the preliminary air modelling conducted in 2005 (see Volume IIA, Section 2: Climate and Air Quality) for the Project. The RSA was used to evaluate the Project effects on potential acid deposition and includes the lands that fall within the predicted sulphur dioxide emissions isopleths estimated in the 2005 air modelling (see Volume IIA, Section 2: Climate and Air Quality).



Basemap Source: NTS Mapsheet 083H15

Figure 5.3-1: Spatial Boundaries of the LSA and RSA

5.3.4 Temporal Boundaries

Three scenarios are used in the assessment: baseline, application and closure. Baseline refers to conditions in the LSA and RSA as of October 2006. Application is assessed at maximum disturbance or 6,000 t/d production capacity. This approach determines the Project's impact as if all facilities were fully developed and operational at the same time. Impact predictions during the application case are considered worst case and conservative. Closure is considered when all project facilities have been decommissioned and reclamation has taken place. It is assumed that closure occurs five years after decommissioning and reclamation once soils have been stabilized by vegetation growth.

5.3.4.1 Project Inclusion List

The project inclusion list includes the various anthropogenic disturbances on the landscape that must be included in each assessment case in order to effectively determine Project and cumulative effects. Table 5.3-1 provides the list of projects included in each case.

Table 5.3-1: Project Inclusion List

Status	Baseline Case	Application Case	Cumulative Effects Case
Existing and Approved	Canexus Chemicals	Canexus Chemicals	Canexus Chemicals
	ERCO Worldwide	n/a	n/a
	Triton	Triton	Triton
Project		Bruderheim Sulphur Forming and Shipping Facility	Bruderheim Sulphur Forming and Shipping Facility
Planned Projects and Activities		n/a	n/a

Note:
n/a – not applicable.

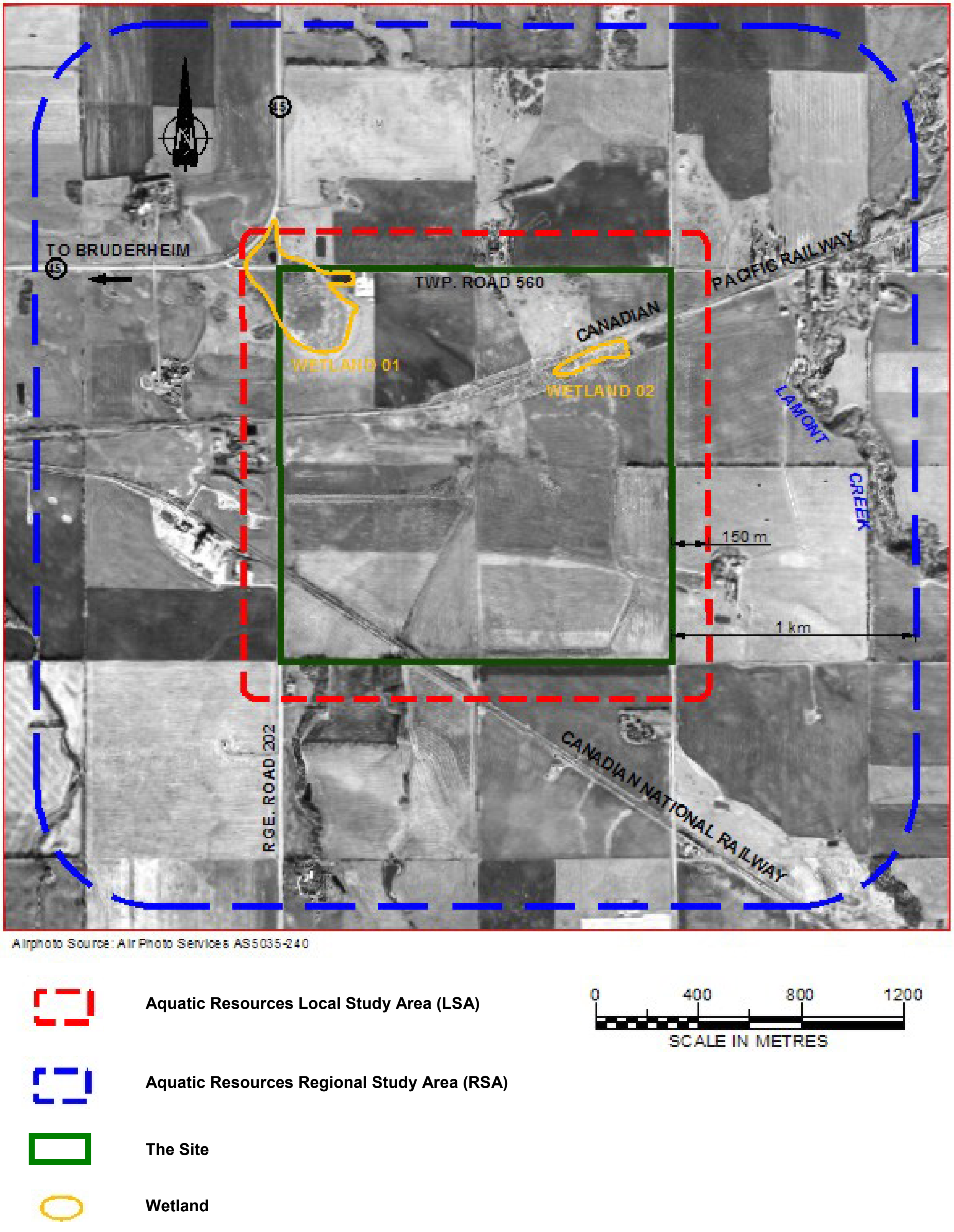
5.4 Aquatic Resources at Baseline

5.4.1 Approach

An air photo of the property and surrounding area was used to identify potential aquatic habitats including drainages, ponds and wetlands (see Figure 5.4-1). A reconnaissance survey of the property and surrounding area was conducted on June 13, 2006 to groundtruth the air photo and verify drainages and their connectivity to other aquatic habitats.

5.4.1.1 Habitat Inventory

On June 14 and 15, 2006, the aquatic habitat and its suitability for fish in Lamont Creek and Wetland 01 (see Figure 5.4-1) were investigated (AAR 2006a). Lamont Creek was sampled at six transects located north from Twp Rd 560 (downstream); restricted access on private property precluded sampling on the south side of Twp Rd 560. Physical parameters including channel bankfull and wetted widths, bank height and water depth were quantified across sampling transects. Channel width was measured to the nearest 0.1 m, and bank height and water depth were measured to the nearest 0.01 m.



Airphoto Source: Air Photo Services AS5035-240

Figure 5.4-1: Aquatic Resource Features of Wetland 01, Wetland 02 and Lamont Creek

Water temperature, pH, conductivity and dissolved oxygen concentrations (DO) were measured using a MultiLine P4™ multimeter. Bank stability and shape, dominant and sub-dominant substrate, and embeddedness were described qualitatively. All parameters relevant to aquatic habitat in the dugout (which does not have typical channel morphology) were evaluated. Watercourse and riparian vegetation characteristics that affect fish habitat potential were described. These included substrate composition, instream and overhead cover, riparian vegetation composition and canopy closure. Fish habitat was rated as high, moderate, or low according to its potential to support spawning, rearing, wintering and migrating fish species.

Fish habitat was investigated again at Wetland 01 and Wetland 02 at the end of the dry summer season (October 18, 2006) to determine the nature of the aquatic habitats when water levels were near their lowest. Water temperature, pH and DO were measured.

5.4.1.2 Fish Population Inventory

Fish were sampled from Lamont Creek (6 traps) and Wetland 01 (6 traps in the dugout) on June 14 and 15, 2006 using baited ‘Gee’ type minnow traps (AAR 2006a). Fish collected in the traps were identified to species, measured to the nearest mm, and sex and life-history stage was determined (if discernible externally). All fish were returned unharmed to the Creek or dugout from where they were captured. Catch per unit effort (CPUE) was quantified as fish captured per trap-hour.

A backpack electrofisher (Smith-Root, Type LR-24, pulsed DC) was also used to sample for fish in Lamont Creek on June 14, 2006. A total effort of 800 seconds was expended, after which it was clear that no fish would be caught using this method.

Fish were sampled again in the dugout part of Wetland 01 (3 traps) on October 18, 2006 using baited Gee type minnow traps.

5.4.1.3 Benthic Invertebrate Inventory

In June 2006, benthic invertebrate samples were collected from transects on Lamont Creek and sample points in the dugout part of Wetland 01 using a modified kick net sampling method (AAR 2006a). At each transect, three samples were collected by agitating sediment for 15 seconds and immediately sweeping the net through the sediment cloud. Modification of kick net sample technique was necessary because the low flow in Lamont Creek and lack of flow in the dugout were not sufficient to push invertebrates into the net. Each sample was washed through a 30-mesh sieve, placed into a sealable jar, and preserved with 2-propanol for subsequent laboratory analysis.

Large benthic invertebrates were extracted by hand from the Lamont Creek samples due to its potential connectivity with downstream watercourses. Subsamples of sediment were then viewed under a stereo dissecting microscope for any remaining miniscule invertebrates. Invertebrates were identified to family and a tally was kept for each sample. Samples from the dugout were not examined in detail given its seasonally limited connectivity with any other natural watercourse.

5.4.2 Description of Local Aquatic Resources

5.4.2.1 __Wetland 01__

5.4.2.1.1 Channel Characteristics

Wetland 01 consisted of a marsh and dugout (see Figure 5.4-1). The dugout was a small man-made basin assumed to hold water for cattle on the property, evident from extensive pugging on its banks. The dugout was a 75 m by 35 m rectangle with a depth of approximately 1 m in June 2006 (see Appendix I, Photo I–1) and 0.5 m in October 2006 (see Appendix I, Photo I–2). The adjacent marsh covers an area of approximately 122,000 m^2 (see Appendix I, Photo I–3), including small areas at all four corners of the intersection of Twp Rd 560 and R.R. 202. Approximately two thirds of the marsh is located on the Site. Water depth in the marsh was estimated to be an average of 0.3 m in June and no standing water was present in October (see Appendix I, Photo I–4).

Drainage from Wetland 01 was observed in June after a period of heavy rain (see Appendix I, Photo I–3 and Photo I–5). The marsh drains through a series of culverts in a northwest direction, eventually draining under Highway 45 and continuing through private lands in a northwest direction until reaching Beaverhill Creek. The drainage appears to be ephemeral in nature, only holding water during the wettest season.

The nature of the dugout gives it strictly pool habitat, and it contains only fine substrate. In June 2006, the water temperature was warm (17.1°C), pH slightly basic (7.8), conductivity high (783 µS/cm) and DO concentrations were low (2.9 mg/L, 34% saturation). In October 2006, the water temperature was 2.7°C, pH was 8.1 and DO was 6.9 mg/L. Although many channel morphology parameters typically examined do not apply to a waterbody of this type, a catalogue is included in Appendix II.

5.4.2.1.2 Fish Presence and Habitat Potential

Minnow trapping in June resulted in capture of large numbers of brook stickleback (n=47) and fathead minnow (n=1311; total CPUE=14.6 fish/trap-hour; see Appendix I, Photo I–6). Brook stickleback captured ranged in length from 45–64 mm, and fathead minnow from 45–79 mm. A clear pattern of multiple age classes was not evident for both species (see Figure 5.4-2 and Figure 5.4-3). Wintering is possible in the dugout for these fish, given the multiple length classes present. However, their presence in the pond is more likely the result of translocation of fry from elsewhere by waterfowl during spring. No other fish were encountered in the pond. The presence of brook stickleback and fathead minnow is typical of waterbodies that suffer severe oxygen depletion and become anoxic by late winter or summer.

Minnow trapping in the dugout part of Wetland 01 in October 2006 resulted in high numbers of brook stickleback (n=349; 38 fish/trap-hour) and some fathead minnow (n=30).

The dugout is likely to contain water year-round although it may freeze to bottom in winter depending on precise water levels and temperatures. Habitat potential in Wetland 01 is negligible for salmonids given low DO concentrations (which do not support rearing and wintering), lack of flow, very limited connectivity to other watercourses and lack of suitable spawning substrate. Wetland 01 is eutrophic-hypereutrophic and full of submerged vegetation (*Potamogeton* spp.). Bulrush and cattail (*Typha latifolia*) are present. Summer (and winter) kill is a possibility given the abundant macrophyte growth and shallow water and low DO concentrations. The dugout also provides habitat for amphibians (see Appendix I, Photo I–7), mammals such as muskrat, and birds such as waterfowl, blackbirds and herons.

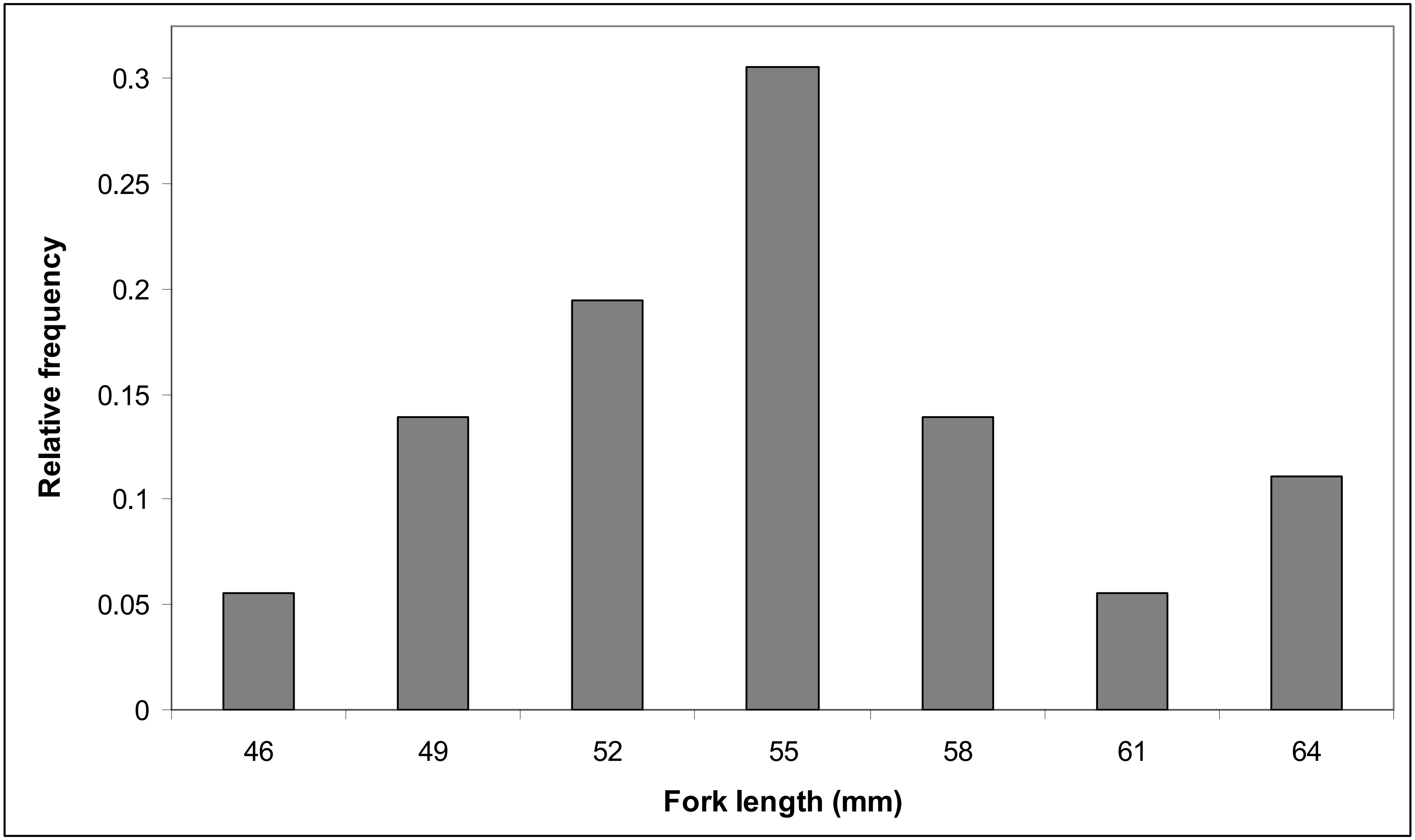


Figure 5.4-2: Distribution of Brook Stickleback Size Classes from the Dugout in Wetland 01 (June 2006)

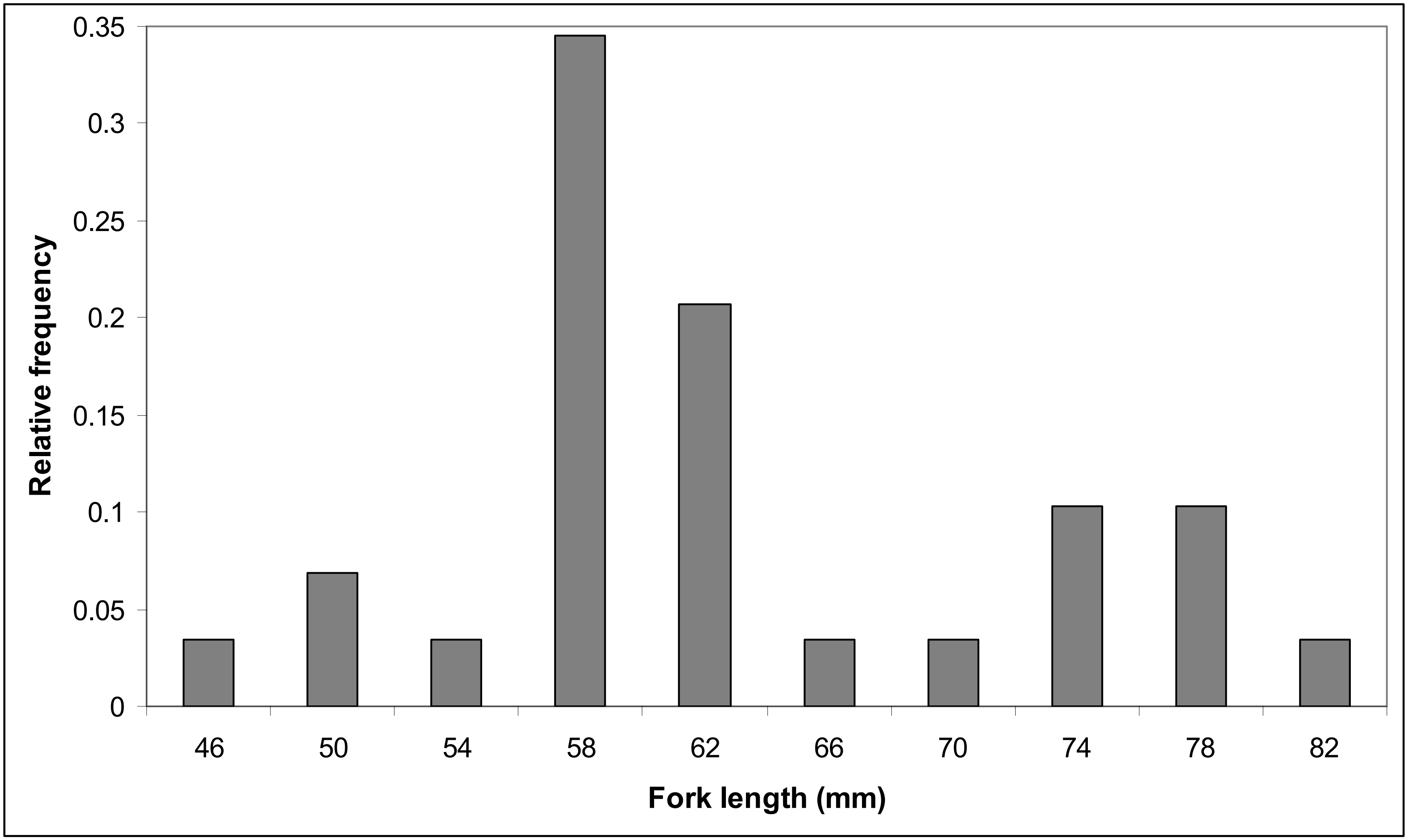


Figure 5.4-3: Distribution of Fathead Minnow Size Classes from the Dugout in Wetland 01 (June 2006)

5.4.2.2 Wetland 02

5.4.2.2.1 Channel Characteristics

Wetland 02 consists of a marsh area approximately 275 m by 65 m (Appendix I, Photo I–8) located within a right of way for the Canadian Pacific Railway (CPR) rail line (Figure 5.4-1). Wetland 02 had a depth of approximately 0.2 m or less in June 2006 and contained no water in October 2006 (see Appendix I, Photo I–9). The wetland only contains fine silty substrates. Drainage from Wetland 02 was northward through a culvert under the CPR rail tracks. The drainage exits the Site midway along its northern boundary and continues north through private property where it eventually disappears into the ground before connecting with any other waterbody.

5.4.2.2.2 Habitat Potential

Cattail (*Typha latifolia*) is present in the centre of the wetland (approximately 100 m by 30 m) with grasses and patches of shrubs around the perimeter. No sampling for fish or invertebrates was conducted given it is dry most of the year and is not connected with any other waterbody. Wetland 02 does not provide habitat for fish but does provide suitable habitat for amphibians and wetland birds such as blackbirds, herons and waterfowl.

5.4.3 Description of Regional Aquatic Resources

5.4.3.1 Lamont Creek

5.4.3.1.1 Channel Characteristics

Lamont Creek is located outside of the Site approximately 0.5 km east of the eastern property boundary. Lamont Creek is a perennial, meandering watercourse that is occasionally confined and has moderately stable, vertical banks with a mean height of 0.31 m (see Appendix I Photo I–10, Photo I–11, Photo I–12, Photo I–13 and Photo I–14). Mean channel and wetted widths are 4.02 m and 3.94 m, respectively. Mean channel depth was 0.58 m, and habitat is characterized as a continuous run. Substrate throughout the study section was composed almost entirely of fines (98%) with occasional boulders (2%). Water was warm (18.6°C), pH slightly basic (7.7), conductivity high (991 µS/cm) and DO concentrations were low (4.03 mg/L, 50% saturation). Flow was not discernible in June and October 2006. A stream catalogue for Lamont Creek is included in Appendix II.

5.4.3.1.2 Fish Presence and Habitat Potential

Lamont Creek is a tributary to Beaverhill Creek, which is a tributary to the North Saskatchewan River located approximately 11 km downstream from the Site. Beaverhill Creek was found to have no connectivity with the North Saskatchewan River in June 2006. Beaverhill Creek is known to support populations of fathead minnow (*Pimephales promelas*), brook stickleback (*Culaea inconstans*) (Wingert 2006, pers. comm.) and lake chub (*Couesius plumbeus*) (AAR 2006b). In 1975, there were also white sucker (*Catostomus commersonii*) and northern pike (*Esox lucius*) when a 1-in-100 year flood allowed access from the North Saskatchewan River (Wingert 2006, pers. comm.). Since Lamont Creek is a tributary to Beaverhill Creek, it is expected to have a similar fish community.

Minnow trapping in Lamont Creek resulted in the capture of 14 brook stickleback and two fathead minnow (CPUE=0.17 fish/trap-hour). Brook stickleback and fathead minnow are both cool-water forage fish and are found typically where others will not go because of poor water quality. Both species provide insight into a watercourse where DO concentrations drop below 5 mg/L – a minimum requirement for many fish (Barton and Taylor 1996). Most north temperate, freshwater fish need higher DO concentrations to survive winter and summer.

Habitat potential in Lamont Creek is poor for salmonids given the low DO concentrations that do not support rearing and wintering and the lack of suitable spawning substrate. Some deep runs provide moderate rearing and wintering habitat potential for brook stickleback which is tolerant of low DO concentrations. Low water could result in many culverts becoming migration barriers to fish as are beaver dams (see Appendix I, Photo I–10, Photo I–11 and Photo I–13). Use of the creek by livestock upstream could potentially contribute to low DO concentrations through eutrophication caused by manure input (see Appendix I, Photo I–14). A further potential impact to water quality is the release of treated wastewater into the creek from the Town of Lamont's wastewater treatment lagoons (Holowach 2006, pers. comm.). Lamont Creek has moderate spawning potential for northern pike given instream vegetation, but it is limited to rearing and wintering habitat because of high temperatures and low DO concentrations. Duckweed (*Lemna* sp.) is prevalent throughout the Creek (see Appendix I, Photo I–11, Photo I–12 and Photo I–13).

5.4.3.1.3 Invertebrates

Subsamples from Lamont Creek contained a predominance of oligochaete worms and chironomid larvae. Consistently, 90% of individual samples were made up by these two groups. This is as expected given the soft substrate and low flow. Therefore, the invertebrate community is characterized by low diversity with few occurrences of other insect larvae (e.g., *Zygoptera*, *Heteroptera*, *Dytiscidae*). The water column contained numerous daphnids, indicators of a low flow regime.

5.4.4 Summary of Aquatic Resource Features

Within the LSA, two aquatic resource features were identified: Wetland 01 and Wetland 02. Within the RSA, one additional aquatic resource feature was identified – Lamont Creek. Wetland 01 and Lamont Creek were found to contain two species of fish, fathead minnow and brook stickleback. These fish are considered forage fish and would not likely be consumed by people due to their small size. These aquatic environments were characterized as shallow with poor water quality and severe oxygen depletion. Lamont Creek was also found to have multiple beaver dams which are potential fish migration barriers. Wetland 02 was observed to be completely dry in the fall and was found to have no connectivity with any other waterbody at other times of the year; therefore would not be considered fish habitat. Wetland 01 and Lamont Creek are considered low value fish habitat. All three aquatic resource features provide a filtering function for surface water runoff as well as habitat for birds, mammals, amphibians and invertebrates.

5.5 Environmental Effects Assessment at Application and Closure

5.5.1 Assessment Methods

The impact assessment identified potential sources of impact that could occur at each of the three phases of the Project: siting the facility, construction and operation. Potential impacts on aquatic resource indicators within the LSA were assessed by using the rating criteria of direction, geographic extent, magnitude, duration, reversibility and confidence as described in Volume IIB, Section 1: Introduction. A final impact rating of Class 1, 2, 3 or 4 was applied to estimated residual impacts after all mitigation measures were applied.

5.5.2 Proposed Development Case

The initial stage of development will consist of a facility capable of processing 3,000 t/d of sulphur. Subsequent expansions to the facility will increase the processing capacity to 6,000 t/d of sulphur. The development case assessed assumed maximum disturbance at the full processing capacity of 6,000 t/d of sulphur.

5.5.3 Aquatic Resource Indicators

The health of aquatic ecosystems within the LSA and RSA are primarily governed by water quality and quantity. Therefore, the aquatic resource indicators selected for the impact assessment are:

- water quality – pH, temperature, dissolved oxygen
- water quantity – water volume or depth

5.5.4 Potential Sources of Impact

Potential sources of impact to aquatic resources resulting from the Project could occur at each of the three phases of development: siting, construction and operation. The potential sources of impact and their associated potential impacts are summarized in Table 5.5-1. Each potential impact, associated mitigation strategies and residual impacts at application and closure are discussed in more detail in Sections 5.5.5–5.5.10.

Table 5.5-1: Potential Sources of Impact and Associated Potential Impacts to Aquatic Resources

Project Stage	Source of Impact	Potential Impact
Siting	Siting	Surface disturbance that alters or disconnects watercourses
		Surface disturbance resulting in removal of aquatic habitats
Construction	Excavation and fill placement	Surface disturbance causing the release of sediment into aquatic habitats
Operation	Fugitive emissions from sulphur piles	Deposition of sulphur dust to surrounding lands that could result in acidification of surrounding lands and surface water
	Stack emissions to air	Stack emissions of sulphur particulates and gases that could result in acidification of surrounding lands and surface water
	Wastewater and stormwater	Release of contaminated stormwater to aquatic environments
	Water supply	Extraction of groundwater could lower the water table in nearby aquatic environments
	Contaminant spills	Release of deleterious substances into aquatic environments

5.5.5 Surface Disturbance

5.5.5.1 Description

The degree of surface disturbance impacts to aquatic resources is primarily influenced by the siting of the facility and construction activities and practices. Potential surface disturbance impacts include:

- alteration of drainages that charge aquatic habitats
- destruction of aquatic habitats
- degradation of water quality within aquatic habitats during construction, particularly during wet weather

5.5.5.2 Mitigation

The Project is well sited on the property to avoid the loss of aquatic habitats or interfere with drainages that greatly influence aquatic habitats. The use of a previously disturbed area for the facility reduces the amount of new clearing and avoids disturbing wetlands.

The Site is located within the Alberta Industrial Heartland and both Canadian Pacific Railway (CPR) and Canadian National (CN) rail lines run through it minimizing disturbance that would otherwise be required to establish rail access.

Construction activities such as excavation and fill placement during wet weather could result in turbid runoff that enters Wetland 01. The fish species present in Wetland 01 are able to tolerate poor water quality conditions and would not likely be sensitive to minor water quality disturbances. The wetland itself would act as a filter to reduce suspended sediments. It is recommended that sediment control measures be implemented during construction to avoid the release of sediments into Wetland 01.

5.5.5.3 Residual Impacts

At application, the direction of surface disturbance impacts as a result of siting is neutral with a Class 4 impact rating.

Surface disturbance impacts as a result of construction is negative in direction, short term in duration, and negligible in magnitude with mitigation. Surface disturbance during construction is a Class 4 impact.

At closure, all facilities and infrastructure will be removed and the surface of the Site reclaimed. The impact at closure will be neutral in direction and confidence in this prediction is high. This is a Class 4 impact. The harmful alteration, disruption or destruction of fish or fish habitat is unlikely to occur as a result of the construction of the Project with proper mitigation.

5.5.6 Dust Deposition

5.5.6.1 Description

Elemental sulphur dust is expected to be released as fugitive emissions in the order of 1.11 kg/ha/y. Sulphur dust deposition on surrounding lands could result in the acidification of surface water runoff that enters aquatic environments, thus acidifying aquatic resources. Fish, invertebrates and amphibians are generally sensitive to pH outside of the range of 6.0 and 9.0, with the exception of the collection area where dust will be deposited.

Modelling based on predicted size distribution of sulphur particles indicates there will not be appreciable deposition of particles beyond the PDA (Leahey and Whitford 2005).

5.5.6.2 *Mitigation*

Sulphur storage piles will be sheltered from the wind by a wind screen to reduce the potential for wind erosion of dust.

A dust suppression management plan is outlined in Volume 1: Project Description – Section 3.6. A proprietary dust suppression agent and release aid will be used to suppress dust on the sulphur pastille storage pad, transfer points and rail load-out area. Dust suppression agents will be applied at the load-out hopper and at the rail load-out. The agents will be stored in make-up tanks and delivered via pump.

The usage rates of the dust suppression agents are estimated to be less than 100 kg/d during initial operations, increasing to less than 200 kg/d for full-scale operations. The actual amounts used will depend on the size of the trains being loaded and the conveyor size. Dustbind S5 will be applied at the transfer points and IPAC SRB Plus will be applied at each individual Rotoformer.

5.5.6.3 *Residual Impacts*

At application, the impact of dust deposition on aquatic resources is negative, confined to the LSA and considered low to moderate in magnitude. The duration of the impact is considered mid-term as this impact will occur during the operational lifespan of the sulphur forming and shipping facility. The impact of the dust deposition is considered reversible and mitigation techniques will be implemented to reduce or prevent dust deposition. It is expected that the buffering capacity of the soils will neutralize acidifying runoff prior to entering aquatic habitats. The confidence in this impact prediction is moderate because there is a lack of directly applicable data that indicates how much dust deposition will occur, how much will be buffered prior to entering aquatic environments, and what effects the dust will have on aquatic resources. This is a Class 3 impact.

At closure, all facilities and infrastructure will be removed and dust deposition will no longer occur. The direction of this impact is neutral and the confidence in this prediction is moderate. This will be a Class 4 impact. It is not anticipated that dust deposition will result in the input of a deleterious substance into fish habitat.

5.5.7 Air Emissions

5.5.7.1 *Description*

Potential air emissions of acidifying gaseous compounds include H_2S, SO_2 and NO_2. Air emissions of sulphur particulates are possible from two Rotoform stacks and a boiler stack. The Rotoform process is known to represent state-of-the-art technology regarding particulate sulphur emissions. An air quality study predicted that particulate deposition would be 1.1 kg/ha/y at the eastern property boundary (see Volume IIA, Section 2: Climate and Air Quality). These emissions have the potential to acidify soils and surface water runoff entering aquatic environments.

5.5.7.2 *Mitigation*

No mitigation measures are planned relating to gaseous or particulate stack emissions due to the low levels predicted.

5.5.7.3 Residual Impacts

At application, air emission impacts on aquatic resources are predicted to be negative in direction, local in extent and low to moderate in magnitude. The duration of the impact is considered mid-term and reversible. The confidence in this impact prediction is moderate and the impact of air emissions is considered reversible. It is expected that the buffering capacity of the soils will neutralize acidifying runoff prior to entering aquatic habitats. The confidence in this impact prediction is moderate because there is a lack of directly applicable data that indicates how much sulphur particulate deposition will occur, how much will be buffered prior to entering aquatic environments, and what effects air emissions will have on aquatic resources. This is a Class 3 impact.

At closure, the facilities and infrastructure will not generate further air emissions. The impact is neutral and confidence is moderate. This is a Class 4 impact. It is not anticipated that air emissions will result in the input of a deleterious substance into fish habitat.

5.5.8 Stormwater Discharge

5.5.8.1 Description

Stormwater, if contaminated and released into the environment, has the potential to adversely impact water quality.

The sulphur forming and shipping operations do not generate wastewater that requires release to the environment. Domestic wastewater will be generated from washroom facilities.

Stormwater, if uncontrolled on site, has the potential to collect and transport sulphur particles into aquatic environments.

5.5.8.2 Mitigation

Domestic wastewater generated from washroom facilities will be stored and routinely trucked offsite. The sulphur forming and shipping operations will not generate wastewater that requires releases to the environment. Cooling water is the only water that will be used in the process. The cooling system will include a non-contact spray system, filtering and conditioning, a cooling tower for temperature conditioning and water reuse. Surface water management systems are described in Volume I, Project Description: Section 3.5.2 and the key components include:

- collection and containment of potentially impacted surface runoff
- reuse of collected surface water in the sulphur cooling process
- treatment, monitoring and discharge of any excess surface water that may be collected during extreme runoff events

5.5.8.3 Residual Impacts

At application, residual impacts to aquatic resources are predicted to be negative in direction, local in extent and low to moderate in magnitude. It is anticipated that some stormwater near the facility (e.g., around rail lines) will be uncontrolled. However, due to the buffering capacity of soils, acidifying surface water runoff is likely to be neutralized prior to entering aquatic environments. This is a Class 3 impact.

At closure, there will be no further generation of wastewater or presence of sulphur to contaminate stormwater. This is a Class 4 impact. It is not anticipated that stormwater discharge with mitigation will result in the input of a deleterious substance into fish habitat.

5.5.9 Groundwater Drawdown

5.5.9.1 Description

Wetlands are dependent on surface water inflow and groundwater to keep the wetland charged. Water supply to the Project using groundwater could lower the water table thus impacting water levels in Wetland 01. The water volume in Wetland 01 varies considerably throughout the year and is considered to maintain a minimal volume throughout winter months to support fish. Any significant change to water volumes available to the wetland could result in an insufficient supply of water to support fish.

5.5.9.2 Mitigation

Groundwater and surface water studies have estimated that the contribution of groundwater to Wetland 01 is less than 0.5% and that the wetland is primarily charged with surface water (see Volume IIB, Section 2: Groundwater Quantity and Quality).

Groundwater supply requirements will be minimized through the collection, storage and recycling of surface water that falls on the sulphur handling and pastille storage areas.

5.5.9.3 Residual Impacts

At application, impacts on aquatic resources are predicted to be negative in direction, local in extent and negligible in magnitude given the small contribution of groundwater estimated to contribute to aquatic resources in the LSA. The impact rating is a Class 3.

At closure, no further groundwater extraction will take place by the Project and the impact is neutral. The impact rating is a Class 4.

5.5.10 Contaminant Spills

5.5.10.1 Description

Spills of degassed liquid sulphur from the above-ground storage tanks, shipping containers or pipelines could impact aquatic resources. Spills of sulphur pastilles may occur during the loading of the product for storage or shipping. If left in the environment, acidification of the spill could result in low pH runoff entering aquatic environments.

5.5.10.2 Mitigation

Any sulphur spills will be responded to immediately and cleaned up. The contingency plan for managing sulphur spills is described in Volume I, Appendix V: Preliminary Emergency Response Plan.

All storage facilities will comply with the requirements of the Alberta Energy and Utilities Board (EUB) Guide 55 and Alberta Environment (AENV) guidelines for the containment of potentially hazardous materials. All liquid products will be stored in steel tanks that include double-containment and leak detection monitoring. Liquid products will be managed and applied in enclosed systems with minimum opportunity for accidental release to the environment. None of these products are expected to contain substances that are Canadian Environmental Protection Act (CEPA) toxics, Accelerated Reduction/Elimination of Toxics (ARET), Track 1 or on the National Pollutant Release Inventory (NPRI).

The asphalt storage pad for sulphur pastilles will include primary asphalt containment, a secondary clay soil liner, surface water runoff, run-on controls and a leak detection layer.

The leak detection monitoring plan is outlined in Volume I: Project Description – Section 5.5. Leak detection monitoring will be implemented for the surface water runoff collection pond and asphalt stockpile pad to assess potential leakage relative to an action leakage rate (ALR), which is defined in Volume I: Project Description – Section 5.5. Leak detection monitoring will be implemented monthly until the integrity of the primary liners is confirmed, after which the monitoring frequency will be reduced to twice yearly.

5.5.10.3 Residual Impacts

Solid and liquid sulphur is essentially insoluble in water and the formation of acid occurs through bacterial oxidation processes. If a spill of sulphur is detected and cleaned up immediately, there should be a very low risk of impact to aquatic resources given the facility is located at least 500 m from aquatic resources. Spills of liquid sulphur will be readily apparent as the sulphur will solidify immediately.

At application, the impact of degassed liquid sulphur and sulphur pastille spills on aquatic resources is negative, is confined to the PDA and considered to be low to moderate in magnitude. The duration of the impact is considered mid-term as this impact will occur during the operational lifespan of the sulphur forming and shipping facility. The impact of the spills is considered reversible as mitigation techniques will be implemented to reduce or prevent spills. The confidence in this impact prediction is moderate because the frequency and magnitude of spills is unknown. This is a Class 3 impact.

At closure, all facilities and infrastructure will be removed and the potential for spills will no longer exist. The direction of this impact is neutral and the confidence in this prediction is moderate. This will be a Class 4 impact.

5.6 Cumulative Effects Assessment

Cumulative effects for each identified impact on aquatic resources were evaluated on a regional scale. Industrial disturbances to the landscape that have occurred within the RSA include Canexus sodium chlorate plant, Triton fabrication facility and AltaLink electrical substation. Other anthropogenic disturbances within the RSA include agriculture, road construction and rural residential development.

Cumulative effects were only assessed when an impact (see Section 5.5) was classified as Class 1, 2 or 3. Impacts of such classes were identified for dust deposition, air emissions, wastewater and stormwater discharge, groundwater drawdown and contaminant spills. The impacts of wastewater and stormwater discharge, groundwater drawdown, and contaminant spills are not addressed on a regional scale because specific plans of other projects in the RSA regarding these issues are currently unavailable. Impacts of wastewater and stormwater discharge, groundwater drawdown and contaminant spills are not addressed on a regional scale because these impacts are unlikely to extend beyond the property boundary. Surface disturbance was classified as a Class 4 impact is not of regional significance. Surface disturbances from road construction (drainage impedance) and the construction of the dugout within Wetland 01 (pool creation), likely resulted in the creation of a new waterbody that retains sufficient water year round to support fish.

The impacts of dust and air emissions in the RSA are discussed in detail in the cumulative effects case in Volume IIA, Section 2: Climate and Air Quality. Acidifying emissions may interact with emissions from other industrial sources to produce possible adverse effects on aquatic resources. Estimated sulphur deposition is 0.3 kg/ha in the vicinity of nearby sodium chlorate plants (Canexus is located west of the Project). Sodium chlorate forms chlorine dioxide, a disinfectant, in acid aqueous reaction. Chlorine dioxide is a gas that absorbs readily into water but is unstable and typically converts to chlorite. Chlorine dioxide has been found to be moderately toxic to fish (0.21 mg/L) but chlorite has been found to be only slightly toxic to fish (3.3 mg/L) (Svecevičius et al. 2005).

The buffering capacity of the surrounding lands is expected to neutralize low pH near the facility, and thus water quality is not expected to deviate from baseline conditions. However, it is recommended that monitoring be conducted to determine whether acidification of surface waters does occur in surrounding areas.

5.7 Monitoring and Adaptive Management

With respect to aquatic resources, monitoring measures should be initiated to address the following:

- sediment control and water quality during construction
- water quality of discharges leaving the facility during its operation
- water quality of surface waters (outside the facility) entering aquatic environments
- groundwater quality and water table level

Planned monitoring activities with respect to surface water and groundwater include:

- monitoring water that is potentially discharged from the Site for:
  - visible sheen
  - $6<pH<9$
  - chemical oxygen demand <50 mg/L
  - chloride<500 mg/L
  - total suspended solids<50 mg/L
  - grab samples will be conducted immediately prior to discharge
- monitoring groundwater twice annually for:
  - water table level
  - temperature, pH and electrical conductivity
  - potability

In addition to the planned monitoring activities, it is recommended that:

- surface water in Wetland 01 be monitored for turbidity during construction
- surface water in Wetland 01 be sampled twice annually for temperature, pH and dissolved oxygen during operations

5.8 Summary and Recommendations

The harmful alteration, disruption or destruction of fish or fish habitat is unlikely to occur as a result of the construction of the Project with mitigation. The input of a deleterious substance into fish habitat is not anticipated to occur as a result of the Project with mitigation and the recommended water quality monitoring.

The Project has the potential to impact aquatic resources within the LSA, primarily through dust deposition, air emissions and stormwater discharge. Table 5.8-1 summarizes the impacts at application to aquatic resources. All potential impacts at application have an impact rating of Class 3 or Class 4 after mitigation.

Table 5.8-1: Final Impact Ratings on Aquatic Resources at Application

Project Stage	Potential Impact	Geographic Extent	Magnitude	Direction	Duration	Reversibility	Confidence	Impact Rating
Siting	Surface disturbance	Local	Negligible	Neutral	Short-term	Reversible	High	Class 4
Construction	Surface disturbance	Local	Negligible	Negative	Short-term	Reversible	High	Class 4
Operation	Dust deposition	Local	Low to moderate	Negative	Mid-term	Reversible	Moderate	Class 3
	Air emissions	Local	Low to moderate	Negative	Mid-term	Reversible	Moderate	Class 3
	Wastewater and stormwater discharge	Local	Low to moderate	Negative	Mid-term	Reversible	Moderate	Class 3
	Groundwater drawdown	Local	Negligible	Negative	Mid-term	Reversible	Moderate	Class 3
	Contaminant spills	Local	Low to moderate	Negative	Mid-term	Reversible	Moderate	Class 3

At closure, residual impacts of dust deposition, air emissions, wastewater and stormwater discharge, groundwater drawdown and contaminant spills are considered to be neutral in direction. The confidence in these predictions is moderate. All potential impacts at closure have an impact rating of Class 4. Table 5.8-2 summarizes the residual impacts at closure to aquatic resources in the LSA.

Table 5.8-2: Final Impact Ratings on Aquatic Resources at Closure

Project Stage	Potential Impact	Direction	Confidence	Impact Rating
Siting	Surface disturbance	Neutral	High	Class 4
Construction	Surface disturbance	Neutral	High	Class 4
Operation	Dust deposition	Neutral	Moderate	Class 4
	Air emissions	Neutral	Moderate	Class 4
	Wastewater and stormwater discharge	Neutral	Moderate	Class 4
	Groundwater drawdown	Neutral	Moderate	Class 4
	Contaminant spills	Neutral	Moderate	Class 4

A potential cumulative effect on aquatic resources was identified relating to dust deposition and air emissions interacting with sodium chlorate. Sulphur emissions have the potential to acidify surface waters in the vicinity of the Canexus sodium chlorate plant. Sodium chlorate forms chlorine dioxide in acid aqueous reaction, and chlorine dioxide has been found to be moderately toxic to fish. This impact is predicted to be unlikely to occur given the buffering capacity of the soils.

Recommendations for further mitigation and monitoring relating to aquatic resources include:

- implement sediment control measures during construction to prevent sediment laden waters from entering Wetland 01
- monitor surface water in Wetland 01 for turbidity during construction
- monitor surface water in Wetland 01 twice annually for temperature, pH and dissolved oxygen during operations

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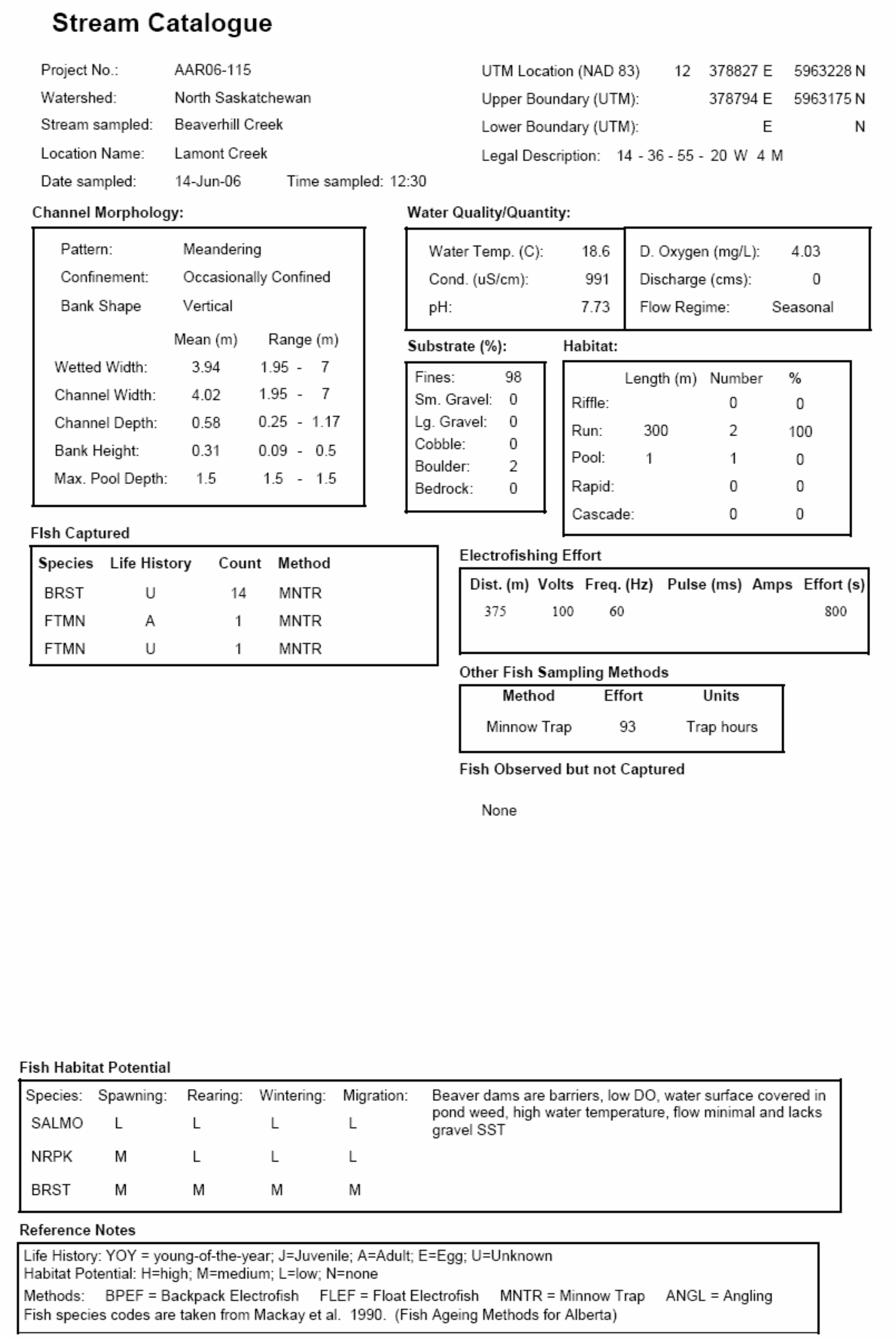

Stream Catalogue

Project No.: AAR06-115
Watershed: North Saskatchewan
Stream sampled: Beaverhill Creek
Location Name: Lamont Creek
Date sampled: 14-Jun-06 Time sampled: 12:30

UTM Location (NAD 83) 12 378827 E 5963228 N
Upper Boundary (UTM): 378794 E 5963175 N
Lower Boundary (UTM): E N
Legal Description: 14 - 36 - 55 - 20 W 4 M

Channel Morphology:

Pattern: Meandering
Confinement: Occasionally Confined
Bank Shape Vertical

	Mean (m)	Range (m)
Wetted Width:	3.94	1.95 - 7
Channel Width:	4.02	1.95 - 7
Channel Depth:	0.58	0.25 - 1.17
Bank Height:	0.31	0.09 - 0.5
Max. Pool Depth:	1.5	1.5 - 1.5

Water Quality/Quantity:

Water Temp. (C):	18.6	D. Oxygen (mg/L):	4.03
Cond. (uS/cm):	991	Discharge (cms):	0
pH:	7.73	Flow Regime:	Seasonal

Substrate (%):

Fines:	98
Sm. Gravel:	0
Lg. Gravel:	0
Cobble:	0
Boulder:	2
Bedrock:	0

Habitat:

	Length (m)	Number	%
Riffle:		0	0
Run:	300	2	100
Pool:	1	1	0
Rapid:		0	0
Cascade:		0	0

FIsh Captured

Species	Life History	Count	Method
BRST	U	14	MNTR
FTMN	A	1	MNTR
FTMN	U	1	MNTR

Electrofishing Effort

Dist. (m)	Volts	Freq. (Hz)	Pulse (ms)	Amps	Effort (s)
375	100	60			800

Other Fish Sampling Methods

Method	Effort	Units
Minnow Trap	93	Trap hours

Fish Observed but not Captured

None

Fish Habitat Potential

Species:	Spawning:	Rearing:	Wintering:	Migration:
SALMO	L	L	L	L
NRPK	M	L	L	L
BRST	M	M	M	M

Beaver dams are barriers, low DO, water surface covered in pond weed, high water temperature, flow minimal and lacks gravel SST

Reference Notes

Life History: YOY = young-of-the-year; J=Juvenile; A=Adult; E=Egg; U=Unknown
Habitat Potential: H=high; M=medium; L=low; N=none
Methods: BPEF = Backpack Electrofish FLEF = Float Electrofish MNTR = Minnow Trap ANGL = Angling
Fish species codes are taken from Mackay et al. 1990. (Fish Ageing Methods for Alberta)

Stream Catalogue

Project No.: AAR06-115
Watershed: North Saskatchewan
Stream sampled:
Location Name: Wetland 01
Date sampled: 15-Jun-06 Time sampled: 9:12

UTM Location (NAD 83) 12 376662 E 5963253 N
Upper Boundary (UTM): E N
Lower Boundary (UTM): E N
Legal Description: 13 - 35 - 55 - 20 W 5 M

Channel Morphology:

Pattern: Irregular
Confinement: Unconfined
Bank Shape Sloping

	Mean (m)	Range (m)
Wetted Width:	90	90 - 90
Channel Width:	90	90 - 90
Channel Depth:	0.82	0.55 - 1.2
Bank Height:	0.1	0.1 - 0.1
Max. Pool Depth:	1	1 - 1

Water Quality/Quantity:

Water Temp. (C):	17.1	D. Oxygen (mg/L):	2.9
Cond. (uS/cm):	783	Discharge (cms):	0
pH:	7.83	Flow Regime:	Perennial

Substrate (%):

Fines:	100
Sm. Gravel	0
Lg. Gravel:	0
Cobble:	0
Boulder:	0
Bedrock:	0

Habitat:

	Length (m)	Number	%
Riffle:		0	0
Run:		0	0
Pool:	100	1	100
Rapid:		0	0
Cascade:		0	0

Fish Captured

Species	Life History	Count	Method
BRST	U	47	MNTR
FTMN	A	419	MNTR
FTMN	U	892	MNTR

Electrofishing Effort

Electrofishing not conducted

Other Fish Sampling Methods

Method	Effort	Units
Minnow Trap	93	Trap hours

Fish Observed but not Captured

None

Fish Habitat Potential

Species:	Spawning:	Rearing:	Wintering:	Migration:
SALMO	L	L	L	L
NRPK	M	L	L	L
BRST	M	M	M	M

Turbid water, low dissolved oxygen, high temperature, lacks coarse substrate, poor D/S conductivity, shallow, likely to freeze in winter, vegetation present could provide habitat for NRPK spawning, but poor access

Reference Notes

Life History: YOY = young-of-the-year; J=Juvenile; A=Adult; E=Egg; U=Unknown
Habitat Potential: H=high; M=medium; L=low; N=none
Methods: BPEF = Backpack Electrofish FLEF = Float Electrofish MNTR = Minnow Trap ANGL = Angling
Fish species codes are taken from Mackay et al. 1990. (Fish Ageing Methods for Alberta)