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SOUTH BISON HILL SOIL CAPPING RESEARCH SYNTHESIS

MILDRED LAKE MINE

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EXECUTIVE SUMMARY

In 1999, Syncrude Canada Ltd. (Syncrude) initiated a multi-disciplinary study to evaluate the performance of various reclamation capping thicknesses for saline/sodic (Clearwater Formation) overburden fill material at Syncrude's Mildred Lake mine. An instrumented watershed was created at Syncrude's South Bison Hill (SBH) that included three one-hectare reclamation plots to test soil capping thicknesses of 35, 50 and 100 cm. The prescribed thickness of reclamation material at the time of the capping study was 100 cm for Clearwater fills.

Current regulatory approvals mandate a cover thickness of 150 cm, an increase to the 100 cm standard in place prior to 2006. Syncrude has implemented a total reclamation capping thickness of 150 cm for Clearwater overburden material at Mildred Lake since imposition of this standard.

While intended to mitigate risks (primarily salinization of the soil cover), the increase in soil cover thickness has resulted in the need to salvage and stockpile larger volumes of soil. This in turn has resulted in an increase in the disturbance footprint, reduced availability of water to downstream features, and increased costs of reclamation.

In 2012, Syncrude established a multi-disciplinary research team to synthesize existing data, collect additional data, and conduct modeling to clarify the current performance of different cover thicknesses and project future performance under different climatic conditions. The goal of the study was to determine the minimum soil cover depth required to deliver an appropriate amount of water for targeted boreal forest vegetation, without compromising the quality of the cover by salt ingress. Fieldwork was completed in the summer and fall of 2012. The SBH research team conducted a risk assessment to identify potential performance risks associated with plant growth on the various soil cover thicknesses using a Failure Mode and Effect Analysis approach.

The 2012 field program was conducted for a 49 ha study area on SBH that included a portion of the dump plateau, adjacent slopes and the original 1999 capping study area. A field survey and sampling campaign assessed the effects of reclamation capping thickness on soil salinity and both above-ground and below-ground vegetation response. The results of the 2012 program are included in Appendix A to F. A modeling study was conducted to evaluate the sensitivity of water storage and water dynamics to reclamation cover thickness, and a long-term assessment of evapotranspiration and net ecosystem exchange monitoring data was conducted for the site. The scientific research compilation indicates that a capping thickness of 50 cm has been sufficient to ensure an equivalent forest capability to date, with little to no increase in vegetation growth with capping thicknesses greater than 50 cm. However, since the site has experienced near normal growing season precipitation, the vegetation may experience reduced performance during a prolonged drought on soil covers less than 50 cm. The study water modeling suggests a soil cover of 75 cm is sufficient in

providing enough soil-water to vegetation during drought conditions. Conversely the research shows that a thick capping (>100 cm) is likely to reduce the amount of water released downstream to adjacent wetlands, while allowing more extensive salt ingress into the capping soils as summarized in the tables below.

It is the professional opinion of the research team that a thickness of 75 cm will provide adequate water supply to vegetation during droughts while also allowing for the release of water to the downstream reclaimed landscape.

Summary of Design, Observed, Modeled Characteristics and Risk Assessment Results

Characteristics		Capping Thickness Scenarios					
		35 cm	50 cm	75 cm	100 cm	125 cm	150 cm
Design	Peat thickness (cm)	15	20	20	20	20	30
	Secondary thickness (cm)	20	30	55	80	105	120
	Period of effect of soil capping thickness approval requirements	n/a	n/a	n/a	1990-2006	n/a	2006-present
Observed (2012)	Capping thickness average (cm)	30	49	-	106	-	-
	Current vegetation performance (poor, fair, good)	Good	Good	Good	Good	Good	Good
	Current tree growth versus equivalent capability of natural stands	Meets/ Exceeds	Meets/ Exceeds	-	Meets/ Exceeds	-	-
	Rooting biomass (Mg/ha)	<10		10 - 36.6			
	Overburden rooting limitation (Yes, No)	Yes	Yes	Yes	Yes - No	No	No
	Median height (cm) of salt ingress into base of soil cover	30		60 - 85			
	Median height (cm) of change of EC soil rating from Fair to Good due to salt ingress into base of soil cover	0 - 5		25 - 30	30 - 35		
	Median height (cm) of change of EC soil rating from Poor to Fair due to salt ingress into base of soil cover	-5 - 0		0 - 5	0 - 5		
	Median height (cm) of change of SAR soil rating from Fair to Good due to salt ingress into base of soil cover	20 - 25		35	45 - 50		
	Median height (cm) of change of SAR soil rating from Poor to Fair due to salt ingress into base of soil cover	5		10 - 15	15 - 20		
	Peak evapotranspiration rate (mm/day) (versus mature boreal forest)	-	-	-	3.9 (Comparable)	-	-
	Peak LAI (since 2008)	-	-	-	3.5	-	-
Modeled	Evapotranspiration (LAI = 3.5) (mm)	275	296	317	329	336	341
	Total annual yield (runoff + net percolation) (LAI = 3.5) (mm)	77	57	38	26	19	15
	Rainfall (mm)	310.6					
	Snowmelt volume (mm)	115.6					

(-) Information for capping depth not available

Plant Growth Risk Assessment Summary

Plant Growth Risk Assessment Classes: *Likely to Occur, Unlikely to Occur, Very Unlikely to Occur, Remote*	**Capping Thickness Scenarios**					
	35 cm	**50 cm**	**75 cm**	**100 cm**	**125 cm**	**150 cm**
Water availability	Likely	Unlikely	Very Unlikely	Remote	Remote	Remote
Salt diffusion causing drought stress	Likely	Unlikely	Unlikely	Very Unlikely	Remote	Remote
Salt effects due to evapo-concentration	Unlikely	Very Unlikely	Remote	Remote	Remote	Remote
Sodification of the soil structure	Unlikely	Very Unlikely	Remote	Remote	Remote	Remote
Sodium toxicity	No significant risk – not included in full risk assessment					
Water logging of the root zone						

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LIST OF ABBREVIATIONS

AESRD	Alberta Environment and Sustainable Resource Development
AWHC	Available Water Holding Capacity
BGS	Below Ground Surface
BML	Base Mine Lake
CEMA	Cumulative Environmental Management Association
Cl^-	Chloride
cm	Centimeters
CO_2	Carbon dioxide
dS/m	DeciSiemens per metre
EC	Electrical Conductivity
EPEA	Environmental Protection and Enhancement Act
EPL	End Pit Lake
ET	Evapotranspiration
FMEA	Failure Mode and Effect Analysis
GI	Growth-intercept
ha	hectare
K^+	Potassium
Kc	Cretaceous Clearwater Formation
Kca	Informal Syncrude Created Subdivision of the Clearwater Formation
Kcb	Informal Syncrude Created Subdivision of the Clearwater Formation
Kcc	Informal Syncrude Created Subdivision of the Clearwater Formation
Kcw	Cretaceous Clearwater Wabiskaw Member
Kfs	Field saturated hydraulic conductivity
Kh	Horizontal hydraulic conductivity
Km	McMurray Formation
km/h	Kilometers per hour
Kv	Vertical hydraulic conductivity
LAI	Leaf Area Index
LCCS	Land Capability Classification System
LFH	Litter-fibric-humic
Mg^{2+}	Magnesium
Mg	Megagrams

mg	Milligrams
mm	Millimetres
N	Nitrogen
Na^+	Sodium
^oC	Degrees Celsius
P	Phosphorus
PET	Potential Evapotranspiration
Pg/ Pl	Pleistocene Tills
S	Sulphur
SAR	Sodium Adsorption Ratio
SBH	South Bison Hill
SSOB	Saline Sodic Overburden
Syncrude	Syncrude Canada Ltd.
TPR	Timber Productivity Rating
Tr	Annual Transpiration

1.0 INTRODUCTION

This report provides a synthesis of 14 years of reclamation research and landscape performance of the Syncrude Canada Ltd. (Syncrude) South Bison Hill (SBH[1]) reclamation site (Figure 1.1, Drawings 00, 1, and 2), with intent to answer two questions:

1. What are the measured and predicted responses to reclamation-material depth over Clearwater overburden fill from data collected to date on the SBH study site?
2. What is the minimum reclamation-cover depth required to support reclamation vegetation requirements on saline-sodic Clearwater overburden?

This report provides background on the construction and reclamation of SBH; results from the reclamation cover test plots and performance of all reclamation in the study area, and modeling to predict future performance under drought conditions.

The study authors have been involved to various degrees with the design, reclamation, and research of SBH since 1999. The results of their work are synthesized in the body of this report. Individual research reports and analyses, focusing on climate and evapotranspiration (ET), below-ground (rooting) performance, above-ground vegetation performance, soil moisture, and soil salinity are included in the attached appendices.

This report focuses on the performance of three reclamation test plots on SBH, each 1 hectare (ha) in area, with reclamation material thicknesses of 35 centimetres (cm), 50 cm, and 100 cm, respectively. It also looks at the performance of 49 ha of reclamation over time. Particular examination of the performance of various cover thicknesses against three key risks to plant growth is undertaken:

- Water available to plants under drought conditions;
- Salinization of the lower layers of the reclamation cover through diffusion of salts from the Clearwater overburden; and
- Sodification of the lower layers of the reclamation cover through diffusion of salts from the Clearwater overburden.

This body of work comprises one of the largest, most comprehensive, and longest studies of reclamation performance in the region and provides, in Syncrude’s opinion, a sound basis to answer the study questions. The study is intended to establish an optimal capping depth on Clearwater overburden based on the best available science and professional judgment. This “optimal capping depth” seeks to balance potential reclamation risks of Clearwater overburden with availability of suitable soil reclamation materials and other environmental and economic considerations.

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[1] Note that South Bison Hill (SBH) was referred to as the 30 Dump or SW 30 Dump during.

Figure 1-1. SBH reclaimed (looking south). Photo from September 2012.

1.1. Background

Oil sands mine reclamation requires the salvaging of cover soils and secondary material in advance of mining, in order to subsequently cover underlying (placed) strata such as Clearwater overburden and provide a suitable growth medium for boreal forest landscapes. Since a finite volume of suitable reclamation material exists within the project development footprint, soil cover design optimization (considering layering, thickness and quality of capping material) is the focus of ongoing research and monitoring. The arising intellectual capital will define and improve best management practices such that soil materials are used appropriately and efficiently in reclamation activities.

The Environmental Protection and Enhancement Act (EPEA) Permit 26-02, as amended (the Permit) stipulates the current requirements in respect to thicknesses and quality of reclamation cover for the Syncrude Project. The Land Capability Classification System (LCCS) (CEMA, 2006) provides methods to assess soil quality. Syncrude understands the objective of both instruments to be the attainment of land capability equivalent to that of the predisturbance landscape for the reclaimed landscape as a whole. This study focuses on determining design parameters for boreal forest ecosites on disturbed lands that yield tree productivity similar to that of predisturbance conditions.

Clearwater Formation (Kc) overburden[2] is a saline-sodic marine clayshale layer that immediately and conformably overlies the McMurray Formation (Km) oil sand ore body. Significant quantities of Kc overburden require mining, placement, and reclamation at the Syncrude Mildred Lake mine. Research was initiated in 1998 to determine the thickness of reclamation material placed over Kc required to provide adequate rooting depth, protection against salinity, and provision of soil water holding capacity similar to that of natural soils in the region. Based on a literature review of sites (mostly located outside of the oil sands region), a thickness of 100 cm was selected.

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[2] In some previous reports this material was termed fill, shale, clayshale, or simply overburden, sometimes leading to confusion, especially with the reclamation material, which is also overburden. Syncrude's EPEA approval also refers to this material as Clearwater overburden.

Upon completion of placement of Kc overburden material in SBH, an “instrumented watershed” was created that included three large test plots focused on re-examination of the role of cover thickness on reclamation performance, with the objective of confirming or revising the 100 cm prescribed thickness. Results from the study were intended to provide data upon which to consider changes to the Permit prescription for reclamation material thickness for the subsequent Kc overburden dumps at Syncrude.

In 2007, the Permit stipulated an “average minimum” of 150 cm of capping material on Clearwater overburden. Syncrude understands this increase in thickness was intended to maintain 100 cm thickness of reclamation material unaffected by salts diffusing upward from the Kc overburden. Syncrude further understands that this increase was intended to ensure that there would be equivalent capability for white spruce and aspen tree growth in reclaimed areas. However, this soil prescription change has had several other direct consequences, including:

- The need to salvage and stockpile much larger volumes of soil, some of which have to be stripped from, and in some cases stockpiled, outside the mine footprint;
- A change in the water balance for areas reclaimed with 150 cm of soil – specifically, a decrease in yield (particularly runoff), with less water available to support reclaimed wetlands and end pit lakes (EPL) downstream; and
- A significant increase in costs associated with additional salvage and stockpiling of soil reclamation materials.

In 2012, Syncrude initiated a program and assembled the SBH research team to synthesize the existing data, collect additional data in the field, and conduct modeling to clarify the existing projected performance of Kc overburden soil cover under different climatic conditions. The results of this program are included in Appendices A to F.

1.2. Goals

The 2012 study had the following goal:

> *“For Clearwater overburden fill landforms, determine the optimum soil cover depth required that will deliver an appropriate amount of water for targeted boreal forest vegetation without compromising the quality of the cover with salt ingress*.”

1.3. Study Objectives

Study objectives were as follows:

- Compile and map landform history, including construction dates, construction materials, reclamation materials and placement dates, revegetation species, planting densities, climatic data, and soil moisture monitoring data;
- Collate soil salinity data from previous research programs. Collect additional soil salinity data, and compare to previous sample events;

- Measure root development in soil reclamation materials and underlying overburden to compare root distribution of reclaimed soils with undisturbed soils of the region and determine the presence (and potential) for rooting in saline-sodic overburden;
- Measure tree growth performance at SBH to date across different topographic slope positions and aspects, and compare to tree growth yields within targeted native vegetation ecosites;
- Model soil-water availability of various reclamation capping thicknesses with 60 year climate data of the region that span from dry (drought) to wet conditions.
- Integrate the model results and site performance to estimate the reclamation performance of the study area and compare it to targeted native vegetation species and communities;
- Compile results from the research programs to determine if the key messages of reclamation potential on Clearwater overburden are consistent with the progress to date and that expected in the future;
- Compile a table of measured and predicted performance for various capping thicknesses; and,
- Recommend the optimum capping thickness for Clearwater overburden dumps at Syncrude.

1.4. Research Team

A multi-disciplinary research team was assembled to examine the current state of the SBH study area (Table 1-1). Research team members were chosen on the basis of experience and past participation in research undertaken at SBH. A description of the research personnel backgrounds and project role is provided in Appendix G. Journal articles published by the team for research at SBH prior to the 2012 field study have been included in Appendix H.

Table 1-1. South Bison Hill Soil Capping Research Synthesis research team.

Personnel	Organization	Position	Study Role
Marty Yarmuch (MSc, PAg)	Syncrude Canada Ltd.	Soil Scientist	Project Manager
Elisa Scordo (MSc, PAg, GIT)	BGC Engineering Inc.	Hydrologist	Technical Support
Gord McKenna (PhD, PEng, PGeo)	BGC Engineering Inc.	Senior Geotechnical Engineer	Technical Support and Review, Study Guidance
Julian McGreevy (BASc, EIT)	BGC Engineering Inc.	Junior Geological Engineer	Technical Support
Justin Straker (MSc, PAg)	Integral Ecology Group	Forest Ecologist / Soil Scientist	Project Lead of Above-ground Vegetation Response
Joel Hilderman (MSc, PEng)	Klohn Crippen Berger	Senior Geoenvironmental Engineer	Project Lead of Salt Profiles and Transport
Ken Van Rees (PhD)	University of Saskatchewan	Professor of Forest Soils in Agriculture and Bioresources	Project Lead of Below-ground Root Distribution
Lee Barbour (PhD, PEng)	University of Saskatchewan	Professor in Civil and Geological Engineering	Project Lead of Soil-Water Dynamics modeling and Technical Expert for Salt Profiles and Transport
Robbie Price (BSc)	NorthWind Land Resources Inc.	Soil Scientist	Field Lead for Salt Profiles and Transport and Below-ground Root Distribution
Sean Carey (PhD)	McMaster University	Associate Professor in School of Geography and Earth Sciences	Project Lead of Evapotranspiration and Net Ecosystem Exchange Assessment

2.0 LANDFORM HISTORY

2.1. Study Area

SBH was one of six overburden placement sites constructed in the South Hills area on the southern edge of the Syncrude Mildred Lake leases (Drawings 1 and 2). Table 2-1 provides a timeline in respect to reclamation and research activities.

Table 2-1. Key study dates.

Year	Event
1977-1996	Mining of West-in-pit occurs. Current location of SBH is one of the first mining areas.
1986-1996	SBH landform construction (placement of mining fill). Landform grading occurred over two years.
1998	Initiation of soil capping study including site selection and experimental design
1999	Instrumentation of capping study area
1996 – 2003	Placement of reclamation material
2000 – 2004	Revegetation
1996 – 2013	Landscape performance monitoring
2012	Initiation of SBH synthesis and field program
2013	Synthesis complete, report presented

SBH was the first overburden structure at Mildred Lake mine constructed primarily with Kc overburden. Kc overburden presents unique challenges to reclamation due to its high salinity/sodicity and higher clay/silt proportions. An instrumented watershed was constructed at SBH, with weather stations, weirs, soil moisture stations, and groundwater wells supporting research at the site (Drawings 2 and 3).

The SBH study area was formally defined for the purposes of the SBH Research Synthesis. The study area covers an area of 49 ha, with nominal dimensions of 0.5 km by 1.1 km. The study area contains five primary landscape units: a north-facing slope, an east-facing slope, a south-facing slope, a west-facing slope, and a plateau. A swale drains the plateau down the west slope and into Peat Pond and Golden Pond (constructed marshes) and into Base Mine Lake (BML; Drawing 4). These downstream areas are excluded from the present soil-capping study area, but are the subject of research and monitoring under other programs.

2.2. Climate

SBH is located in the mixedwood ecoregion of Northern Alberta. The Köppen Climate Classification System, based on vegetation distribution, air temperature and precipitation trends, describes this area as hemiboreal (regional climate between northern temperate and subarctic). Climate at SBH is typified by substantial seasonal variations, ranging from long, cold winters to short, moderately warm summers.

Two automated meteorological stations; 30T on the plateau and 30W on the north-facing slope, were installed to collect standard climatic parameter data. Table 2-2 shows the annual averages for climate data recorded within the study area.

Table 2-2. Annual averages for selected climate data recorded at SBH.

Data Element	South Bison Hill*		Fort McMurray Airport	
	Annual Average	Period of Record	Annual Average	Period of Record
Air Temperature (°C)	-	-	0.3	1944-2009
Wind Speed (km/h)	-	-	9.6	1953-2009
Wind Direction	Southeasterly	2006-2011	Southerly	1953-2009
Total Precipitation (mm)	-	-	437.0	1944-2009
Rainfall (mm)	250.5	2006-2011	322.0	1944-2009
Snowfall (mm)	119.0	2008-2011	143.1	1944-2007
Potential Evapotranspiration (mm)	-	-	607***	1953-2007
Potential Evaporation (mm)	583.8**	2006-2011	-	-
Dew Point Temperature (°C)	-	-	-6.2	1953-2009

* (O'Kane 2008, 2009, 2010, 2011, 2013)

** Potential evaporation computed using the Penman (1948) method.

*** Long-term potential evapotranspiration (PET) data is synthetic and was created since Environment Canada records were not available for the Oil Sands region. PET was calculated according to Morton et al., (1985) and was set equal to the estimated evaporation from a 1 m deep lake. The model uses average monthly global solar radiation air temperature and dew point temperature. BGC calculated PET for the period of January 2002 to November 2009, and PET data prior to 2002 were obtained from a monthly time series produced by AMEC and AQUA TERRA Consultants (2004). (BGC, 2012)

2.3. Predisturbance Conditions

Prior to development of the Mildred Lake Project , a mix of upland forest, down-cutting river and stream valleys, and flat-lying bogs and fens dominated the landscape with water tables at or near the land surface. Mining and subsequent backfilling of the mined out-pit with Kc overburden altered all predisturbance conditions in the study area.

2.4. Landscape Performance Objectives

Syncrude's reclamation philosophy, as provided in the 2011 Life of Mine Closure Plan, is as follows:

"Syncrude's goal is to progressively create a self-sustaining closure landscape that:

- *Has capability equivalent to that existing prior to development;*
- *Is integrated with the surrounding area;*
- *Establishes boreal forest upland and lowland communities;*

- *Yields water suitable for return to the natural environment; and*
- *Is planned in direct consultation with local, directly affected stakeholders."*

"Reclamation of the site is considered successful and suitable for custodial transfer when these objectives are achieved. Landscape performance objectives adopted for this plan are:

- *Areas of land capability classed suitable for commercial timber production;*
- *Extensive areas returned to a natural state and suitable for traditional land uses such as hunting, trapping, fishing, and harvesting of traditional plants; and*
- *Wildlife habitat deemed within the range of natural variability in the region."*

The research group considered this philosophical approach and identified the following design constraints in respect to minimum soil thickness:

- Has enough soil cover thickness to provide available water holding capacity (AWHC) (so that there will be enough water to sustain boreal forest uplands during periods of drought in a way similar to natural surrounding areas);
- Has sufficient thickness, layering, and geometry to limit the salt ingress from the underlying Clearwater overburden; and
- Provides suitable quantities and qualities of runoff, interflow, and groundwater to support downstream aquatic ecosystems.

As noted, Syncrude seeks to create reclaimed landscapes that have equivalent capacity to predisturbance conditions. Syncrude is not targeting ideal conditions or a guarantee against reduced growth, disease, or mortality under drought conditions; rather, Syncrude has designed its reclaimed landscape to have performance similar to that of the surrounding natural areas.

Reclamation productivity potential of the closure landscape is determined on the basis of soil quality of the landform characteristics (e.g., substrate type or quality, landform slope and topography, and position in the landscape or location within the mine footprint), soil quality of the materials available for soil reclamation placement, and soil reclamation cover design (soil horizon placement lifts or horizons and total reclamation capping thickness).

The soil reclamation cover design and water availability for reclamation covers over saline/sodic overburden are intended to provide the ability to support target tree species. The land capability of current reclaimed saline/sodic areas is generally Class 2 as defined in the LCCS, which is moderate capability for forest use (CEMA, 2006).

Reclaimed saline/sodic overburden landscapes are intended to be most similar to d-ecosite vegetation communities of the region (Beckingham and Archibald, 1996). Drier sites will trend more to b and c ecosites, while wetter parts of the landscape will be more like e to l ecosites. Table 2-3 provides a brief description of the different ecosites. Vegetation species present through seeding, planting or natural ingress must be self-sustaining and/or allow the ingress of targeted native vegetation.

Table 2-3. Ecosites of the boreal mixedwood region.

Ecosite	Ecosite Description*		
	Name	**Moisture Regime**	**Nutrient Regime**
b	Blueberry	Submesic	Medium
c	Labrador tea-mesic	Mesic	Poor
d	Low-bush cranberry	Mesic	Medium
e	Dogwood	Subhygric	Rich
f	Horsetail	Hygric	Rich
g	Labrador tea-subhygric	Hygric	Poor
h	Labrador tea/horsetail	Subhydric	Medium
i	Bog	Subhydric	Very poor
j	Poor fen	Subhydric	Medium
k	Rich fen	Subhydric	Rich
l	Marsh	Hydric	Rich

* Field Guide to Ecosites of Northern Alberta (Beckingham and Archibald, 1996).

Soil cover design must also recognize the risk of soil salinization of the soil reclamation profile (or soil rooting depth). Upward movement of salts from saline/sodic overburden into the soil reclamation cover, as well as the potential for additional salt generation from the oxidation of the saline/sodic overburden, can reduce the vegetative capability of the reclaimed saline/sodic landscape. To reduce the risk of soil salinization of the soil reclamation covers, a suitable capping thickness is placed above the overburden to provide an adequate rooting depth net of salinization impacts to support growth of vegetation affiliated with targeted ecosites.

Constructed landforms and their soil covers are also designed to minimize risk of slumps and erosion of the soil cover or the underlying substrates.

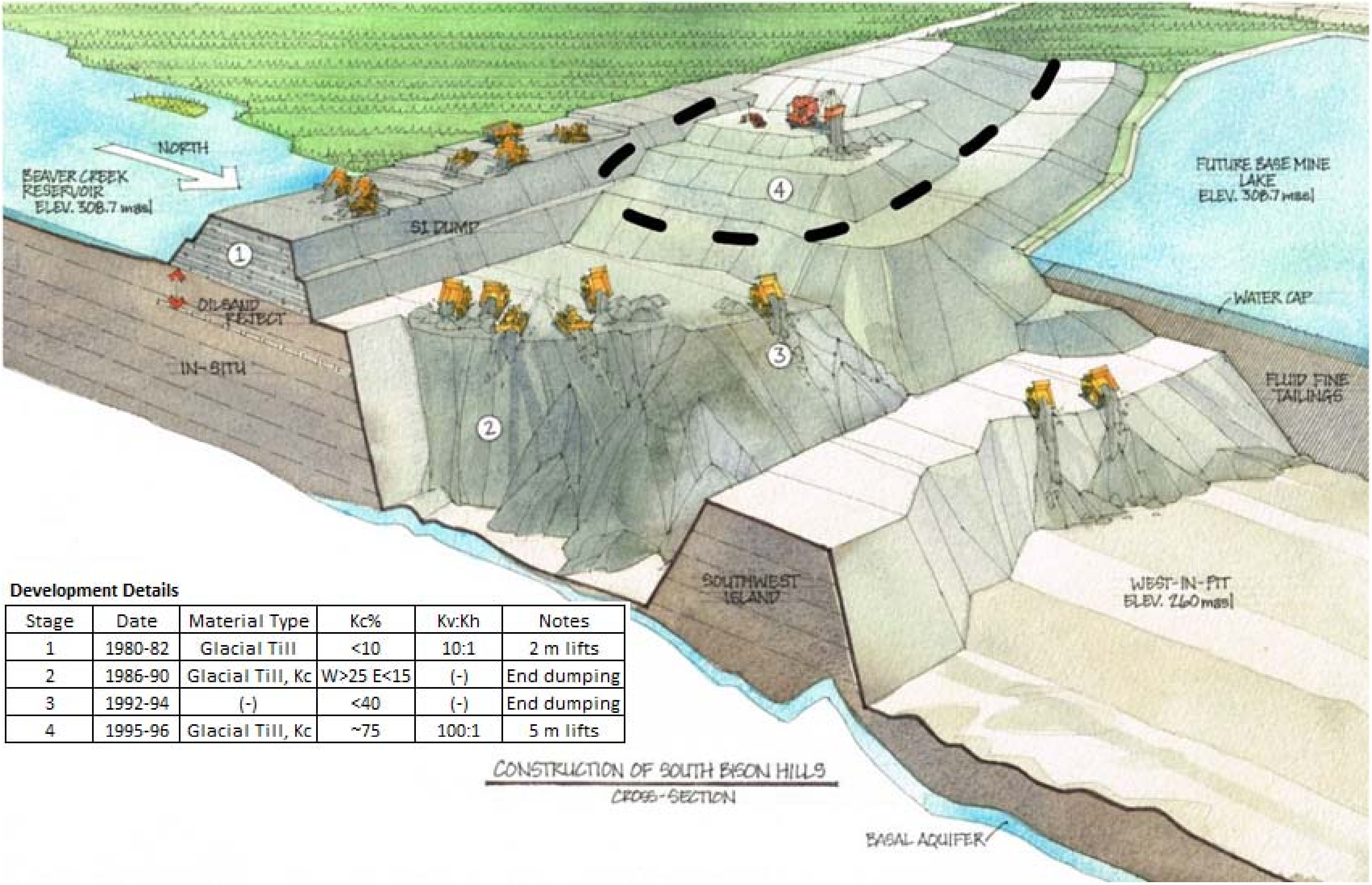
2.5. Construction History

The Syncrude mining sequence requires the removal and stockpiling of organic surficial soils for use as reclamation material, and the subsequent removal of inorganic “overburden”, stored in perimeter facilities or in mined out pits. The exposed deposit of oil sand ore is removed and processed in the Extraction Plant to recover the bitumen resource.

As the Mildred Lake mine expanded westward, the overburden being stripped began to include Cretaceous Clearwater Wabiscaw Formation (Kcw) sand and clay and Kc clayshale. (For a discussion of bedrock geology see Carrigy, 1959.) This overburden was deposited into surficial and in-pit overburden landforms (Figure 2-1).

The SBH landform is located on a backfilled pit. The primary fill within SBH is Kc, a saline/sodic shale with approximately 0.5% pyrite. This landform also contains considerable volumes of lean (low grade) Km oil sands and Pleistocene glacial tills. For the purposes of this study, the fill materials are termed “Clearwater overburden.

A placement time series and construction details for SBH is presented in Table 2-4 and Drawing 5. The study area is located on the upland portion of the dump, and is predominantly influenced by Stage 4 (Figure 2-1). Appendix I and Drawing 6 provide historical photographs of SBH.



Development Details

Stage	Date	Material Type	Kc%	Kv:Kh	Notes
1	1980-82	Glacial Till	<10	10:1	2 m lifts
2	1986-90	Glacial Till, Kc	W>25 E<15	(-)	End dumping
3	1992-94	(-)	<40	(-)	End dumping
4	1995-96	Glacial Till, Kc	~75	100:1	5 m lifts

Figure 2-1. SBH construction sequence. Black dashed line highlights the approximate extents of the SBH study area.

Table 2-4. SBH fill placement and construction details.

Stage	Construction Period	Details
1	1980 - 1982	• Fill material comprised of Pleistocene (P_g and P_l) tills with less than 10% K_c clays. • Constructed in 2 m lifts; dozers were used to create the flattened benches. • K_v:K_h ratio estimated to be 10:1 based on field pit studies (Lussier et al., 2000 and Strueby, 1996).
2	1986 - 1990	• Fill material is a mixture of glacial material integrated with Kca and Kcw as well as some lean oil sand (Syncrude, 1999). • 50 m end dumped fill, i.e. fill that was dumped or pushed off the edge of the dump into the pit and did not receive additional compaction.
3	1992 - 1994	• Fill material contains less than 40% Kc. • Fill was end-dumped and dozed off the bench and allowed to slide 40 to 50 m into the pit.
4	1995 - 1996	• Fill material contains approximately 75% Kc, mostly Kca, Kcb, and Kcc units with the remaining material low-grade oil sands (Km) and a small amount of glacial till (Pg). Boulders of indurated Kc and Km known locally as siltstone range from about 1 kg to 100 tonnes mass and account for about 1 to 5% of the dump by volume (Syncrude, 1999). • From 320 to 350 m elevation the fill contains mostly Kc. • Much of the construction occurred in the winter, meaning that snow layers were present between some fill layers. This may be responsible for zones of increased saturation in this section (Chapman 2008). • Where constructed in 5 m thick lifts, the top 2 m of each lift is denser, receiving more compaction from equipment traffic. The bottom of each lift is loose / lower density. • K_v:K_h ratio estimated at approximately 100:1 (Lussier et al., 2000; Strueby, 1996).

Material at depth was placed in an unstructured manner, whereas surface materials were compacted by equipment and vehicle traffic. Given the variability in both material type and construction format, subsidence is expected to be both spatially and temporally irregular.

2.6. Landform Design and Landform Grading

SBH was the first landform in the region to be formally designed on the basis of currently accepted principles of landform grading (Schor and Gray, 1995). Dump construction was largely complete by this time with landform grading being largely a retrofitting exercise.

Prior to this design, SBH slopes were designed to include 4H:1V intermediate slopes separated by flat benches, capped with 100 cm of reclamation material, and revegetated with pasture grass. The east slope was constructed and reclaimed using this initial design.

Some geotechnical slippage occurred on the east slope in 1996, with potential mixing of reclamation material and Clearwater overburden taking place during slope remediation. In 1997, the east slope was revegetated to establish a pasture. In later years, the east slope was reclassified as a commercial forestry area and planted with an Aspen-White Spruce mix. The main swale and plateau was engineered and constructed in 1997-1998 horseshoeing such manner as to encourage drainage from the dish-shaped plateau downward to Peat Pond (Schor and Gray, 2007). The drainage route was designed to follow a haul ramp, which has a favourable slope angle of 8%. The remaining slopes were designed and landform graded to a maximum 5H:1V slope, and benches were removed or graded outward to promote drainage (Figure 2-2).

Figure 2-2. North side of SBH during regrading of upper lifts. Photo taken between 1994 and 1999.

2.7. Landform Reclamation and Revegetation

Soil reclamation placement occurred in different areas of the SBH study area in 1996, 1999, 2001, 2002 and 2003. Syncrude operated under several operating approvals over this time frame, with variations in the soil replacement requirements of these approvals.

A 100 cm average target reclamation material thickness was used for all 46 ha of the SBH study area outside of the cover trials, but there was variation in the soil cover design. The three 1 ha cover trials, are denoted as D1 (50 cm cover thickness), D2 (35 cm cover thickness), and D3 (100 cm cover thickness). Figure 2-3 shows the locations of the soil cover trials. Drawing 7 provides a history of reclamation material placement, with additional details in Table 2-5. Figures 2-3 and 2-4 show SBH shortly after placement of reclamation material.

Figure 2-3. North side of SBH after reclamation, featuring capping trial area (2001).

Figure 2-4. East slope several years after reclamation repairs (2001).

Table 2-5. Soil placement activities in SBH study area.

Soil Placement Year	Area (ha)	Comments
1996	5.6	East slope • Slope failures in spring following winter placement. • Seeded to pasture grass mix to stabilize slopes.
1999	12.0	North slope • Includes SBH capping study research area. • Portions amended with Peat in 2001 (30 cm).
2001	28.9	Plateau and West, South, East slopes • West, South slopes include soil amendment areas of 1999 soil placement.
2002	1.3	North slope • Additional soil placement on north slope.
2003	1.2	South slope • Peat surface amendment 2001 soil placement (30 cm).
Total	**49.0**	

Four soil material types were used in the soil replacement profiles in the study area:

- Direct placement: material containing a suitable balance of organic (Muskeg) and mineral (Secondary) soils, salvaged from the surficial 50 cm of the predisturbance salvage area. This material was placed without a further cover soil layer.
- Peat: predominantly organic soil generally containing little to no mineral soil and placed as a cover soil layer over mineral subsoil (secondary).
- Secondary: mineral soil containing little to no organic materials. This material is suitable (Good to Fair soil quality) for use as subsoil (AAFRD, 1987) and is overlain by a cover soil layer.
- Non-sodic: mineral soil material similar to secondary, but not meeting all Good to Fair soil suitability requirements. Generally, these soils exceeded the percent clay fraction and/or soil pH ratings.

The majority of the soil placement in the study area consists of 20 cm of peat[3], 30 cm secondary, and 50 cm non-sodic soil (Drawings 7 and 8). This design covers the plateau, south, west and upper east portions of the study area. The north portion of the study area consists of 20 cm of peat over 80 cm of secondary soil.

The capping study trial cover designs are:

1. D3 – 20 cm peat and 80 cm secondary;
2. D1 - 20 cm of peat and 30 cm secondary; and,
3. D2 - 15 cm of peat and 20 cm secondary.

The remainder of the study area (east slope) consists of 50 cm of direct placement and 50 cm non-sodic soil. Some portions of the area reported in Drawing 7 report total capping thicknesses greater than 100 cm (additional peat surface placement); these areas were subject to supplemental soil placement to amend areas identified in the post-placement assessment that did not meet target thickness.

Revegetation activities within the study area took place in 1999 and 2002 - 2004. Regulatory requirements required disturbed land to be returned to 70% upland ecosystems and 30% to wetland ecosystems. For upland ecosystems, 50% were to be productive forest (stocked with trees to meet standards of a commercial forest) and 20% non-commercial forest (including shrubland and grassland). This was adjusted in later years of the site reclamation to establish a revegetation plan that complied with the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (1998 Table 2-6 and Drawings 5 and 9 provide an overview of revegetation activities.

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[3] This study uses the term “peat” to describe the top reclamation material placement. Some earlier reports refer to this layer as muskeg, peat-mineral, or peat mineral mix.

Table 2-6. Revegetation activities in SBH study area.

Location	Revegetation Information	
	Cover Crop Information	Reforestation Information
East slope	Cover crop (1997): pasture seed mix (wheatgrass (slender and intermediate), russian wild rye, birdsfoot trefoil, alsike clover and timothy) Rate: 27 kg / ha Fertilizer: 10:30:15:4 N-P-K-S[1] (570 kg / ha)	Year – 2002 Density: 2,074 stems / ha Species: 1:1 (aspen : white spruce) Year – 2003 (toe slope) Density: 1,411 stems / ha Species: white spruce Year – 2003 (upper-crest slope) Density: 2,383 stems / ha Species: 0.6:1 (aspen : white spruce) Year – 2004 (toe and upper-crest slopes) Density: 622-857 stems / ha Species: Shrub (green alder)
North slope	Cover crop: barley Rate: 20-26 kg / ha Fertilizer: 10:30:15:4 N-P-K-S (355-363 kg / ha)	Year – 1999 (capping study) Density: 1,600 stems / ha Species: 1:1 (aspen : white spruce) Year – 2002 (northeast) Density: 2,074 stems / ha Species: 1:1 (aspen : white spruce) Year – 2004 (northwest) Density: 2,125 stems / ha Species: 0.7:1 (aspen : white spruce)
Plateau	Cover crop: barley Rate: 20-25 kg / ha Fertilizer: 10:30:15:4 N-P-K-S (326 kg / ha)	Year – 2003 Density: 1,944 stems / ha Species: 0.3:1 (aspen : white spruce) Year – 2004 Density: 857 stems / ha Species: Shrub (green alder)
South slope	Cover crop: barley Rate: 20-42 kg / ha Fertilizer: 10:30:15:4 N-P-K-S (326-327 kg / ha)	Year – 2003 Density: 2,383 stems / ha Species: 0.6:1 (aspen : white spruce)
West slope	Cover crop: barley Rate: 20-25 kg / ha Fertilizer: 10:30:15:4 N-P-K-S (326 kg / ha)	Year – 2003 Density: 2,383 stems / ha Species: 0.6:1 (aspen : white spruce)

1: Ratio of Nitrogen (N): Phosphorus (P): Potassium (K): Sulphur (S)

3.0 STUDY METHODS

The research and monitoring of SBH has been ongoing since 1998, covering aspects such as soil-water availability, geochemistry, hydrology, water quality, growing season carbon balances, nutrient availability, and vegetation response (above- and below-ground). In 2012, research activities focused on confirming trends identified in previous years to document reclamation progress and to address data gaps. This outlines the research methodology for the capping study at SBH.

3.1. Study Approach

Established in 1999, SBH became Syncrude's first research watershed (Barbour et al., 2010). The focus of the study was to understand the mechanisms associated with water and salt migration within the soil cover and the affiliated impact on vegetation, to facilitate selection of optimum reclamation material cover thickness.

Study scope includes:

- Compilation of history, data, reports, and published theses and papers;
- Design and completion of a targeted field program;
- Synthesis, analysis and modeling of all data;
- Identification of risks to plant growth using a Failure Mode and Effect Analysis (FMEA) to predict performance of various cover thicknesses against closure plan goals; and,
- Preparation of reports.

The fundamental hypothesis in respect to this study is that the vegetation communities have matured such that the water demand has reached a maximum/steady-state condition, and that the fluxes and water pathways measured are similar to those that will exist in the future, and similar to conditions in the surrounding undisturbed landscape.

Table 3-1 provides a list of cover soil thicknesses evaluated in the present study.

Table 3-1. Reclamation cover thicknesses considered.

Soil cover thickness (cm)	Comment
35	Thinnest cover under consideration, tested in D2 trial.
50	Tested in D1 trial.
75	Intermediate between 50 and 100 cm.
100	Tested in D3 trial. This was the prescription for Clearwater overburden (and other similar materials) from 1990 to 2006.
125	Intermediate between 100 and 150 cm.
150	Thickest cover under consideration, this is the prescription for reclaiming Clearwater overburden since 2006.

3.2. Literature Review: Results of 2010 synthesis

The watershed research program was established to address significant questions concerning landforms in the post-mine landscape. Questions were grouped into either scientific or design categories (Barbour et al., 2010), as follows:

a. Scientific:
   i. What are the water and energy balances within a reclaimed landscape and what processes control moisture and energy dynamics?
   ii. What are the salt, major ions, nutrients, metals and organics balances and what processes control these mass fluxes?
   iii. How do vegetation and other ecological parameters respond to moisture, energy and salt fluxes?
   iv. Can the temporal and spatial distribution of these fluxes be defined?

b. Design:
   i. How can industry optimize the design of reclaimed watersheds to create a sustainable boreal forest landscape?
   ii. How can the guidelines for reclamation be improved based on research findings?

By 2006, this soil-capping research had resulted in 17 theses and numerous reports and journal articles. At this point in time, the need to transfer the knowledge gained from lessons to recommendations for reclamation design and practice was acknowledged.

3.2.1. Technology Synthesis

The Technology Synthesis was designed to discuss and evaluate research performed on soil capping design from program initiation through 2006. Three main issues were of concern were evaluated:

- Water balance – soil structure evolution and soil moisture regimes;
- Salt balance – salt loading to covers; and
- Biological – response to covers from saline sodic overburden (SSOB) and tailings sands.

Further focus of the synthesis was to understand how these areas of research integrated and affected one another to influence soil cover, and the impact of such influences on landscape design.

Key discoveries related to saline/sodic overburden from this research are as follows:

1. Soil Water and Structure:
   a. Field saturated hydraulic conductivity (K_{fs}) observations show that K_{fs} increases very rapidly in the five years after placement for peat mineral mixtures, mineral "secondary" soils, and Clearwater overburden. After five years K_{fs} reaches equilibrium. (Meiers, 2002; Meiers et al., 2006; Fact Sheet 5);
   b. Estimates of AWHC for reconstructed and natural soil profiles, as calculated by the LCCS for Forest Ecosystems in the Athabasca Oil Sands Region (CEMA, 2006), are conservative;

   c. Bulk density, soil penetration resistance, and infiltration of reclaimed soils have been found to be equal to or better than that of natural soils (Macyk et al., 2004; Fact Sheet 4);
   d. Reconstructed soils appear to have enhanced water holding capacity as a result of layering and the presence of peat-mixes (Chaikowsky, 2003; Burgers, 2005; Fact Sheet 2; Moskal, 1999; Fact Sheet 6; Macyk et al., 2004; Fact Sheet 4).;
   e. Several lines of evidence indicate that 35-cm layered covers (15 cm of peat-mix overlaying 20 cm of fine-textured mineral) cannot meet all of the water demands placed on them. This may indicate that ecosites drier than mesic are likely to develop where covers of this thickness are placed (Boese, 2003); and
   f. From a soil water perspective, 50 to 100 cm layered covers provide the lowest risk of water deficits in the long term, and provide sufficient to excess soil water for the vegetation communities that were monitored (6 to 20 year old stands and high water using non-forested communities) (e.g., Elshorbagy and Barbour, 2007; Fact Sheet 11; Shurniak, 2003).

2. Vegetation Community Response to Soil Salinity:
   a. Based on laboratory studies, the presence of saline water in the root zone of boreal forest vegetative species has been found to negatively influence plant physiological function (Bertness, 1991; Greenway and Munns, 1980; Purdy et al., 2005; Renault et al., 1999). However, water availability may be more critical than water quality for some species;
   b. Boreal plant communities can exist in areas where salinity and sodicity values are greater than current guidelines for soil quality (wetlands, riparian, and meadow zones). However, treed systems do not exist where topsoil (0 to 20 cm) salinity exceeds 4 deciSiemens per metre (dS/m) (Purdy et al., 2005; Fact Sheet 12);
   c. Treed boreal forests can exist in areas where subsoil salinity and sodicity have reached higher levels than previously thought possible. The hydrology of these systems is not yet well understood; however, it is of interest to determine the equilibrium states where such systems can exist. At the time of the 2006 research publication, the design of cover systems, which attempted to duplicate such an environment, were not recommended; and
   d. Salinity and sodicity deductions outlined in the 2006 LCCS document are overly conservative, based on the SBH research performed up to 2006.
3. Salinization in SSOB Systems:
   a. Oxidation of reduced sulphur (S) in SSOB material can result in an increase in the amount of mobile salts available for upwards migration into soil covers (Wall, 2005; Fact Sheet 18);
   b. Mobile salts in the SSOB, located below the cover-shale interface, diffuse upwards into the lower 20 to 30 cm of cover material in recharge areas at the time of cover placement. This is independent of cover thickness (Kessler, 2007; Fact Sheet 17).

   c. Salt flushing will occur by interflow along the cover-overburden interface as well as through deep percolation (Kelln et al., 2006, 2007a,b; Fact Sheet 20).
   d. Flushing rates are primarily controlled by the water balance of the landscape, the hydraulic conductivity of the overburden present, and the presence of topography that encourages interflow flushing (Shurniak, 2003; Fact Sheet 7; Renaud, 2009; Fact Sheet 19; Kelln et al., 2006; Fact Sheet 20).
   e. Analysis of field data and the review of geochemical and transport modeling suggest:
      i. salinity and sodicity will be isolated to the bottom portion of lower subsoils for 100-cm layered covers placed on *sloped* SSOB surfaces, the (Renaud 2009; Fact Sheet 19).
      ii. interflow is not an effective flushing mechanism for 100-cm layered covers placed on *flat* SSOB surfaces,.
   f. Salts flushed from upland areas will flow into receiving streams and wetlands.
   g. Monitoring of salt ingress to soil cover systems placed over SSOB areas will need to occur for 15 to 20 years following cover placement. Salt ingress will evolve over this time due to the long-term nature of the mechanism and the potential for substantial intra-year variability.
   h. The production of acidic drainage water within SSOB should not be an issue of concern. Excess levels of calcium carbonate present in these materials should buffer any acid released. (Wall, 2005; Fact Sheet 18)
   i. The oxygen consumed by reduced S in SSOB will lower subsurface oxygen levels but should not lead to levels in the soil covers that may cause poor plant growth. (Wall, 2005; Fact Sheet 18)

4. Soil Nutrients and Biological Response:
   a. Ecosites developed on coarse textured soils (*a/b* ecosites) have poorer nutrient concentrations and drier moisture regimes than those developed on fine textured soils (*d* ecosites) (AMEC/Paragon 2007; Fact Sheet 38).
   b. While a typical rooting zone for plants is 1 m in depth, most roots are found in the top 20 cm of the soil profile in undisturbed soils. Few roots are found in the 20- to 50-cm zone of the upper subsoil and even fewer in the deepest portion (50 to 100 cm below ground surface (bgs)). As such, the top 20 cm is the most important zone for assessing soil quality and for determining whether adequate essential nutrients are available. Rooting studies of reclaimed soils indicate a similar root distribution occurs in comparison to undisturbed environments, thus indicating the need to weigh topsoil health and nutrient profiles more stringently and lower subsoil less so with respect to soil salinity parameters (Close, 2007; Fact Sheet 13; Macyk and Richens, 2002; Fact Sheet 28).
   c. Organic carbon present in the topsoil of a reconstructed cover was found to equal or exceed the amount found in undisturbed upland soil in the region. This was true of the soil materials studied: peat-mix, mineral “secondary” materials, and LFH derived from *d* ecosites (Lanoue, 2003; Fact Sheet 23).

d. Pools of total N in topsoil reconstructed with peat-mix and LFH derived from *d* ecosites equal or exceed those found in undisturbed, fine textured (*d* ecosite) soils in the region. Total N levels in the reclaimed topsoil were overall significantly higher than those typical of *a* and *b* ecosites in the region (Lanoue, 2003; Fact Sheet 23).
e. Total phosphorus (P) can be effectively replaced by using peat-mix or a suitable fine-textured mineral soil “secondary” in the topsoil of reconstructed soil profiles. In the 20 to 100 cm zone, the pools of total P are only adequately replaced if soil material from the top 1 m of the undisturbed soil root zone is salvaged and used as part of the soil cover prescription (Lanoue, 2003; Factsheet 23).
f. Available P and associated elements are plentiful within the 20 to 100 cm bgs zone of natural *a* and *b* ecosites (Lanoue, 2003; Factsheet 23). None of the reclamation prescriptions studied had available P pools in the sub soils (20-100 cm) that compared to the *a* and *b* ecosites.
g. Nitrogen, the primary limiting nutrient in forest ecosystems, reaches peak demand between 20 and 30 years following tree establishment. Forest ecosystem model (FORECAST) outputs indicate a 20 cm peat-mix cap will result in tree production levels that are approximately 40 to 70% less than those reported for natural *a*, *b*, *d*, and *e* ecosites in the region (Alberta-Pacific Forest Industries Inc.; Welham, 2005; Fact Sheet 39).
h. Plant communities in reclaimed study areas (up to 25 years of age) are in the early successional stages for above and below ground community composition, including floral, mesofaunal, fungal and microbial. The ingress of native species into reclaimed study areas has been observed; however, whether communities are evolving towards community compositions similar to typical natural ecosites is unclear (Lilles et al., 2010 and Fact Sheet 32; Mackenzie 2006 and Fact Sheet 31). It was found that the use of LFH accelerated the establishment of native plant species and soil mesofaunal communities (Macyk et al., 2004; Fact Sheet 35; Battigelli, 2006; Fact Sheet 36).

3.2.2. Post-Technology Synthesis

Hilderman (2011) found that the percolation observed on the plateau was much greater than that observed on the slope. The percolation acts to oppose the upward diffusion of salts from the SSOB.

Carey (2008) and Carey (2011) reported on surface-atmosphere water exchanges for SBH for the first three and seven years, respectively. This work highlighted the early years after vegetation was established, and noticed that there was considerable inter-annual variability in vegetation composition and water use. For the first two years of record (2003 and 2004), climate variability largely controlled evapotranspiration rates, whereas vegetation controls, largely through surface resistance, increased its dominance as the site matured. As the aspen forest developed, a sharp increase in evapotranspiration and a reduction in soil moisture were observed and it was hypothesized that there may be insufficient water to sustain future site production, yet subsequent years or data (2010-2012) reported here show that in fact a relatively stable water use regime has ensued.

Kelln, Barbour, and Qualizza (2008) mapped the spatial distributions of soil water content and salt transport at the SBH study site. Conclusions were as follows:

- lower slope positions were wetter in the spring with down-slope movement of runoff and inter-flow waters. These wetter conditions in lower slope positions increased the extent of upward salt diffusion, while drier conditions at mid- and upper-slope positions limited salt transport.
- one dimensional modeling of Na+ transport indicates that interflow and deep percolation act to mitigate vertical salt movement.

Kelln (2008) and Kelln, Barbour and Qualizza (2009) developed and verified a model for fracture-dominated lateral subsurface flow and transport for the SBH site based. This model indicates that lateral sub-surface flow is initially dominated by fresh snow melt water in macropores, which chemically equilibrates with pore-water in the soil matrix. A porous media transport model was used to simulate the Na+ concentration of collected subsurface flow with time. This work demonstrates that interflow discharge concentrations increase as the depth of perched water diminishes with time and the drainage water is that associated with higher solute concentrations lower in the cover profile.

Keshta, Elshorbagy, and Barbour (2010) extended the system dynamics watershed (SDW) model developed Elshorbagy and Barbour (2007) into a generic system dynamics watershed model (GSDW). They utilized this model to highlight the differences in annual transpiration that would occur between covers of varying thickness. This work suggests that a hypothetical 70 cm cover (20 cm peat/mineral of 50 cm secondary) would have a comparable performance (in terms of transpiration) to that of a 100 cm cover.

Keshta, Elshorbagy and Carey (2009) also utilized the SDW model to compare reclamation sites (including SBH) with natural boreal stands. Furthermore, Keshta, Elshorbagy and Carey (2012) used the same modeling framework to assess changes to the water balance to project climate change from global climate model outputs. Results suggested that soil moisture deficits would slightly decrease in the future as increased precipitation would offset additional demand from evapotranspiration. It was noted the dynamic changes in vegetation were not included in the model, so it was difficult to assess the interaction between species adaptation and water use.

Lazorko and Van Rees (2012) collected soil cores to examine the effect of reclaimed Clearwater overburden soils on root distributions of planted and volunteer vegetation three years after planting. Root length distributions were concentrated in the upper 30 cm of the soil profile and roots were observed in the Clearwater overburden that accounted for 1.3% to 2.2% of the total root length in the profile. Root length density was also negatively correlated with Na and EC; however, when controlling for soil depth these relationships were not as strong at SBH. The root distributions on the young reclaimed sites were similar to those from undisturbed boreal forest stands overlying saline soils and appear to be unaffected by the Clearwater overburden.

3.3. 2012 Study

The objective of this report is to provide a recommendation to Syncrude in respect to the optimum reclamation material thickness for Clearwater overburden. To achieve this, the research team reviewed related existing information and designed a field and office program for SBH for 2012. Several research activities were advanced as part of this study, and are outlined in later sections. Activities ranged from collating findings and information of previous research and monitoring programs to repeat sampling of past research locations and/or sampling of newly established sites within SBH.

The purpose of these 2012 activities was to:

1. Confirm trends and projections of previous research – Several research programs measured site characteristics and changes in early stages of site development, with subsequent development of site models and projections of future development and capability. The 2012 program reviewed this earlier work and offered comment as to its validity.
2. Address data gaps – existing information and findings from previous research were evaluated in the context of the objectives of this research synthesis to identify data gaps. Where possible, the 2012 study included activities to address these data gaps.
3. Provide a snapshot of site development – a large portion of the research at the site took place while the site was still in its early years of development (vegetation growth and salt transport). Subsequent vegetation growth provides an opportunity to evaluate soil-water dynamics and salt transport mechanisms taking place at a more developed vegetative stage.

3.3.1. Study Area and Transect Layout

The 2012 study program selected a specific portion of SBH for the field program (Drawing 10). The total extent of the study area was 49 ha. The study area focused on terrestrial upland locations and did not include wetland areas. The study area incorporated slopes on the north, south, east and west sides of SBH. Nine transects were selected within the study area that were used as sample location sites to link several of the 2012 field activities (Drawings 10, 11, 12 and 13):

- Transects 1 to 3 are located on each cell of the capping study;
- Transect 4 is an additional transect on the north slope;
- Transect 5 is on the east slope;
- Transects 6 to 8 represent south slope aspects; and,
- Transect 9 is located on the west slope.

The study area was delineated into the following slope position units:

- Plateau – located on the shallow sloped upper plateau;
- Crest – located on the side slopes at or near the slope inflection between the plateau and the side slopes;
- Upper slope – located at the approximate midpoint between the midslope sampling location and the crest sampling location. On slopes with benches and multiple slope sections the upper slope sampling location is located on the uppermost slope section;
- Midslope – located at the approximate midpoint of the slope elevation and distance downslope between the crest and toe sampling locations;
- Lower slope – located at the approximate midpoint between the midslope sampling location and the toe sampling location. On slopes with benches and multiple slope sections the lower slope sampling location is located on the lowermost slope section; and
- Toe – located at the bottom of the slopes above any drainage structures located at the bottom of the slopes.

Slope positions were delineated using a digital elevation map (Drawings 4 and 14) of the site and the CorridorDesigner Toolbox topography position index map program with ARCGIS (Majka et al., 2007).

Sampling for the 2012 program occurred on transects and within slope position units.

3.3.2. Soil Quality, Salt Profiles and Movement in the Landscape

A salinity profile investigation was undertaken, incorporating previous salinity research programs at SBH with the 2012 field sampling program. This investigation was conducted by Joel Hilderman (Klohn Crippen Berger), Lee Barbour (University of Saskatchewan), O'Kane Consultants and NorthWind Land Resources Inc. The objectives of this activity were to:

- Produce salinity profiles (Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR) and soluble sodium (Na^+)) for the 2012 soil salinity data collected from the study site;
- Analyze the 2012 salinity profiles and provide interpretations of spatial trends, if any exist; and
- Compare the 2012 salinity profiles to historic profiles (2002 and 2008) from SBH research and provide interpretations of any apparent temporal trends in the data.

A detailed description of the sampling methodology, sampling locations, field notes and results are provided Appendix A and the analysis and interpretation of the results is provided in Appendix E.

3.3.3. Soil-water Dynamics

Mingbin Huang and Lee Barbour (University of Saskatchewan) and Sean Carey (McMaster University) undertook a modeling study to evaluate the sensitivity of water storage and water dynamics to reclamation cover thickness. This work included an assessment of the monitored performance of long-term, instrumented cover sites at SBH and a sensitivity study to evaluate the variation in long-term transpiration (Tr) releases from covers of different thicknesses placed over Clearwater overburden.

The objectives of the study were to:

- Compile and interpret existing field monitoring and site data on the hydrologic performance of reclamation covers on SBH;
- Develop a calibrated numerical model to simulate the available monitoring data obtained on 4 different cover thicknesses at SBH; and,
- Simulate the long-term performance of a series of hypothetical covers of varying thickness using long-term climate data for the region.

A detailed description of the study methodology, results and analysis is provided in Appendix F.

3.3.4. Vegetation Response

Two studies were conducted to assess the vegetation response to various cover thicknesses and soil salinity.

3.3.4.1. Above-ground vegetation response

Justin Straker and Katherine Garrah (Integral Ecology Group Ltd) conducted a field survey and sampling campaign to assess the effects of reclamation capping thickness on above-ground vegetation response. The objectives of the study were to:

- Collect data on a number of vegetation variables of interest;
- Use the data to advance understanding of reclamation performance on covered upland overburden structures; and,
- Identify any effects of cover thickness on this performance.

The primary variables measured as part of the evaluation included site index[4], stand density and stocking, and leaf area index. A detailed description of the study methodology, results and analysis is provided in Appendix C.

3.3.4.2. Below-ground root distributions

Ken Van Rees (University of Saskatchewan) investigated root biomass distributions at SBH. Previous work by Lazorko and Van Rees (2012) in 2003 had shown that root distributions had penetrated the reclamation cover and into the Clearwater overburden three years after planting. This study was a follow up on the root work done in 2003. The objective was to quantify the root biomass distributions for a larger area of SBH and determine if root systems

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[4] Site index is a term used to describe the potential for trees to grow at a particular location, a complete description of site index can be found in Appendix C.

are impeded by Clearwater overburden. Another purpose of the study was to confirm the root distribution pattern and depth for the Soil-Water Dynamics modeling study.

Under the direction of Ken Van Rees, NorthWind Land Resources Inc. conducted the field sampling program. A description of the sampling methodology, sampling location and field notes is provided in Appendix A and analysis and interpretation of the results is provided in Appendix D,

3.3.5. Evapotranspiration and Net Ecosystem Exchange Assessment

Sean Carey (McMaster University) has measured 10 years of growing season water, energy and Carbon Dioxide (CO_2) exchange atop SBH using the eddy covariance tower installed on the site. The objective of this activity was to:

- Compile 10 years of growing season ET and CO_2 flux data;
- Report temporal patterns of these fluxes and associated hydrometric measurements, and evaluate the link to the development of vegetation atop SBH; and,
- Compare values reported at SBH with those reported at other disturbed and undisturbed boreal forest aspen and mixed stands.

A detailed description of the methodology, results and interpretation is provided in Appendix B.

3.4. Synthesis

The modeling efforts used data from all parts of the 2012 study and previous research, and constitute a synthesis activity in their own right. These efforts are presented in Chapter 4.

Risk assessment is a systematic technique used to identify potential limitations to achieving a desired outcome, and is widely used in the oil sands industry. The risk assessment approach was used to classify the risks associated with the range of researched capping thicknesses over Clearwater overburden. Risks were quantified through estimating the probability of conditions causing plants to experience abnormal stress (stress which would not be experienced by the average natural ecosystem), such that establishment and/or growth is affected to the degree that the site might not meet reclamation objectives.

Risks to plant growth were identified by the research team and a probability of such plant growth risk occurring at a given cover thickness was determined. Plant growth risks were considered at the scale of the landform as a whole; small, underperforming areas were not considered a failure where the entire landform was performing adequately. The research team identified six potential plant growth risks (illustrated in Figure 3-1):

1. Water availability,
2. Salt effects due to evapo-concentration,
3. Salt diffusion causing drought stress,
4. Sodifiction of the soil structure
5. Sodium toxicity, and
6. Water logging of the root zone.

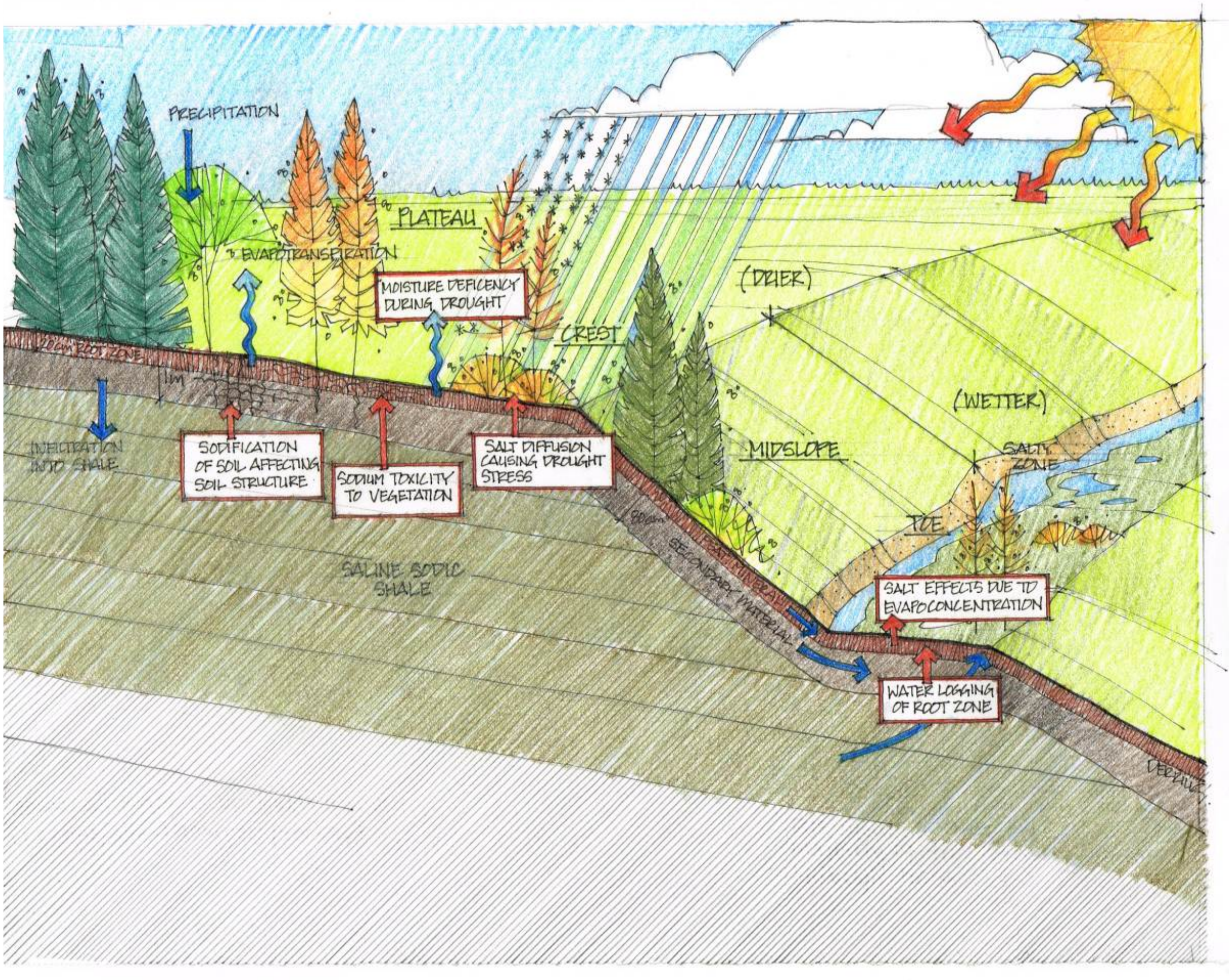

Figure 3-1. Clearwater overburden disposal area reclamation plant growth risks.

4.0 2012 FIELD RESULTS

This section provides a summary of the results and discussion of the individual 2012 research studies. A description and details of these research studies can be found in the reports provided in Appendices A to F.

4.1. Measured Soil Cover Thicknesses

The target cover thickness for the SBH study site was 100 cm, with the exception of the 35 and 50 cm capping trial plots. Net of placement variability, the mean thickness for all SBH sites is 106 cm, while the mean for the 35 cm (Transect 2) and 50 cm (Transect 1) capping trial plots is 30 and 49 cm, respectively (Table 4-1).

Excluding the shallow cover trial plots, the mean transect cover thickness ranges from 88 to 120 cm, and the mean slope position thickness ranges from 90 to 117 cm (excluding shallow capping trial plots). Although there is a significant range among individual sites, transects and slope position means are generally within 10 cm of the 100-cm target.

Although the placement thickness variation makes it more difficult to compare differences among aspects and slope position, the increased range in cover thickness of the SBH study site enhances the ability to assess the impact of capping thickness.

Table 4-1. Soil cover thickness summary in SBH study area (cm).

Transect	**Slope Position**							**Mean**
	Crest	**Upper**	**Middle**	**Lower**	**Toe**	**Plateau 1**	**Plateau 2**	
1	108	64	46	41	50	-	-	**49[1,2]**
2	124	30	43	25	10	-	-	**30[1,2]**
3	84	148	97	65	68	-	-	**106[2]**
4	67	185	92	145	96	-	-	**117**
5	93	76	74	68	194	-	-	**101**
6	69	72	100	124	76	-	-	**88**
7	110	-	115	-	115	133	127	**120**
8	102	-	60	-	77	115	112	**93**
9	100	88	93	83	88	-	-	**90**
Mean	**95**	**114[3]**	**90[3]**	**97[3]**	**102[3]**	**117[2]**		**106[3]**
Range	**67-124**	**72-185**	**60-115**	**65-145**	**68-194**	**87-145[2]**		**60-194[3]**

[1] Excludes Crest slope position (outside capping trial).; [2] Includes additional vegetation study plots not shown in table.; [3] Excludes 35- and 50-cm capping trial sites.

4.2. Evapotranspiration and Net Ecosystem Exchange Assessment

Appendix B summarizes 10 years (2003-2012) of ET, soil moisture and leaf area coverage information collected at SBH using the eddy covariance technique. The following sections summarize the results of this assessment.

4.2.1. Climate

The site has experienced considerable variation in growing season rainfall amounts during the 2003-2012 data collection period (Figure 4-1). The growing season rainfall was highest in 2012 (321 mm), whereas 2011 and 2007 were the lowest at 180 and 178 mm, respectively. The 30-year normal (1971-2000) rainfall amount for Fort McMurray during May to September is 312 mm; only 2012 exceeded the normal rainfall of the region. There was considerable intra-annual variability in the rainfall, as a wet or dry year was not necessarily wet or dry throughout. For example, 2012 (wettest year) had two extremely wet months (July and September) and a very dry August.

Most growing season months had temperatures slightly greater than the 30-year climate normal, with the exception of 2004 and 2005.Growing season temperature was coolest in 2004 (12.7°C), and warmest in 2011 (15.7°C). There was no apparent relationship between precipitation and temperature on a seasonal basis.

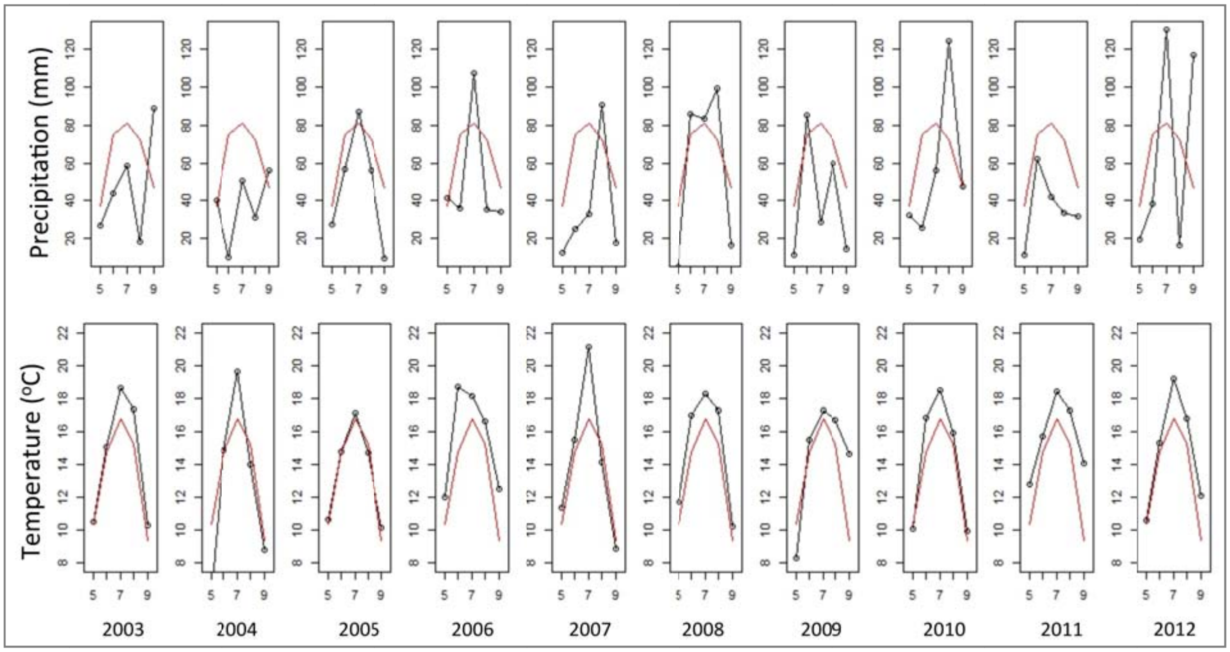

Figure 4-1. **Mean growing season monthly precipitation (a) and air temperature (b) for the 2003-2012 study period. Measured values are in black with circles, red line is the climate normal (1971-2000) for Fort McMurray. Month of year is on the x-axis.**

4.2.2. Soil Moisture and Suction

Soil water content within the upper 25 cm of the profile has varied both within and among years (Figure 4-2), but there is little variability in soil water content below 40 cm (data not shown). Soil water volumes are generally the highest in May due to snowmelt recharge and decline through the growing season. Rainfall during the growing season acts to recharge the soils.

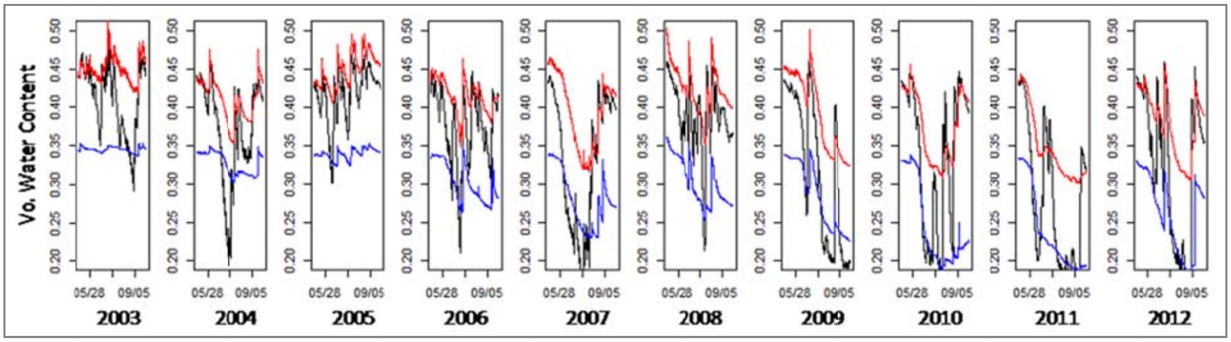

Figure 4-2. **Soil moisture in the upper 25 cm of the profile from 1 May to 30 September for all years. Black line is 5 cm, red line is 15 cm, and blue line is 25 cm depth.**

There are changes in the soil water content with time that reflect the development of the site vegetation. Aspen began to emerge in the site data collection area in 2006. 2004 was a notably dry year with a long period of summer soil moisture decrease; however, soil water contents at 25 cm depth did not show a large decline. Conversely, beginning in 2007 and increasing thereafter, soil water deficits became much greater at both the surface and at depth as the growing aspen drew increasing amounts of water from the root zone. Regardless of growing season rainfall amount, soil water deficits are evident, suggesting water uptake by vegetation has increased with observed development of the aspen. The soil water contents at the site clearly shows two states: pre-2007, during which emergent and perennial vegetation was less effective in utilizing near-surface water, and post-2007, after aspen emergence caused much greater soil-water uptake.

4.2.3. Evapotranspiration Rates

Average monthly ET rates (mm/day) follow a similar trend as Leaf Area Index (LAI), with increasing rates through the growing season followed by a steep decline in September. ET rates also follow a similar increasing trend as the site vegetation has developed. Prior to the emergence of aspen as the dominant species, ET rates were as low as 2.3 mm/day. Since 2008 the pattern and magnitude of ET has been consistent with rates as high as 3.9 mm/day in 2010 (Figure 4-3). In all cases, ET values are greater than seasonal rainfall, relying on soil water recharge during snowmelt to sustain ET and plant growth.

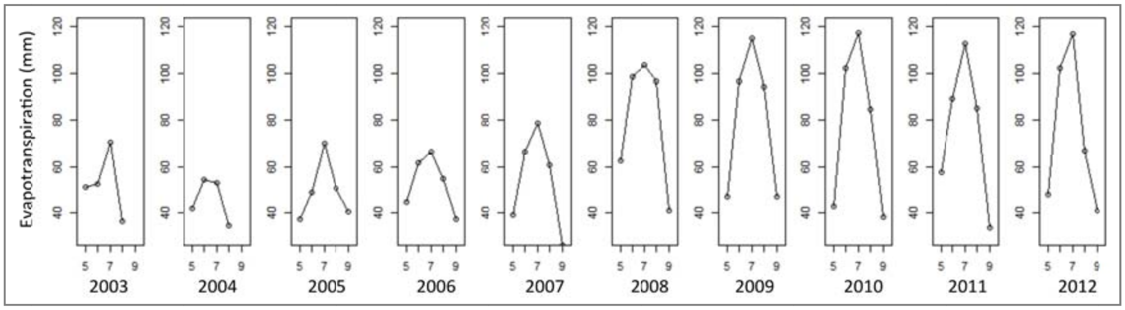

Figure 4-3. **Monthly ET for the 2003-2012 study period. Month of year is on x-axis.**

4.2.4. Leaf Area Index and Vegetation

For all measured years, LAI increases rapidly in June, typically peaks in July and gradually declines thereafter (Figure 4-4). From 2003 to 2005 vegetation consisted mainly of annual vegetation species (barley in 2003, sweet clover in 2004, no dominant species in 2005) that have a relatively short growing season and return low LAI values during the growing season. In 2006, there was an increase in plant diversity and the emergence of aspen.

Once established, aspen became the dominant species and in 2008 saw a rapid increase in its foliar area, as reflected in LAI measurements. LAI during this rapid growth phase of aspen is approximately three times greater than that observed at the beginning of the study (2003). Since 2008, LAI values appear to have reached a maximum LAI of approximately 3 to 3.5, which corresponds with the increased water withdrawal from the soil and increased ET.

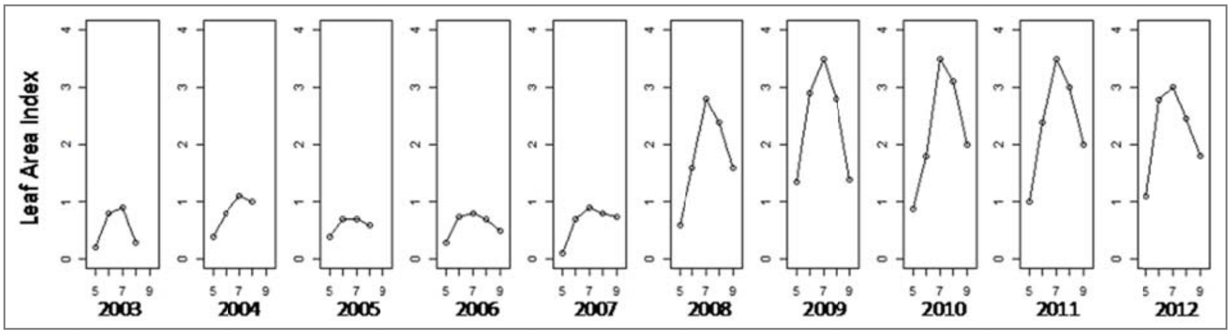

Figure 4-4. **Growing season leaf area index (LAI) for the 2003-2012 study period. Month of year is on the x-axis.**

4.2.5. Evapotranspiration and Net Ecosystem Exchange Assessment Summary

Since 2008, ET has achieved relatively consistent values, with ET rates reaching a plateau at ~4 mm/day, similar to rates reported for mature aspen stands in the boreal forest (Blanken et al., 2001; Brummer et al., 2012). Other metrics measured at the site also support the position that the aspen stand atop SBH is, with regard to its growing season water and carbon fluxes, similar to young and mature boreal stands (Barr et al., 2007; Brummer et al., 2012). Based on the data collected at the site, it does not appear the vegetation are exhibiting abnormal stresses and that, despite large differences in summer precipitation, the trees are able to sufficiently utilize soil water reservoirs to promote growth, store carbon and evapotranspire at levels comparable to undisturbed systems.

4.3. Vegetation Response

The vegetation response portion of the study consists of two investigations: above-ground (overstory) tree response and below-ground (root) distribution.

4.3.1. Above-ground Vegetation Response

4.3.1.1. Site index

Site index of white spruce and aspen was the primary vegetation performance measure of the study. Site index is a measure of the potential productivity of a site for forest growth, and in this study is a projection using current height and age data to project total height of the 100 largest trees per ha of a single species at 50 year breast-height age.

White spruce site index for the capping trial ranged from approximately 17 to 25 m for all treatments and 16 to 22 m for aspen (Figures 4-5 and 4-6). Mean white spruce site index for each of the capping trial treatments was 20.7 m (35 cm), 21.6 m (50 cm) and 21.3 m (100 cm), and for aspen was 18.2 m (35 cm), 17.5 m (50 cm) and 19.1 m (100 cm) (Tables 4-2 and 4-3). There was no significant difference among treatment thicknesses (α = 0.05) for white spruce and aspen.

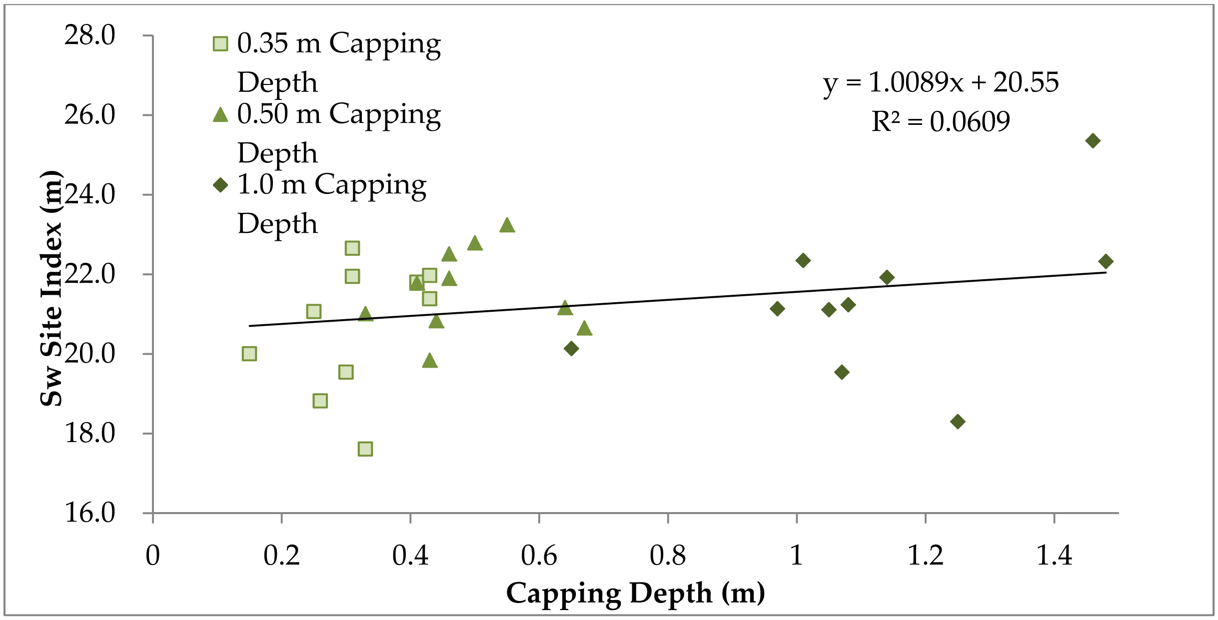

Figure 4-5. Relationship between white spruce site index and capping thickness in the capping depth trial. Capping depth trial is indicated by squares (D2 - 0.35 m), triangles (D1 - 0.5 m), and diamonds (D3 - 1.0 m).

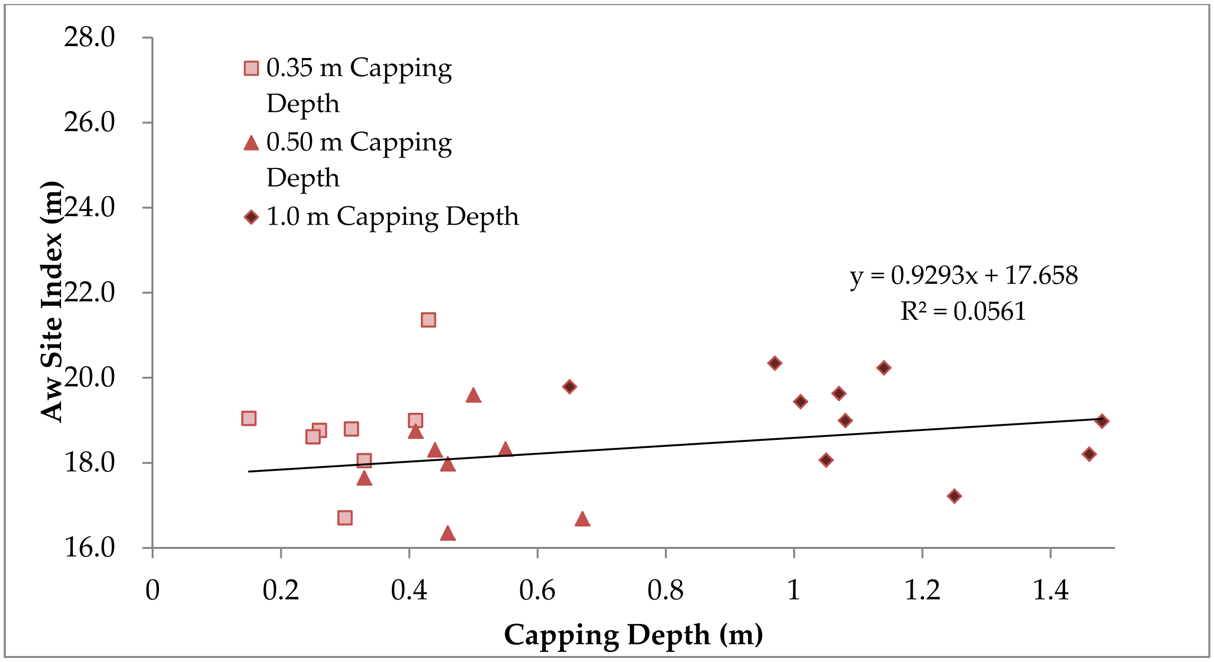

Figure 4-6. Relationship between aspen site index and capping thickness in the capping depth trial. Capping depth trial is indicated by squares (D2 - 0.35 m), triangles (D1 - 0.5 m), and diamonds (D3 - 1.0 m).

Table 4-2. White spruce average site index in the capping depth trial area.

Capping Thickness	Number of Plots	Average (m)	Standard Deviation (m)	Standard Error (m)	95% Conf. Interval (m)
35 cm	10	20.7	1.6	0.5	19.7–21.6
50 cm	10	21.6	1.5	0.5	20.7–22.4
100 cm	10	21.3	1.9	0.6	20.2–22.4

Table 4-3. Aspen average site index in the capping depth trial area.

Capping Thickness	Number of Plots	Average (m)	Standard Deviation (m)	Standard Error (m)	95% Conf. Interval (m)
35 cm	10	18.2	1.73	0.55	17.2–19.2
50 cm	10	17.5	1.35	0.43	16.7–18.3
100 cm	10	19.1	1.01	0.32	18.5–19.7

When all plots in the SBH study area are combined, white spruce site index across the site ranged from approximately 16 to 26 m, while aspen site index ranged from approximately 16 to 26.5 m (Figures 4-7 and 4-8).

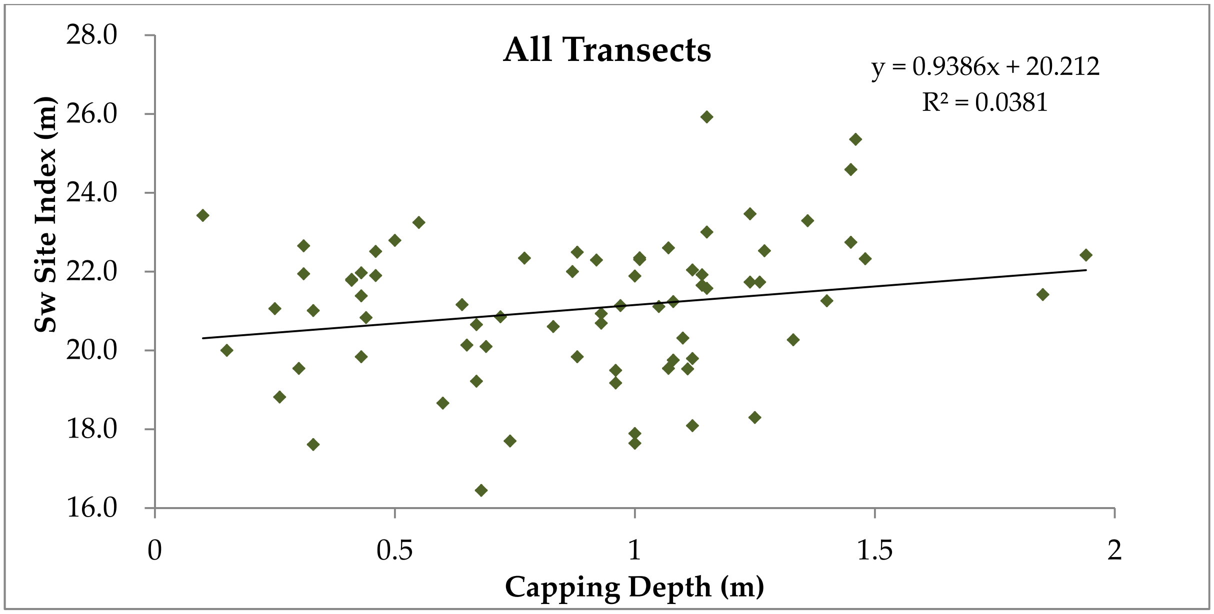

Figure 4-7. Relationship between white spruce site index and capping thickness for all areas.

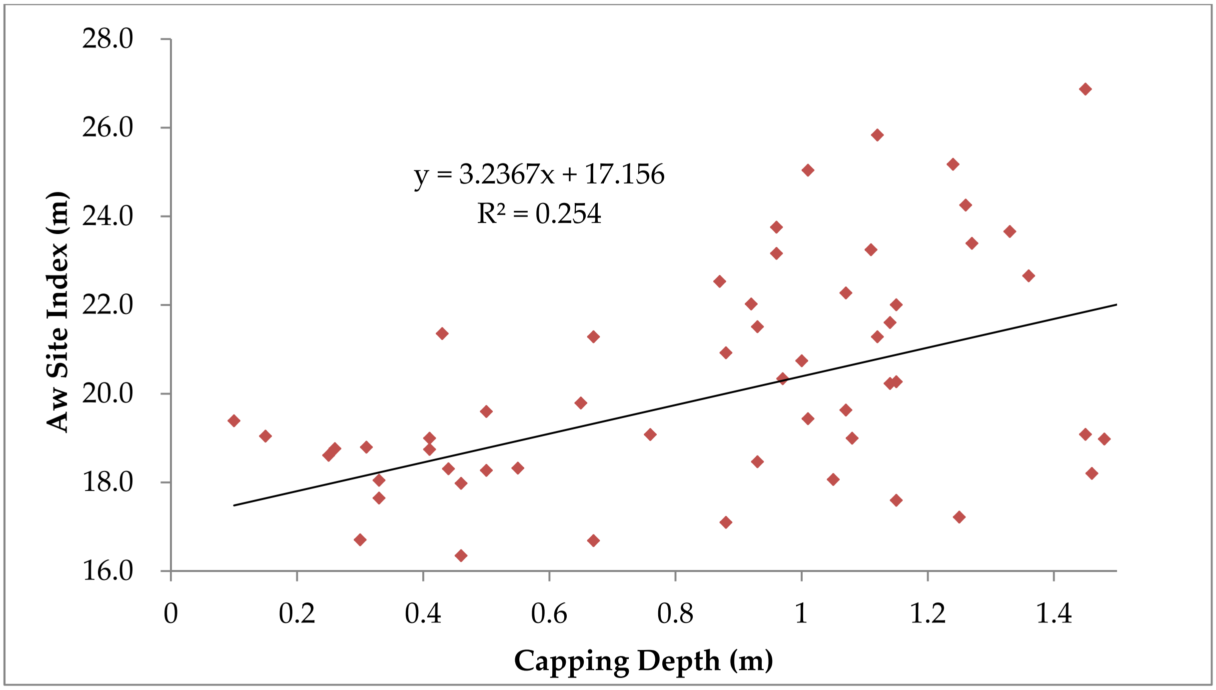

Figure 4-8. Relationship between aspen site index and capping thickness for all areas.

There was no significant relationship between white spruce site index and capping thickness. Growth-intercept (GI) site index estimates, which were generated for white spruce, may be a more direct measure of white spruce growth on the site. When GI site index and cover thickness for the capping trial depths were evaluated a significant positive relationship was evident (Figure 4-9). The data suggests there is an increase in site index as cover thickness increases from 15 to 50 cm (an approximate 1.7 m increase of site index), followed by a diminishing increase with thickness from 50 to 150 cm.

A comparison of aspen site index for all SBH sites found a significant (positive) relationship between thickness and site index (Figure 4-8). The results must be viewed with caution as they might be an artefact of aspen age differences among the ranges in capping thickness and potential differences in tree growth rates of planted and volunteer aspen.[5]

The trend line for white spruce suggests a 0.18 m increase in capping thickness is associated with a 1 m increase in site index for capping depths ≤50 cm and a 0.26 m increase in capping thickness is associated with a 1.0 m increase in site index capping depths of 0.5 to 1.5 m (Figure 4-9). For aspen the trend line suggests a 0.3 m capping thickness increase is associated with a 1.0 m increase in site index.

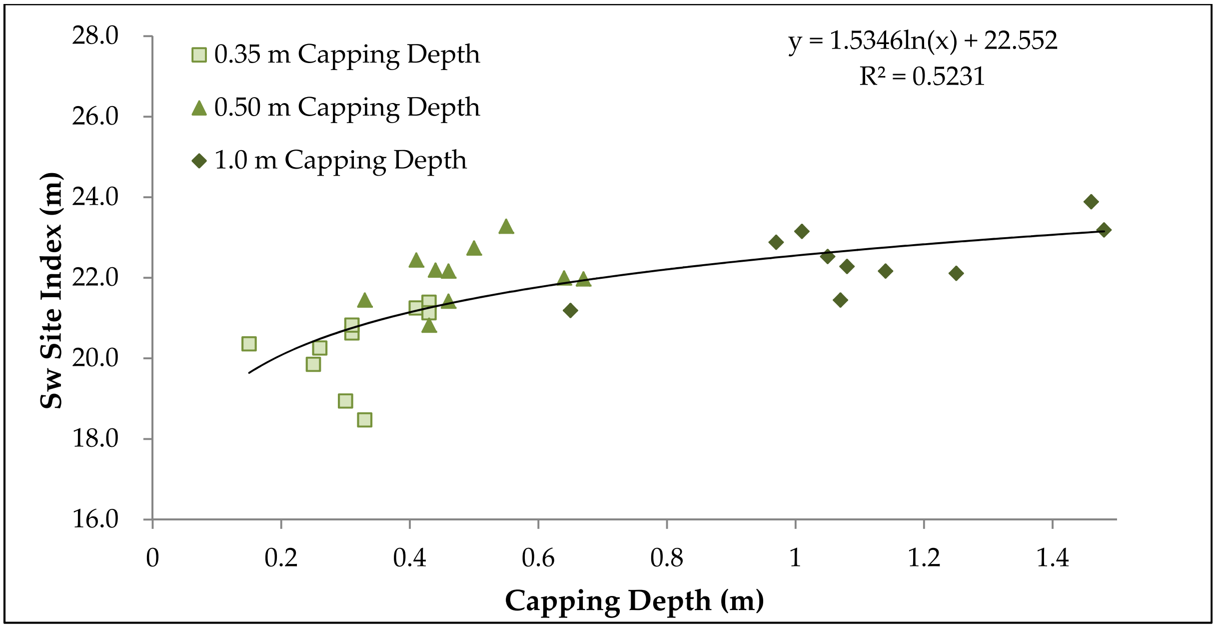

Figure 4-9. Comparison of white spruce GI-based site index estimates to measured total capping thickness across the SBH capping trials (toe and crest plots removed).

Even though a statistically significant relationship was found with aspen site index and capping thickness, and trend lines for both aspen and white spruce suggest an increased site index with capping thickness, SBH site indices meet and exceed all pre-disturbance and revegetation tree growth rates and targets. Comparison of the pre-disturbance site indices of

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[5] In order to assess the potential effect of error in age estimation on site index, we generated site index estimates for aspen where establishment date was uncertain (Transects 4-9 and the plateau sample points), by adding a year to total age, thus reducing site-index estimates. The average decrease in site index in this test was 1.4 m, which is substantial, but not sufficient to affect overall findings reported above. Note this uncertainty does not apply to the capping study (Transects 1-3) where date of planting is well documented.

the Mildred Lake lease area, based on timber productivity ratings (TPR), found aspen and white spruce site indices not only meet, but are predominantly in the high range of pre-disturbance timber ratings (Figures 4-10 and 4-11). All aspen and white spruce site indices at SBH returned Medium to Good TPR ratings, with the majority falling within the Good TPR range. When superimposed over the pre-disturbance TPR distribution for aspen- and white spruce-dominated AVI polygons in the Mildred Lake lease area, these results make it clear the site is not only meeting but often exceeding pre-disturbance conditions.

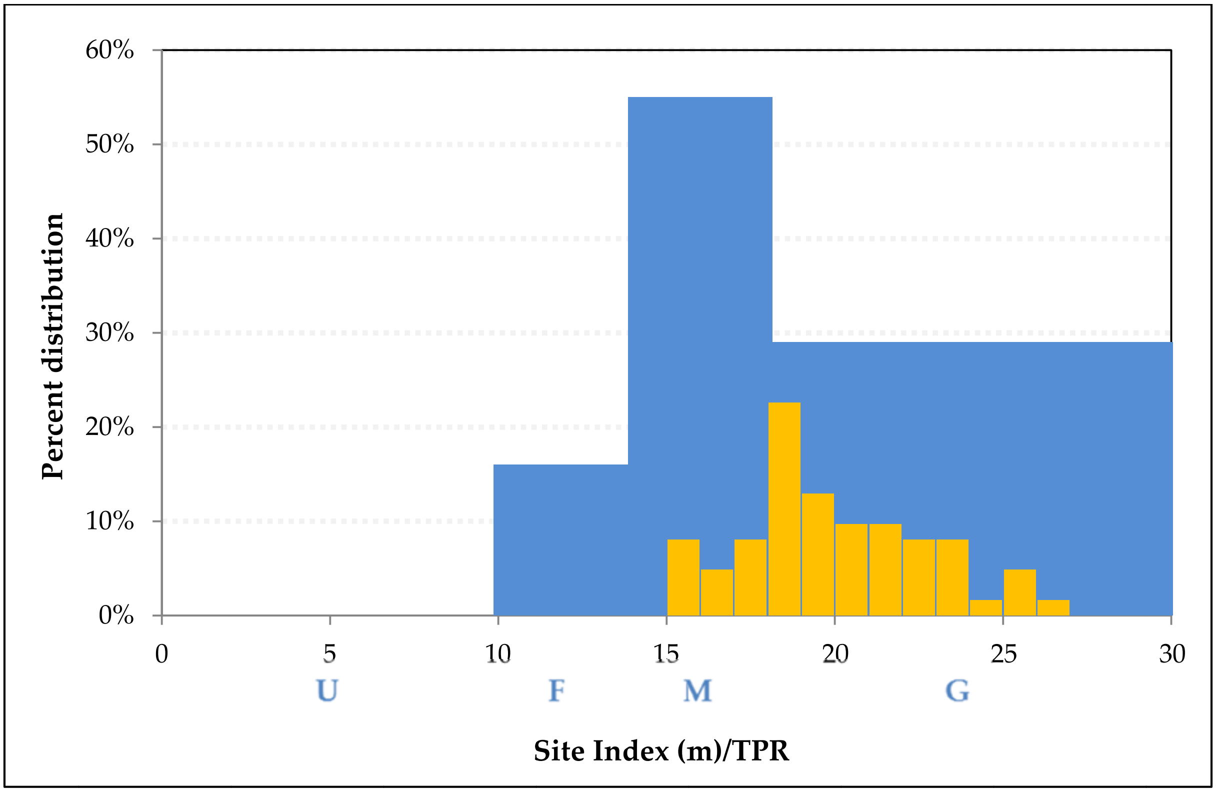

Figure 4-10. **Frequency distribution of aspen TPR on the pre-development landscape (blue bars) in comparison to observed data from the SBH study area (yellow bars), using GYPSY-based site index estimates and corresponding TPR classes (U = Unproductive; F = Fair; M = Medium; G = Good).**

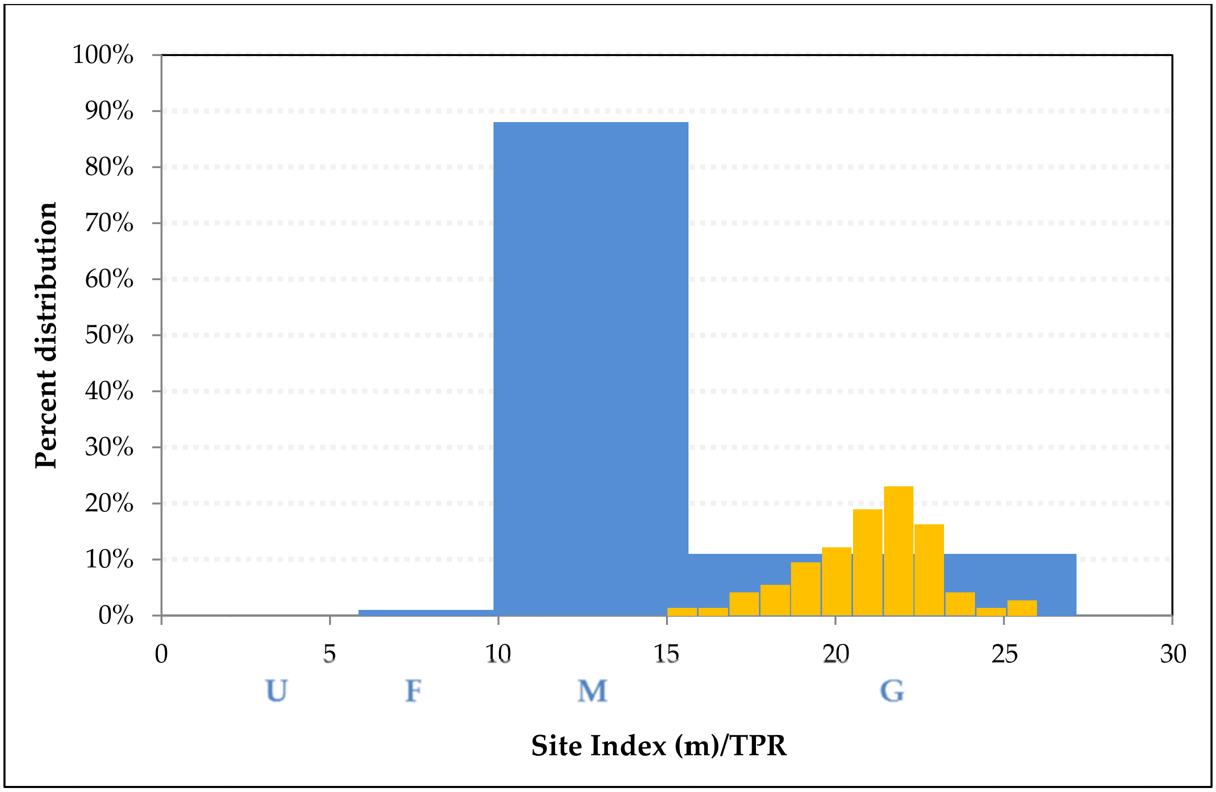

Figure 4-11. **Frequency distribution of white spruce TPR on the pre-development landscape (blue bars) in comparison with observed data from the SBH study site (yellow bars), using GYPSY-based site-index estimates and corresponding TPR classes (U = Unproductive; F = Fair; M = Medium; G = Good).**

Comparison of the SBH site indices to current revegetation guidelines (AENV, 2010) for the oil sands region confirms that the site meets reclamation revegetation targets (Table 4-4). Revegetation guidelines require that a reclaimed landscape meet a minimum Fair TPR rating for the specified species. A Fair TPR rating threshold can be interpreted in two ways: 1) the lowest value in the Fair TPR range, or 2) the mid-point in the Fair TPR range. The mid-point Fair TRP rating is a higher value, and thus, is considered a more conservative threshold value. The SBH study area site index for white spruce and aspen greatly exceeds both threshold values. In addition, the SBH site index exceeds site index values of a natural d ecosite (Beckingham and Archibald, 1996), which is the dominant target ecosite for upland Clearwater overburden reclamation areas.

Table 4-4. Site index from the study site compared to the Revegetation Manual and Ecosite Guide.

	Revegetation Manual[1]		Ecosite Guide[2]		Study Site	
	Top Height to Fair (m)	**Top Height of Fair mid-range (m)**	**d ecosite Mean (m ± SE)**	**e ecosite Mean (m ± SE)**	**Mean (m)**	**Minimum (m)**
White spruce	7.1	9.3	16.8 ± 0.2	17.8 ± 0.3	21.0	15.6
Aspen	11.6	13.5	18.2 ± 0.2	21.4 ± 0.4	20.0	15.3

[1] Alberta Environment (AENV). 2010. Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region, 2nd Edition.

[2] Beckingham, J.D. and Archibald, J.H. 1996. Field Guide to Ecosites of Northern Alberta.

4.3.1.2. Tree stand height distributions, density and stocking rates

As site index may not capture all tree-growth responses, due to its focus on “top-height” trees, other measures related more to overall tree stand dynamics and performance were investigated. Height distribution for white spruce and aspen were measured within the capping study trial to determine if this measure could detect tree stand performance differences that were not captured in site index measurements.

Height distributions of white spruce and aspen for each capping depth trial are displayed in Figures 4-12 and 4-13. Although there is no clear trend with the data, the white spruce tree heights for the capping trial plots suggest similar tree stand heights regardless of capping depth. The aspen tree heights suggest the 50 and 100 cm capping thicknesses may be able to support greater stand growth. A greater proportion of the 0.35 m capping trial appears to be present in the lower height classes (4 to 7 m), whereas the capping trial has a greater proportion in the 6 to 8 m range. The height distribution results are generally consistent with the site index results, which suggest site index is an appropriate measure to evaluate tree productivity at SBH.

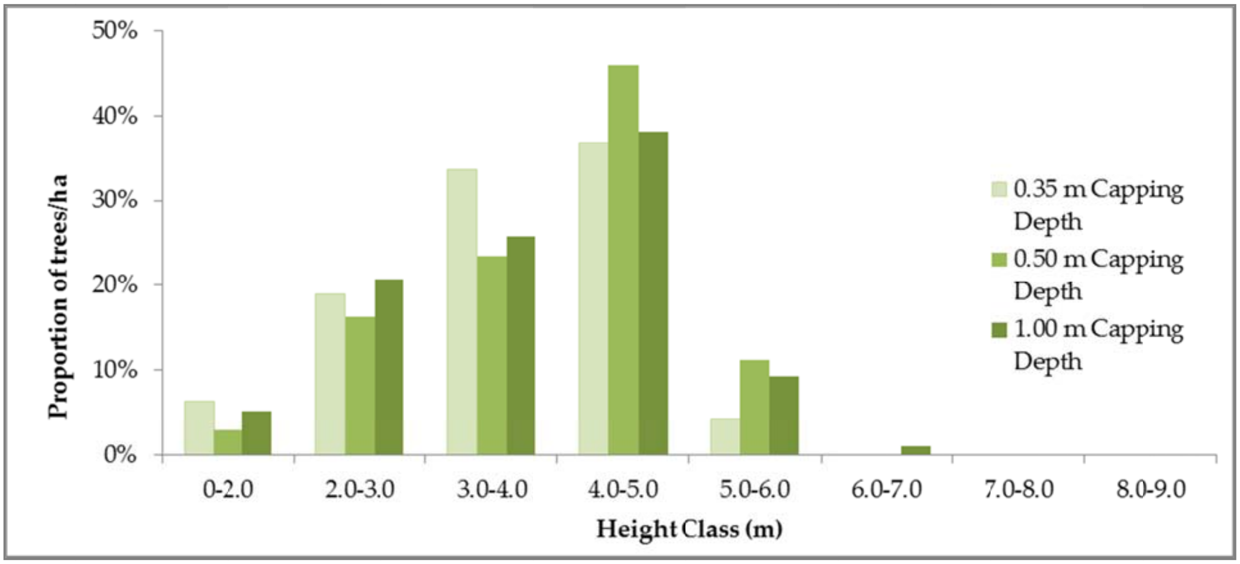

Figure 4-12. **Distribution of white spruce tree heights in the capping depth trial.**

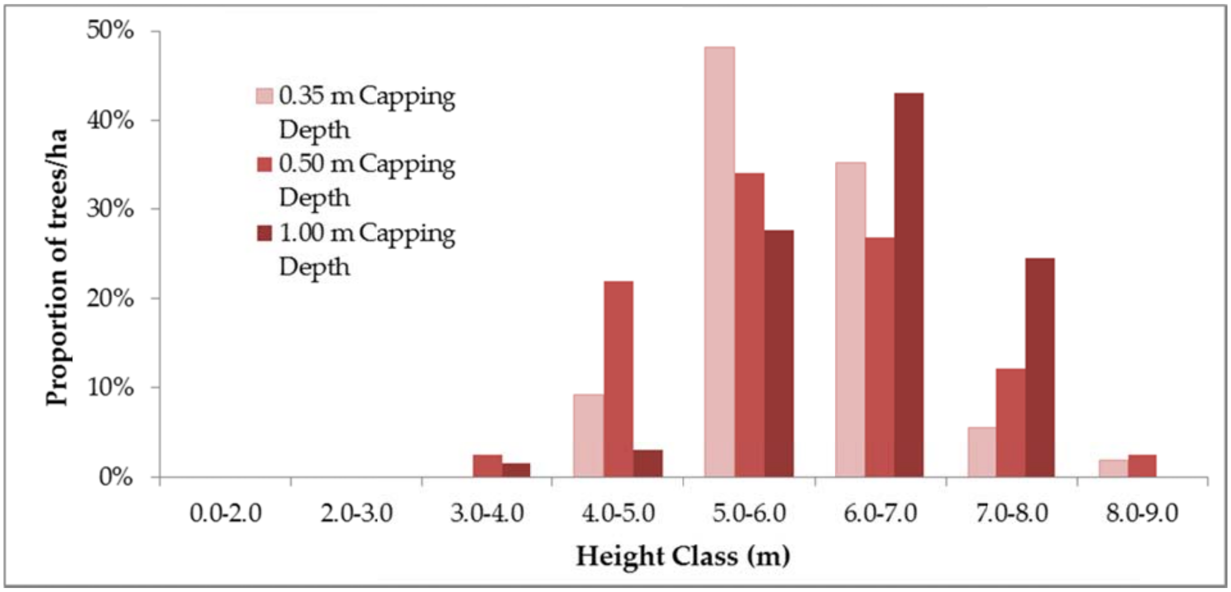

Figure 4-13. **Distribution of aspen tree heights in the capping depth trial.**

The SBH sample plots were found to generally have >1,000 stems/ha. The majority of the plots (49%) were stocked with a mixedwood “d2” (white spruce and aspen) reclamation designation, 36% of the plots were stocked to only aspen, 10% of the plots were stocked to only white spruce and only 5% of the plots were non-stocked. The sum of the tree-stocked plots equals 95% which is well above the conventional 80% target for successful commercial reforestation. All potential strata are sufficiently stocked – even the south-facing aspect (Transect 6-9) has a stocking rate of 81%.

These stand-density and stocking metrics confirm there is adequate forest regeneration at SBH to measure the tree response at SBH.

4.3.1.3. Foliar nutrients

Foliar nutrient concentrations measured in this study were intended primarily to confirm that nutrient deficiencies are not a significant impediment to tree growth in the study area. Site monitoring and observations of the vegetation growth at SBH do not indicate nutrient deficiency. Macronutrient analysis (Nitrogen [N], Phosphorus [P], Potassium [K], and Sulphur [S] found consistent white spruce and aspen foliar concentrations between capping trial depths and other areas in the site (Table 4-5). There were no significant differences among these comparisons for both white spruce and aspen foliar concentrations.

Table 4-5. Statistics for foliar nutrients (N, P, S) for white spruce and aspen.

Nutrient/ Species	Transect/ Cap Depth	Trees Sampled	Average (%)	Std. Dev. (%)	Std. Error (%)	Lower CI[1] (%)	Upper CI (%)
Nitrogen (N)							
White spruce	2 (35 cm)	4	1.31	0.13	0.063	1.11	1.51
	1 (50 cm)	5	1.34	0.07	0.031	1.26	1.43
	3 (100 cm)	3	1.39	0.05	0.027	1.27	1.50
	Others	25	1.33	0.13	0.026	1.27	1.38
	All	37	1.33	0.12	0.019	1.29	1.37
Aspen	2 (35 cm)	5	1.94	0.14	0.061	1.77	2.11
	1 (50 cm)	5	1.92	0.10	0.043	1.80	2.04
	3 (100 cm)	5	2.00	0.14	0.063	1.82	2.17
	Others	24	1.89	0.21	0.042	1.80	1.98
	All	39	1.91	0.18	0.029	1.85	1.97
Phosphorus (P)							
White spruce	2 (35 cm)	4	0.15	0.01	0.006	0.13	0.17
	1 (50 cm)	5	0.16	0.01	0.004	0.15	0.18
	3 (100 cm)	3	0.17	0.01	0.003	0.15	0.18
	Others	25	0.16	0.03	0.005	0.15	0.18
	All	37	0.16	0.02	0.004	0.16	0.17
Aspen	2 (35 cm)	5	0.18	0.02	0.011	0.15	0.21
	1 (50 cm)	4	0.17	0.01	0.006	0.15	0.19
	3 (100 cm)	5	0.16	0.02	0.008	0.14	0.18
	Others	22	0.16	0.03	0.006	0.15	0.17
	All	36	0.16	0.03	0.004	0.16	0.17
Sulphur (S)							
White spruce	2 (35 cm)	4	0.10	0.01	0.003	0.09	0.10
	1 (50 cm)	5	0.10	0.00	0.002	0.09	0.10
	3 (100 cm)	3	0.09	0.00	0.002	0.08	0.10
	Others	25	0.09	0.01	0.001	0.09	0.09
	All	37	0.09	0.01	0.001	0.09	0.09
Aspen	2 (35 cm)	5	0.37	0.32	0.144	-0.03	0.77
	1 (50 cm)	4	0.37	0.10	0.051	0.21	0.53
	3 (100 cm)	5	0.21	0.03	0.015	0.17	0.25
	Others	22	0.22	0.04	0.009	0.20	0.23
		36	0.25	0.14	0.023	0.21	0.30

1: Confidence Interval (CI)

Although there is limited published information regarding typical foliar concentrations in juvenile white spruce and aspen in the boreal forest, the study site's foliar concentrations appear to be within a typical range. The only exception may be white spruce S foliar concentrations. Mean S concentrations in white spruce foliar samples was 0.09, which may suggest a potential S deficiency. However, site index measurements do not suggest that the supply of S or any other nutrients are limiting tree growth on the SBH study area.

4.3.1.4. Soil salinity and sodicity

Since Clearwater overburden has elevated EC and SAR, the presence of the overburden within the soil root zone could be an impendent to vegetation growth. Therefore a thinner capping thickness presents the potential of Clearwater overburden coming in greater contact with plant roots.

In order to determine the magnitude of salinity and sodicity at SBH and to evaluate its influence on tree growth, weighted averages for EC and SAR were calculated for the top 100 cm of each sample site. The sample sites were interpreted as a whole data set and also stratified for each capping trial plot and as all sites outside the capping trial. The Clearwater overburden was included in the weighted calculation if it was present within the 100 cm soil profile. Weighted averages were calculated for topsoil (TS) (0-20 cm), upper subsoil (US) (20-50 cm) and lower subsoil (LS) (50-100 cm) depths (Table 4-6). As Clearwater overburden has elevated EC and SAR values relative to the reclamation soil cover, soil horizon depths (topsoil, subsoil and lower subsoil) containing the overburden return a higher mean EC and SAR. Therefore, shallow capping profiles exhibit higher EC and SAR, and for all sites there is a progressive increase in EC and SAR with depth (topsoil to upper subsoil to lower subsoil).

Table 4-6. Statistics for EC and SAR by soil cover horizon.

Parameter/ Layer	Transect/ Cap Depth	n	Average	Std. Dev.	Std. Error	Lower CI	Upper CI
EC (dS/m)							
TS (0-20 cm)	2 (35 cm)	5	2.44	1.43	1.09	-0.59	5.47
	1 (50 cm)	5	0.92	0.49	0.41	-0.22	2.06
	3 (100 cm)	5	1.02	0.34	0.46	-0.25	2.28
	Others	30	1.44	0.57	0.26	0.90	1.98
	All	45	1.45	0.77	0.22	1.01	1.88
US (20-50 cm)	2 (35 cm)	5	5.50	2.88	2.46	-1.33	12.33
	1 (50 cm)	5	1.66	1.73	0.74	-0.40	3.72
	3 (100 cm)	5	1.80	1.06	0.81	-0.44	4.04
	Others	30	2.04	1.21	0.37	1.28	2.80
	All	45	2.36	1.84	0.35	1.65	3.07

Parameter/ Layer	Transect/ Cap Depth	n	Average	Std. Dev.	Std. Error	Lower CI	Upper CI
LS (50-100 cm)	2 (35 cm)	4	6.26	3.49	3.13	-3.70	16.23
	1 (50 cm)	5	4.38	3.22	1.96	-1.06	9.82
	3 (100 cm)	5	3.91	2.47	1.75	-0.95	8.77
	Others	30	3.84	1.54	0.70	2.41	5.28
	All	44	4.13	2.11	0.62	2.88	5.39
SAR (no units)							
TS (0-20 cm)	2 (35 cm)	5	5.11	3.26	2.29	-1.24	11.46
	1 (50 cm)	5	1.29	1.29	0.58	-0.31	2.90
	3 (100 cm)	5	1.74	0.81	0.78	-0.42	3.90
	Others	30	1.23	1.11	0.23	0.77	1.69
	All	45	1.73	1.87	0.26	1.21	2.25
US (20-50 cm)	2 (35 cm)	5	10.26	5.20	4.59	-2.48	23.00
	1 (50 cm)	5	3.63	3.14	1.62	-0.88	8.13
	3 (100 cm)	5	3.24	1.91	1.45	-0.78	7.26
	Others	30	2.25	2.04	0.41	1.41	3.09
	All	45	3.40	3.56	0.51	2.38	4.42
LS (50-100 cm)	2 (35 cm)	4	11.26	5.58	5.63	-6.66	29.17
	1 (50 cm)	5	7.51	5.13	3.36	-1.81	16.84
	3 (100 cm)	5	7.74	3.95	3.46	-1.87	17.34
	Others	30	6.34	3.07	1.16	3.97	8.71
	All	44	7.08	3.81	1.07	4.93	9.23

The shallow capping trial depth (35 cm) contains higher EC and SAR relative to the other study sample sites. Topsoil EC and SAR ratings[6] for this profile are Fair and upper and lower subsoil EC and SAR are rated Poor (Table 4-7). All other capping depth strata are rated as Good for topsoil and upper subsoil EC and SAR, while lower subsoil EC and SAR are rated Fair.

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[6] Site quality guidelines (AAFRD, 1987) – EC ratings for topsoil are Good (<2 dS/m), Fair (2-4 dS/m), Poor (4-8 dS/m) and Unsuitable (>8 dS/m), and subsoil are Good (<3 dS/m), Fair (3-5 dS/m), Poor (5-8 dS/m) and Unsuitable (>8 dS/m). SAR ratings for topsoil and subsoil are Good (<4), Fair (4-8), Poor (8-12) and Unsuitable (>12).

Table 4-7. EC and SAR soil quality ratings of soil cover horizons.

Cover Depth	Horizon	EC Rating	SAR Rating
35 cm Capping Trial			
	Topsoil	Fair	Fair
	Upper Subsoil	Poor	Poor
	Lower Subsoil	Poor	Poor
All cover depths			
	Topsoil	Good	Good
	Upper Subsoil	Good	Good
	Lower Subsoil	Fair	Fair

Comparison of topsoil, subsoil and lower subsoil EC and SAR with site index revealed no significant relationship for white spruce, but revealed a statistically significant negative correlation for upper subsoil SAR and lower subsoil EC and SAR for aspen (data not shown, see Appendix C). No aspen site indices above 21.5 m were observed with subsoil EC values >4 dS/m and no aspen site indices above 20.0 m were observed with subsoil SAR values >12. Regardless, all values measured at SBH meet applicable revegetation guidelines (AENV, 2010).

The study results are generally consistent with current understanding of soil salinity and sodicity impacts on vegetation growth — elevated salinity and sodicity can be an impediment to vegetation growth. Although salinity and sodicity are not limiting the site productivity below pre-disturbance tree productivity conditions or below revegetation reclamation targets, they may be limiting the ability of the site to reach a higher tree growth potential. These results are consistent with recent research (Close et al., 2007; Lilles et al., 2012) in the oil sands region on boreal forest growth potential on saline soils. The presence and growth potential of boreal forest tree species in the region has been found to be linked to the soil salinity concentration. Their research suggests that typical boreal forest vegetation is not associated with a topsoil EC >4 dS/m. However, they did observe typical boreal forest communities with highly saline subsoil conditions (EC >20 dS/m), provided the topsoil EC remained <4 dS/m. They also found that topsoil EC >2 dS/m and/or subsoil EC >4 dS/m are associated with declining forest productivity. The thresholds reported in these studies are consistent with this study's findings. Soil EC and SAR at the SBH study are below the reported threshold levels that can support white spruce and aspen growth, but the significant negative correlation of aspen site index with elevated EC and SAR is within the reported range of declining forest productivity.

4.3.1.5. Above-ground vegetation summary

Above-ground vegetation data collected in the study indicate adequate tree establishment and growth across the SBH study site, including the thinner capping thicknesses found on the cover-trial plots. Site index values on the SBH site, including those on the thinnest cover (35 cm), show equal or higher site productivity than tree growth rates inferred for the predisturbance area. Additional measures of height distributions, tree density and stocking meet appropriate reclamation revegetation guidelines and/or support the site index findings.

Examination of tree growth performance by cover thickness indicates significant positive relationships. These relationships are strongest for white spruce (GI site index; capping trial study) as cover thickness increases from 15 to 50 cm, with diminishing gains with additional increases in cover thickness. The aspen site index (all SBH sites) also displayed a significant positive relationship with capping thickness, although this relationship may be confounded by different aspen origins and potentially by errors in age estimation.

Foliar nutrient analysis confirmed the supply of nutrients appears to be within the normal range for boreal forest community development. There were no apparent deficiencies or excessive concentrations for macro- and micro-nutrients.

Measured EC and SAR determined that thinner covers generally have higher EC and SAR values within the topsoil, upper subsoil, and lower subsoil, with the EC and SAR generally increasing with depth. EC and SAR serve to evaluate the impact of soil salinity and sodicity on tree growth. There was no significant trend with white spruce site index and EC and SAR levels at the SBH study site. However, there was a significant decrease in the aspen site index detected with elevated SAR in the upper and lower subsoils and EC in the lower subsoil. The EC and SAR levels present at the site and observed tree-growth responses are consistent with comparisons to EC and SAR threshold values inferred from published studies of boreal-forest responses to soil salinity and/or sodicity. A comparison of the EC and SAR levels at the site to these threshold values suggests a minimum reclamation cover thickness of 50 cm is required for the development of productive boreal forest stands with target tree species.

Above-ground tree responses observed in this study suggest that a minimum reclamation depth of 50 cm is required for the productive development of targeted white spruce and aspen boreal forest tree species. Research by Carey (Appendix B) concludes that ET and leaf-area index has levelled off in recent years of monitoring, suggesting the SBH site has reached (or is nearing) a steady-state vegetation transpiration demand. As such, there is no reason to expect a declining site index over time. However, during this period the growing season precipitation has been similar to, or slightly below, the long-term climate record. Since drought periods are expected over the lifespan of a forest stand, the ability of a 50 cm reclamation cover to support vegetation during an extended drought requires further validation. A greater cover thickness (e.g., between 50 cm and 100 cm) that considers the long-term climate conditions as reported in Appendix F may be required to meet the vegetation demands.

4.3.2. Below-ground Root Distribution

Root biomass was measured at select SBH transect sample locations. Results were displayed as total root biomass at sample depth intervals at each site location and total root biomass for the entire profile of the site location. The results do not identify the species of the roots collected.

4.3.2.1. Root biomass of transects and slope positions

Total root biomass for each transect and slope position exhibited no apparent spatial trends across SBH (Table 4-8). Average root biomass by slope position was highest at the crest slope position and showed a slight decreasing trend towards the toe slope position (Figure 4-14). Site factors may affect these results; there were different soil placement materials and cover designs, as well as different vegetation planting dates and success across the transect sample sites.

Table 4-8. Total root biomass per core for each transect and slope position.

Transect	**Slope Position**						
	Crest	**Upper**	**Middle**	**Plateau 1**	**Plateau 2**	**Lower**	**Toe**
	Mg/ha						
1	32.22	16.94	24.22	-[†]	-	9.39	7.73
2	21.54	3.87	8.17	-	-	3.22	4.57
3	1.96	8.27	21.22	-	-	14.35	6.63
4	36.62	12.91	14.33	-	-	7.33	8.40
5	10.94	18.07	12.27	-	-	18.05	11.53
6	5.49	7.27	24.93	-	-	28.26	11.73
7	11.60	-	9.91	13.71	20.33	-	13.93
8	5.51	-	5.94	-	-	-	1.85
9	20.27	4.73	2.79	-	-	1.98	12.28
Mean	**16.24**	**10.29**	**13.75**	**13.71**	**20.33**	**11.80**	**8.74**

[†] not sampled.

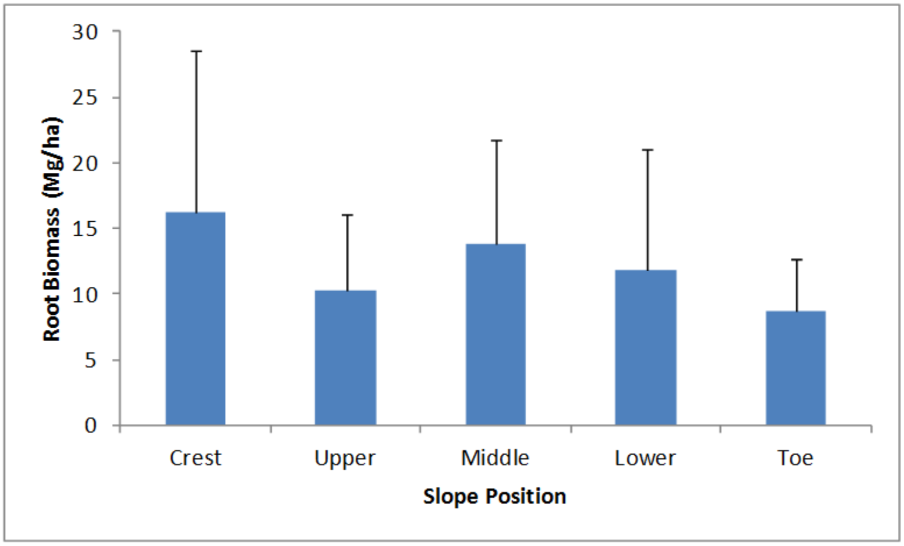


Figure 4-14. **Average root biomass for each slope position (number of samples (n)=9 for Crest, Middle and Toe; n=7 for Upper and Lower). Error bars represent standard deviation**

Root biomass and tree density were compared to determine relationship. Number of trees within a 2 m radius of the sample hole for planted trees and planted plus volunteer were surveyed. No relationship was found for either test (data not shown).

4.3.2.2. Root biomass with cover thickness

Root density distributions (mg·cm^{-3}) for all combined data (transect and slope position) showed the highest rooting densities at the surface and an exponential decline in biomass with depth (Figure 4-15). The rooting densities for this study are comparable to rooting densities and exponential decline in biomass of several different aged boreal forest stands in Saskatchewan growing on loam/clay loam soils (Figure 4-16; Van Rees, 1997). The highest root densities in the top 30 cm of the cover profile are also similar to the pattern found in boreal species from native forests (Strong and La Roi, 1985). This research found root densities were highest in the surface and decreased with depth. This decrease was much greater with depth especially with a Bt (clay) horizon at 30 cm depth, which is comparable to the glacial and glaciolacustrine mineral subsoil placed at SBH and used for other reclamation at the Mildred Lake mine.

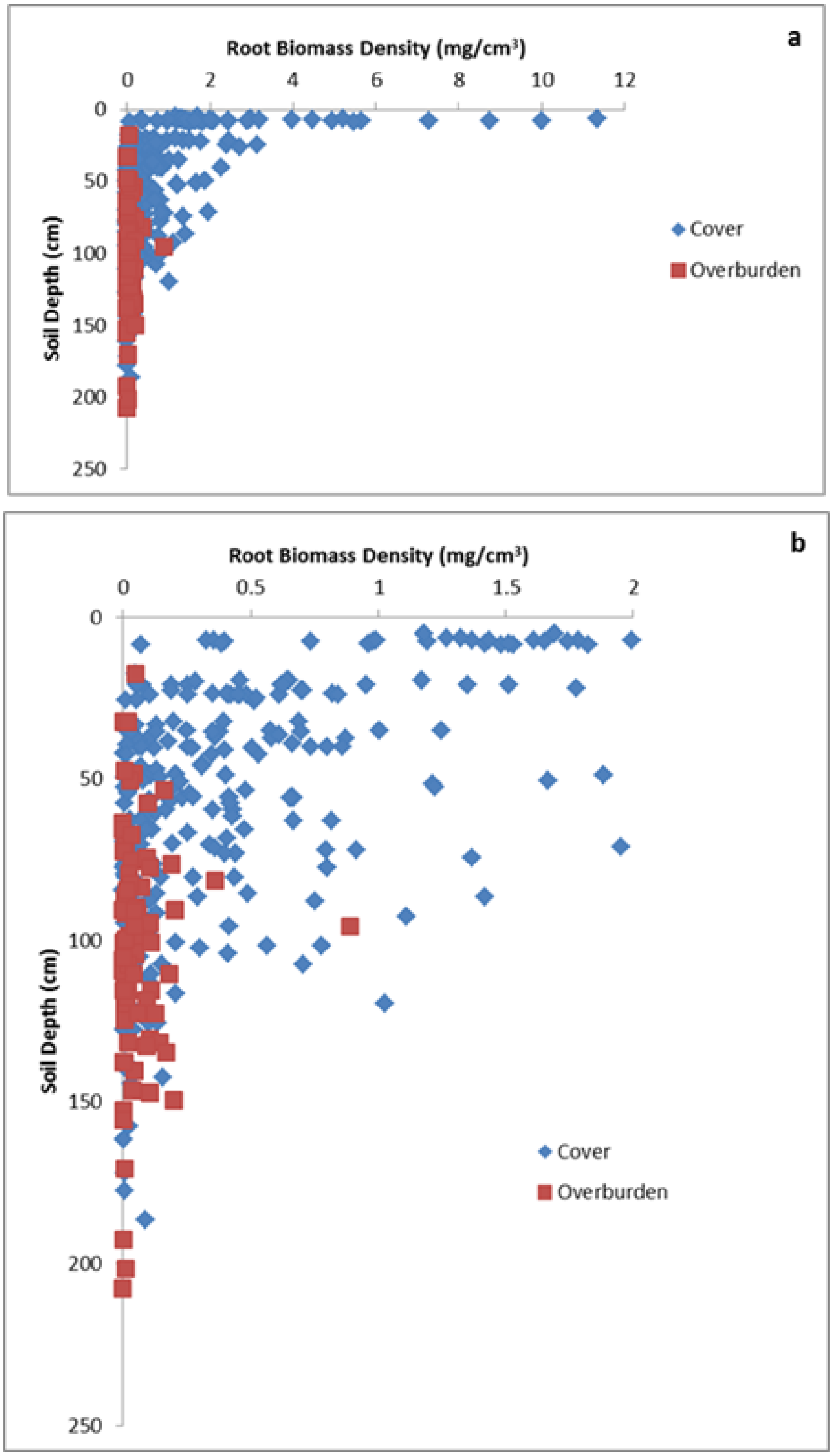


Figure 4-15. **Root biomass density for samples in the cover and Overburden materials. All data is presented in (a) and the scale was changed (< 2 mg/cm^3) to see the spread of data for soil depths > 50 cm in (b).**

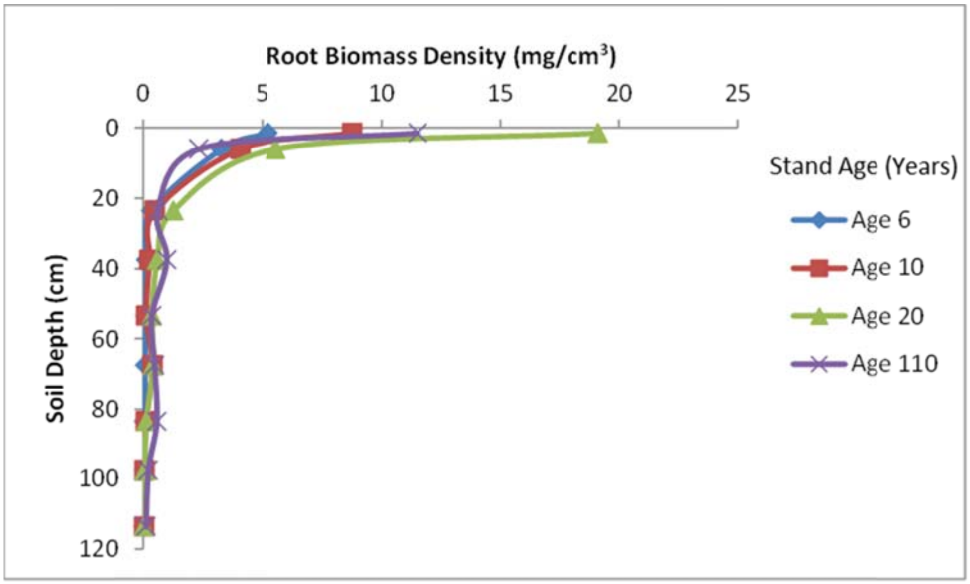


Figure 4-16. **Root Density Distribution for forests (aspen, white spruce, and understory) of various ages growing on Luvisolic soils in Saskatchewan (source: Van Rees, 1997).**

Although rooting densities decrease with depth, there are roots present in the Clearwater overburden. Comparison of the root biomass in overburden with reclamation cover root biomass of similar depths suggests that Clearwater overburden does present a root limitation compared with reclamation cover materials (e.g., mineral subsoil reclamation material). This is evident in Figure 4-15 where the majority of rooting in OB is <0.25 mg·cm^{-3}, but cover samples with a soil depth <100 cm show higher rooting densities in the subsoil depth range (20-100 cm). The study did not explore if the cause of this limitation is related to a physical restriction and/or chemical limitation.

A comparison of total root biomass with depth to Clearwater overburden material showed that for shallow covers (*i.e.*, <50 cm) the total root biomass was <10 Mg/ha, while covers >50 cm ranged from 10 to 36.6 Mg/ha (Figure 4-17). The majority of the data reaches a maximum with a cover thickness of approximately 100-120 cm.

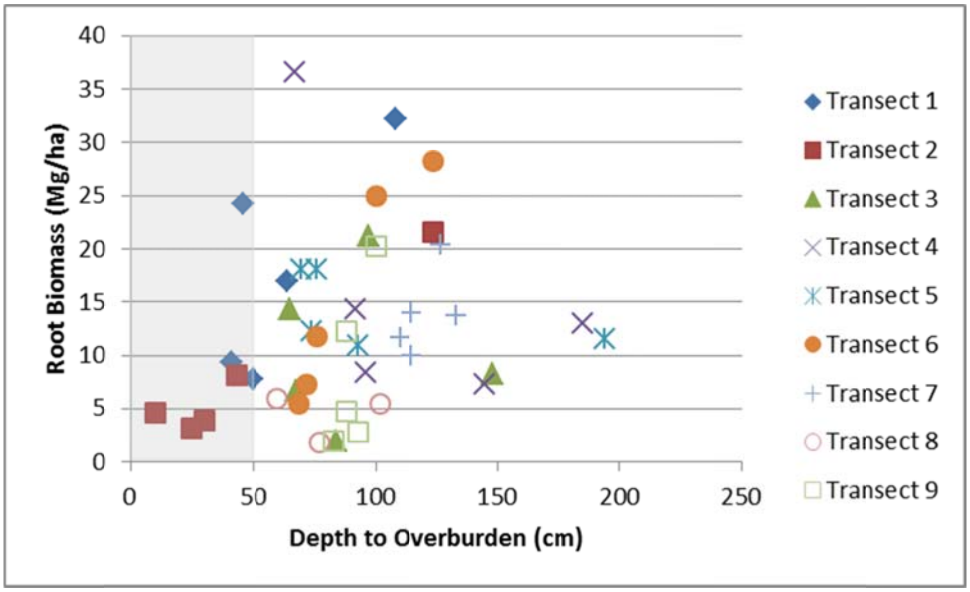


Figure 4-17. **Distributions of total root biomass in relation to depth to Overburden for each transect and slope position. The shaded box represents samples in covers <50cm.**

4.3.2.3. Below-ground vegetation summary

Root distribution with cover depth appeared to follow the natural rooting patterns of other boreal forests. The majority of the roots are located in the surface and generally show an exponential decrease with depth. Although roots are present in the Clearwater overburden, for cover thicknesses <100 cm the density of rooting in the overburden was lower than in the reclamation cover at similar depths. This was also reflected in the total root biomass, as covers <50 cm thick had lower root biomass than covers >50 cm. A maximum root biomass appears to occur with a cover thickness of 100-120 cm thick. Cover thicknesses between 50 and 100 cm may be satisfactory for root development, but the current forest is still young enough to warrant caution on being certain with the conclusions made in this study.

4.4. Salt Profiles and Transport in the Landscape

The 2012 SBH study covered a broader area of SBH than previous sampling programs, which focused primarily on the capping trial and plateau areas. The study was expanded to include transects covering all aspects. The expanded scope was intended to confirm if the findings of previous work on salt transport that focused on the capping trial and plateau areas are consistent across SBH and to potentially evaluate the effect of slope position and aspect.

4.4.1. Compiled Salinity Results

Analyzed saturated paste extracts of soil cover samples confirmed the occurrence of salt ingress from the Clearwater overburden into the soil cover. This resulted in elevated EC and SAR in the soil cover. Na^+ was the primary ion contributing to the elevated EC, with Ca^{2+} and Mg^{2+} being significant contributors (Table 4-9). K^+ was negligible in most soil samples.

Chloride (Cl^-) was negligible for most samples, except for isolated locations of elevated Cl^- (192 to 403 mg/L). Most of the elevated Cl^- values were near the shore of Peat Pond and may be more related to water cycling taking place at the edge of the pond and the toe of the slope.

Table 4-9. Average salinity values from 2012 saturated paste extracts

Sample Type	Moisture Content (%)	pH	EC (dS/m)	SAR	Soluble Cations and Anions					
					Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Cl^- (mg/L)	$S\text{-}SO_4^{2-}$ (mg/L)
Cover Soil Samples	25	7.3	2.4	4.5	258	80	332	9	40	305
Shale Samples	20	7.4	7.1	11.6	451	322	1334	54	56	1636

When all 2012 salinity data was compiled (irrespective of capping thickness, aspect, or slope) it was found that EC, SAR and Na^+ levels in the soil cover were elevated relative to background conditions to a median profile height of 60 cm above the cover-overburden interface (Figures 4-18, 4-19, and 4-20). Soil quality guidelines for EC and SAR (AAFRD, 1987) are used to characterize soil materials for use in reclamation. Syncrude currently salvages Good and Fair EC and SAR materials. Comparison of the EC and SAR measured at SBH to soil quality guidelines found that salt ingress has not resulted in a lowering of the EC soil rating in the soil cover. Measured SAR indicates the lowermost 10 to 15 cm of soil above the cover soil-Clearwater overburden interface has been reduced to a Poor rating, Fair to 35 cm and Good for the remainder of the soil cover. The EC soil quality rating of the soil cover is Fair for the 15 to 20 cm of soil directly above the interface and is Good for the remainder of the soil cover.

The study also found that the near-surface Clearwater overburden has undergone changes in chemistry. There has been a decrease in the salinity and sodicity in the near-surface Clearwater overburden as a result of both salt migration into the cover and flushing of salts. Clearwater overburden samples collected by Kessler (2007) at the SBH capping trial in 2002, shortly after reclamation, estimated the mean EC and SAR of Clearwater overburden to be 10.0 dS/m and 16.9, respectively. Comparison of these values to the EC and SAR profiles at SBH (Figures 4-18 and 4-19) suggests that the salinity and sodicity of the near-surface Clearwater overburden has been reduced from levels in 2002.

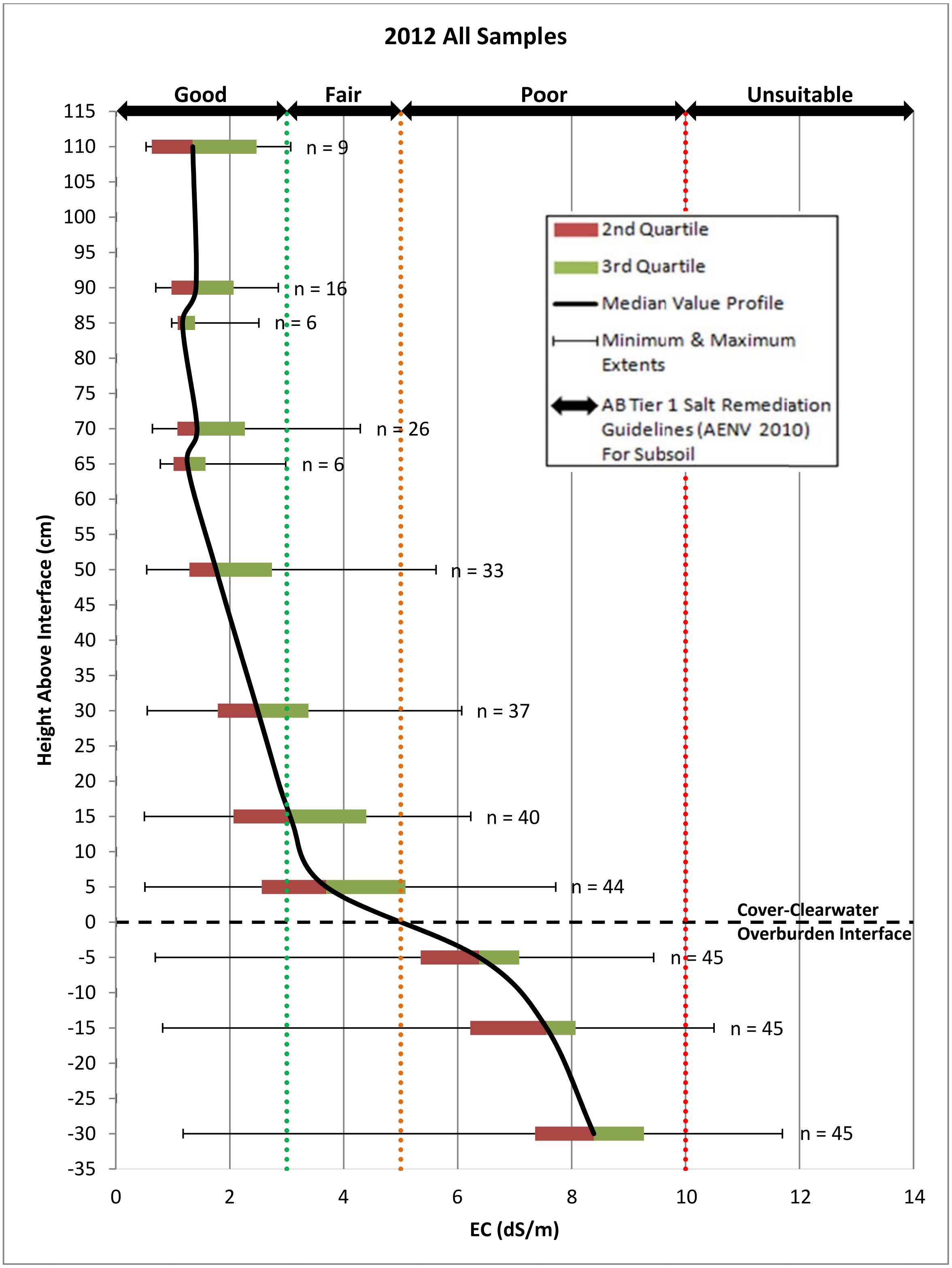


Figure 4-18. 2012 EC profile for all locations

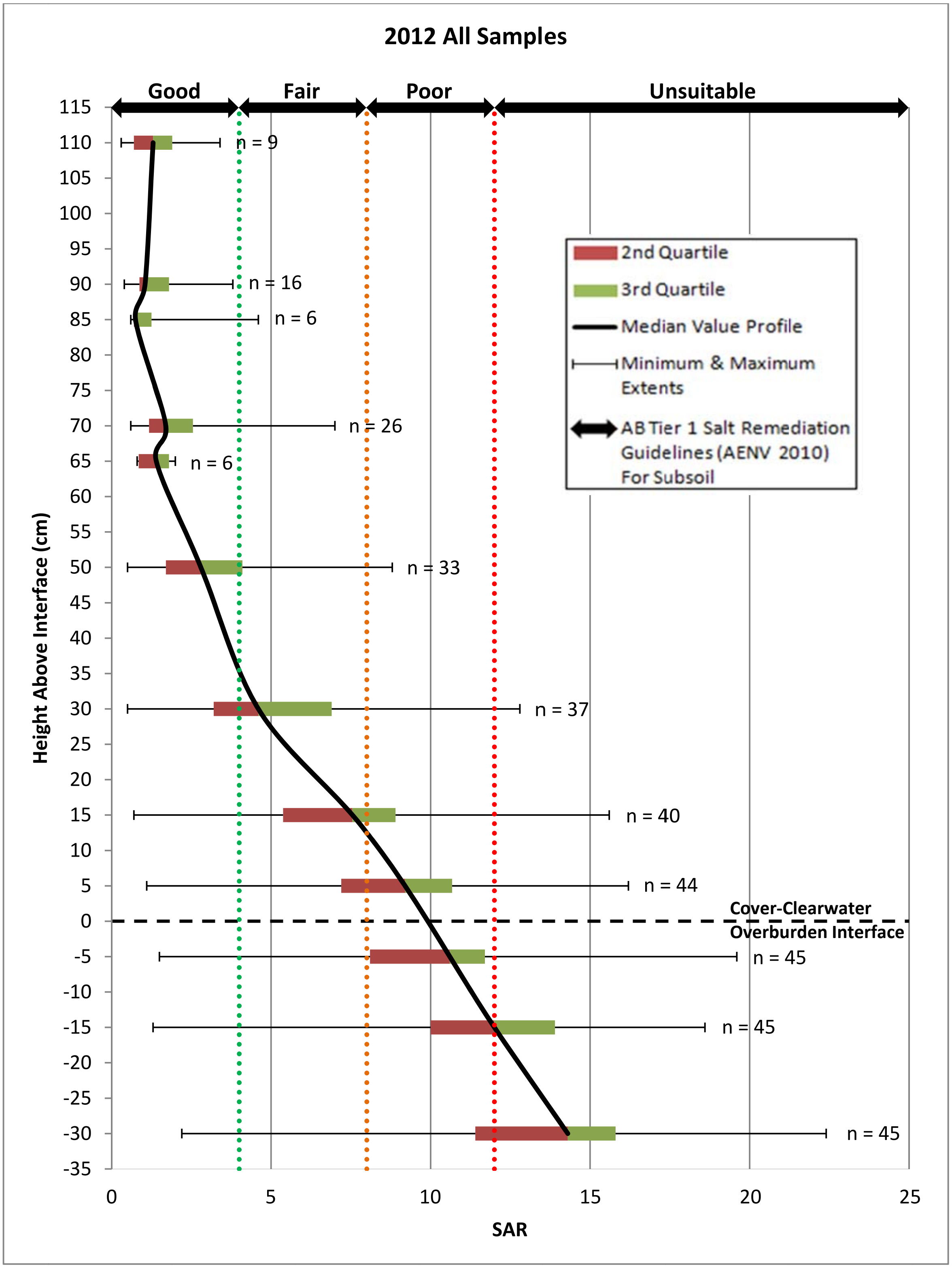


Figure 4-19. 2012 SAR profile for all locations.

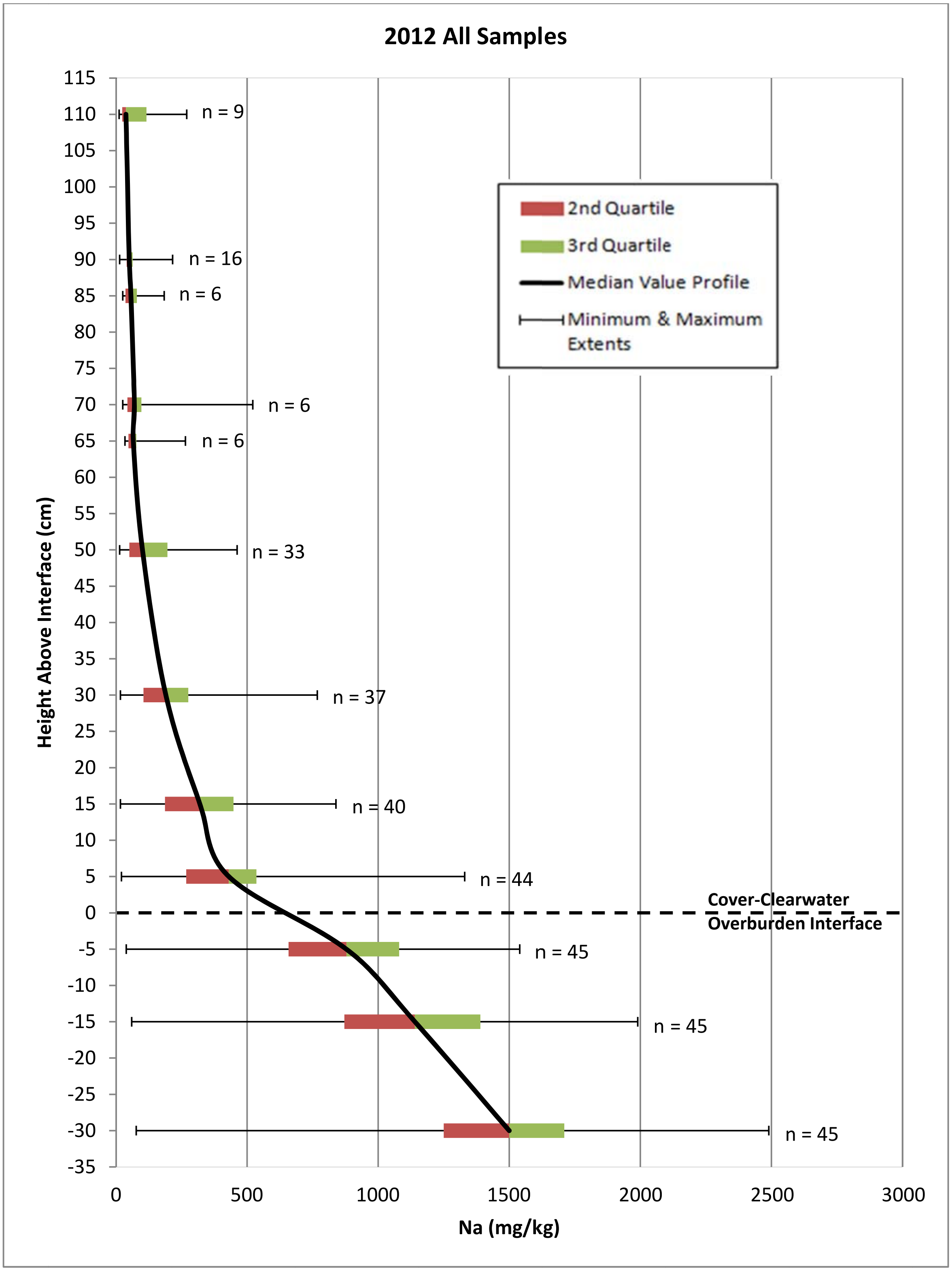


Figure 4-20. 2012 Na$^+$ profile for all locations.

4.4.2. Slope Position Influence

There is no apparent relationship between slope position and the extent of salt ingress in the soil cover. Normal salt transport mechanisms suggest that the upper slope positions will flush salts downslope via interflow (Greenlee et al., 1968). This would result in relocation of salts from upper slope positions to lower slope positions. Although monitoring has confirmed that salts are being flushed downslope by interflow, historical and current salinity profiles have not provided evidence of an accumulation of salinity at lower slope locations. This may be related to the defined boundaries of the study site. At the end of the capping trial plots and all transects of this study a drainage outlet is present, which provides an opportunity for all surface and interflow water along the slope to be removed from the sample study area, reducing the amount of salt that is available to collect and evapo-concentrate at the lower slope positions. Therefore, the capping study trial plots and study transects may not be capturing the accumulation of salts in lower slope positions typical of natural profiles in saline soils in the prairies.

Counteracting processes may also help to explain the similarity between the salinity profiles from upper and lower slope positions. Lower slope positions are expected to be wetter than upper slope positions, which means the salt diffusion coefficient will be greater, potentially resulting in greater salt ingress by upward diffusion. However, the more persistent perched water table at lower slope positions likely increases the net percolation occurring at these locations.

4.4.3. Aspect Influence

The 2012 salinity profiles suggest that aspect has no influence on salt transport. Soil EC, SAR and Na^+ profiles for north aspect transects (3 and 4) and south aspect transects (6 to 8) are shown in Figures 4-21 to 4-23. Each of these parameters shows a similar profile in the reclamation soil cover and near surface Clearwater overburden.

It would be expected that slope aspect should have an influence on hydrological processes such as snow melt (timing and magnitude) and seasonal cycles in evapotranspiration which would influence water and salt migration processes. However, previous research at SBH (Kelln et al., 2008) may explain why aspect is not influencing salt transport. This work shows deeper soil moisture and interflow primarily originates from snow melt and infiltrates through the cover via macropores (preferential flow). Monitoring at the site shows the snow depth across the site to be relatively uniform, which suggests the salt transport mechanism of net percolation and interflow may be similar across the site regardless of aspect.

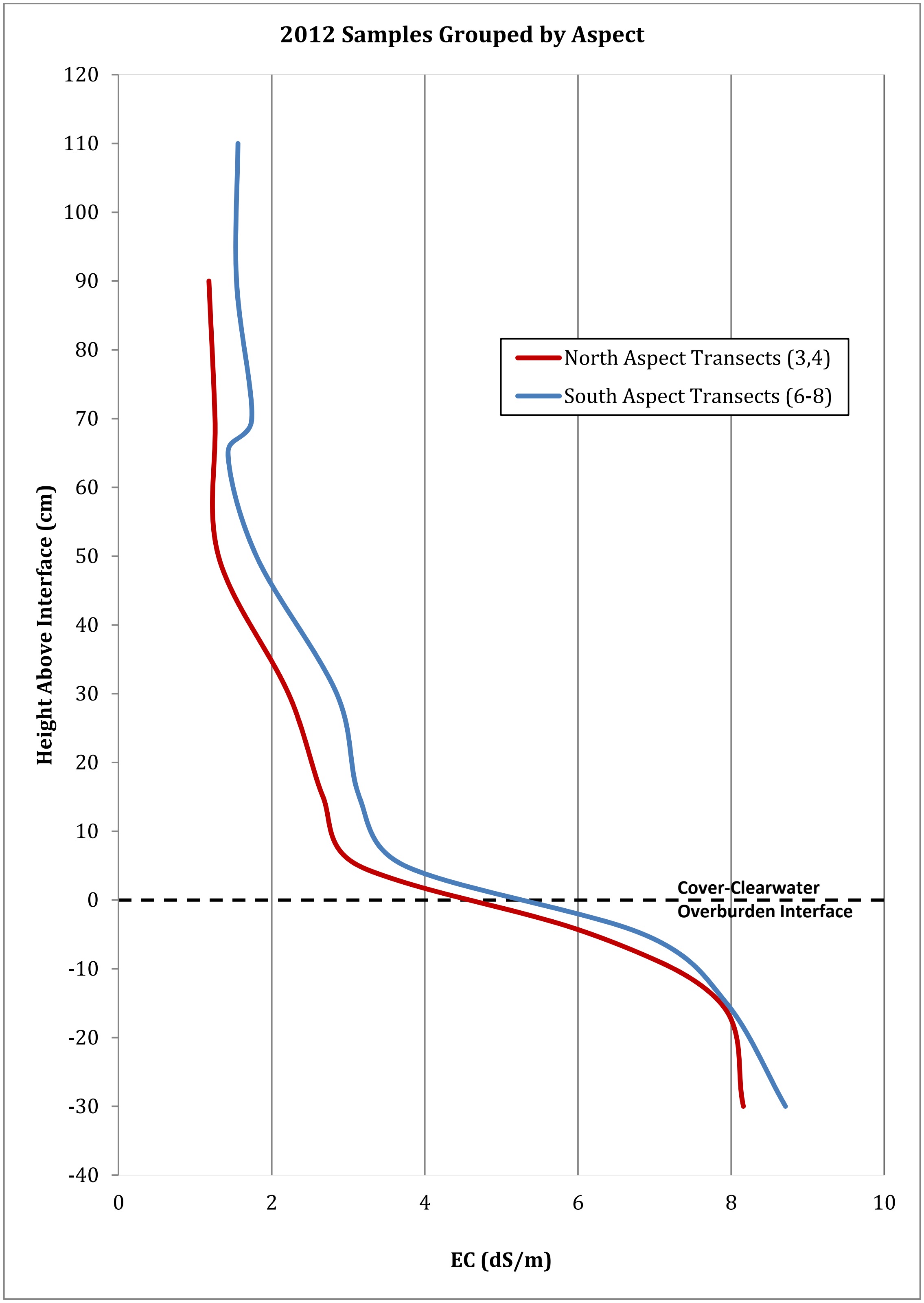


Figure 4-21. 2012 statistical median EC profile for north- and south-facing aspects

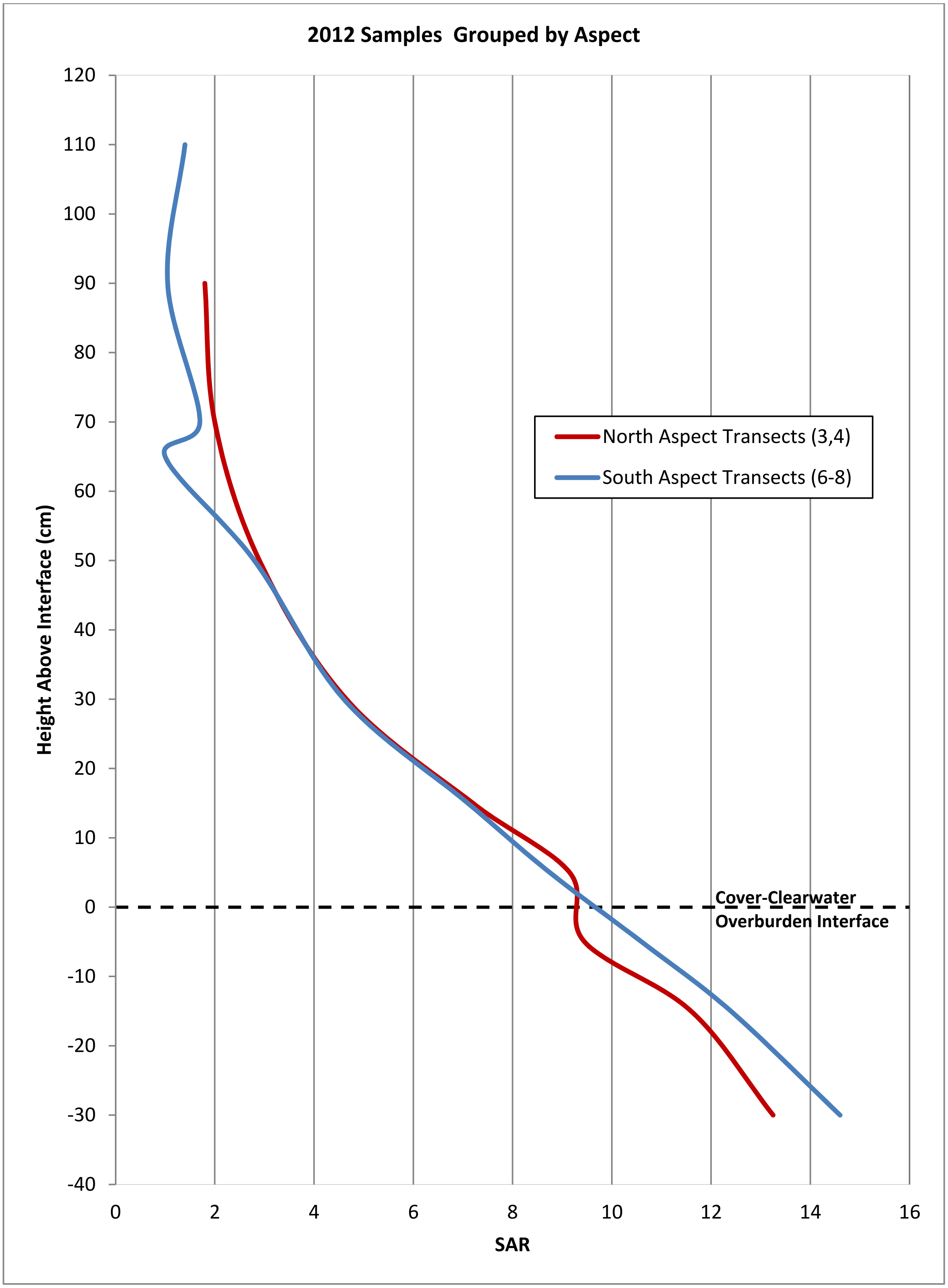


Figure 4-22. **2012 statistical median SAR profile for north- and south-facing aspects.**

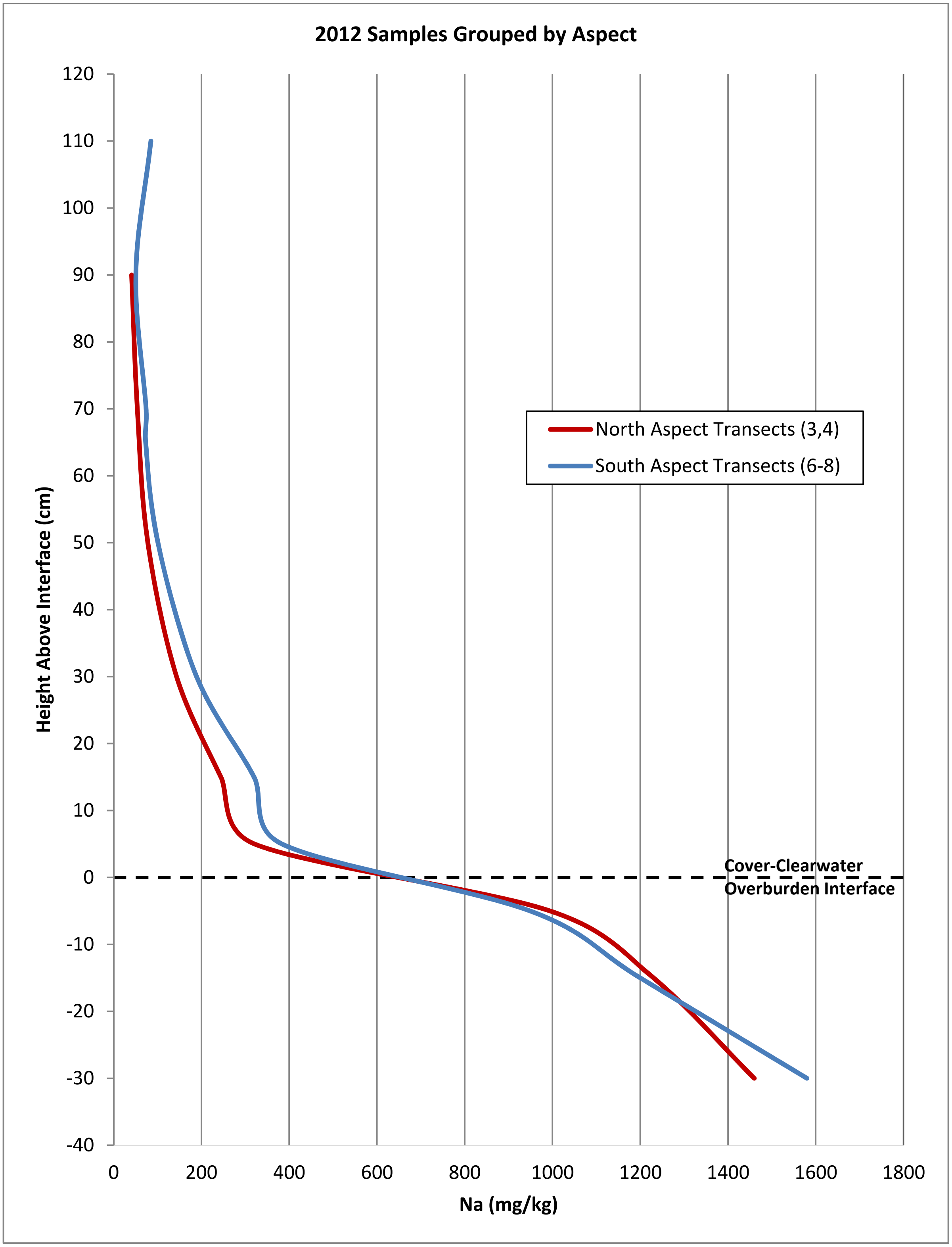


Figure 4-23. **2012 statistical median Na^+ profile for north- and south-facing aspects.**

4.4.4. Capping Thickness Influence

The 2012 salinity profiles suggest that cover thickness influences the rate of salt ingress into the soil cover. Salinity data was subdivided into three capping-thickness ranges of <75 cm, 75-100 cm and >100 cm. The 75-100 and >100 cm thickness ranges show similar extents of salt ingress for EC, SAR and Na^+ (Figures 4-24 to 4-26). Covers <75 cm thick, however, showed a marked difference in salt ingress relative to the thicker covers. The salt ingress in the shallow cover range (<75 cm) does not reach as high up the soil cover profile as it does in the thicker cover ranges. The <75 cm cover range suggests that EC, SAR and Na^+ reach assumed baseline (no decrease in salinity as height above the shale increases) concentrations in the soil cover at approximately 30 cm above the soil cover-shale interface. In contrast, the 75-100 cm and >100 cm reach baseline concentrations 60 to 85 cm above the soil cover-shale interface.

The increased height of salt ingress for thicker cover soils measured at SBH is in agreement with Merrill et al. (1983). They assessed the salinization of a 30 cm thick reclamation soil cover over saline-sodic coal mine spoil in North Dakota. Their calculations predicted increased salt accumulation and a greater thickness of salt-affected soil as cover soil thicknessed increased, based on upward salt diffusion being the dominant salt transport process at the site.

Soil cover thickness also appears to have an impact on near-surface Clearwater salinity and sodicity. The near-surface Clearwater overburden (top 30 cm) has lower EC, SAR and Na^+ concentrations in the <75 cm cover range compared to the thicker cover intervals. Soil EC, SAR and Na^+ in near-surface Clearwater overburden appears to increase with increased soil cover thickness (Figures 4-24 to 4-26). Data indicates a more pronounced difference in the near-surface Clearwater overburden EC, SAR and Na^+ between the <75 cm and 75-100 cm cover thickness range, and little to no difference between 75-100 and >100 cm cover thicknesses.

The observed results suggest that:

1. The upper Clearwater overburden beneath the thinner covers experienced more rapid initial oxidation, and the concentration of salts has already peaked and has since decreased; or
2. The thinner covers are experiencing greater rates of oxidation and salt production but are also experiencing greater rates of flushing by interflow and/or net percolation.

Thinner soil covers have a lower AWHC, and thus, use less water for evapotranspiration (Appendix F). This means that more of the rainfall and snowmelt on the thinner covers will leave as net percolation, interflow or runoff. However, the data from SBH cannot confirm that one or more of these flow mechanisms are greater for the thinner covers. Conversely, thicker soil covers have a higher AWHC which might result in less water flowing through as net percolation and interflow and potentially greater soil water contents in the soil cover. A reduction in net percolation and interflow will result in less salt “flushing” and an increase in soil water contents, which in turn increases the diffusion coefficient and increases salt ingress in the soil cover. The potential for deeper covers retaining all available water and limiting net percolation and interflow is discussed in more detail in Section 4.5 and in Appendix F.

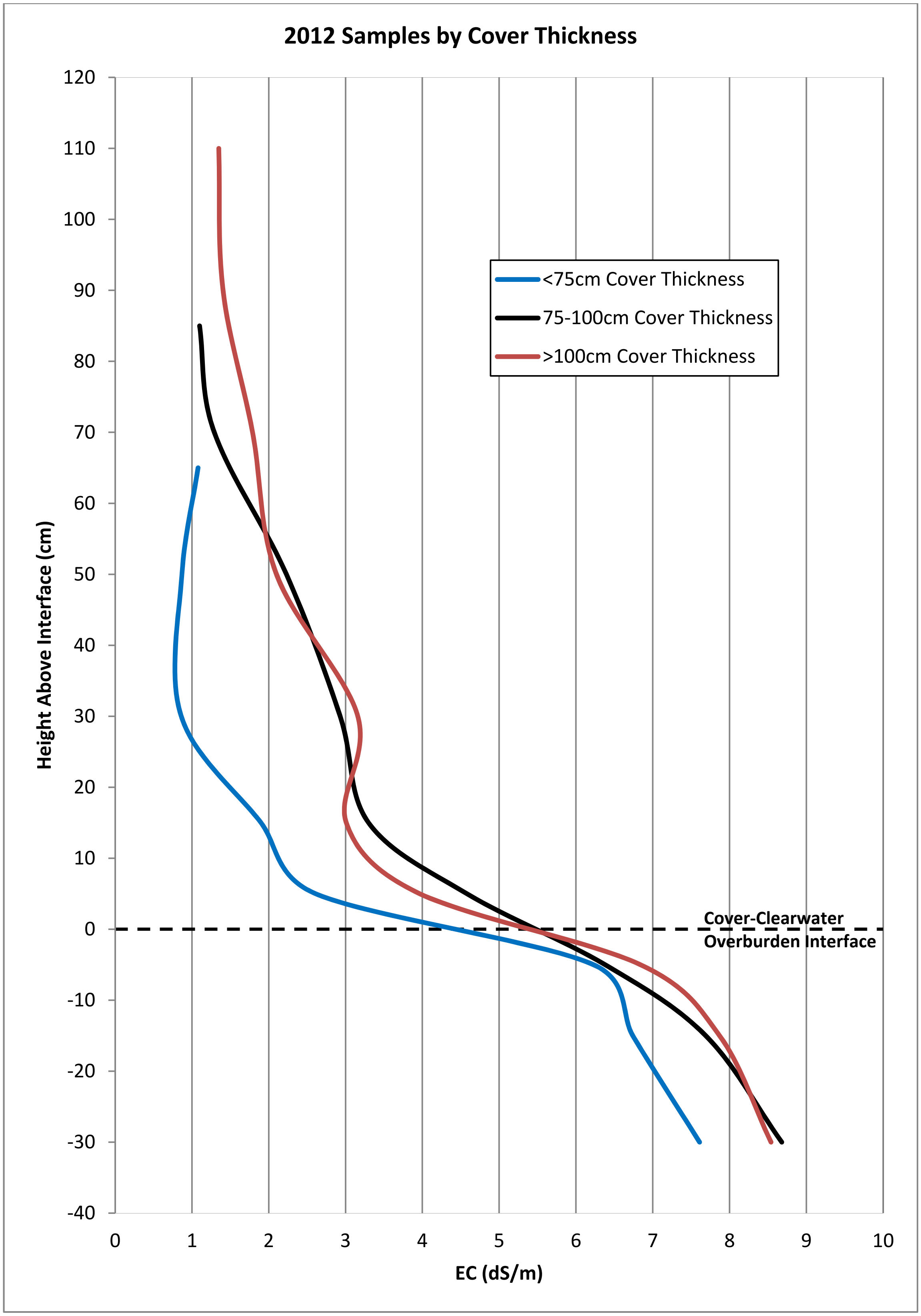


Figure 4-24. 2012 EC profiles of capping thickness ranges.

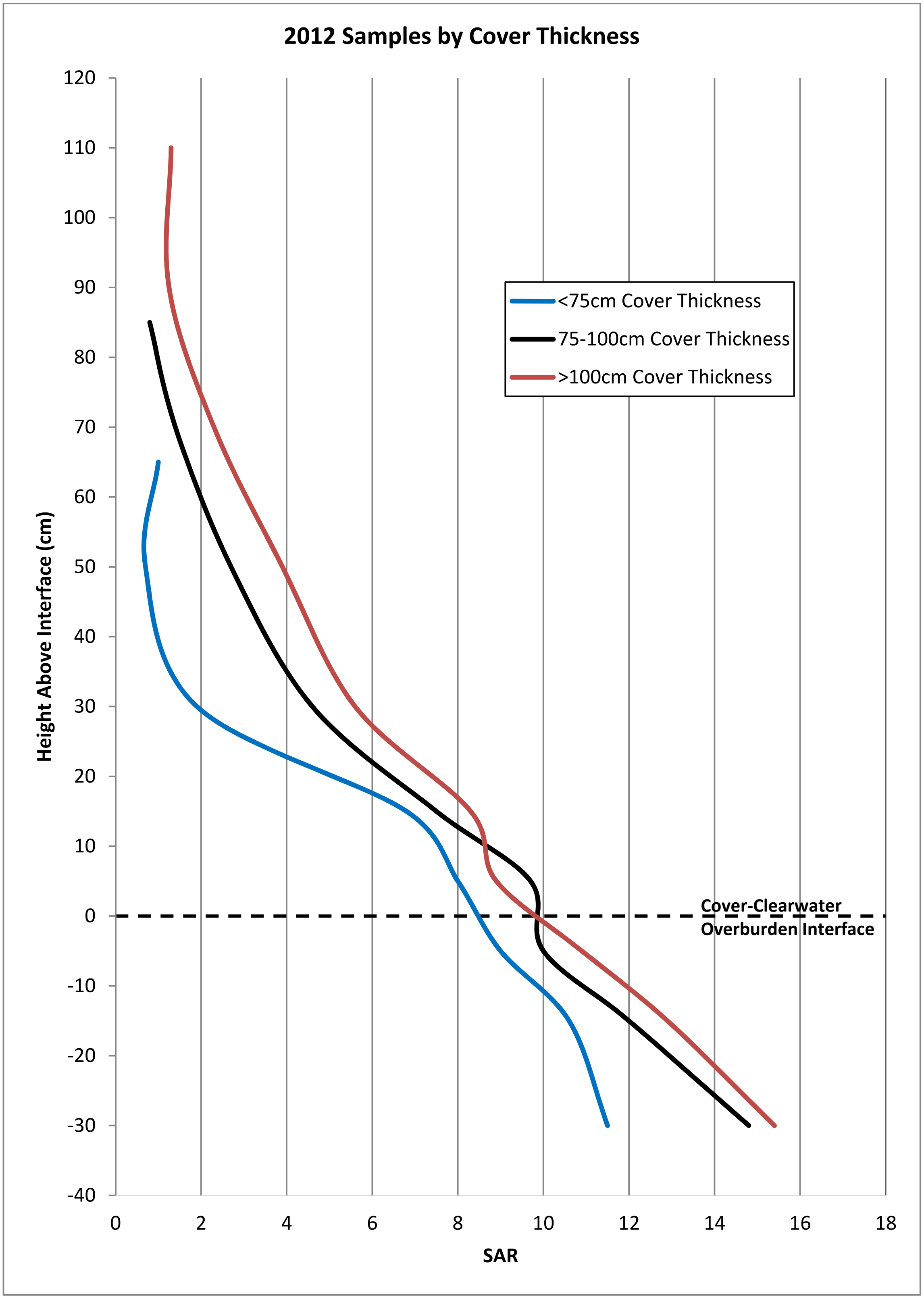


Figure 4-25. **2012 SAR profiles of capping thickness ranges.**

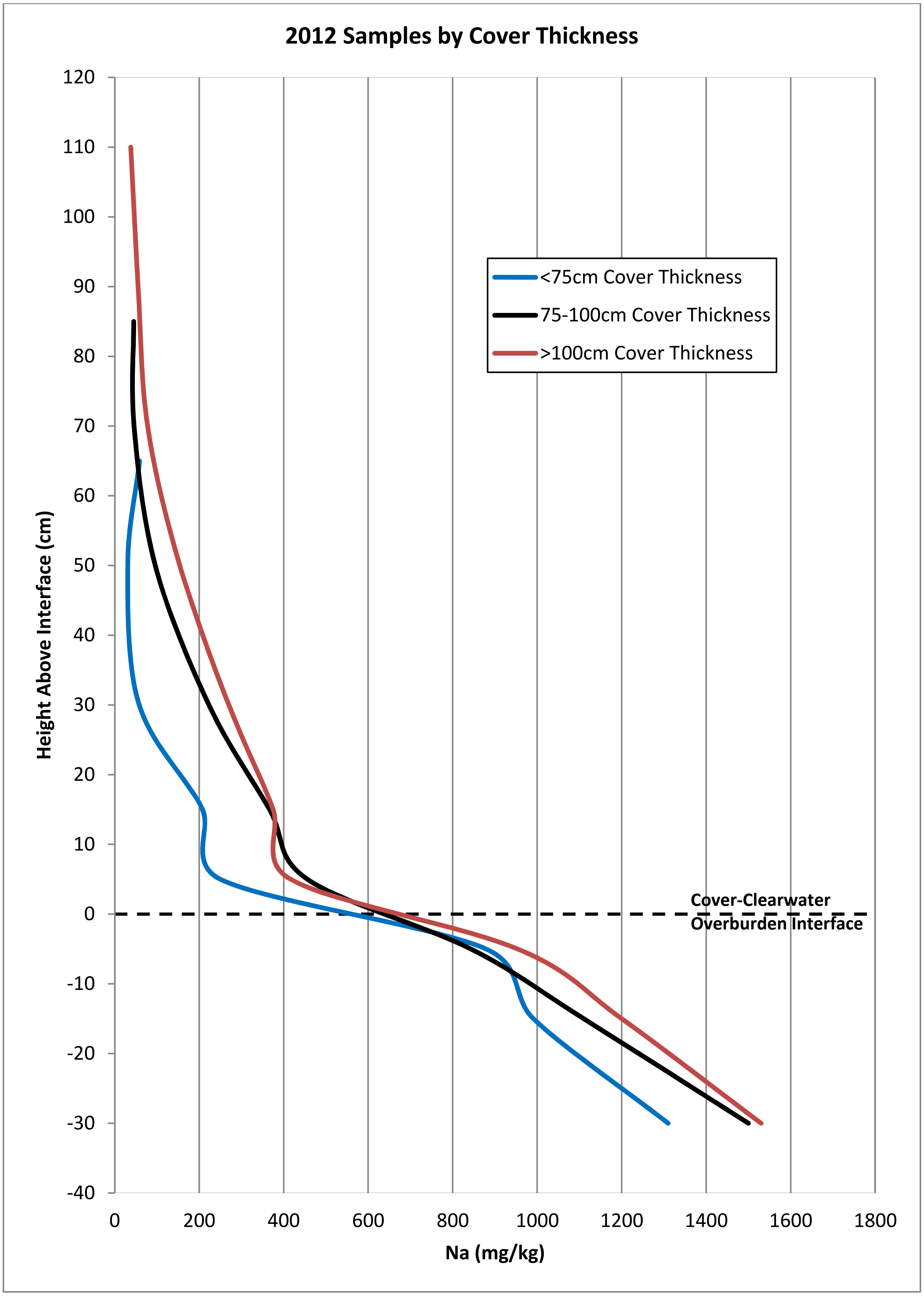


Figure 4-26. 2012 Na^+ profiles of capping thickness ranges.

4.4.5. Comparison of 2012 and Historic Salt Profiles

The median statistical profile of 2012 capping trial dataset was compared to 2002 and 2008 capping trial datasets (Figures 4-27 and 4-28). The statistical EC and SAR profiles from 2002, 2008 and 2012 suggest that EC in the upper 30 cm of Clearwater overburden decreased from 2002 to 2008, but has been relatively stable from 2008 to 2012. The EC and SAR in the cover soil appears to have increased from 2002 to 2008 and from 2008 to 2012.

The observed trends in the historic and current profiles suggest that salt has been migrating upward from the Clearwater overburden into the cover soil and has not stabilized. However the EC and SAR profile in the Clearwater overburden appears to have reached equilibrium with salt production through pyrite oxidation and salt flushing out the Clearwater overburden (via upward diffusion and downward net percolation).

Although salt concentrations in the cover soil show an increase, the depletion of salts in the near surface Clearwater overburden suggests that the upward flux of salts by diffusion is, or will soon begin, decreasing. Reduced upward diffusion of salts will eventually lead to a salt flux balance in the cover soil, with upward diffusion counteracted by net percolation and interflow. Subsequently, a reduction of salt concentrations in the soil cover will occur.

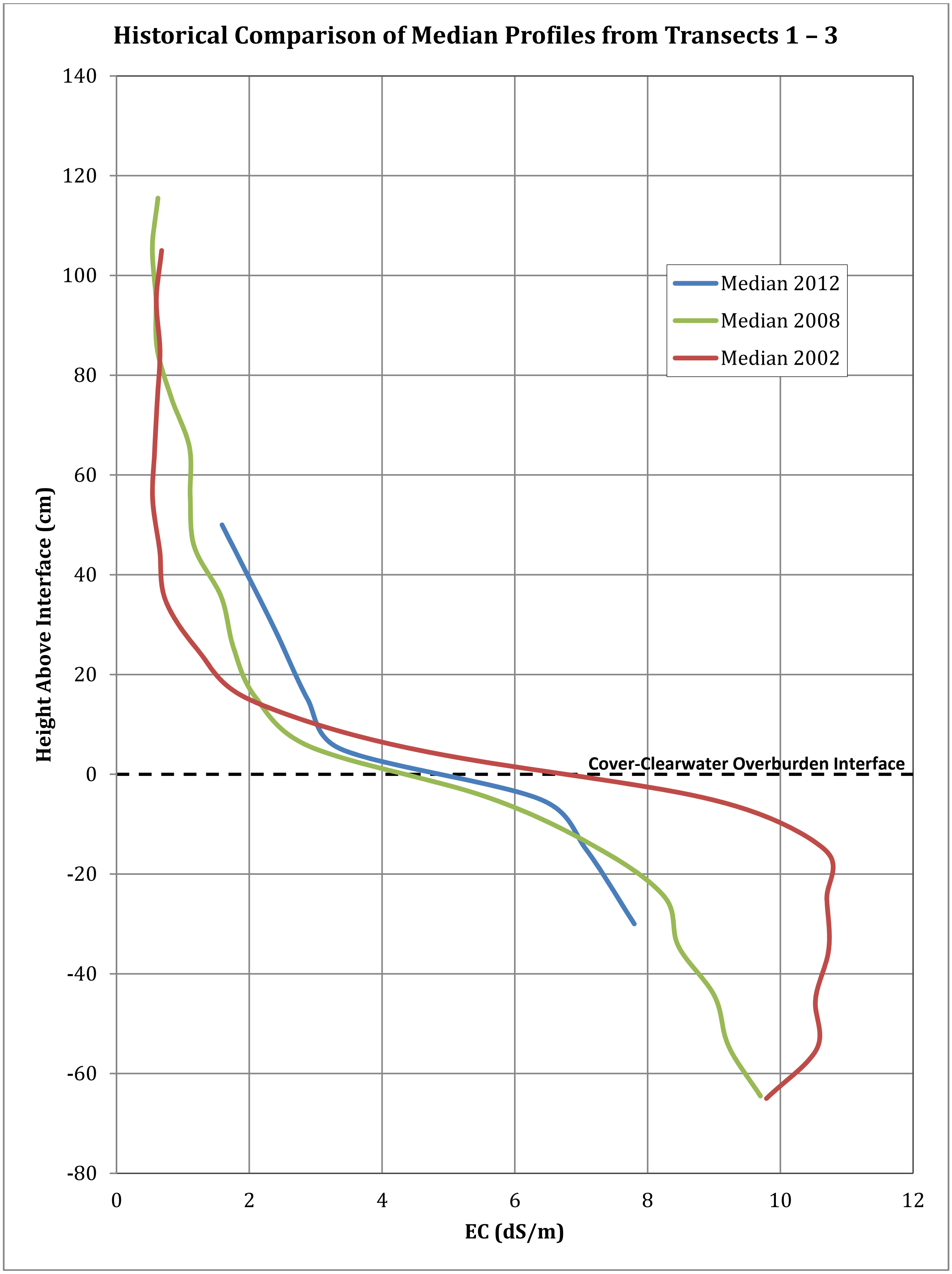


Figure 4-27. **Statistical EC profile for 2012 (T1-3), 2008 and 2002.**

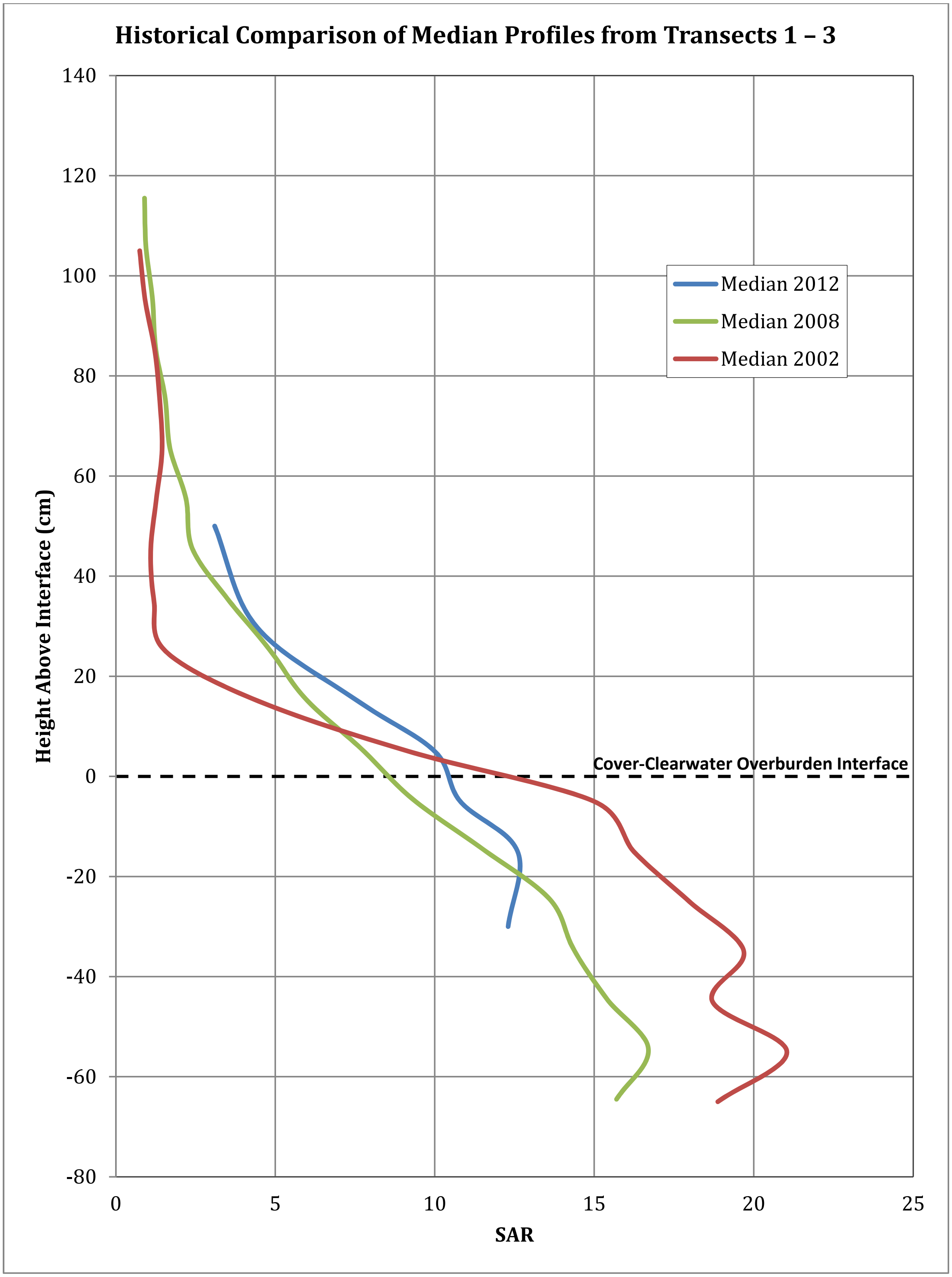


Figure 4-28. **Statistical SAR profile for 2012 (T1-3), 2008 and 2002.**

4.4.6. Salt Transport Changes with Time

The research work conducted to date can be interpreted to estimate future geochemical evolution of the covers. A subsequent round(s) of soil sampling and salinity profiling can validate these estimations.

The salinity profiles of this study indicate that salinity and sodicity in the near surface Clearwater overburden is reduced at locations with thinner covers (<75 cm) as compared with locations with thicker covers. It is suspected that the Clearwater overburden beneath the thinner covers experienced higher rates of oxidation in early years of reclamation than thick covers. Thinner covers and likely drier soil conditions (Appendix F) increase the potential for oxygen to reach near surface Clearwater overburden, which increases the rate of pyrite oxidation (and salt generation). As the pyrite concentration in the overburden is depleted, the oxidation front moves deeper into the overburden, which reduces the upward diffusion of salts in the cover. If the rate of net percolation and interflow remains relatively constant, this will result in an overall flushing of salt from the cover soil. Confirmation of net flushing of salts in the thinner cover(s) was not evaluated in this study.

The higher salinity and sodicity in the near-surface Clearwater overburden on the thicker covers suggests that the overburden salinity at these locations peaked or will peak later than it did for the thinner soil covers, although EC and SAR values for near-surface Clearwater overburden were lower in 2012 than the mean EC and SAR values measured in 2002 (Kessler, 2007). Furthermore, Hilderman (2011) showed no obvious increase in salinity of near-surface Clearwater overburden in the 100 cm cover trial plot and the EC and SAR in the overburden were relatively unchanged in 2008 and 2012. Therefore it is believed that salt production and salt flushing of the near-surface Clearwater overburden for thicker covers (100 cm) is near equilibrium.

4.4.7. Soil Profiles and Transport Summary

The 2012 soil salinity data covers a much broader area of SBH than any previous soil sampling program. Samples were collected from 9 transects extending down the SBH slope at varying aspects.

Compiled SBH data shows the salt ingress is approximately 60 cm into the soil cover from the near surface Clearwater overburden. Slope and aspect do not appear to be affecting salt ingress; however, capping thickness appears to be influencing upward salt movement. Salt ingress in capping thicknesses <75 cm is approximately 30 cm, and 60-85 cm for the medium (75-100 cm) and thick covers (>100 cm).

Although salt ingress is evident in the cover, it has not resulted in a significant degradation of the soil quality in relation to applicable guidelines. Salt ingress has had a greater impact on soil cover SAR ratings than EC ratings. Comparison of the 2012 sampling locations with soil quality guidelines (subsoil) found the EC of the cover soil is rated Fair to approximately 20 cm above the interface and Good above 20 cm. For SAR the cover soil is Poor from 0 to 15 cm above the interface, Fair to 35 cm and Good above 35 cm. When categorized by cover thickness, the thin cover (<75 cm) SAR is Poor 5 cm above the interface. This zone of Poor soil (based on the SAR quality guidelines) extends 10-15 cm above the interface for medium thickness covers (75 – 100 cm) and 15-20 cm above the interface for thick covers (>100 cm).

Comparison of previous sampling events (2002 and 2008) with 2012 has shown that salts are migrating upward into the soil cover, resulting in increased salinity in the lower cover. Meanwhile, the near-surface Clearwater overburden has shown a drop in EC and SAR between 2002 and 2008. Comparison of the 2008 and 2012 sampling events suggests that a balance may have been reached in the upper Clearwater overburden between salt production and salt transport via upward diffusion, downward net percolation and interflow. In the thinner covers (<75 cm), it is apparent that these processes have resulted in a net flushing of salts from the upper Clearwater overburden.

4.5. Soil-Water Dynamics

The results in this section focus on long-term simulations of the hypothetical covers. Details regarding the data compilation for the model and the calibration of the model can be found in Appendix F.

Long-term simulations of several hypothetical covers were performed using the 60-year climate data record of the region. Hypothetical covers of 35, 50, 75, 100, 125 and 150 cm were chosen for the simulation. The hypothetical covers assume a 20-cm peat-mineral surface layer (except 35 cm cover – 15 cm peat-mineral surface layer) over typical mineral subsoil for SBH and Mildred Lake Mine reclamation.

Four seasonal values of LAI were applied to the covers consisting of 1.5, 2.5, 3.5 and 4.5. A maximum LAI that each cover could support based on PET and annual total precipitation (rainfall and snowpack volumes) for each hypothetical cover was also investigated.

An important assumption made in the modeling was that all hypothetical covers were assumed to have free drainage at the lower boundary. This means that any excess water (i.e. water contents greater than field capacity) is allowed to drain away via interflow or percolation. This is viewed as a conservative approach to estimate plant-available water, as any excess water is not made available for vegetation. Some excess water could become available to vegetation at that location if it is held below the simulated depth, but still captured by roots, or another location if the water is transported via percolation or interflow to that location.

4.5.1. Annual Transpiration for Long-term Simulations

Frequency distributions of annual Tr were estimated for the simulated cover thicknesses over the range of LAIs (1.5 to 4.5) for the 60 year climate record. The annual values of Tr from the simulations were plotted in the form of a cumulative probability distribution as shown in Figure 4-29. In these figures the 0% passing is the lowest simulated Tr, 50% is the median value and 100% is the highest simulated Tr. This approach evaluates the influence of soil cover thickness on plant available water and consequently on vegetation productivity.

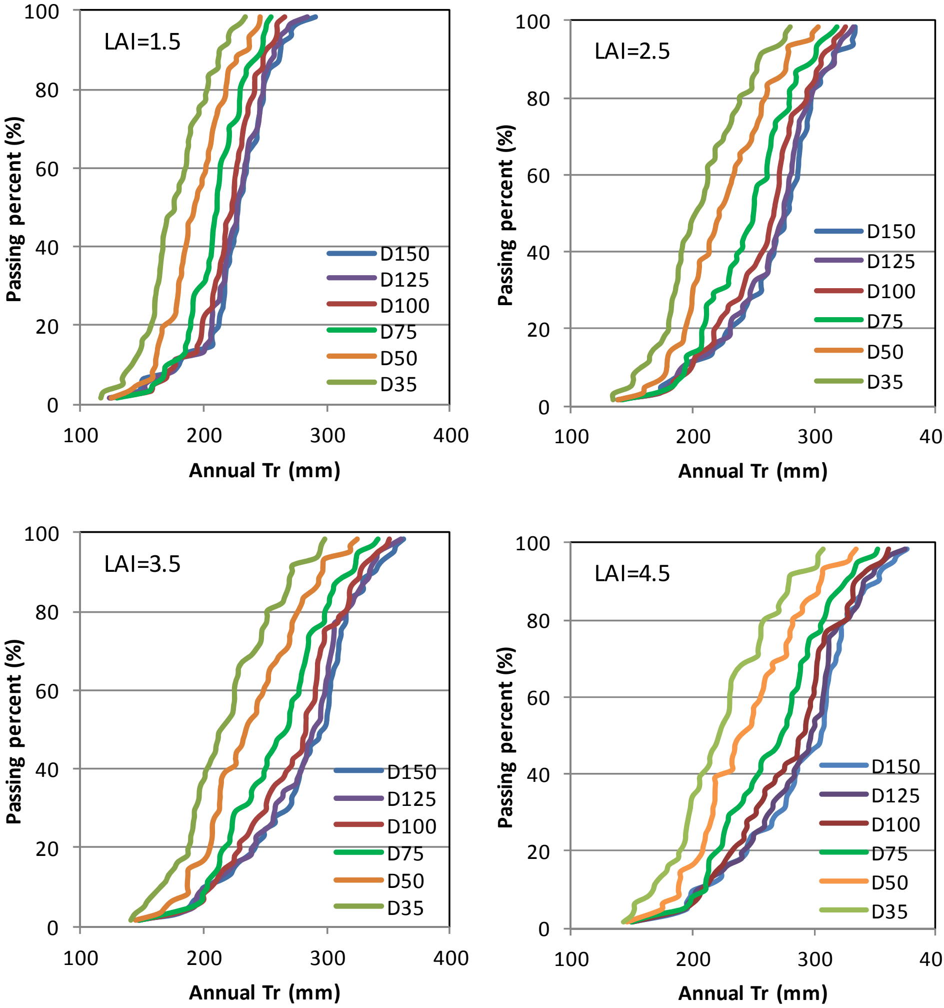


Figure 4-29. Frequency distribution of annual Tr for different cover thickness.

As the values of Tr increase, it is expected that vegetation productivity will increase. Since LAI is a measure of vegetation abundance (productivity), an increase in LAI will also produce a corresponding increase in annual Tr. The maximum and range of Tr that can be produced by any particular cover decreases with decreasing cover thickness. Tr varied from 142 mm to 299 mm in the 35 cm cover with an LAI of 3.5, while it ranged from 148 to 350 mm for the 100 cm cover with the same LAI.

Increases in Tr are not proportional to cover thickness. Median values of Tr for each LAI show that the greatest Tr increases are returned with increases in the shallow cover depth ranges, but diminish with increased cover depth. At a capping thickness of 100 cm there is little incremental gain in Tr and from 125 cm to 150 cm the gain is negligible.

Diminishing return with increased capping thickness is primarily related to the ability of the cover to store snow-melt infiltration. Water available to the covers from precipitation received during the growing season is fully utilized by the covers for Tr, regardless of cover thickness. Consequently, the enhanced Tr from thicker covers can be credited in large part to their enhanced ability to store snow melt water. However, the volume of snow melt water that each cover can store is limited. Continuing to increase cover thickness beyond that which is required to store snowmelt water does not provide any further benefit or increase in Tr. Based on annual snowpack information collected at the site (unpublished data) and the typical soil texture of the mineral reclamation subsoil, the analysis indicates that 35 cm of secondary would be able to store the average water amount provided by the snowpack. This also indicates that thick covers may hold all water available and limit the ability of the upland landscape to provide water to adjacent surface waters (e.g., opportunistic or planned wetlands) in the closure landscape.

4.5.2. Annual Tr Estimation for Hypothetical Covers

The values of LAI are held constant in the simulations regardless of transpiration rates. In order to evaluate whether the simulated transpiration rates were sufficient to sustain the specified LAI, a maximum sustainable LAI was estimated for each of the covers and superimposed over the simulated Tr for a range of LAI values. Figure 4-30 shows the Tr distributions for the 35 and 100 cm covers for the estimated Tr and the range of LAI values. For the 35-cm cover the estimated Tr adjusts from a low LAI value of 1.5 in the driest years to an LAI of approximately 2.5 through the median climate range and then increases to a maximum sustainable LAI between 2.5 and 3.5 in the wettest years. Conversely, the 100-cm cover demonstrates it is able to support high LAI values between 2.5 and 4.5, regardless of the yearly water input. This suggests that once the cover exceeds 75 cm, there is little incremental increase in the Tr based on the 60-year climate data record.

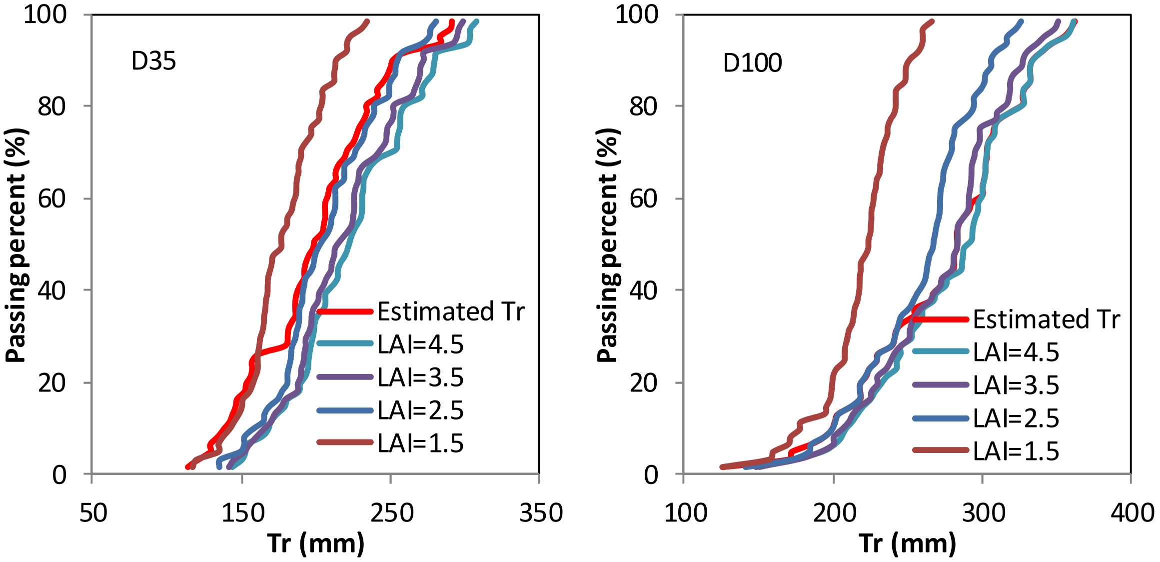


Figure 4-30. **Frequency distribution of annual Tr for different cover thickness.**

4.5.3. Soil-Water dynamics summary

A validated soil-water model was developed for hypothetical soil cover thicknesses on Clearwater overburden using information collected from previous research studies at SBH. Frequency distributions of Tr for the hypothetical cover thicknesses with a range of LAI cases were developed. The Tr frequency distributions reflected the differences in plant water consumption among the hypothetical covers and four LAI values.

Tr frequency distributions were then modified by coupling Tr and LAI to provide insight into the influence of cover thickness on plant-available water and consequently vegetative productivity. The results suggest that for thinner covers, productivity is affected by dry year cycles in which the maximum available Tr leads to limitations in plant growth, which further restrict Tr and productivity.

The modified frequency distributions for annual Tr value for the hypothetical cover thicknesses highlight the strong non-linearity of the distribution of Tr over the 60-year climate record of the region, in that incremental increases in cover thickness do not produce proportional increases in Tr. In fact, once the cover thickness exceeds 75 cm, there is little incremental increase in the median value of Tr over the 60-year climate record of the region.

5.0 SYNTHESIS

A summary table that integrates the results of the 2012 studies in presented in Table 5-1. The table presents an overview of the key values for each study based on capping thick scenarios ranging from 35 to 150 cm. This section integrates the results of the studies and synthesizes the findings to evaluate the appropriate depth(s) for upland reclamation of Clearwater overburden.

Table 5-1. Summary of Design, Observed, Modeled Characteristics and Risk Assessment Results

Characteristics		Capping Thickness Scenarios					
		35 cm	50 cm	75 cm	100 cm	125 cm	150 cm
Design	Peat thickness (cm)	15	20	20	20	20	30
	Secondary thickness (cm)	20	30	55	80	105	120
	Period of effect of soil capping thickness approval requirements	n/a	n/a	n/a	1990-2006	n/a	2006-present
Observed (2012)	Capping thickness average (cm)	30	49	-	106	-	-
	Current vegetation performance (poor, fair, good)	Good	Good	Good	Good	Good	Good
	Current tree growth versus equivalent capability of natural stands	Meets/ Exceeds	Meets/ Exceeds	-	Meets/ Exceeds	-	-
	Rooting biomass (Mg/ha)	<10		10 - 36.6			
	Overburden rooting limitation (Yes, No)	Yes	Yes	Yes	Yes - No	No	No
	Median height (cm) of salt ingress into base of soil cover	30		60 - 85			
	Median height (cm) of change of EC soil rating from Fair to Good due to salt ingress into base of soil cover	0 - 5		25 - 30	30 - 35		
	Median height (cm) of change of EC soil rating from Poor to Fair due to salt ingress into base of soil cover	-5 - 0		0 - 5	0 - 5		
	Median height (cm) of change of SAR soil rating from Fair to Good due to salt ingress into base of soil cover	20 - 25		35	45 - 50		
	Median height (cm) of change of SAR soil rating from Poor to Fair due to salt ingress into base of soil cover	5		10 - 15	15 - 20		
	Peak evapotranspiration rate (mm/day) (versus mature boreal forest)	-	-	-	3.9 (Comparable)	-	-
	Peak LAI (since 2008)	-	-	-	3.5	-	-
Modeled	Evapotranspiration (LAI = 3.5) (mm)	275	296	317	329	336	341
	Total annual yield (runoff + net percolation) (LAI = 3.5) (mm)	77	57	38	26	19	15
	Rainfall (mm)	310.6					
	Snowmelt volume (mm)	115.6					

(-) Information for capping depth not available

5.1. Integration of Results

Synthesis of the study results involved integrating the study findings in a Failure Mode and Effect Analysis (FMEA). The FMEA focused on the ability of the landscape to produce the intended species at the density and productivity required to match equivalent capability requirements. Failure is considered at the scale of an entire landform and underperforming areas are not considered a failure if the entire landform is performing adequately. This rationale was chosen for several reasons:

- Although small areas may not meet equivalent capability they may provide variability and fulfill a function (or niche) that has value in the closure landscape;
- Underperforming small-scale areas within a landform performing adequately may perform marginally in the initial stages but eventually progress to an adequate performance level; and
- Supplemental reclamation of large-scale (landform) reclamation areas is generally not considered to be economically feasible, while small-scale areas are feasible (and have been performed) on a case-by-case basis.

The consequence of failure does not suggest the site would be devoid of vegetation; it means the landform has vegetation present, but it does not meet forest productivity targets.

5.1.1. Risk Rating Definitions

A risk matrix assessment, based on professional judgement, was developed by the research group. Risk ratings of ‘likely’, ‘unlikely’, ‘very unlikely’ and ‘remote’ were chosen for the assessment (Table 5-2). A probability was assigned to each of the rankings ranging from a 50% probability (1 in 2) of occurrence for Likely to a 0.1% (1 in 1000) for Remote. The timeline of occurrence considered in the assessment ranges from the time to establish and maintain a mature forest (decades) to sustaining several forest rotations (centuries).

Table 5-2. Failure Risk Rankings and Associated Probabilities

Failure Risk	Risk Probability[1]
Likely	50% (1 in 2)
Unlikely	10% (1 in 10)
Very Unlikely	1% (1 in 100)
Remote	0.1% (1 in 1000)

[1] Assumes approximate timeline of occurrence to establish and maintain a mature forest (decades) to sustaining several forest rotations (centuries).

5.2. Summary of Risks to Plant Growth

Potential risks related to tree growth that may be relevant at SBH and Clearwater overburden reclamation areas were identified by the research group. These include water availability, salt effects due to evapo-concentration, salt diffusion causing drought stress, sodification of the soil structure, sodium toxicity and water logging of the root zones. The following sections assess these risks and Table 5-3 is a summary matrix of the risk assessment.

Table 5-3. Plant Growth Risk Assessment Summary

Plant Growth Risk Assessment Classes: ***Likely to Occur, Unlikely to Occur, Very Unlikely to Occur, Remote***	**Capping Thickness Scenarios**					
	35 cm	**50 cm**	**75 cm**	**100 cm**	**125 cm**	**150 cm**
Water availability	Likely	Unlikely	Very Unlikely	Remote	Remote	Remote
Salt diffusion causing drought stress	Likely	Unlikely	Unlikely	Very Unlikely	Remote	Remote
Salt effects due to evapo-concentration	Unlikely	Very Unlikely	Remote	Remote	Remote	Remote
Sodification of the soil structure	Unlikely	Very Unlikely	Remote	Remote	Remote	Remote
Sodium toxicity	No significant risk – not included in full risk assessment					
Water logging of the root zone						

5.2.1. Water Availability

Soil-water numerical modeling using a long-term, 60 year climate data record for the region suggests that there is a limit to the increase in water availability for plant growth associated with increasing reclamation cover thickness.

Evapotranspiration is the greatest loss of water from SBH (Figure 5-1). The water budget is largely vertical, where inputs in precipitation are returned to the atmosphere, with smaller amounts of water reporting as runoff and deep percolation comparatively. Therefore, the amount of soil-water storage plays a vital role in supplying water to vegetation during drought periods (i.e., low growing season precipitation) and also has a strong influence on the amount of water released as runoff, interflow or net percolation. The modeling illustrated that for the 60 year climate data for the region, approximately 35 cm of secondary would be able to store the average water amount provided by the snowpack while precipitation received during the growing season is fully utilized by evapotranspiration. This highlights that incrementally increasing cover depth will only be effective in increasing evapotranspiration through its ability to store snow melt water.

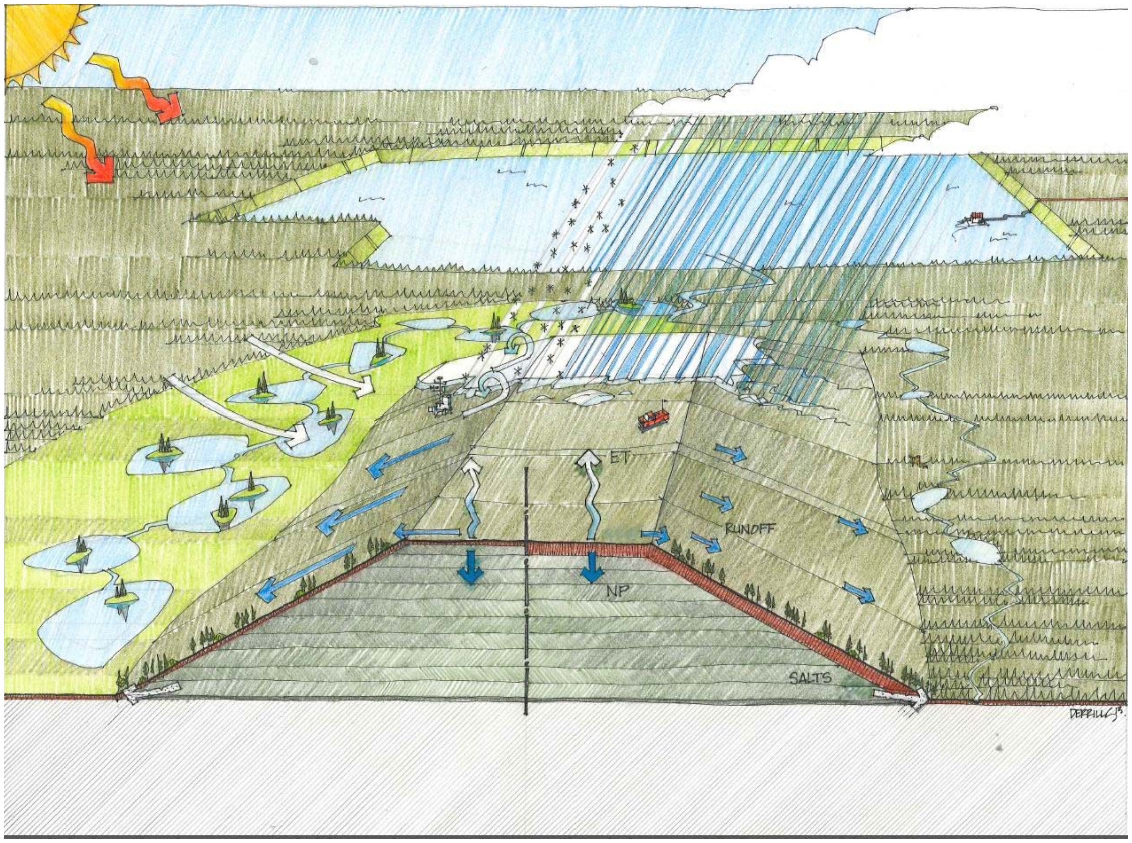


Figure 5-1. Conceptual water balance for a thick and a thin soil cover.

It is evident that there are incremental increases in transpiration when capping thicknesses are increased from 35 cm to approximately 75 cm. There are negligible increases in transpiration with further increases in capping thickness, indicating that the soil profile has maximized its ability to capture and hold all climate-water inputs.

Vegetation growth at the site supports the water modeling results. Site vegetation growth indicates that none of the current capping depths at SBH are experiencing water deficits sufficient to significantly affect productivity. Since reclamation, the site has experienced a wide range of growing season rainfall (178 to 321 mm) with 2012 having greater than climate normal rainfall of 312 mm. There has also been considerable intra-annual variability in rainfall. Notwithstanding this variability in rainfall, vegetation growth at SBH exceeds the current target for terrestrial Clearwater overburden reclamation regardless of capping depth. Vegetation growth measured at SBH suggests that there is little to no improvement in tree growth (site index) with capping depths greater than 50 cm.

Evapotranspiration rates since 2008 have plateaued at ~4 mm/day, similar to those reported for mature aspen stands in the boreal forest (Blanken et al., 2001, Brummer et al. 2012). Other metrics of comparison such as net ecosystem exchange and stomatal conductance also support the position that the aspen stand on the plateau of SBH is similar to young and mature boreal stands. As such, there is confidence that the current growth performance measured at SBH is indicative of what should be expected to maturity.

There are some limitations and uncertainties that must be considered when assessing the water deficiency risk. The tree growth at SBH suggests a soil cover of 50 cm is sufficient to meet (and exceed) target growth rates; however, the site has not experienced prolonged water-stress conditions over several years. It may be prudent to consider the water modeling results (Appendix F) that suggest a thicker soil cover based on the climate record of the region, rather than just the tree growth results based on a shorter climate period.

It is the opinion of the research team that the risks to plant growth associated with water availability are ‘likely’ for 35 cm, ‘unlikely’ for 50 cm, ‘very unlikely’ for 75 cm and ‘remote’ for 100, 125 and 150 cm (Table 5-3).

5.2.2. Salt Effects due to Evapo-concentration

Research at SBH has found no evidence of evapo-concentration of salts resulting in salinization of the soil cover. Although salt ingress is occurring at SBH, salt diffusion is not dominating the salt transport process and is being offset by other mechanisms such as salt flushing (i.e., percolation and interflow). Salinity sampling within various landscape features (e.g., slope position and aspect) has not found evapo-concentration of salts within upland study areas. The salt profiling work conducted in 2012 suggests that soil cover thickness can influence the amount of salt ingress into the soil cover, in that thicker covers result in salt ingress further into the soil cover than thinner soil covers. However, thicker soil covers contain the bulk of the salt accumulation to the lower subsoil.

For salt ingress into the soil cover to salinize the soil, salt diffusion processes must dominate offsetting flushing processes such as percolation and interflow. Salt diffusion does dominate salt migration processes within the earlier years, due to the high concentration gradients created by placing the capping material directly on the Clearwater overburden surface (Kessler 2007). However, concentration gradients diminish as salt concentrations increase in the soil cover, due to flushing of salts from interflow and net percolation and reduced oxidation of Clearwater overburden. Flushing mechanisms then become the dominant processes controlling salt migration.

All covers can salinize in discharge areas if there is no mechanism available for removal of salt discharged from the cover through surface water movement. This phenomenon has not been observed to date within study areas of SBH. Normal recharge-discharge processes are occurring at SBH; however, the discharge sites within the study area are well drained, limiting the height of the water table and the potential for evapo-concentration. Most of the lower/toe slopes in the SBH study area are drained through ditches, swales or wetlands. This means salt transport continues further downstream and outside the study area to such landforms as wetlands or end-pit lakes.

Salt ingress evident at SBH suggests that the thinnest soil covers measured (35 cm) in upland slope positions are at risk of salinization. However, thicker soil covers pose little risk of salinization now and in the future. Therefore the risk to plant growth from salinization and evapo-concentration of salts is ‘unlikely’ for a 35 cm soil cover, ‘very unlikely’ for 50 cm and ‘remote’ for 75, 100, 125 and 150 cm soil covers (Table 5-3).

5.2.3. Salt Diffusion Causing Drought Stress

To ensure establishment and prevent abnormal drought stress on targeted tree species, it is important that salt migration does not result in salinity levels exceeding threshold concentrations in the soil cover. Studies on the presence and growth potential of boreal forest tree species on saline soils in the region found typical boreal forest vegetation is not associated with a topsoil EC >4dS/m, while declining forest productivity was associated with topsoil EC >2dS/m and subsoil EC >4dS/m (Close et al. 2007; Lilles et al. 2010). However, they did observe typical boreal forest communities with highly saline subsoil conditions (EC >20 dS/m), provided the topsoil EC remained below 4 dS/m.

Salt profiles at SBH indicate that the EC concentrations are well below the threshold EC concentration of 4 dS/m in the topsoil, regardless of capping thickness. Assuming these thresholds apply to reclaimed oil sands soils, the shallowest soil cover (35 cm) has the ability to support targeted boreal forest tree species (white spruce and aspen). However, shallower soil covers are within the range of 2-4 dS/m in the topsoil and >4 dS/m for subsoil which may result in reduced forest productivity. The tree growth measurements at SBH are in general agreement with these threshold values. SBH is currently supporting the growth of white spruce and aspen, but growth limitations may be evident with elevated EC in the subsoil.

Assuming the previously mentioned thresholds are accurate for SBH tree growth, the salt profiles measured in 2012 indicate that a 35 cm soil cover may be limiting to white spruce and aspen growth. A 50 cm soil cover would likely support white spruce and aspen, but may exhibit stress and limited growth in adverse conditions. However, a soil cover of ≥75 cm likely has the ability to support white spruce and aspen with no limitations in growth.

Salt ingress measured in 2012 and previous sampling events at SBH suggests that salt diffusion is counteracted by flushing mechanisms, so that salt ingress into the soil cover is near, or has reached, its maximum. There is evidence to suggest that the thinner covers may be at a stage of net flushing of salts from soil cover. Therefore, there is confidence that the current salt ingress at SBH is near its maximum in the soil cover and there should not be any significant increases in the future that could reduce the current tree growth rate.

The plant growth risk associated with salt diffusion causing drought stress is ‘likely’ for a cover soil depth of 35 cm, ‘unlikely’ for 50 and 75 cm, ‘very unlikely’ for 100 cm and ‘remote’ for 125 and 150 cm (Table 5-3).

5.2.4. Sodification of the Soil Structure

Salt-affected soils can be classified as saline, saline-sodic or sodic (Brady and Weil 1996). Saline soils have an EC >4 dS/m with calcium and magnesium dominating the soil exchange complex, and SAR <13. Saline-sodic are soils with an EC >4 dS/m and SAR >13, with sodium making up a large portion of the soil exchange complex but with a significant concentration of other cations. Sodic soils have an EC <4 dS/m, SAR > 13, with sodium dominating the soil exchange complex.

Sodic soils are generally viewed as being the most troublesome of the salt-affected soils (Brady and Weil 1996). Sodium is unfavorable in soil exchange complexes because they are not attracted closely to soil colloids. As a result soil aggregates break-up and disperse, clogging up soil pores and reducing water infiltration. Since saline-sodic soils still contain an appreciable amount of calcium and magnesium, the soil structure is stable and water infiltration is maintained. Several sources have illustrated the relationship between EC, SAR and colloid stability (Oster and Rhoades 1984, Shainberg and Letey 1984, Sposito 2008).

The scatter plot of the EC and SAR of the soil cover samples illustrates the reclamation materials at SBH are primarily classified as normal (Figure 5-2). However, the salt ingress in the soil cover has resulted in some of the soil cover materials being classified as saline soil, followed by lesser amounts classified as saline-sodic and sodic soils. The 2012 salinity profile study has shown the soil cover near the Clearwater overburden has increased EC and SAR, with affected soils currently developing more toward a saline-type soil rather than a sodic soil. This suggests that the soil cover materials currently contain sufficient calcium and other base cations to counteract the sodium addition.

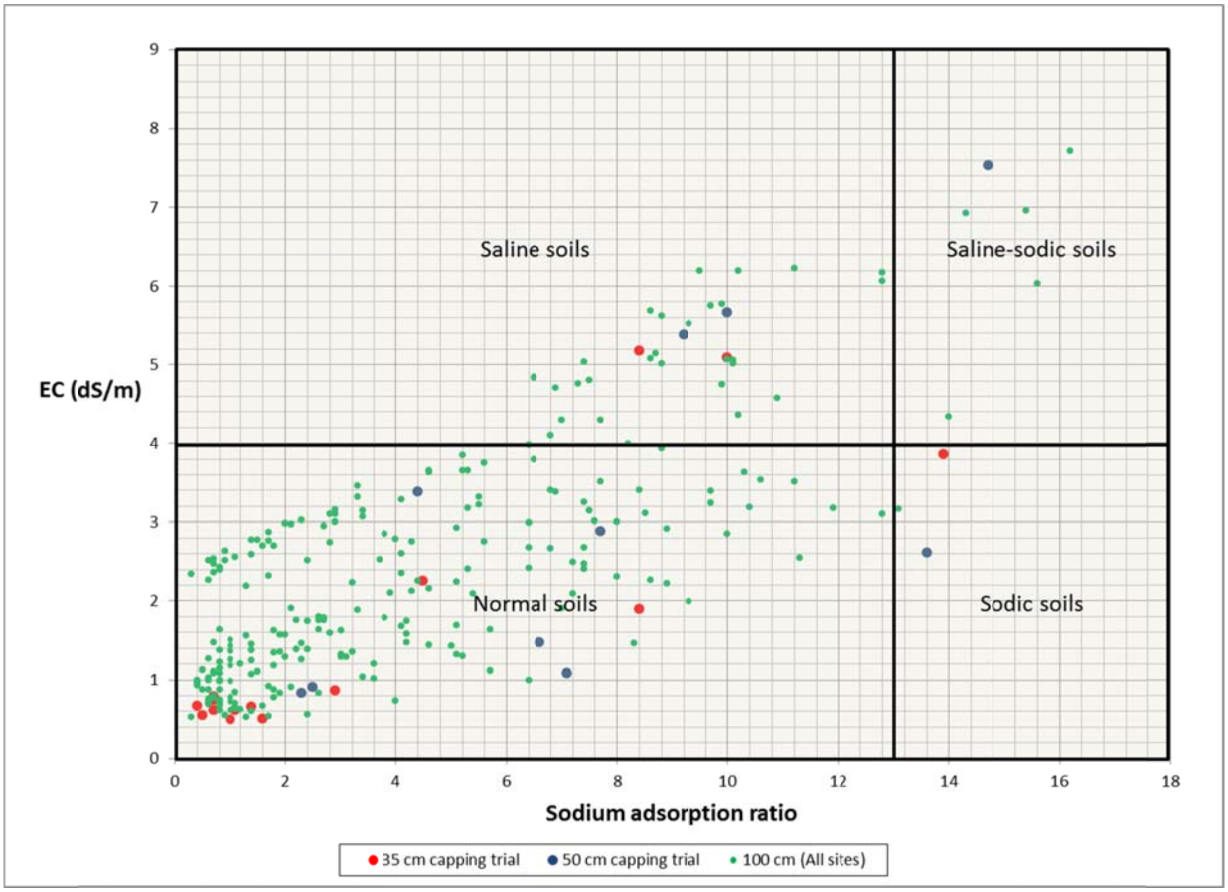


Figure 5-2. Saline and sodic soil classification of 2012 cover material samples at South Bison Hill (Adapted from Brady and Weil 1995).

A scatter plot of the EC and SAR for Clearwater overburden samples collected in 2012 at SBH suggest a saline and saline-sodic classification (Figure 5-3). There were no samples from the top 30 cm of Clearwater overburden that returned a sodic classification. Plotting the mean EC (10 dS/m) and SAR (16.9) values that Kessler (2007) measured for unweathered Clearwater overburden also concludes a saline sodic soil classification. The salinity and sodicity characteristics of the Clearwater overburden at SBH to date suggests near-surface Clearwater overburden is not progressing to a sodic soil classification that could result in soil aggregate dispersion. This suggests that there has been a sufficient reservoir of base cations present to buffer the sodium present in the overburden.

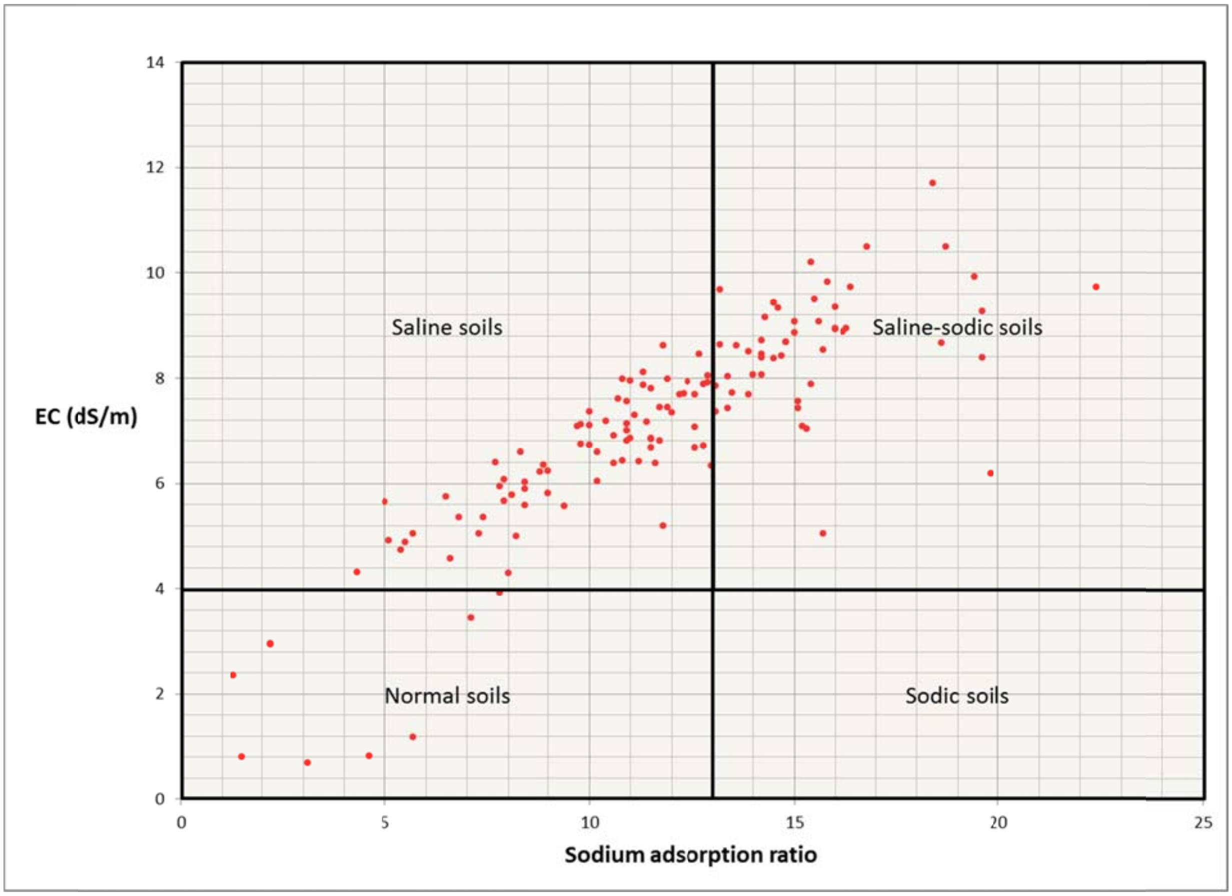
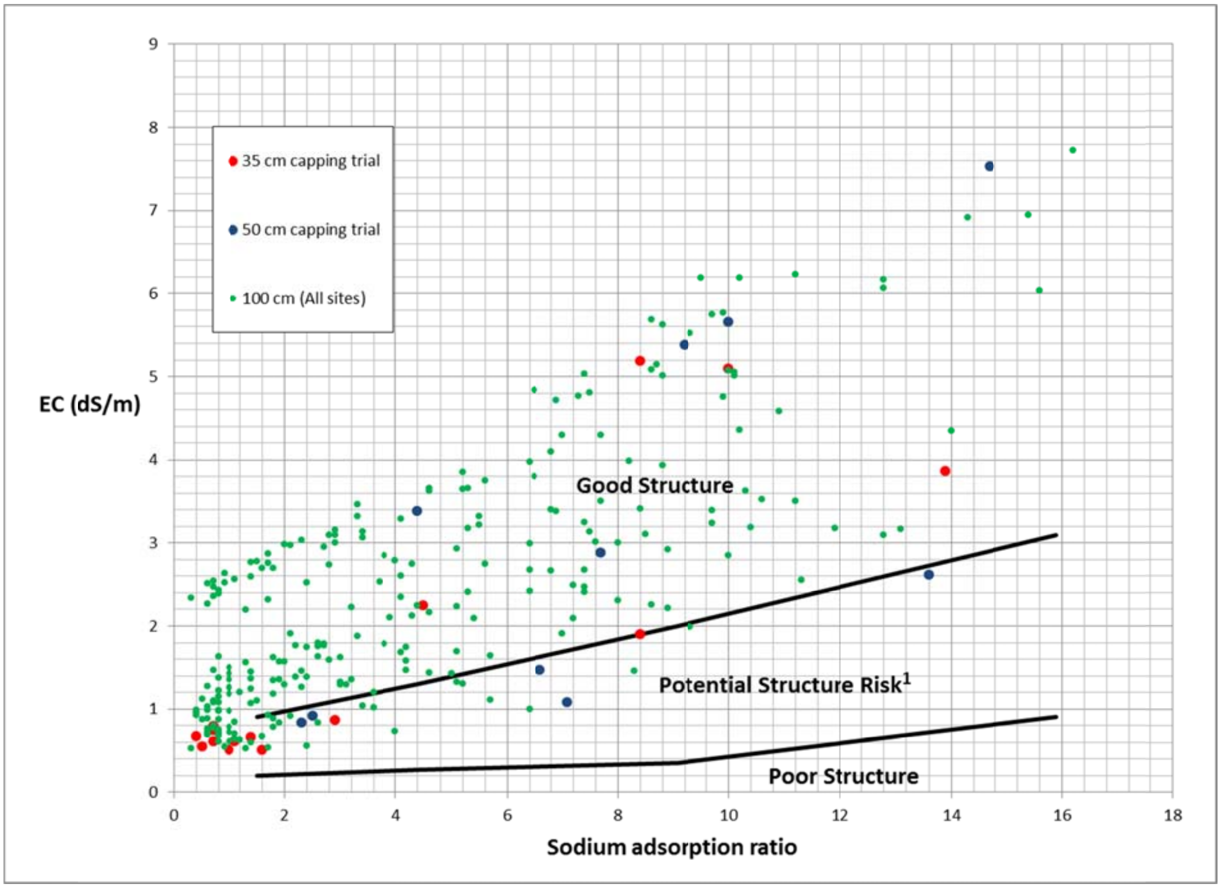


Figure 5-3. Saline and sodic soil classification of 2012 Clearwater overburden samples at South Bison Hill (Adapted from Brady and Weil 1995).

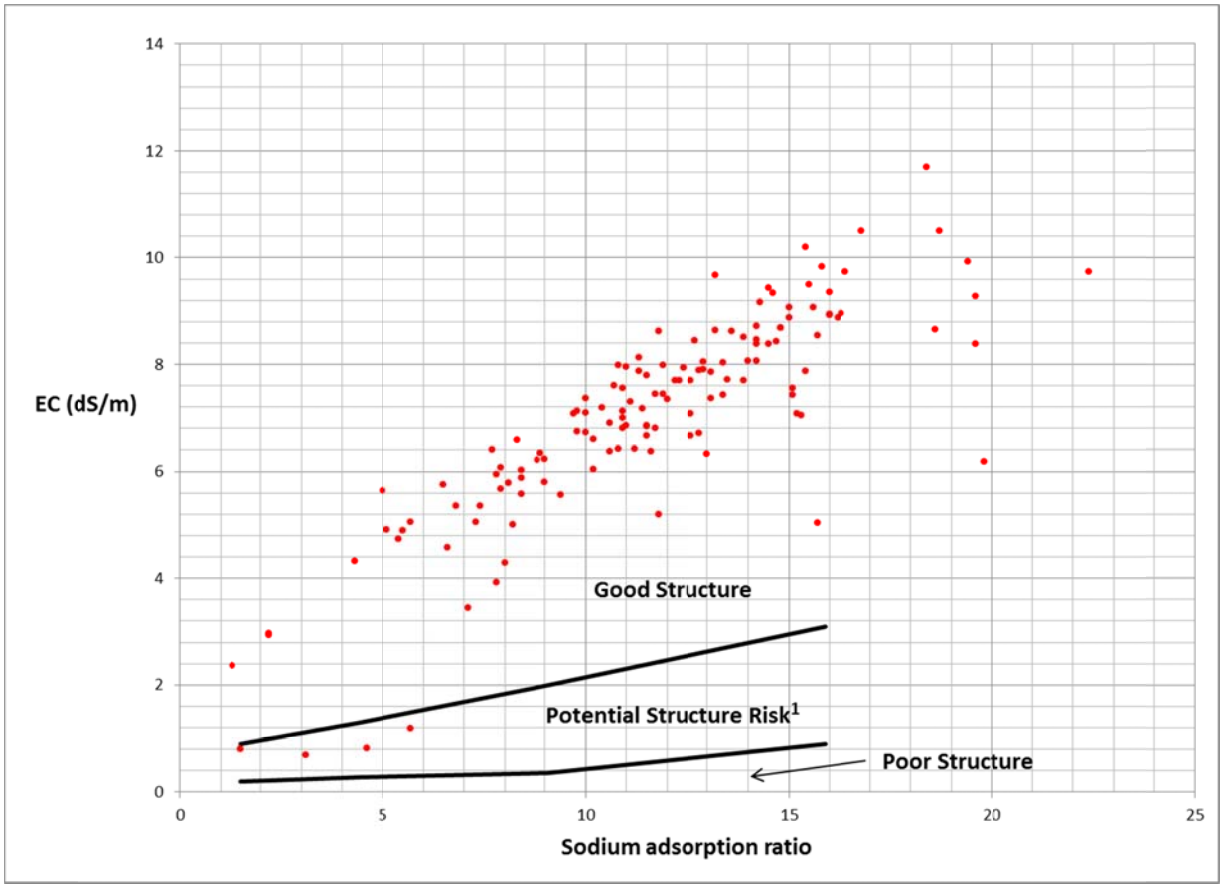
Previous synthesis of earlier studies at SBH (Barbour et al. 2010), suggested that the soil cover may be susceptible to the development of a sodic soil. It was speculated that salt ingress in the soil cover would result in sodium replacing calcium on the soil exchange sites, and with eventual salt flushing occurring, sodium would dominate the exchange sites of the soil and result in sodification of the soil. The potential for sodification was considered to be greater with shallower cover depths such as 35 and 50 cm, because these soils had less cover material, and thus, less of a calcium reservoir to buffer the sodium ingress. This condition has not occurred at SBH to date. Superimposing a threshold line of soil structure stability and instability (Sposito 2008) on the EC and SAR scatter data shows that the majority of the sample sites are staying within the stable soil structure zone (Figure 5-4). A portion of the sites fall into the potential risk range, which is dependent on pH and soil variability, but no samples fall below this zone into the poor soil structure zone. The 35 and 50 cm capping trials do not appear to be exhibiting different characteristics than the 100 cm soil cover areas.



[1] Threshold line of Good and Poor structure is located within this zone and is dependent on pH and soil variability.

Figure 5-4. **Relationship of reclamation cover EC and SAR for 2012 samples at SBH and soil structure (Adapted from Sposito 2008).**

The near-surface Clearwater overburden also appears to be staying within a stable soil structure zone (Figure 5-5). Only 4 of the 135 total Clearwater samples collected in 2012 fall into the potential risk range and none of the samples fall into the poor structure zone. The 4 samples in the potential risk range are from lower and toe slope of Transect 1, which suggests this is likely a localized occurrence (i.e., material characteristic difference), rather than a process-driven result.



[1] Threshold line of Good and Poor structure is located within this zone and is dependent on pH and soil variability.

Figure 5-5. Relationship of Clearwater overburden EC and SAR for 2012 samples at SBH and soil structure (Adapted from Sposito 2008).

Although salt ingress in the soil cover is observed at SBH and the Clearwater overburden is saline-sodic, the results suggest that the soil cover and near-surface Clearwater overburden are not developing sodification characteristics. The relatively high abundance of calcium in the soil cover and Clearwater overburden and/or the higher affinity of soils to select divalent cations (Ca^{2+} and Mg^{2+}) instead of a sodium monovalent cation (Sposito 2008) appear to be maintaining stable soil structure in the soil cover and Clearwater overburden. Shallower soil covers, which could be more susceptible to soil sodification, appear to remain stable. Therefore, the plant growth risk associated with sodification of soil affecting soil structure is Unlikely for a cover soil depth of 35 cm, Very Unlikely for 50 and Remote for 75, 100, 125 and 150 cm (Table 5-3).

5.2.5. Sodium Toxicity

Sodium toxicity was examined and resolved to not be a failure mode. A paper written by the Saskatchewan Water Corporation (1987) examined irrigation water quality and soil compatibility. It suggested that sodium had a greater impact in terms of its contribution to total salinity, soil structure, and nutrient imbalance, than toxicity to vegetation. Recent research in boreal forest development in naturally saline sites in the oil sands region found SAR to have no significant effect on foliar sodium concentrations, with aspen and white spruce foliar sodium concentration near background levels (Lilles et al. 2012). In comparison, the EC and SAR of these study sites were significantly higher than the values measured at SBH. The results of this study did not find a relationship with foliar sodium concentration and tree growth (Close 2007; Lilles et al. 2012).

Therefore the plant growth risk associated with sodium toxicity was not considered to be as great a risk as the previously discussed risks, and thus, was removed from the assessment (Table 5-3).

5.2.6. Water Logging of Root Zone

Water logging of the root zone was determined to not be a significant risk to plant growth. Clearwater overburden areas across the Mildred Lake mine have not exhibited any widespread water logging of the root zone resulting from perched water table conditions. Any permanent water logging in reclaimed Clearwater overburden structures evident at Mildred Lake has occurred prior to site vegetation establishment or in designed wetlands (e.g., Peat Pond) and opportunistic ponding areas that are small and localized in the landscape (e.g., Bill’s Lake). Regardless, designed wetlands and opportunistic ponding areas are preferred in the closure landscape. Since the occurrence of water logging of soils is not occurring in the upland portion of the landscape, which is the scope of this study, water logging of the root zone was not examined as a potential plant growth risk (Table 5-3).

5.3. Selection of an Optimum Capping Thickness

Selection of an optimal capping depth involves placing a minimum soil cover to minimize the environmental risks of the landforms to an acceptable level, without over-building soil cover and expending unnecessary time and resources that result in no additional benefits to reclamation performance, while reducing the ability to improve reclamation of other landforms in the closure landscape (e.g., various tailings structures).

The risks considered to be the greatest issue to plant growth are water availability and salt diffusion causing drought stress (Table 5-2). For both these risks a shallow soil cover 35 cm would likely pose a significant risk to plant growth. A soil cover of 50 cm would likely be able to support plant growth, but may have limitations during prolonged adverse conditions. A soil cover of 75 to 100 cm poses no significant risk.

Salt effects due to evapo-concentration and sodification of soil structure only posed a significant risk for the shallow soil cover (35 cm). Salinization and sodification pose little risk with capping depths of 50 cm or greater. Sodium toxicity and water logging of the root zone risks were not considered to be significant relative to the other risks, and thus, were not fully assessed.

It is concluded on a scientific basis, a capping thickness of 75 to 100 cm is optimum for upland reclamation of Clearwater overburden.

6.0 DISCUSSION

This section provides some additional discussion of various findings and comments on future monitoring and research.

6.1. Steady State Evapotranspiration

The ET measured on the SBH plateau has maintained roughly consistent levels since 2009, (‘steady state’). The values observed, and this consistent behaviour, implies that the forest is using water at rates similar to those reported for mature boreal forests, and that future water use at SBH is not expected to increase beyond what would typically be expected from normal inter-annual climate fluctuations. This conclusion is further supported by the observed rooting patterns which are comparable to the natural rooting patterns of mature aspen-white spruce forests on Luvisolic soils in Saskatchewan. The forests have also undergone significant intra-annual and inter-annual variability in precipitation since 2009. Therefore, it is thus believed that the forest has been not been subjected to unusually beneficial or unusually detrimental climatic conditions. These metrics show that the forest on SBH is performing the same as would be expected of a natural mature stand.

6.2. Measurable Salt Ingress versus Measurable Soil Degradation

The 2012 study found thicker covers promote greater ingress of salt than thinner covers. The use of an average height of salt ingress overstates the height of salt ingress in thin covers and understates the height of salt ingress in thick covers. If average salt ingress height is not explicitly linked to soil thickness, confusion may be created over the impacts of salt ingress on cover performance. The 2012 salinity sampling found that the average ingress of salinity into the covers, regardless of thickness, is 60 cm, while the average ingress of salinity is 30 cm for covers <75 cm, 50 cm for covers 75 to 100 cm, and 85 cm for covers greater than 100 cm. An average of 60 cm thus clearly overestimates the impact on thin covers, and underestimates the impact on thick covers.

An alternative way to describe salt ingress is to determine the height above the Clearwater overburden interface, at which a certain threshold of salinity or SAR is measured. This method of description describes salinity ingress as an effective height at which there is a noticeable effect (Tables 6-1, and 6-2; Appendix E). Evaluating salt ingress in this way highlights that, though salts and sodium have increased in the soil cover, they have had little impact to the soil quality when compared to applicable guidelines for evaluating soil reclamation materials in the oil sands (AAFRD 1987). Furthermore, the lack of ecological significance with the increased salinity and sodicity in the soil cover has been shown in the vegetation response. Rooting is present in the soil cover and Clearwater overburden and the tree growth response meets or exceeds target growth rates.

Table 6-1. Salinity (EC) magnitude and average ingress above Clearwater overburden soil cover interface.

Salinity (EC) guidelines[1]	Height of Ingress Above Cover-Clearwater Overburden Interface (cm)			
	Cover Thickness <75 cm	Cover Thickness 75 cm – 100 cm	Cover Thickness >100 cm	All Samples
Subsoil Poor-Fair boundary (5 dS/m)	-5 - 0	0 - 5	0 – 5	0
Subsoil Fair-Good boundary (3 dS/m)	0 - 5	25 - 30	30 - 35	15 - 20

[1] Alberta Agriculture, Food and Rural Development (AAFRD; 1987).

Table 6-2. Sodicity (SAR) magnitude and average ingress above Clearwater overburden soil cover interface

Sodicity (SAR) guideline[1]	Height of Ingress Above Cover-Clearwater Overburden Interface (cm)			
	Cover Thickness <75 cm	Cover Thickness 75 cm – 100 cm	Cover Thickness >100 cm	All Samples
Subsoil Poor-Fair boundary (8)	5	10-15	15-20	10-15
Subsoil Fair to Good boundary (4)	20-25	35	45-50	35

[1] Alberta Agriculture, Food and Rural Development (AAFRD; 1987).

6.3. Variation in Placed Reclamation Material Cover Thickness

The selection of a suitable soil cover thickness for Clearwater overburden is an optimization problem requiring a balance between the need for the landform to provide water for productive forest vegetation while also providing water for downstream receptors, including opportunistic and designed wetlands and EPLs. Thicker covers limit the release of water to downstream receptors while thinner covers may not provide sufficient water to ensure productive forest vegetation under drought conditions. The advantages and disadvantages of different soil thicknesses have been described in Sections 5.1 to 5.3 and are illustrated in Figure 5-1. These advantages and disadvantages have been identified both from empirical observations, modeling, and professional experience.

The soil covers found on SBH exhibited a large variance in observed thickness. This has allowed for observations of soil salinity ingress and vegetation performance over a larger range of thicknesses than expected. It is unclear, however, whether this variation can be used to anticipate the performance of a different soil cover designs.

6.4. Rooting in the Clearwater Overburden

Roots were found to have penetrated into the Clearwater overburden; however, research did not differentiate roots present are from targeted vegetation species (e.g., white spruce and aspen) from more salt tolerant species. It is also apparent that, while roots penetrate the overburden, they are limited in their growth (see Figure 4-15). Roots in the overburden have an average biomass density of less than 0.5 Mg/ha. It is unclear what is limiting the roots' establishment in the Clearwater overburden. It may be a physical limitation due to soil structure, a chemical limitation due to soil salinity, and/or another unidentified process.

6.5. Uncertainty in Net Percolation

Net percolation is the most difficult portion of the water balance to measure. The magnitude of net percolation is expected to be highly variable spatially and affected by small changes in texture and topography. The study has not focused on measuring this parameter.

Research on SBH has been performed using stable isotopes of water to estimate net percolation rates (Hilderman et al., 2011). The research was performed on the D3 cover and the plateau and it was found that net percolation changed significantly between plateaus and slopes. No study was performed to see if net percolation changed between thicker and thinner covers.

Net Percolation through the Clearwater overburden will result in the release of salts to down-gradient discharge areas and consequently may have an effect on the long-term salt loading to downstream aquatic ecosystems, notably wetland and EPLs. Some of the effects may be delayed by decades or centuries due to the slow and complex groundwater seepage regimes in Clearwater overburden fills.

6.6. Insensitivity to Slope Position and Aspect

Differences in salinity profiles and vegetation response relative to slope position were anticipated with fresh water inputs near the crests of slopes resulting in less saline conditions than downslope toe slope positions receiving interflow water containing flushed salts from upslope positions. The effect of aspect on salt movement in the Clearwater overburden and soil cover was also expected. However, differences in salinity profiles with slope position and aspect have not been observed at SBH to date. These results suggest the site conditions within the landform remain relatively uniform, rather than having dramatic salt flushing in one area of SBH that result in above-average vegetation growth and accumulation of those salts in another area that results in below-average growth. A further benefit to the study regarding the uniformity across SBH is that it allowed the data from all sites of the 2012 study to be pooled for analysis.

The reason for the lack of influence of slope position on salinity and water content is unclear. Several hypotheses have been advanced by the research team to explain the lack of difference:

- Snowmelt has a major influence on the water content of the soil cap. As SBH has a relatively uniform snow-depth across the dump, recharge rates are similar and the magnitude of interflow in the soil covers is small;
- Many of the toes have steep-sided swales running perpendicular to the slope. These swales are efficient at carrying away seepage and interflow water before evapo-concentration of salts can occur. There may be benefits to engineering similar geometries into future landforms; and
- All aspects and the plateau of SBH likely exhibit similar soil water availability given the relatively shallow slopes (5H:1V and flatter). Differences in soil water conditions on south-facing slopes can occur as compared with north-facing slopes, due to differences in energy and evapotranspiration, but the slopes at SBH are less than those cases where this phenomena has been documented (Carey and Woo, 2001).

6.7. Future Research and Monitoring

Syncrude plans to continue to monitor SBH for the foreseeable future. The studies conducted in 2012 at SBH have provided some suggestions to address outstanding issues and to confirm current conclusions and recommendations, as the site continues to mature and experience different climate conditions. The specific details of the suggested future research and monitoring can be found in the individual reports provided in Appendix A through F.

The 2012 field studies documented the application of specific sampling techniques applied to specific locations. This provides the opportunity to undertake a similar sampling program in future years to evaluate changes taking place at SBH.

This study undertook address of a key question in respect to evaluating the capability of a reclaimed landscape – ‘What stage, or how old, must a site be before we can confidently assess the site’s current and future capability?’. The SBH synthesis adopted a variety of techniques to confirm that SBH has reached a stage of development such that current research can not only assess the site’s existing capability, but provide reliable predictions of its future capability or sustainability. These findings can be used to identify other suitable candidate sites to expand and reach-out from the work done at SBH.

The steps taken to determine if a site has reached an appropriate age for assessment will help future reclamation efforts in several ways;

- they have helped researchers confirm the conclusions and recommendations made in this study;
- they may also help in selecting other candidate sites on Clearwater overburden;
- they will assist in selection of other appropriate sites as they reach a suitable age, or development stage; and
- The techniques adopted in this study could support discussions regarding site assessment criteria for certification.

Syncrude offers the following summary, in respect to further monitoring and research on capping of Clearwater overburden:

- Syncrude plans to continue to conduct research and monitoring of reclaimed Clearwater overburden landscapes;
- The 2012 research activities have provided some suggestions for future research and monitoring studies to address remaining data gaps and to confirm the recommendations and conclusions and made in the SBH synthesis;
- The 2012 field study has established sample location sites and measurement techniques that can be repeated in the future to continue monitoring the site progression;
- The study assessed the site in several ways to ensure it has reached a reasonable age/stage of development to measure current site capability and assess the site's future capability or sustainability. These techniques will help with future work at SBH, assist with selection of other Clearwater overburden sites for monitoring and potentially assist with site certification discussions regarding oil sands reclamation.
- Although the impact of Clearwater overburden reclamation on the entire watershed (e.g., downstream receptors) was beyond the scope of the study, the study recognizes the importance of considering the results within the context of a watershed. Other research programs are currently underway that can further address full watershed impacts.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This research compilation indicates that a capping thickness of 50 cm is sufficient to ensure an equivalent forest capability, but vegetation may potentially experience reduced performance during drought conditions. A capping thickness of 100 cm provides vegetation production which exceeds equivalent capability. A capping thickness greater than 75 cm promotes more salt diffusion than a soil cover less than 75 cm. Thicker soil covers will also reduce the amount of excess water available for downstream receptors such as wetland and EPLs. It is the professional opinion of the research team that a thickness of 75 to 100 cm will provide adequate water supply to vegetation during droughts while also allowing for the release of water to the downstream reclaimed landscape.

The 2012 field program was conducted for a 49 ha study area on SBH and included a portion of the dump plateau, adjacent slopes and the original 1999 capping study area which included three one-ha test plots of 35, 50 and 100 cm thickness. Although a thickness of 75 cm was not included as part of the 1999 capping study experimental design, results from an assessment of risks to plant growth were used to recommend a target capping thickness. The results of the program indicated the following key results:

- Historical measurements of LAI and ET indicate that the water demand for the reclaimed land at SBH reached a maximum (peak) demand after about 8-10 years. This is an indication that vegetation growth to date at SBH should be maintained as the forest stand ages.
- Measurements of soil water over 14 years indicates the 35 cm thick cover does experience water stresses which could lead to reduced levels of transpiration. The 50 cm and 100 cm thick covers provide sufficient water holding capacity to meet normal vegetation demands each year.
- Above-ground vegetation data collected indicates establishment and growth across the SBH study site meets or exceeds natural forests of the region, regardless of capping thickness. Tree growth performance by capping depth found some significant positive relationships. The strongest relationship was white spruce; a positive relationship was found with cover thickness increases from 10-50 cm, followed by less rapid gains with increased depth.
- Below-ground (root) productivity is similar to that of natural forests, with a similar exponential decline in root density with depth and a maximum rooting depth. Roots were found in the overburden, but there is evidence of a rooting limitation relative to the mineral reclamation subsoil material.
- Salt ingress from the Clearwater overburden into the base of the reclamation layer is as expected based on accepted diffusion calculations While the increase in salts has been detected at heights of 60 cm above the interface, soil quality is only affected in the bottom 5 to 15 cm for SAR.
- Application of accepted salt transport model theory and parameters indicate that there will be little additional impact from ongoing salt movement, and that salt ingress

has reached, or will reach, a steady state balance with flushing of the soil profile by snowmelt and precipitation.

- Modeling indicates that for soil thicknesses of less than 50 cm, drought stress may have an impact on tree growth during periods of prolonged drought. Enhanced water availability for cover thicknesses greater than 100 cm do not translate in greater rates of transpiration.
- Increasing soil cover thickness will result in less water being available for wetland and EPL development.

Based on the results of the 2012 program, the research team recommends that Syncrude consider the following to further their understanding of Clearwater overburden reclamation:

- Continue to monitor the reclamation performance at SBH and develop a revised long-term monitoring program. This should consider integrating downstream water quantity and quality.
- Continue plans for monitoring on other Clearwater overburden landforms as they are reclaimed.
- Examine other reclamation scenarios (e.g., different substrates, different reclamation materials, soil placement techniques and surface preparation techniques).
- Develop revised guidelines for landform design, construction and reclamation of Clearwater Formation and other landforms using the information and in particular the methods gained from the SBH study.

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APPENDIX A

SOUTH BISON HILL 2012 RESEARCH SYNTHESIS – ROOT SAMPLING AND SALINITY SAMPLING FIELD PROGRAMS METHODOLOGY AND RESULTS

SYNCRUDE CANADA LTD.

SOUTH BISON HILL 2012 RESEARCH SYNTHESIS - ROOT SAMPLING AND SALINITY SAMPLING FIELD PROGRAMS - METHODOLOGY AND RESULTS

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1.0 INTRODUCTION

NorthWind Land Resources Inc. (NorthWind) was commissioned by Syncrude Canada Ltd. (Syncrude) to conduct field sampling as a component of Syncrude's collaborative research project assessing Clearwater overburden (OB) reclamation within Syncrude leases. The field work consisted of soil sampling at sites along nine pre-determined transects at Syncrude's SW30 Dump. Sampling was conducted for two different components of the research project and was completed in two separate sampling events.

During the first event, root samples were collected for evaluation and assessment by the South Bison Hill (SBH) Research Synthesis team. Field activities were conducted by NorthWind field personnel with the assistance of Syncrude Research field staff between August 25 and 28, 2012 under sunny conditions.

During the second event, soil samples were collected for salinity evaluation and assessment by the SBH Research Synthesis team. Field work was conducted by NorthWind with the assistance of O'Kane Consultants Inc. (O'Kane) between September 10 and 13, 2012. Sampling was conducted in the morning and early afternoon on Monday, September 10 before heavy rains started, shutting down field activities at approximately 1:30 PM. Heavy rain continued on-site for the remainder of the day, overnight and into the morning on Tuesday, September 11. All mine roads were closed for 24 hours; therefore, field activities were shut down and resumed on Wednesday, September 12. Site conditions remained wet for the remainder of this sampling event.

Riverside (Bucket) augers were used to collect soil samples at each site for both sampling programs as per the methodology outlined in this report. Once the field work was completed, root samples were shipped to the University of Saskatchewan (U of S) for processing. Salinity samples were taken to NorthWind's office for processing, followed by submission to Exova in Edmonton, Alberta for analysis of selected parameters.

2.0 FIELD METHODS

2.1 ROOT SAMPLING PROGRAM

Soil sampling was conducted along nine pre-determined transects. These transect locations were selected by the SBH Research Synthesis team during the August 2, 2012 meeting at Syncrude's Edmonton office. The nine transects include one in each of the three treatments (transect 1 - 50 cm cover, transect 2 - 35 cm cover, and transect 3 - 100 cm cover) within the existing Capping Study along the north/northwest facing aspect, with six additional transects being added at different aspects around the SW30 Dump structure. Five sampling locations along each transect were selected which generally included toe, lower, mid, upper and crest slope positions. Two sites on the plateau along transect 7 and 8 replaced the lower and upper slope positions along these transects. The south slope is significantly shorter from toe to crest along this portion of the south facing slope due to a dissecting mine haul road and older (different soil placement prescription) below the haul road. A map displaying the study area with the transect locations and slope positions is shown in Appendix 1. Samples were collected at the two plateau sites from transect 7 during the root sampling event; however, none were collected from the two plateau sites along transect 8 at that time. The slope positions were generated by BGC Engineering Inc. (BGC) using elevation models. Once finalized, surveyors marked the location in the field using a Trimble GPS system, survey stakes and flagging. NorthWind field personnel navigated to the locations using handheld GPS systems. Any stakes that were placed in immediate proximity to planted trees, making hand augering not possible, were moved at the time of the root sampling, with the distance and direction documented. In cases where auger refusal occurred due to increased stoniness in the profile, the hole was moved in close proximity (within 20 to 30 cm of selected sample location) and the distance to the new location was documented.

At each site, a pilot hole was advanced using a 5 cm diameter combination soil auger prior to sampling to determine the capping depths (peat mix depth and depth to OB). The depth to OB was used to establish the sampling intervals for the root program. From the subsoil/OB interface, one 15 cm subsoil interval was collected from directly above the interface and two 15 cm intervals were collected from within the OB. The remainder of the intervals above the 15 cm subsoil interval were determined using a 2-step calculation at each site. The first step consisted of taking the total depth to OB minus 15 cm (as each site had one 15 cm interval above the interface) and dividing this by 15; this determined the number of sample intervals that would be taken. The second step took the total depth to OB minus 15 cm and dividing by the number of sample intervals. This resulted in the remaining sample interval thickness at each site, which ranged between 13 cm and 17 cm. Using this method, the 15 cm sample interval directly above the OB was consistent across sites and could be used for comparison. The surface intervals, where the majority of roots were expected to be found, although varying slightly in depth, are adequately thick to conduct root evaluations. Figure 1 displays the sample intervals for this program.

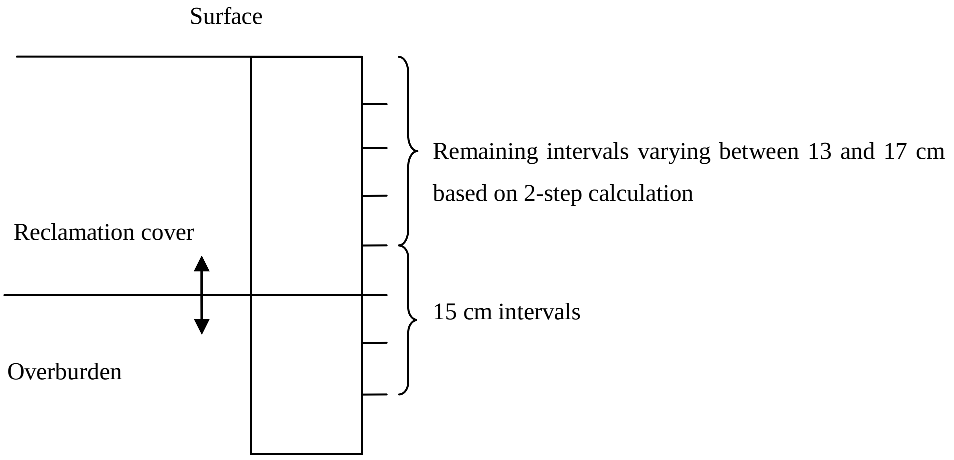

Figure 1. Example of sample intervals for root sampling program.

In cases where the reclamation material/OB interface was different from the depth determined from the pilot hole, minor adjustments were made to the 15 cm increments directly above the OB to account for these differences.

It was decided prior to field sampling that the peat mix/mineral interface would not influence the sampling intervals for this program, therefore the majority of sites have one sample that is composed of a mixture of peat mix and subsoil.

All samples were collected using a 7 cm outside diameter Bucket auger. Once the auger was brought to the surface full of soil, large plastic containers were used to collect the soil to ensure that none was lost while removing soil from the auger head. The plastic containers were cleared of any remaining soil between sample intervals to prevent the contamination of subsequent soil samples. Samples were collected in airtight bags and then placed in coolers after each site was completed. At the end of each day, the coolers were hauled to the Environment Research warehouse at Mildred Lake for freezer storage. Following completion of the field work, the frozen samples were shipped to the University of Saskatchewan for processing and analysis. A total of 338 samples were collected for analysis during the sampling event.

2.2 SALINITY SAMPLING PROGRAM

Soil sampling was conducted along the same nine pre-determined transects described in Section 2.1. Samples were collected at all transect locations, including the two plateau sites in transect 8 which weren't sampled during the root sampling event. NorthWind and O'Kane field personnel navigated to the locations using handheld GPS systems. Salinity sampling was conducted directly adjacent to the auger hole from the root sampling event, as this had already been conducted. Again, in cases where auger refusal occurred due to increased stoniness in the profile, the hole was moved in close proximity with the distance to the new location documented.

One auger hole was advanced at each location for sample collection using a 7 cm outside diameter Bucket auger. Sampling intervals for this program were based on the depth of the reclamation cover/OB contact, which was recorded during the root sampling event. At the locations that weren’t assessed during the root sampling (Transect 8 – Plateau 1 and Plateau 2), a pilot hole was advanced to determine the depth to OB. From this interface, two samples at 10 cm intervals above and below the interface were collected. One additional 20 cm OB sample was gathered directly below the 10 cm intervals. From the remainder of the reclamation cover (above the two 10 cm intervals), 20 cm sample intervals were collected, with a remaining depth (ranging between 1 and 19 cm) being collected at the surface. Figure 2 provides an example for a 108 cm profile.

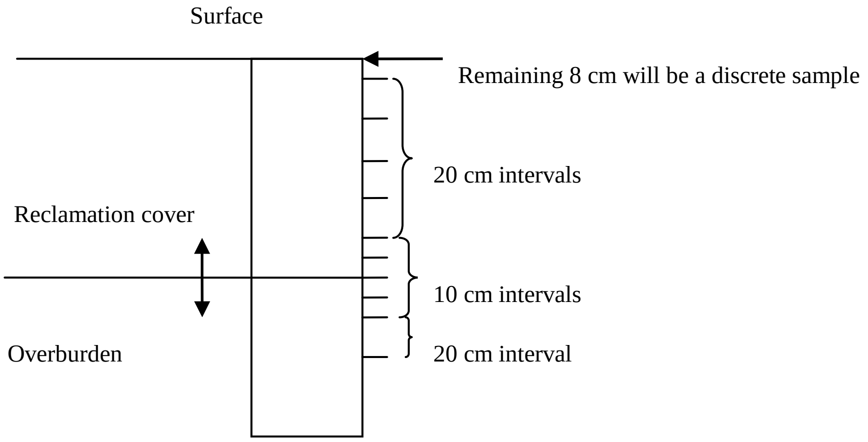

Figure 2. Example of sample collection design for salinity sampling program.

In some cases where the remaining surface increment was very small, the material was included with the 20 cm sample interval below. Within the shallow treatments (50 and 35 cm cover), the two 10 cm sample intervals from the reclamation material were collected at each site (where possible), with any remaining surface material being taken as a separate sample. In cases where the reclamation material/OB interface was different from the depth determined during the root sampling, minor adjustments were made to the 10 cm increments to account for these differences.

It was decided prior to field sampling that the peat mix/mineral interface would not influence the sampling intervals for this program, therefore the majority of sites have one sample that is composed of a mixture of peat mix and subsoil.

All samples were collected using a 7 cm outside diameter Bucket auger. Once the auger was brought to the surface full of soil, large plastic containers were used to collect the soil to ensure that none was lost while removing soil from the auger head. The plastic containers were cleared of any remaining soil between sample intervals to prevent the contamination of subsequent soil samples. All samples were placed in airtight bags with the air removed, followed by placement directly into coolers on-site. At the end of each day samples were hauled to the Environment Research warehouse where they were stored for the duration of the sampling trip in the coolers at ambient warehouse temperature. Once field sampling was complete, samples were taken to Edmonton where they were sorted and processed by NorthWind before submission to Exova for selected laboratory analyses.

3.0 LABORATORY ANALYSIS AND METHODS

3.1 ROOT SAMPLING PROGRAM

Once field sampling was completed by NorthWind, samples were shipped to the University of Saskatchewan for all sample processing and laboratory work. No further work was conducted by NorthWind with regards to laboratory data collection and evaluation.

3.2 SALINITY SAMPLING PROGRAM

A total of 400 samples were collected during the salinity sampling program. Samples were submitted to Exova in Edmonton for the following lab analyses (the list includes the analysis name, the Exova service code, and the samples which were analyzed):

- Detailed Salinity – S32 (pH, EC, SAR, SAT%, Ca, Mg, Na, K, Cl, SO_4) – all samples;
- Gravimetric moisture – TDW (dry weight, wet weight) – all samples; and
- Particle Size Distribution, hydrometer - PS1 (% sand, silt, clay) – 20 cm OB interval, 20 cm subsoil interval directly above 10 cm intervals (where possible).

Each of the analytical methods used by Exova is outlined below, as described in Exova’s method summary sheets (received electronically in November and December 2012) and the reference methodologies.

3.2.1 Detailed Salinity

Detailed salinity analysis was conducted on each of the 400 samples submitted to Exova. A saturated paste was prepared for the analysis of pH, electrical conductivity (EC), soluble ion concentrations and determination of sodium adsorption ratio (SAR). A minimum of 50 g (50-200 g depending on sample volume) of dried and ground soil was used for the analysis. Deionized water was added to saturate the soil sample, typically done at a 2:1 soil to water ratio. Saturated pastes were re-examined after 1 hour to ensure the sample was still at saturation. The saturated paste was allowed to stand for a minimum equilibration time of 4 hours. The samples were then thoroughly mixed and the pH measured on the paste using an electrode and pH meter. Following pH measurement, the paste was filtered using vacuum filtration through highly retentive filter paper until sufficient filtrate was collected. The extract was stored at 4°C for further analysis. EC was then measured using a calibrated conductivity meter. Calcium, magnesium, sodium, potassium and sulfate ions were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES) on the saturated paste extract. Chloride ions were measured using colorimetric techniques on the saturated paste extract. A ferric nitrate reagent was prepared, with mercury thiocyanate being used as a colorimetric analyzer. The absorbance of the resulting test solution was measured and compared to a series of standards (Exova 2012b, Exova 2012c, Carter et al. 2008, APHA 2005).

3.2.2 Gravimetric Moisture

Gravimetric moisture analysis was conducted on each of the 400 samples. For each sample, a wet weight was measured when received by the laboratory. The sample was then placed in a drying oven at 105+/- 3°C for a minimum of 12 hours. The sample was weighed again, and the moisture content was calculated using these two values (Exova 2012d).

3.2.3 Particle Size Distribution

The hydrometer method was used to calculate particle size on selected samples using a standard hydrometer. Fifty grams of sample were used for the analysis. Soil particles were separated using first a chemical dispersing agent (Calgon®) and were soaked overnight. This was followed by two minutes of mechanical agitation. Readings taken after 40 seconds determined the weight percentage of sand, and the weight percentage of clay was determined from a second reading taken after 6 hours (Exova 2012a, Carter et al. 2008).

4.0 RESULTS/OBSERVATIONS

All of the transect locations that were sampled had a muskeg (peat mix) cap overlying subsoil as a target soil cover design with variable peat thickness throughout the area. The mineral component of the peat mix varied in percent composition, as well as the peat mix's mineral type (fine or coarse).

Two sites along the east facing aspect appeared to have direct placement overlying OB in the mid and lower slope positions where the area had been reworked in the summer of 1997. Direct placement is described as material containing a balance of mineral and organic material, with no overlying coversoil placement.

The subsoil (secondary) encountered throughout the study area included a mixture of glacially deposited material which was predominantly PG3 till and PL2 glaciolacustrine clay. PG3 describes material which is moderately fine textured (typically L, SCL, CL), poorly sorted till deposits with varying amounts of coarse fragments. PL2 is used to describe finer textured (CL, C, HC) pink to brownish or grayish pink, stratified glaciolacustrine deposits with occasional gravel and thin silt/sand lenses.

A review of the soil placement history for the SW30 Dump structure indicated a significant amount of the area consisted of non-sodic material underlying secondary subsoil in two separate lifts. Non-sodic refers to mineral subsoil that did not meet the soil suitability requirements at the time of soil placement (typically exceeded clay fraction and/or pH). The non-sodic and secondary subsoil material types were difficult to differentiate in the field in most cases. Notes and soil descriptions, in conjunction with soil analytical data, could potentially be used to differentiate them; however, for the purposes of this write-up the materials are not distinguished in the field observation summaries.

While the sample intervals differed between the two sampling programs, similar details were collected for both with regards to soil profile characteristics. The auger holes for the two events were in very close proximity to one another, but within these short distances differences were often seen in the material composition. The results and observations for the two programs are summarized separately in Sections 4.1 and 4.2. Section 4.3 discusses in greater detail the total capping depths (depth to OB) encountered throughout the study area.

4.1 ROOT SAMPLING PROGRAM

Cover soil (peat mix) depth and total capping depth (depth to OB) were recorded at each site. Basic soil information was also documented for each sample interval and included some or all of the following:

- material type;
- composition of peat mix and subsoil;
- soil texture, presence of coarse fragments or other inclusions;
- presence of peat in subsoil;
- presence of oil sand in overburden;
- changes in soil moisture or presence of water table; and
- other anomalies that may have been encountered.

Planted trees present within 2 m of the auger location were documented at each site, with the species and distance being recorded. In addition, a tally of the volunteer species (those which are present but didn't appear to be planted) was also recorded for each sample location. Photos of the canopy and ground cover were taken at each site and were provided to members of the SBH Research Synthesis team for use during root sample analysis. A copy of the field sheets was also provided for reference during data analysis.

A summary of the capping depths for the root sampling program, which were taken from the pilot holes, as well as any significant observations recorded at each site are presented in Appendix 2.

4.2 SALINITY SAMPLING PROGRAM

Cover soil (peat mix) depth and total capping depth (depth to OB) were recorded at each site. Basic soil information was also documented for each sample interval, and included some or all of the following:

- material type;
- composition of peat mix and subsoil;
- soil texture, presence of coarse fragments or other inclusions;
- presence of peat in subsoil;
- presence of oil sand in overburden;
- changes in soil moisture or presence of water table; and
- other anomalies that may have been encountered.

A copy of the field sheets was provided to members of the SBH Research Synthesis team for reference during data analysis. A summary of the capping depths for the salinity sampling program, as well as any significant observations recorded at each site, is presented in Appendix 2. The depths recorded during the salinity sampling program differed slightly (in some cases) from those collected during the root sampling. The sampling intervals for the salinity program were based on the depth to OB that was recorded from the pilot hole augered during the root sampling program (listed in Appendix 2). The salinity holes were advanced with the Bucket auger in close proximity to the pilot holes (typically within 20-30 cm), assuming this OB depth to be consistent. However, within this short distance the capping depths changed in some cases. The modified depths (where present) used for salinity sampling are also recorded in Appendix 2; however, these should not be considered the "actual" capping thickness for each location.

An additional 35 sites were selected in the field by Integral Ecology Group during their vegetation survey, and capping depths were recorded for these sites during the salinity sampling event. These additional sites were located both within the Capping Study (adjacent to transects 1, 2 and 3) and on the plateau. Table 1 displays the depths from the additional 35 sites.

Table 1. Capping depth summary for additional sites selected during vegetation field program.

Location	Site ID	Total Capping Depth (cm)	Peat Mix Depth (cm)	Location	Site ID	Total Capping Depth (cm)	Peat Mix Depth (cm)
T1	SW30-1A	67	17	T3	SW30-3G	114	23
T1	SW30-1B	43	8	T3	SW30-3H	107	20
T1	SW30-1D	50	19	T3	SW30-3J	105	29
T1	SW30-1E	44	24	Plateau	LAI1	124	32
T1	SW30-1G	46	36	Plateau	LAI2	136	34
T1	SW30-1H	55	28	Plateau	LAI3	111	5
T1	SW30-1J	33	24	Plateau	SW30-PA	126	9
T2	SW30-2A	33	19	Plateau	SW30-PB	112	24
T2	SW30-2B	26	10	Plateau	SW30-PC	112	5
T2	SW30-2D	41	10	Plateau	SW30-PD	96	6
T2	SW30-2E	15	15	Plateau	SW30-PE	145	46
T2	SW30-2G	31	13	Plateau	SW30-PF	87	16
T2	SW30-2H	31	31	Plateau	SW30-PG	100	10
T2	SW30-2J	43	27	Plateau	SW30-PH	107	11
T3	SW30-3A	125	20	Plateau	SW30-PI	140	17
T3	SW30-3B	146	68	Plateau	SW30-PJ	101	13
T3	SW30-3D	101	22	Plateau	SW30-PK	114	5
T3	SW30-3E	108	25				

A summary of the results from the laboratory analyses conducted on soil samples from the salinity sampling program are presented in Appendix 3, which includes the measured units and the detection limits outlined by Exova for each analyzed parameter.

4.3 CAPPING DEPTH SUMMARY

A total of 45 sites were originally selected for sampling (9 transects with 5 slope positions/locations per transect), and with the additional 35 sites there was a resulting total of 80 sites with capping depth information.

The target total capping thickness was 100 cm across the majority of the study area. The exceptions are in transects 1 and 2 of the Capping Study with 50 cm and 35 cm targets, respectively. A total of 58 sites (37 from transects and 21 additional sites – 14 on the plateau and 7 near transect 3) have a target capping thickness of 100 cm. This includes all sites except the toe, lower, mid and upper slope positions in transects 1 and 2. The mean capping depth for these sites is 106 cm and ranges between 60 and 194 cm. A total of 11 sites were assessed in transect 1 with a target capping thickness of 50 cm (4 from transects and 7 from additional sites). The mean capping depth for these sites is 49 cm and ranges between 33 and 67 cm. A total of 11 sites were assessed in transect 2 with a target capping thickness of 35 cm (4 from transects and 7 additional sites). The mean capping depth for these sites is 30 cm and ranges between 10 and 43 cm.

The mean transect cover thickness ranges from 88 to 120 cm and the mean slope position thickness ranges from 90 to 117 cm (excluding shallow capping trial plots). The results show significant range among the individual sites; however, the means are generally within 10 cm of the target thickness, with a few between 10 and 20 cm of the target. Capping depth appears to be independent of slope position, with high and low values found distributed throughout the slope positions. A summary of the total capping depth data is presented in Table 2.

Table 2. Soil cover thickness summary in South Bison Hill study area (cm).

Transect	**Slope Position**							**Mean**	**Range**
	Crest	**Upper**	**Middle**	**Lower**	**Toe**	**Plateau 1**	**Plateau 2**		
1	108	64	46	41	50	-	-	**49[1,2]**	**33-67[1,2]**
2	124	30	43	25	10	-	-	**30[1,2]**	**10-43[1,2]**
3	84	148	97	65	68	-	-	**106[2]**	**65-148[1,2]**
4	67	185	92	145	96	-	-	**117**	**67-185**
5	93	76	74	68	194	-	-	**101**	**68-194**
6	69	72	100	124	76	-	-	**88**	**69-124**
7	110	-	115	-	115	133	127	**120**	**110-133**
8	102	-	60	-	77	115	112	**93**	**60-115**
9	100	88	93	83	88	-	-	**90**	**83-100**
Mean	**95**	**114[3]**	**90[3]**	**97[3]**	**102[3]**	**117[2]**		**106[3]**	**-**
Range	**67-124**	**72-185**	**60-115**	**65-145**	**68-194**	**87-145[2]**		**60-194[3]**	

[1] Excludes Crest slope position (outside capping trial); [2] Includes additional vegetation study plots; [3] Excludes 35 and 50 cm capping trial sites.

5.0 CONCLUSION

NorthWind conducted the 2012 root sampling field program with the assistance of Syncrude Research field staff and the 2012 salinity sampling field program with the assistance of O’Kane, in August and September 2012, respectively. The work was conducted at the nine pre-determined transect locations around the SW30 Dump structure as a part of Syncrude’s 2012 collaborative research effort to investigate suitable Clearwater Overburden capping thickness.

All of the capping depth information and relevant field observations collected by project personnel has been summarized in this report, along with the field methodology used to collect samples for both project components. For the salinity sampling program, NorthWind managed all sample processing and submission, and conducted preliminary review of the analytical results. Results were then formatted into summary tables before being passed on to the SBH Research Synthesis team for further analysis.

6.0 CLOSURE

We trust that the contents of this report meet your current requirements. Should you have any questions or require further information, please contact the undersigned at (780) 481-9777.

Respectfully,
NorthWind Land Resources Inc.

Robbie Price, B.Sc.
Environmental Scientist

7.0 REFERENCES

American Public Health Association, 2005. *Standard Methods for the Examination of Water and Wastewater, 21st Edition.*

Carter, M.R. and Gregorich, E.G., 2008. *Soil Sampling and Methods of Analysis, 2nd Edition. Canadian Society of Soil Science*. ISBN 978-0-8493-3586-0. CRC Press. 1224 pp.

Exova. 2012a. *Particle Size Analysis of Soil by Hydrometer.* Received November 27, 2012.

Exova. 2012b. *Sodium Adsorption Ratio, pH and EC in Soil by Saturated Paste.* Received November 27, 2012.

Exova. 2012c. *Soluble Chloride, Soluble Sulfate, Soluble Cations.* Received within e-mail November 29, 2012.

Exova. 2012d. *Total Dry Weight of Samples.* Received December 6, 2012.

8.0 LIMITATIONS OF LIABILITY

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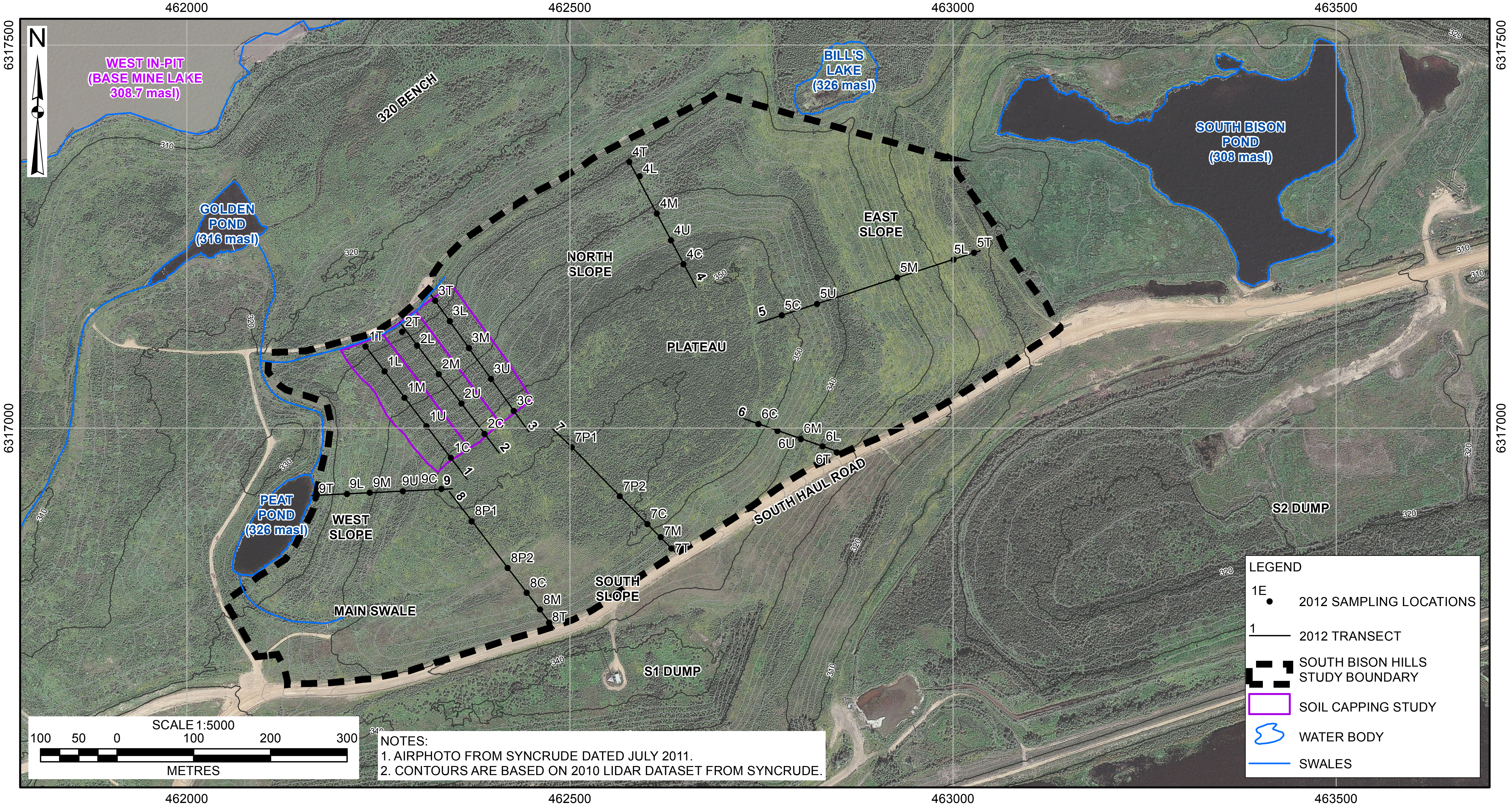
APPENDIX 1

TRANSECT/SAMPLE SITE LOCATION MAP



LEGEND

- 1E ● 2012 SAMPLING LOCATIONS
- 1 ─ 2012 TRANSECT
- ▬ SOUTH BISON HILLS STUDY BOUNDARY
- ☐ SOIL CAPPING STUDY
- WATER BODY
- SWALES

NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

X:\Projects\0534_Syncrude\107_SouthHills\Workspace\20121205_2012_Field_Program_Transect_and_Sample_Location\01_2012_Field_Program.mxd Date: Wednesday, December 05, 2012 Time: 5:19 PM

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: 1:5000
DATE: OCT 2012
DRAWN: RC
DESIGNED: ES, JTM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
2012 FIELD PROGRAM TRANSECT AND SAMPLE LOCATIONS

PROJECT No.: 0534107
DWG No.: 01
REV.:

APPENDIX 2

TRANSECT CAPPING DEPTH SUMMARY/FIELD OBSERVATIONS

Appendix 2. Table summarizing capping depth, cover soil characteristics, and general soil profile and site observations taken during the root and salinity sampling 2012 field programs.

Transect	Slope Position	Capping depth (cm)^1		Root Sampling Program			Salinity Sampling Program		General Site Comments
		Peat Mix	Total Depth	Peat Mix	Profile Observations^2	Planted Trees within 2m Proximity of Auger Hole (species, distance in cm)^3	Peat Mix	Profile Observations^2	
1	Crest	31 (30)	108	- approx. 5-10% fine mineral in peat - 15 cm peat mix/1 cm mineral in 16-32 cm interval	- peat pocket from 40-48 cm - auger refusal on first hole (gravel) at 55 cm - peat pockets in 93-108 cm subsoil interval	Aw - 100 cm, 40 cm Sw - 150 cm, 150 cm	- approx. 5-10% fine mineral in peat - 2 cm ptmix/18 cm subsoil in 28-48 cm interval	- minor gravel from 28-48 cm - gravel at 75 cm - predominantly peat (10-15% mineral) from 55-75 cm	- crest outside of capping study; vegetation more sparse than within adjacent capping study
	Upper	14 (15)	64 (58)	- approx. 10% fine mineral in peat - 14 cm peat mix/2 cm mineral in 0-16 cm interval	- approx. 10% gravel in 49-64 cm interval - greenish inclusions in OB from 79-94 cm	Aw - 100 cm, 80 cm Volunteer - 8 Aw	- approx. 10% fine mineral in peat - 15 cm peat mix/3 cm subsoil in 0-18 cm interval	- inclusions of firm, brownish gray silty material in upper portion of OB - greenish inclusions in OB from 78-98 cm	- site approx. 3 m east of survey stake, as site was located using handheld GPS prior to survey staking
	Middle	37 (35)	46	- approx. 15% fine mineral in peat - woody debris inclusions from 16-31 cm in peat mix - 6 cm peat mix/9 cm subsoil in 31-46 cm interval	- gravel in OB at 60 cm - gravel at peat/subsoil interface	Aw - 126 cm Sw - 130 cm, 160 cm Volunteer - 6 Aw, 3 Pb	- approx. 15% fine mineral in peat - woody debris inclusions from 6-26 cm in peat mix - 9 cm peat mix/1 cm subsoil in 26-36 cm interval	- gravel in OB at 60 cm - gravel at peat/subsoil interface (35 cm)	- site approx. 3 m south of survey stake, as site was located using handheld GPS prior to survey staking
	Lower	24	41	- approx. 5-10% fine mineral in peat - 11 cm peat mix/2 cm subsoil in 13-26 cm interval	- 5-10% fine GLLC material mixed into upper portion of OB (41-56 cm interval)	Aw - 120 cm Volunteer - 13 Aw, 1 Pb, several willow	- approx. 5-10% fine mineral in peat - 3 cm peat mix/7 cm subsoil in 21-31 cm interval	- 5-10% fine PL2 clay mixed into upper portion of OB (41-51 cm interval) - 10% gravel in OB from 61-81 cm	- site approx. 2 m south of survey stake, as site was located using handheld GPS prior to survey staking
	Toe	10	50	- approx. 10-20% fine mineral in peat - 10 cm peat mix/7 cm subsoil in 0-17 cm interval	- approx. 5-10% gravel in subsoil (17-50 cm) - OB coarser textured with hydrocarbon odour	Volunteer - 1 Aw, 1 Pb, several willow	- approx. 10-20% fine mineral in peat - sample interval exactly on peat mix/subsoil interface	- OB coarser textured with hydrocarbon odour	- close to edge of capping study - no planted trees in close proximity
2	Crest	24	124 (114)	- approx. 15% fine mineral in peat - 8 cm peat mix/8 cm subsoil in 16-32 cm interval	- auger refusal at 72 cm in first hole due to gravel - PG3 and sand in OB from 124-139 cm	Aw - 46 cm Sw - 70 cm, 152 cm Volunteer - 13 Aw, 1 Pb, several willow	- approx. 15% fine mineral in peat - sample interval exactly on peat mix/subsoil interface	- auger refusal at 100 cm in first hole due to gravel	- crest outside of capping study
	Upper	22 (19)	30	- <5% fine mineral in peat - 7 cm peat mix/8 cm subsoil in 15-30 cm interval	- minor peat pockets present in subsoil lift - cobble present at subsoil/OB interface	Aw - 125 cm, 170 cm Volunteer - 4 Aw, several willow	- <5% fine mineral in peat - 9 cm peat mix/1 cm subsoil in 10-20 cm interval	- 5-10% gravel at bottom of subsoil near OB interface	
	Middle	19	43	- approx. 10-15% fine mineral in peat - 5 cm peat mix/9 cm subsoil in 14-28 cm interval	- approx. 10-15% gravel/cobble inclusions from 28-43 cm - fine pink GLLC inclusions in OB - moist, sticky OB near bottom of 58-73 cm interval	Sw - 60 cm Volunteer - 3 Aw, several willow	- approx. 10-15% fine mineral in peat - 19 cm peat mix/4 cm subsoil in 0-23 cm interval - 3 cm surface peat interval included with 3-23 cm interval	- 5% gravel inclusions from 23-43 cm	- site moved 50 cm from stake due to close proximity to tree
	Lower	12	25	- approx. 20% fine mineral in peat - 2 cm peat mix/13 cm subsoil in 10-25 cm interval	- approx. 30% organic material in subsoil from 12-25 cm - approx. 10% gravel with $CaCO_3$ deposits in OB from 40-55 cm	Aw - 95 cm, 182 cm Sw - 196 cm Volunteer - 3 Aw, 2 Pb, several willow	- approx. 10% fine mineral in peat - 7 cm peat mix/8 cm subsoil in 5-15 cm interval	- approx. 20% organic material in subsoil from 12-25 cm - 10-20% OB mixed in with 15-25 cm subsoil interval	
	Toe	10	10	- approx. 20% fine mineral in peat	- approx. 5% peat in OB from 10-25 cm	Aw - 64 cm, 133 cm, 186 cm Volunteer - 3 Aw, 1 willow	- approx. 15% fine mineral in peat		- site moved approx. 8 m south to be inside capping study
3	Crest	0	84	- no peat cap, just mineral	- <5% peat from 0-28 cm - increased carbonates in subsoil - coarser textured OB with hydrocarbon odour from 84-113 cm	Aw - 77 cm, 100 cm Volunteer - 2 Aw, 1 Pb	- no peat cap, just mineral	- auger refusal due to gravel at 55 cm, 85 cm - coarser textured OB with hydrocarbon odour from 84-94 cm; finer material and loses odour near bottom of 104-124 cm interval	- crest outside of capping study
	Upper	25	148	- 11 cm peat mix/3 cm mineral in 14-28 cm interval	- approx. 5-10% gravel throughout subsoil (25-148 cm) - subsoil is predominantly pink PL2 clay	Aw - 90 cm Sw - 140 cm, 195 cm	- 17 cm peat mix/3 cm mineral in 8-28 cm interval	- 10% gravel at 68-80 cm - cobble at 110 cm	- site moved 20 cm away from research equipment present in area

Transect	Slope Position	Capping depth (cm)[1]		Root Sampling Program			Salinity Sampling Program		General Site Comments
		Peat Mix	Total Depth	Peat Mix	Profile Observations[2]	Planted Trees within 2m Proximity of Auger Hole (species, distance in cm)[3]	Peat Mix	Profile Observations[2]	
3	Middle	31	97	- 15 cm peat mix/1 cm subsoil in 16-32 cm interval	- approx. 5% peat present in subsoil from 32-64 cm - wavy boundary between subsoil/OB - woody debris in OB from 112-128 cm	Aw - 87 cm, 105 cm, 160 cm, 173 cm, 200 cm Sw - 127 cm, 173 cm Pb - 135 cm Volunteer - 5 Aw, several willow	- 14 cm peat mix/6 cm subsoil in 17-37 cm interval	- wavy boundary between subsoil/OB	
	Lower	12	65	- approx. 5-10% fine mineral in peat - 12 cm peat mix/5 cm subsoil in 0-17 cm interval - large root encountered in peat mix	- approx. 5-10% gravel in 17-34 cm interval	Aw - 105 cm Sw - 106 cm, 174 cm, 193 cm Volunteer - 2 Aw	- approx. 5-10% fine mineral in peat - 7 cm peat mix/13 cm subsoil in 5-25 cm interval	- greenish material in OB from 65-75 cm	- site moved approx. 50 cm southeast due to proximity to tree
	Toe	22	68	- approx. 10% fine mineral in peat - 9 cm peat mix/4 cm subsoil in 13-26 cm interval	- approx. 20% gravel at 55 cm (near auger refusal) - increased moisture in OB from 88-108 cm	Aw - 177 cm, 181 cm Volunteer - several willow	- approx. 10% fine mineral in peat - 14 cm peat mix/6 cm subsoil in 8-28 cm interval	- auger refusal due to gravel at 72 cm, moved hole 50 cm southeast - increased moisture in OB from 88-108 cm	- site is in low lying area with predominantly willow and sparse Aw
4	Crest	20	67	- approx. 20% fine mineral in peat - 7 cm peat mix/6 cm subsoil in 13-26 cm interval	- pockets of peat in 26-39 cm subsoil interval - hydrocarbon odour in OB from 82-95 cm	Aw - 103 cm, 111 cm, 128 cm Sw - 60 cm Volunteer - 13 Aw, 7 Pb	- approx. 20% fine mineral in peat - 13 cm peat mix/7 cm subsoil in 7-27 cm interval	- pocket of peat at 45 cm - minor gravel inclusions through peat mix and subsoil	
	Upper	4	185	- 4 cm includes leaf litter on surface - 4 cm peat mix/13 cm subsoil in 0-17 cm interval	- approx. 5-10% gravel encountered throughout subsoil portion of profile (17-185 cm) - bits of OB mixed in at 140 cm - subsoil is a mixture of glacial materials	Sw - 135 cm, 185 cm	- 4 cm includes leaf litter on surface - 4 cm peat mix/1 cm subsoil in 0-5 cm interval	- pockets of peat at 40 cm, 55 cm - gravel encountered throughout subsoil portion of profile (ranging from 5-15% inclusion) - subsoil is a mix of glacial material - OB and green clay inclusions (<5%) in 125-145 cm subsoil interval	- site located along "bench" with few planted trees
	Middle	19	92	- approx 10% fine mineral in peat - 3 cm peat mix/13 cm subsoil in 16-32 cm interval	- subsoil is predominantly pink PL2 clay	Aw -152 cm, 163 cm Volunteer - 3 Aw, large willow beside stake	- approx 10% fine mineral in peat - 7 cm peat mix/13 cm subsoil in 12-32 cm interval	- predominantly pink PL2 clay from 19-52 cm, mix of glacial materials from 52-92 cm	- site moved approx. 50 cm southeast due to proximity to tree
	Lower	23	145	- 7 cm peat mix/9 cm subsoil in 16-32 cm interval	- auger refusal due to gravel at 150 cm	Aw - 154 cm, 160 cm, 173 cm, 181 cm, 192 cm Sw - 98 cm Pb - 141 cm Volunteer - 2 Aw	- 18 cm peat mix/2 cm subsoil in 5-25 cm interval	- auger refusal due to gravel at 85 cm - 5-10% gravel inclusions throughout subsoil	-site moved approx. 7 m north
	Toe	19	96	- approx. 30% fine mineral in peat - 2 cm peat mix/14 cm subsoil in 17-33 cm interval	- approx. 10% gravel in subsoil from 33-96 cm with large cobble at OB interface - approx. 15-25% gravel in OB - subsoil predominantly fine pink PL2 clay with moderately fine textured inclusions - approx. 10% moderately fine textured subsoil inclusions throughout OB	Aw - 54 cm, 68 cm, 102 cm, 143 cm Sw - 36 cm Volunteer - 4 Aw	- approx. 30% fine mineral in peat - 3 cm peat mix/19 cm subsoil in 16-36 cm interval	- approx. 5-10% gravel from 56-136 cm (bottom of subsoil and OB) - subsoil predominantly fine PL2 clay with moderately fine textured inclusions - approx. 10% subsoil inclusion throughout OB	
5	Crest	22	93	- approx. 30% fine mineral in peat - 6 cm peat mix/9 cm subsoil in 16-31 cm interval	- 3 cobbles present within 62-78 cm interval	Aw - 163 cm Sw - 88 cm, 124 cm Volunteer - 4 Aw, 8 Pb, 3 willow	- approx. 30% fine mineral in peat - 9 cm peat mix/11 cm subsoil in 13-33 cm interval	- approx. 5% gravel from 33-73 cm - subsoil is moderately fine textured from 22-73 cm and fine pink PL2 material from 73-93 cm	
	Upper	33	76	- approx. 50% fine mineral in peat - 5 cm peat mix/9 cm subsoil in 28-42 cm interval	- subsoil is PG3 till with charcoal, $CaCO_3$ and iron inclusions; small amount of fine pink PL2 clay - woody debris from 44-55 cm - pocket of peat (approx. 30%) in 55-76 cm interval	Sw - 93 cm, 123 cm Volunteer - 2 Aw, several willow and alder	- approx. 50% fine mineral in peat - 17 cm peat mix/16 cm subsoil in 16-36 cm interval	- subsoil is PG3 till with charcoal, $CaCO_3$, iron and minor pink clay inclusions - OB soft and moist with iron and $CaCO_3$ inclusions	

Transect	Slope Position	Capping depth (cm)[1]		Root Sampling Program			Salinity Sampling Program		General Site Comments
		Peat Mix	Total Depth	Peat Mix	Profile Observations[2]	Planted Trees within 2m Proximity of Auger Hole (species, distance in cm)[3]	Peat Mix	Profile Observations[2]	
5	Middle	74	74		- direct placement with C-CL mineral and pockets of organic matter (10-15%) present to OB interface - approx. 5-10% subsoil inclusions in OB	Aw - 79 cm, 200 cm Sw - 196 cm		- direct placement with C-CL mineral and pockets of organic matter (10-15%) present to OB interface - approx. 5-10% subsoil inclusions in OB	- direct placement
	Lower	68	68		- direct placement with C-CL mineral and pockets of organic matter (10-15%) present to OB interface - gravel/cobble at 27 cm	Sw - 60 cm, 102 cm Volunteer - 1 willow		- direct placement with C-CL mineral and pockets of organic matter (10-15%) present to OB interface	- direct placement - salinity program - 15 cm subsoil interval directly above OB increased to 17 cm (53-70 cm) as OB was 2 cm deeper than in pilot hole
	Toe	14 (10)	194	- 14 cm peat mix/1 cm subsoil in 0-15 cm interval	- gravel in subsoil from 75-105 cm (auger refusal in first hole at 90 cm) and 165-179 cm - gravel in OB (approx. 10%) from 194-209 cm - 5% organic inclusion from 30-45 cm - distinct mineral material change to non-sodic at 55 cm (darker, more firm, heavier textured material); matted roots sitting above this material	Aw - 83 cm, 177 cm Sw - 58 cm, 119 cm Volunteer - 4 Aw, 2 Pb, several willow	- 10 cm peat mix/4 cm subsoil in 0-14 cm interval	- gravel/cobble in subsoil at 15 cm, 65 cm, 90 cm - approx. 10-15% gravel in OB from 214-234 cm - pocket of peat at 170 cm - distinct mineral material change to non-sodic at 66 cm (darker, more firm, heavier textured material)	- saturated subsoil beginning at 170 cm
6	Crest	13	69 (79)	- approx. 5% mineral in peat - sample interval exactly on peat mix/subsoil interface	- 30% peat inclusion within 13-27 cm interval - wavy interface between subsoil and OB; OB has approx. 10% subsoil inclusions	Sw - 106 cm, 200 cm Volunteer - 3 Aw, 5 willow	- approx. 5% mineral in peat - 4 cm peat mix/16 cm subsoil in 9-29 cm interval	- minor pockets of peat throughout subsoil - wavy interface between subsoil and OB; bottom of subsoil has approx. 5% OB inclusions, OB has approx. 10% subsoil inclusions	
	Upper	27	72	- <5% mineral in peat - 13 cm peat mix/1 cm subsoil in 14-28 cm interval	- subsoil is moderately fine textured with minor gravel inclusions	Sw - 93 cm, 149 cm, 177 cm, 183 cm	- <5% mineral in peat - 15 cm peat mix/5 cm subsoil in 12-32 cm interval	- subsoil is predominantly PG3 till with minor gravel inclusions - 5-10% gravel inclusions in OB; visible iron and $CaCO_3$	- very dry subsoil at time of root sampling
	Middle	24	100 (120)	- 10 cm peat mix/4 cm subsoil in 14-28 cm interval	- 10-15% gravel in 28-42 cm subsoil interval - 80% peat inclusion in 100-115 cm interval (directly above OB) with abundant roots	Aw - 36 cm, 95 cm, 182 cm Volunteer - 1 Pb, 8 willow	- 4 cm peat mix/16 cm subsoil in 20-40 cm interval	- white SiL material in 80-100 cm interval - approx. 5% subsoil inclusions in upper OB	
	Lower	7	124	- 7 cm peat mix/9 cm subsoil in 0-16 cm interval	- auger refusal (gravel) at 112 cm - moved 20 cm east - sandy inclusions from 48-63 cm - 5-10% peat pocket from 94-109 cm - upper OB sample (124-139 cm) contains approx. 3 cm of subsoil	Aw - 75 cm, 150 cm, 200 cm Volunteer - 1 Aw, 1 Pb, 1 willow	- 3 cm peat mix/17 cm subsoil in 4-24 cm interval	- subsoil is consistent pink PL2 clay from 24-104 cm; PG3 till from 104-124 cm - 5% gravel from 84-124 cm; cobble at mineral/OB interface (124 cm) - approx. 20% subsoil mixed throughout OB from 134-144 cm	
	Toe	15	76	- <5% mineral in peat - 15 cm peat mix/1 cm subsoil in 0-16 cm interval	- minor gravel present (2-5%) in 46-61 cm subsoil interval - 5% peat inclusions in subsoil from 46-76 cm	Aw - 72 cm, 124 cm, 195 cm Volunteer - 5 Aw, 1 Pb	- <5% mineral in peat - 15 cm peat mix/1 cm subsoil in 0-16 cm interval	- subsoil is PG3 till with $CaCO_3$, charcoal, iron inclusions - sandy inclusions from 56-66 cm - gravel in OB at 90 cm	- site moved approx. 2 m north
7	Plateau 1	12	133	- 12 cm peat mix/2 cm subsoil in 0-14 cm interval	- subsoil is a mix of glacial material - 5-10% peat inclusions from 58-88 cm - 10-20% pink clay mixed throughout OB - OB coarser textured with strong hydrocarbon odour with green inclusions	Sw - 110 cm, 147 cm Volunteer - 5 Aw, 4 Pb	- 12 cm peat mix/1 cm subsoil in 0-13 cm interval	- PG3 till from 28-73 cm; PL2 clay from 73-133 cm - OB coarser textured with strong hydrocarbon odour	- increased moisture in subsoil

Transect	Slope Position	Capping depth (cm)[1]		Root Sampling Program			Salinity Sampling Program		General Site Comments
		Peat Mix	Total Depth	Peat Mix	Profile Observations[2]	Planted Trees within 2m Proximity of Auger Hole (species, distance in cm)[3]	Peat Mix	Profile Observations[2]	
7	Plateau 2	26	127	- <5% mineral in peat - 10 cm peat mix/6 cm subsoil in 16-32 cm interval	- subsoil is predominantly PG3 till with $CaCO_3$ and PL2 (approx. 20%) inclusions - 5-10% peat from 96-127 cm - approx. 5% gravel in subsoil from 26-127 cm	Aw - 17 cm, 53 cm Sw - 90 cm, 101 cm, 158 cm Volunteer - 17 Aw, 3 Pb, 3 Bw, several willow	- <5% mineral in peat - 19 cm peat mix/1 cm subsoil in 7-27 cm interval	- subsoil is PG3 till with $CaCO_3$ and PL2 (approx. 20%) inclusions - peat from 107-117 cm - approx. 5% gravel in subsoil from 27-107 cm; cobble at 124 cm - approx. 5% gravel throughout OB	
	Crest	12 (16)	110	- approx. 15% clay in peat - 12 cm peat mix/4 cm subsoil in 0-16 cm interval	- 5-10% peat inclusion from 80-110 cm - highly calcareous mix of glacial subsoil - approx. 5% gravel in subsoil from 16-64 cm; near auger refusal at 65 cm	Aw - 165 cm Sw - 110 cm, 184 cm, 193 cm Volunteer - 3 Aw, 1 Pb, several willow	- aprrox. 15% clay in peat - 6 cm peat mix/14 cm subsoil in 10-30 cm interval	- small pocket of peat at 50 cm - calcareous moderately fine textured material from 16-100 cm; heavier, firm clay from 100-120 cm	
	Middle	10	115	- 10 cm peat mix/4 cm subsoil in 0-14 cm interval	- abundant roots in peat mix - subsoil predominantly moderately fine textured with minor fine pink PL2 clay inclusions - approx. 30% gravel in subsoil from 10-56 cm; auger refusal in first hole at 50 cm	Sw - 70 cm, 150 cm	- 10 cm peat mix/5 cm subsoil in 0-15 cm interval	- subsoil is predominantly moderately fine textured with minor PL2 clay inclusions - green inclusions in OB from 115-125 cm	- site moved 20 cm east because of auger refusal (gravel) in pilot hole
	Toe	70 (74)	115 (110)	- <5% coarse-grained mineral in peat - 4 cm peat mix/13 cm subsoil in 66-83 cm interval	- approx. 30% gravel in 83-100 cm subsoil interval, difficult to auger through - OB sticky due to increased moisture	Aw - 125 cm, 126 cm, 159 cm	- <5% coarse-grained mineral in peat - 19 cm peat mix/1 cm subsoil in 55-75 cm interval	- minor gravel inclusions (2-5%) from 75-120 cm (into upper OB) - OB sticky due to increased moisture	- deep peat layer on toe of slope - dry peat is falling back into hole during augering - only 5 cm salinity sample interval directly above OB due to difference in OB interface depth from pilot hole
8	Plateau 1	25	115	-no root samples	- no root samples	-no root samples	'- approx. 5% fine grained mineral in peat - 10 cm peat mix/10 cm subsoil in 15-35 cm interval	- subsoil is PG3 till with $CaCO_3$, iron, charcoal and minor pink PL2 clay inclusions - small pockets of peat present (approx. 5-10%) from 75-135 cm - gravel inclusions (approx. 5%) from 35-125 cm (throughout subsoil into upper OB)	
	Plateau 2	21	112	-no root samples	-no root samples	-no root samples	- approx. 15% clay loam in peat - 9 cm peat mix/11 cm subsoil in 12-32 cm interval	- large cobbles present from 0-102 cm - subsoil is mix of glacial materials	- water table at 61 cm; material falling back into hole during sampling - seepage water from heavy rain prior to salinity sampling - site located near bottom of small swale
	Crest	18	102 (92)	- approx. 5% coarse grained mineral in peat - 4 cm peat mix/10 cm subsoil in 14-28 cm interval	- predominantly moderately fine textured subsoil - approx. 15% gravel at peat mix/subsoil interface, 5-10% gravel throughout subsoil with large gravel piece at OB interface	Sw - 200 cm	- approx. 5% coarse grained mineral in peat - 16 cm peat mix/4 cm subsoil in 2-22 cm interval	- subsoil is a mix of glacial materials - only one 10 cm subsoil interval above OB - slight hydrocarbon odour in OB, however texture is fine-grained - only one 10 cm subsoil interval above OB	
	Middle	29	60 (52)	- approx. 5-10% sandy inclusions in peat with pink PL2 pieces mixed in - 14 cm peat mix/1 cm subsoil in 15-30 cm interval	- subsoil is predominantly pink PL2 material - increased sand in OB with strong hydrocarbon odour and greenish coloured inclusions	Sw - 50 cm	- approx. 5-10% sandy inclusions in peat with pink PL2 pieces mixed in - 9 cm peat mix/11 cm subsoil in 20-40 cm interval	- auger refusal (cobble) at 70 cm in first hole - 40-52 cm subsoil sample interval above OB (rather than two 10 cm intervals) - increased sand in OB with strong hydrocarbon odour and greenish coloured inclusions - 40-52 cm subsoil sample interval above OB (not two 10 cm intervals)	- sparse Sw with grass ground cover

Transect	Slope Position	Capping depth (cm)[1]		Root Sampling Program			Salinity Sampling Program		General Site Comments
		Peat Mix	Total Depth	Peat Mix	Profile Observations[2]	Planted Trees within 2m Proximity of Auger Hole (species, distance in cm)[3]	Peat Mix	Profile Observations[2]	
8	Toe	27	77	- approx 5-10% coarse grained mineral in peat - 12 cm peat mix/3 cm subsoil in 15-30 cm interval	- approx. 10% gravel in bottom of peat mix (above subsoil interface) and in bottom of subsoil (above OB interface)	Sw - 200 cm	- approx 5-10% coarse grained mineral in peat - 15 cm peat mix/5 cm subsoil in 17-37 cm interval	- approx. 10% gravel in bottom of peat mix (above subsoil interface) and in bottom of subsoil (above OB interface)	
9	Crest	28	100	- approx 5% clay mineral in peat -sample interval exactly on peat mix/subsoil interface	- calcareous mix of glacial subsoil - layer of gravel from 40-50 cm - auger refusal in first 2 holes - minor subsoil inclusions and greenish coloured inclusions in OB	Sw - 123 cm, 152 cm, 166 cm	- approx 5% clay mineral in peat -8 cm peat mix/12 cm subsoil in 20-40 cm interval	- calcareous PG3 subsoil with minor pink PL2 clay inclusions - minor subsoil inclusions in OB	- site moved 50 cm north due to auger refusal (gravel/cobble) in first 2 pilot holes
	Upper	6	88	- very thin layer, some areas nearby in clearing with no cover soil (moss overlying mineral) - 6 cm peat mix/8 cm subsoil in 0-14 cm interval	- approx. 10-15% gravel from 0-43 cm - subsoil is a mix of calcareous glacial subsoil	Volunteer - 3 Aw, 2 willow poor growth therefore difficult to distinguish planted/volunteer trees	- very thin layer, some areas nearby in clearing with no cover soil (moss overlying mineral) - 6 cm peat mix/2 cm subsoil in 0-8 cm interval	- approx. 10-15% gravel from 0-43 cm - subsoil is a mix of glacial materials	- located in small clearing with low tree density and little ground cover
	Middle	18 (13)	93	- approx 10-15% fine textured mineral in peat - 2 cm peat mix/14 cm subsoil in 16-32 cm interval	- subsoil is a mix of calcareous glacial material - approx. 10% gravel throughout subsoil - minor OB inclusions in 63-78 cm subsoil interval	Aw - 189 cm Sw - 67 cm, 195 cm Volunteer - 2 Aw	- approx 10-15% fine textured mineral in peat - sample interval exactly on peat mix/subsoil interface	- subsoil is a mix of glacial materials - approx. 10% gravel throughout subsoil - small amount of subsoil mixed in throughout OB	
	Lower	19	83	- approx 20-25% clay mineral in peat - 2 cm peat mix/15 cm subsoil in 17-34 cm interval	- subsoil is predominantly moderately fine textured highly calcareous material - upper 10 cm of OB has fine pink clay inclusions - OB has increase in coarse grains, hydrocarbon odour present	Aw - 97 cm, 166 cm	- approx 20-25% clay mineral in peat - 16 cm peat mix/4 cm subsoil in 3-23 cm interval	- subsoil is predominantly moderately fine textured material - OB has increase in coarse grains, hydrocarbon odour present	
	Toe	13	88	- approx. 5-10% clay mineral in peat - 13 cm peat mix/2 cm subsoil in 0-15 cm interval	- subsoil is moderately fine textured from 13-44 cm overlying fine pink PL2 from 44-88 cm	Aw - 161 cm (could be volunteer)	- approx. 5-10% clay mineral in peat - 5 cm peat mix/15 cm subsoil in 8-28 cm interval	- subsoil is predominantly moderately fine textured material - approx. 10% gravel at 40 cm and 70 cm	- site moved 4.0 m east upslope (now approximately 5 m from Peat Pond) - water table at 85 cm (root sampling event) and 55 cm (salinity sampling event)

[1] Depths (in parentheses) differ slightly from "official" capping depths taken from pilot holes during root sampling event using 5 cm combination auger; salinity holes were augered in close proximity, but depths varied slightly in these cases

[2] PG3 refers to medium to dark brown colored, moderately fine textured glacial till used for reclamation in Mildred Lake area; PL2 refers to finer textured, pink coloured glaciolacustrine clay

[3] Aw = Trembling Aspen, Sw = White Spruce, Pb = Balsam Poplar, Bw = White Birch

APPENDIX 3

ANALYTICAL RESULTS

Appendix 3. Analytical results from SW30 Dump 2012 salinity sampling field program.

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
																						Texture	Sand	Silt	Clay
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S		50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	**Position**	**Detection Limit**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 1	**T1-C**	**0-8**	202	259	28.2	7.3	0.75	0.8	77	4.39	68.1	2.44	22.9	1.46	26	0.22	6	0.67	18	3.1	38.4	-	-	-	-
Transect 1	**T1-C**	**8-28**	516	723	40.1	7	0.98	1	91	5.98	109	3.11	34.4	2.26	47	0.08	3	0.53	17	5.95	86.9	-	-	-	-
Transect 1	**T1-C**	**28-48**	761	904	18.8	7.7	0.83	2.6	60	3.09	37.2	1.6	11.6	3.97	55	0.06	1	0.39	8	5.31	51	-	-	-	-
Transect 1	**T1-C**	**48-68**	203	363	78.8	7	1.68	4.1	204	6.56	268	3.58	88.5	9.15	430	0.06	5	0.64	47	14.3	467	-	-	-	-
Transect 1	**T1-C**	**68-88**	496	612	23.4	6.8	3.22	5.5	101	17.6	355	9.07	111	20	463	<0.2	<10	0.73	26	40.8	658	Loam	50.4	28.2	21.4
Transect 1	**T1-C**	**88-98**	278	333	19.8	7.2	3.01	7.6	87	11.6	202	5.99	63.3	22.6	455	<0.2	<9	0.82	25	35.4	495	-	-	-	-
Transect 1	**T1-C**	**98-108**	302	352	16.6	7.3	3.99	8.2	80	14.3	227	8.74	84.4	27.9	512	0.43	13	0.51	14	45.7	584	-	-	-	-
Transect 1	**T1-C-OB**	**108-118**	264	313	18.6	7.2	5.67	7.9	85	25.2	431	19.9	206	37.4	735	0.92	30	0.44	13	75.9	1040	-	-	-	-
Transect 1	**T1-C-OB**	**118-128**	473	564	19.2	7.4	7.19	10.4	88	24	421	29.5	313	54	1090	1.4	49	0.48	15	102	1430	-	-	-	-
Transect 1	**T1-C-OB**	**128-148**	653	780	19.4	7.3	8.12	11.3	106	23	486	37.2	475	61.9	1500	1.9	78	0.53	20	117	1980	Clay Loam	24.4	36.2	39.4
Transect 1	**T1-U**	**0-18**	185	291	57.3	5.8	0.74	0.7	125	4.31	108	2.42	36.6	1.3	37	0.46	22	0.91	40	4.24	84.8	-	-	-	-
Transect 1	**T1-U**	**18-38**	827	948	14.6	7.3	0.86	2.9	56	3.5	38.9	1.47	9.9	4.53	58	0.06	1	0.39	8	4.35	38.7	Clay Loam	44.4	22.8	32.8
Transect 1	**T1-U**	**38-48**	480	552	15.0	7.6	1.9	8.4	58	4.15	48.5	1.78	12.6	14.4	194	0.03	<1	0.38	8	16.6	156	-	-	-	-
Transect 1	**T1-U**	**48-58**	264	320	21.2	7.5	3.86	13.9	75	6.92	104	4.16	37.9	32.8	569	<0.2	<8	0.6	16	38.3	462	-	-	-	-
Transect 1	**T1-U-OB**	**58-68**	356	436	22.5	7.5	7.69	13.9	101	23.8	480	21.8	267	66.3	1540	1.3	53	0.66	24	107	1730	-	-	-	-
Transect 1	**T1-U-OB**	**68-78**	510	628	23.1	7.5	8.87	15	114	22.3	509	28.6	394	75.9	1990	1.7	74	0.7	28	125	2290	-	-	-	-
Transect 1	**T1-U-OB**	**78-98**	617	760	23.2	7	10.2	15.4	111	22.7	505	44.5	599	89.5	2290	2	85	0.95	38	153	2710	Clay	20.4	33.2	46.4
Transect 1	**T1-M**	**0-6**	68.7	138	100.9	5.7	0.66	1.4	218	2.94	128	1.63	43.1	2.06	103	0.46	39	0.51	40	3.99	139	-	-	-	-
Transect 1	**T1-M**	**6-26**	549	655	19.3	5.8	2.25	4.5	64	9.9	126	5.46	42.2	12.6	185	0.16	4	0.54	12	24.8	254	Clay Loam	28.4	35.2	36.4
Transect 1	**T1-M**	**26-36**	331	422	27.5	6.9	5.18	8.4	82	23.1	379	13.6	134	36.2	682	<0.2	<8	0.96	28	66.1	868	-	-	-	-
Transect 1	**T1-M**	**36-46**	263	322	22.4	7.4	5.09	10	80	16.6	268	12.2	119	38	704	<0.2	<8	0.66	19	62.1	800	-	-	-	-
Transect 1	**T1-M-OB**	**46-56**	410	499	21.7	7.2	6.23	9	82	25.6	419	22.5	224	44.4	837	1.2	38	0.75	22	88.4	1160	-	-	-	-
Transect 1	**T1-M-OB**	**56-66**	307	383	24.8	7.2	6.74	9.8	86	24.2	418	27.8	291	49.8	991	1.4	49	0.82	25	95.6	1320	-	-	-	-
Transect 1	**T1-M-OB**	**66-86**	563	708	25.8	7.3	7.8	11.5	93	23.6	441	32.9	371	61.2	1310	1.6	58	1.12	37	112	1670	Clay Loam	23.4	39.2	37.4
Transect 1	**T1-L**	**0-21**	291	447	53.6	6	0.55	0.5	124	3.84	95.5	2.06	30.9	0.8	23	0.2	10	0.66	29	3	59.7	Clay	30	27.6	42.4
Transect 1	**T1-L**	**21-31**	334	409	22.5	7	0.79	0.7	73	6.28	91.8	2.32	20.6	1.41	24	0.12	3	0.37	10	3.32	38.9	-	-	-	-
Transect 1	**T1-L**	**31-41**	444	503	13.3	7.6	0.61	1.1	52	3.75	39.2	1.36	8.6	1.76	21	0.1	2	0.31	6	2.97	24.8	-	-	-	-
Transect 1	**T1-L-OB**	**41-51**	434	494	13.8	7.6	0.8	1.5	65	4.38	57.1	1.67	13.2	2.62	39	0.31	8	0.3	7	5.82	60.7	-	-	-	-
Transect 1	**T1-L-OB**	**51-61**	526	605	15.0	7.2	2.36	1.3	74	21.9	324	7.36	65.8	5.16	88	0.92	26	0.3	8	32	379	-	-	-	-
Transect 1	**T1-L-OB**	**61-81**	906	1050	15.9	7.2	2.96	2.2	75	27	406	12.5	114	9.82	170	1.2	35	0.3	8	46.6	561	Clay Loam	28.4	35.2	36.4
Transect 1	**T1-T**	**0-10**	78.8	161	104.3	7.2	0.67	0.4	225	3.94	177	2.17	59	0.72	37	0.5	44	0.26	20	3.92	141	-	-	-	-
Transect 1	**T1-T**	**10-30**	547	686	25.4	7.4	0.61	0.7	63	3.89	49.3	1.69	13	1.19	17	0.12	3	0.2	4	3.27	33.2	Clay Loam	44.4	27.6	28
Transect 1	**T1-T**	**30-40**	293	346	18.1	7.7	0.5	1	54	2.98	32.4	1.09	7.2	1.39	17	0.14	3	0.22	4	2.42	21	-	-	-	-
Transect 1	**T1-T**	**40-50**	301	356	18.3	7.8	0.51	1.6	51	2.21	22.5	0.97	6	2.08	24	0.22	4	0.24	4	2.27	18.4	-	-	-	-
Transect 1	**T1-T-OB**	**50-60**	581	673	15.8	7.8	0.69	3.1	52	2.17	22.5	1.09	6.8	3.96	47	0.28	6	0.21	4	4.21	34.9	-	-	-	-
Transect 1	**T1-T-OB**	**60-70**	617	703	13.9	7.7	0.82	4.6	49	1.63	16	1.12	6.6	5.38	60	0.3	6	0.19	3	6.38	49.8	-	-	-	-
Transect 1	**T1-T-OB**	**70-90**	883	981	11.1	7.6	1.18	5.7	42	2.11	17.6	1.83	9.2	7.97	77	0.37	6	0.24	4	10.5	70	Sandy Loam	57.4	28.2	14.4
Transect 2	**T2-C**	**0-4**	63.7	120	88.4	5.4	0.53	0.3	200	3.17	127	1.48	35.7	0.51	24	0.74	57	1.14	81	2.82	90.4	-	-	-	-
Transect 2	**T2-C**	**4-24**	402	522	29.9	6.1	0.93	0.4	84	7.66	128	2.94	29.7	1.01	19	0.19	6	0.83	24	4.8	64.3	-	-	-	-
Transect 2	**T2-C**	**24-44**	819	953	16.4	7.4	0.61	1	60	3.73	44.6	1.44	10.4	1.59	22	0.08	2	0.45	10	2.8	26.8	-	-	-	-
Transect 2	**T2-C**	**44-64**	1110	1250	12.6	7.6	0.91	2.1	52	4.38	45.8	1.9	12	3.66	44	0.17	3	0.47	9	6.91	57.8	-	-	-	-
Transect 2	**T2-C**	**64-84**	1280	1410	10.2	7.7	1.04	3.4	44	3.84	34	1.72	9.2	5.66	58	0.18	3	0.82	13	8.04	57	Sandy Clay Loam	58.4	21.2	20.4
Transect 2	**T2-C**	**84-104**	649	725	11.7	7.7	1.32	5.1	54	3.88	42	1.76	11.5	8.63	107	0.22	4	0.6	12	11	95.6	Sandy Clay Loam	55.6	24.4	20
Transect 2	**T2-C**	**104-114**	672	759	12.9	7.8	2.22	8.9	55	4.62	51	2.89	19.3	17.3	220	0.2	4	0.6	12	22.2	196	-	-	-	-
Transect 2	**T2-C-OB**	**114-124**	471	549	16.6	7.4	5.56	9.4	71	22.5	321	17.3	149	42	690	1.1	31	0.61	16	77.4	884	-	-	-	-
Transect 2	**T2-C-OB**	**124-134**	485	589	21.4	7.4	7.07	12.6	92	24	440	23.1	256	61	1290	1.6	57	1	32	104	1520	-	-	-	-
Transect 2	**T2-C-OB**	**134-154**	1020	1220	19.6	7.5	7.88	15.4	92	22.5	414	22.6	252	73.4	1550	1.6	59	1.3	42	114	1680	Clay Loam	33.4	27.8	38.8
Transect 2	**T2-U**	**0-10**	172	261	51.7	6.4	0.83	2.3	117	3.37	78.9	1.86	26.4	3.71	100	0.46	21	0.56	23	5.94	111	-	-	-	-
Transect 2	**T2-U**	**10-20**	109	213	95.4	6.4	1.08	7.1	205	2.09	85.7	0.91	22.5	8.7	411	0.07	6	1.17	85	7.68	252	-	-	-	-
Transect 2	**T2-U**	**20-30**	532	650	22.2	7.5	2.61	13.6	78	4.24	66.6	2.49	23.6	25	451	<0.2	<8	1.36	38	26.6	335	-	-	-	-
Transect 2	**T2-U-OB**	**30-40**	390	466	19.5	7.4	6.43	10.8	91	24.3	440	20.9	230	51.2	1070	1.2	41	0.92	30	93.2	1350	-	-	-	-
Transect 2	**T2-U-OB**	**40-50**	565	671	18.8	7.4	6.9	10.6	92	23.6	433	29	322	54.3	1150	1.4	52	0.91	30	105	1540	-	-	-	-

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
																						Texture	Sand	Silt	Clay
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S		50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 2	T2-U-OB	50-70	738	891	20.7	7.2	7.61	10.7	104	22.7	471	34.8	436	57.5	1370	1.6	67	0.79	29	114	1890	Silty Clay	14.4	42.2	43.4
Transect 2	T2-M	0-23	465	670	44.1	6.6	3.38	4.4	115	22.9	527	12.4	172	18.5	489	0.38	17	1.15	47	48.7	896	Clay	28.4	28.8	42.8
Transect 2	T2-M	23-33	622	709	14.0	7.4	5.38	9.2	59	24.8	292	14.4	102	40.7	550	<0.2	<6	1.13	24	73.4	690	-	-	-	-
Transect 2	T2-M	33-43	377	440	16.7	7.6	7.53	14.7	55	22.8	251	21.2	141	69	876	0.36	8	1.85	36	106	932	-	-	-	-
Transect 2	T2-M	43-53	351	431	22.8	7.6	8.07	14.2	90	24.8	444	29	314	73.4	1510	1.2	43	1.19	38	118	1700	-	-	-	-
Transect 2	T2-M-OB	53-63	376	462	22.9	7.6	8.68	14.8	78	24.8	386	31	292	78.1	1400	1.2	38	1.68	46	128	1600	-	-	-	-
Transect 2	T2-M-OB	63-83	783	961	22.7	7.5	8.95	16.3	90	22.9	415	29.7	324	83.8	1740	1.6	56	1.68	54	132	1920	Clay Loam	26	35.6	38.4
Transect 2	T2-L	0-5	99	173	74.7	6.3	0.91	2.5	153	4.11	126	2.24	41.5	4.43	156	0.39	24	0.87	47	5.69	140	-	-	-	-
Transect 2	T2-L	5-15	321	438	36.4	6.9	2.88	7.7	84	11.3	190	6.58	66.7	23.2	446	<0.2	<8	1.51	45	30.1	403	-	-	-	-
Transect 2	T2-L	15-25	304	362	19.1	7.4	5.66	10	68	27	367	15.4	126	46.1	720	0.62	16	2.68	64	78.6	854	-	-	-	-
Transect 2	T2-L-OB	25-35	321	385	19.9	7.4	6.67	12.6	70	24.6	347	18.2	155	58.4	945	0.86	24	3.05	76	91.9	1030	-	-	-	-
Transect 2	T2-L-OB	35-45	338	409	21.0	7.5	6.71	12.8	72	24.1	349	17.4	152	58.6	974	1	29	2	51	94.9	1100	-	-	-	-
Transect 2	T2-L-OB	45-65	689	840	21.9	7.5	7.56	15.1	80	23.9	380	19.3	186	70.2	1280	1.3	40	2.84	80	107	1360	Clay Loam	36.4	30.8	32.8
Transect 2	T2-T	0-10	194	266	37.1	7.6	1.47	6.6	91	3.2	58.4	2.07	22.9	10.7	224	0.2	7	1.11	36	10.8	157	-	-	-	-
Transect 2	T2-T-OB	10-20	474	584	23.2	7.5	6.38	11.6	76	24.9	381	18	167	53.6	943	0.9	27	2.59	70	89.7	1100	-	-	-	-
Transect 2	T2-T-OB	20-30	307	378	23.1	7.5	8.07	14	83	24.3	404	29.1	293	72.6	1390	1.6	51	3.33	98	115	1530	-	-	-	-
Transect 2	T2-T-OB	30-50	848	1050	23.8	7.5	8.39	14.2	98	23.2	455	31.7	375	74.5	1670	1.8	70	2.02	70	123	1920	Clay	33.4	24.2	42.4
Transect 3	T3-C	0-4	98	129	31.6	6.3	0.78	1	100	4.14	83	2.07	25.2	1.84	42	0.27	10	1.45	52	4.84	77.8	-	-	-	-
Transect 3	T3-C	4-24	954	1100	15.3	7.5	1.29	2	63	7.87	98.9	3.44	26.2	4.67	67	0.15	4	1.12	25	12.2	122	-	-	-	-
Transect 3	T3-C	24-44	941	1080	14.8	7.5	2.6	4.1	63	16.6	210	7.84	59.9	14.4	209	<0.2	<6	1.75	39	32.2	325	-	-	-	-
Transect 3	T3-C	44-64	1060	1170	10.4	7.8	3.25	7.4	58	13.3	155	8.27	58.6	24.3	327	<0.2	<6	2.4	50	40.7	381	Loam	46	28.6	25.4
Transect 3	T3-C	64-74	491	544	10.8	7.9	3.19	10.4	61	9	110	6.1	45.1	28.7	403	<0.2	<6	2.64	57	37.8	369	-	-	-	-
Transect 3	T3-C	74-84	512	573	11.9	7.8	4.58	10.9	60	14	167	10.3	74.6	38.1	526	0.37	9	2.45	52	55.6	533	-	-	-	-
Transect 3	T3-C-OB	84-94	513	567	10.5	7.6	5	8.2	50	19	190	19.9	121	36.1	415	0.92	18	2.05	36	68.9	551	-	-	-	-
Transect 3	T3-C-OB	94-104	489	548	12.1	7.5	6.22	8.8	51	23.2	238	29.2	182	45.3	535	1.2	23	2.21	40	90.1	741	-	-	-	-
Transect 3	T3-C-OB	104-124	1160	1340	15.5	7.3	6.6	10.2	69	24.2	333	26	217	51.3	812	1.3	36	2.3	56	96.9	1070	Sandy Clay Loam	53.4	21.8	24.8
Transect 3	T3-U	0-8	87	120	37.9	5.9	0.61	0.8	160	3.29	105	1.84	35.5	1.28	47	0.39	24	0.64	36	4.07	104	-	-	-	-
Transect 3	T3-U	8-28	770	885	14.9	7.3	0.68	0.8	68	4.26	57.9	2.01	16.6	1.38	22	0.15	4	0.58	14	3.14	34.2	-	-	-	-
Transect 3	T3-U	28-48	721	800	11.0	7.6	0.63	1.2	54	3.42	36.7	1.41	9.1	1.91	24	0.12	2	1.08	20	2.85	24.4	-	-	-	-
Transect 3	T3-U	48-68	931	1060	13.9	7.6	1.18	1.8	63	7.26	92.1	2.67	20.5	4	58	0.17	4	0.78	17	10.8	110	-	-	-	-
Transect 3	T3-U	68-88	887	1020	15.0	7.6	1.63	2.6	68	10	136	3.62	29.6	6.76	105	0.18	5	1.02	24	17.4	189	-	-	-	-
Transect 3	T3-U	88-108	1080	1260	16.7	7.6	2.1	3.9	64	11.7	150	4.07	31.6	11	162	0.22	5	1.03	24	24.2	249	-	-	-	-
Transect 3	T3-U	108-128	911	1070	17.5	7.6	2.41	7.4	70	7.92	110	3.04	25.6	17.2	276	0.19	5	0.85	21	25.3	281	Clay	30.4	24.2	45.4
Transect 3	T3-U	128-138	451	532	18.0	7.8	2.55	11.3	73	5.18	75.8	2.56	22.7	22.3	375	<0.2	<7	0.67	17	27.6	323	-	-	-	-
Transect 3	T3-U	138-148	278	328	18.0	7.9	3.17	13.1	70	6.3	88.4	4.2	35.7	30	485	0.31	8	0.64	16	36.1	405	-	-	-	-
Transect 3	T3-U-OB	148-158	473	575	21.6	7.5	6.8	10.9	94	24.4	460	24	273	53.6	1160	1.5	54	0.46	16	99.6	1500	-	-	-	-
Transect 3	T3-U-OB	158-168	528	658	24.6	7.4	8.05	12.9	100	23.6	474	34.2	415	69.4	1600	1.8	73	0.5	18	118	1890	-	-	-	-
Transect 3	T3-U-OB	168-188	660	797	20.8	7.3	7.7	12.3	97	23.2	452	29.5	347	63.3	1420	1.9	71	0.52	18	114	1780	Clay Loam	20.4	40.8	38.8
Transect 3	T3-M	0-17	354	458	29.4	6.4	0.7	1.1	94	3.76	70.9	1.9	21.8	1.81	39	0.11	4	0.66	22	4.98	75.2	-	-	-	-
Transect 3	T3-M	17-37	815	948	16.3	7.2	0.71	0.8	78	4.67	73.4	2.1	19.9	1.54	28	0.1	3	0.47	13	1.89	23.8	-	-	-	-
Transect 3	T3-M	37-57	1120	1280	14.3	6.9	0.54	1.7	64	2.01	25.9	1.16	9	2.15	32	0.04	<1	0.68	15	3.24	33.4	-	-	-	-
Transect 3	T3-M	57-77	901	1040	15.4	7.1	0.73	4	69	1.72	23.9	0.98	8.2	4.71	75	0.03	<1	0.34	8	5.84	64.9	Heavy Clay	24	15.6	60.4
Transect 3	T3-M	77-87	435	511	17.5	7.4	1	6.4	71	1.82	25.8	0.95	8.2	7.55	123	0.05	1	0.49	12	8.29	94.2	-	-	-	-
Transect 3	T3-M	87-97	526	595	13.1	7.6	1.64	5.7	61	5.06	61.7	2.66	19.6	11.2	157	0.12	3	0.81	18	15.5	151	-	-	-	-
Transect 3	T3-M-OB	97-107	455	539	18.5	7.5	6.8	11.7	86	24.8	428	21.4	224	56.3	1120	1.4	48	1.61	49	95	1310	-	-	-	-
Transect 3	T3-M-OB	107-117	411	514	25.1	7.5	8.93	16	99	23.3	462	30	360	82.5	1880	1.8	72	2	70	129	2050	-	-	-	-
Transect 3	T3-M-OB	117-137	939	1150	22.5	7.4	9.92	19.4	111	23	510	28	375	97.7	2490	1.8	80	2.28	90	144	2560	Clay	20	32.6	47.4
Transect 3	T3-L	0-5	100	151	51.0	6.8	1.1	1.5	149	6.58	196	3.1	56	3.34	114	0.52	30	1.39	74	6.73	160	-	-	-	-
Transect 3	T3-L	5-25	587	720	22.7	7.4	1.59	2.8	68	9.64	132	3.45	28.6	7.1	112	0.18	5	1.44	35	14.7	161	-	-	-	-
Transect 3	T3-L	25-45	739	866	17.2	7.6	2.35	4.1	63	13	164	5.5	42	12.5	182	0.26	6	2.08	47	26.5	268	Clay Loam	42	20	38
Transect 3	T3-L	45-55	521	598	14.8	7.7	3.14	7.5	56	13.7	153	7.24	49.1	24.4	314	<0.2	<6	2.96	59	38.2	343	-	-	-	-
Transect 3	T3-L	55-65	398	449	12.8	7.7	4.36	10.2	59	14.6	171	10.2	72.8	35.7	483	0.31	7	4.36	91	50.9	478	-	-	-	-
Transect 3	T3-L-OB	65-75	494	563	14.0	7.7	6.67	11.5	58	23.1	267	22.6	158	55	728	1.1	24	3.9	80	88.9	820	-	-	-	-

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S	Texture	Sand	Silt	Clay
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		50µm - 2mm	2µm - 50µm	<2 µm
																							% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 3	T3-L-OB	75-85	446	519	16.4	7.7	7.86	13.1	59	22.9	270	30.4	217	67.6	917	1.5	34	4.04	84	112	1060	-	-	-	-
Transect 3	T3-L-OB	85-105	872	1040	19.3	7.7	9.73	16.4	64	22.7	292	37.3	290	90.1	1330	1.7	43	5.7	130	143	1470	Clay Loam	44	27.6	28.4
Transect 3	T3-T	0-8	162	200	23.5	7	0.78	1.8	85	3.56	60.7	1.76	18.1	3.01	59	0.34	11	0.7	21	4.58	62.4	-	-	-	-
Transect 3	T3-T	8-28	697	800	14.8	7.6	1.29	3.1	56	5.94	65.9	2.53	17	6.46	82	0.17	4	1.08	21	10.6	94	-	-	-	-
Transect 3	T3-T	28-48	953	1060	11.2	7.6	3.32	5.5	49	21.6	212	9.21	54.6	21.4	241	0.3	6	2.81	49	46.9	368	Clay Loam	43.4	26.2	30.4
Transect 3	T3-T	48-58	274	305	11.3	7.8	3.4	6.8	49	17.9	177	8.77	52.5	24.7	281	0.31	6	2.94	52	45.9	363	-	-	-	-
Transect 3	T3-T	58-68	494	557	12.8	7.8	3.39	9.7	52	10.5	109	7	44	28.6	342	0.3	6	3.52	65	39.7	330	-	-	-	-
Transect 3	T3-T-OB	68-78	419	495	18.1	7.4	5.89	8.4	99	25	493	24.2	288	41.8	949	1.2	46	2.18	76	83.8	1320	-	-	-	-
Transect 3	T3-T-OB	78-88	493	605	22.7	7.4	6.72	10	98	24.4	481	30.1	358	52	1180	1.6	60	2.17	76	97.4	1530	-	-	-	-
Transect 3	T3-T-OB	88-108	664	833	25.5	7.5	7.17	11.4	94	24.2	457	29.7	340	59	1280	1.6	58	2.41	81	103	1560	Clay	26.4	25.2	48.4
Transect 4	T4-C	0-7	84.4	143	69.4	5.9	1.08	0.8	168	8.32	278	3.52	71.3	2.05	79	0.41	27	0.61	36	9.91	266	-	-	-	-
Transect 4	T4-C	7-27	257	359	39.7	7	0.88	0.6	101	6.68	135	2.57	31.4	1.34	31	0.11	4	0.45	16	6.29	102	-	-	-	-
Transect 4	T4-C	27-47	919	1130	23.0	7.1	2.59	1.4	71	29.3	418	10.4	89.4	6.44	105	<0.2	<7	0.55	14	40.1	456	Clay Loam	38	27.6	34.4
Transect 4	T4-C	47-57	496	589	18.8	7.1	2.79	4	59	19.4	228	9.81	69.7	15.4	208	<0.2	<6	0.81	17	38.7	363	-	-	-	-
Transect 4	T4-C	57-67	461	531	15.2	7.4	2.75	5.6	59	13	154	8.14	58.4	18.3	250	<0.2	<6	0.91	19	35.4	335	-	-	-	-
Transect 4	T4-C-OB	67-77	640	757	18.3	7.3	6.02	8.4	89	24.6	440	26.8	291	42.7	879	1.3	47	1.22	38	89.2	1280	-	-	-	-
Transect 4	T4-C-OB	77-87	412	505	22.6	7.4	7.98	11.9	95	22.9	434	38.9	446	66.3	1440	1.8	65	1.62	54	122	1840	-	-	-	-
Transect 4	T4-C-OB	87-107	1100	1360	23.6	7.4	9.83	15.8	99	22.7	449	41.5	498	89.6	2040	2	78	2.17	76	149	2360	Clay	20.4	30.8	48.8
Transect 4	T4-U	0-5	279	362	29.7	7.2	0.72	0.8	84	4.05	68	2.47	25.1	1.45	28	0.07	2	0.4	12	4.28	57.6	-	-	-	-
Transect 4	T4-U	5-25	711	852	19.8	7.7	0.53	1.3	61	2.5	30.5	1.31	9.7	1.74	24	0.05	1	0.26	6	2.36	23.1	-	-	-	-
Transect 4	T4-U	25-45	614	779	26.9	7.3	1.57	1.9	72	10	145	5.8	50.8	5.35	89	0.11	3	0.27	7	17.2	199	-	-	-	-
Transect 4	T4-U	45-65	453	664	46.6	6.9	2.95	2.7	103	25.9	534	13.5	169	12.2	288	<0.2	<10	0.26	10	47.1	777	-	-	-	-
Transect 4	T4-U	65-85	1180	1390	17.8	7.1	2.52	2.4	53	21.8	232	9.72	62.6	9.5	116	<0.2	<5	0.21	4	37.4	319	-	-	-	-
Transect 4	T4-U	85-105	1100	1260	14.5	7.1	1.91	2.1	48	13.2	126	6.66	38.6	6.66	74	0.12	2	0.32	6	23.8	183	-	-	-	-
Transect 4	T4-U	105-125	1420	1610	13.4	7.2	1.26	2.3	46	6.12	56	3.79	21	5.13	54	0.09	2	0.54	9	12.6	92.8	-	-	-	-
Transect 4	T4-U	125-145	1050	1210	15.2	7.2	1.58	4.2	48	5.42	52.3	3.72	21.7	9.07	101	0.12	2	0.91	16	15	115	-	-	-	-
Transect 4	T4-U	145-165	796	936	17.6	7.5	2.09	7.2	50	5.51	55.3	3.74	22.7	15.5	179	0.19	4	1.05	19	20.7	166	Loam	37.4	37.2	25.4
Transect 4	T4-U	165-175	462	513	11.0	7.3	1.99	9.3	43	3.69	31.7	2.41	12.6	16.3	162	0.13	2	0.73	11	17.8	122	-	-	-	-
Transect 4	T4-U	175-185	463	519	12.1	7.2	3.1	12.8	41	6.12	50.6	3.98	19.9	28.8	274	<0.2	<4	1.05	15	32	212	-	-	-	-
Transect 4	T4-U-OB	185-195	442	554	25.3	7.2	5.19	11.8	107	14.7	316	10.8	141	42	1040	1.1	45	0.65	25	63.6	1090	-	-	-	-
Transect 4	T4-U-OB	195-205	492	603	22.6	7.3	5.04	15.7	112	8.56	192	7.19	97.5	44.2	1140	0.9	39	0.9	36	58.6	1050	-	-	-	-
Transect 4	T4-U-OB	205-225	1360	1650	21.3	7.3	6.19	19.8	112	9.72	219	8.41	114	59.7	1540	1.3	56	1.67	66	73.9	1330	Clay Loam	22.4	39.2	38.4
Transect 4	T4-M	0-12	193	281	45.6	6.8	1.1	0.7	112	7.76	174	3.7	50	1.75	45	0.33	14	0.88	35	6.1	109	-	-	-	-
Transect 4	T4-M	12-32	739	932	26.1	7.1	1.15	0.8	75	8.56	128	3.87	35	2.03	35	0.09	3	1.67	44	5.97	71.3	-	-	-	-
Transect 4	T4-M	32-52	1150	1290	12.2	7.5	1.2	1.2	54	8.35	90.8	3.42	22.5	2.91	36	0.07	1	0.51	10	11.2	97	-	-	-	-
Transect 4	T4-M	52-72	1060	1180	11.3	7.6	1.79	3.8	50	8.62	86.8	3.23	19.7	9.29	108	0.08	2	0.39	7	18	145	Clay Loam	41	26.4	32.6
Transect 4	T4-M	72-82	576	644	11.8	7.5	4.71	6.9	53	24.3	258	11.6	74.9	29.3	358	<0.2	<5	0.41	8	60.1	511	-	-	-	-
Transect 4	T4-M	82-92	253	284	12.3	7.6	5.69	8.6	56	22.9	254	16.9	113	38.4	490	0.34	7	0.4	8	74.3	660	-	-	-	-
Transect 4	T4-M-OB	92-102	276	326	18.1	7.6	7.1	10	90	23.3	420	30.8	336	52.2	1080	1.2	43	0.36	12	98	1410	-	-	-	-
Transect 4	T4-M-OB	102-112	385	462	20.0	7.5	7.95	11	92	22.6	418	36.9	413	59.9	1280	1.5	54	0.4	13	112	1660	-	-	-	-
Transect 4	T4-M-OB	112-132	1400	1650	17.9	7.5	8.62	11.8	98	21.9	430	41.5	493	66.3	1500	1.4	56	0.52	18	127	1990	Silty Clay Loam	12	48.4	39.6
Transect 4	T4-L	0-5	104	175	68.3	6.8	1.12	0.5	131	7.42	194	3.47	55	1.14	34	0.62	32	0.48	22	4.42	92.6	-	-	-	-
Transect 4	T4-L	5-25	603	807	33.8	7.1	1.03	0.6	78	8.02	125	3.23	30.6	1.42	26	0.21	6	0.72	20	2.34	29.2	-	-	-	-
Transect 4	T4-L	25-45	792	918	15.9	7.5	0.6	1.4	50	3.09	31	1.13	6.9	1.97	23	0.05	1	0.37	6	2.03	16.3	-	-	-	-
Transect 4	T4-L	45-65	1150	1270	10.4	7.6	0.88	1.8	53	3.97	42	2.12	13.6	3.24	40	0.06	1	0.23	4	5.86	49.7	-	-	-	-
Transect 4	T4-L	65-85	957	1060	10.8	7.6	1.46	2.3	57	7.48	85.5	4.1	28.4	5.55	73	0.04	<1	0.18	4	14.3	131	-	-	-	-
Transect 4	T4-L	85-105	984	1100	11.8	7.6	1.32	3	52	5.72	59.6	2.96	18.6	6.2	74	0.06	1	0.23	4	11.6	96.5	-	-	-	-
Transect 4	T4-L	105-125	1040	1200	15.4	7.7	1.3	5.2	53	3.32	35.4	1.73	11.2	8.26	101	0.04	<1	0.25	5	9.69	82.7	Sandy Clay	46	18.4	35.6
Transect 4	T4-L	125-135	482	565	17.2	7.8	1.46	8.3	66	2.26	29.8	1.3	10.4	11.1	169	<0.03	<1	0.28	6	10.6	112	-	-	-	-
Transect 4	T4-L	135-145	340	399	17.4	7.7	2.26	8.6	72	4.69	67.2	3.26	28.2	17.1	282	0.08	2	0.29	7	20.6	236	-	-	-	-
Transect 4	T4-L-OB	145-155	575	718	24.9	7.3	6.35	8.9	106	23.3	495	22.7	292	42.7	1040	1.3	54	0.28	11	85	1440	-	-	-	-
Transect 4	T4-L-OB	155-165	368	465	26.4	6.4	7.87	11.3	100	22.3	447	35	424	60.4	1390	1.7	65	0.45	16	111	1780	-	-	-	-
Transect 4	T4-L-OB	165-185	979	1220	24.6	7.4	8.71	14.2	97	22	427	36.4	427	76.7	1710	1.8	67	0.66	23	130	2010	Clay	22	32	46

			Moisture Content			Detailed Salinity (Saturated Paste)																	Particle Size Analysis		
																						Texture	Sand	Silt	Clay
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S		50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 4	T4-T	0-16	304	386	27.0	7.2	1.63	0.8	71	11.9	168	5.81	49.7	2.5	41	0.44	12	1	25	9.86	112	-	-	-	-
Transect 4	T4-T	16-36	706	881	24.8	7.4	0.64	1.1	75	3.16	47.6	1.52	13.8	1.69	29	0.06	2	0.45	12	2.2	26.5	-	-	-	-
Transect 4	T4-T	36-56	918	1140	24.2	7.3	0.56	2.4	83	1.61	26.7	0.9	9.1	2.69	51	0.03	<1	0.46	13	3.33	44.3	-	-	-	-
Transect 4	T4-T	56-76	1060	1240	17.0	7.5	1.35	3.2	72	5.56	80.1	2.78	24.2	6.54	108	0.05	1	0.33	8	12.1	140	Clay	25	18.4	56.6
Transect 4	T4-T	76-86	420	478	13.8	7.6	2.09	5.4	60	9	107	4.45	32.1	14	193	<0.2	<6	0.36	8	23.9	228	-	-	-	-
Transect 4	T4-T	86-96	443	507	14.4	7.5	2.68	7.4	63	9.86	125	5.63	43.2	20.6	300	<0.2	<6	0.37	8	31.2	317	-	-	-	-
Transect 4	T4-T-OB	96-106	567	645	13.8	7.5	5.05	7.3	62	25	309	17.6	132	33.8	481	0.61	15	0.37	8	71.8	710	-	-	-	-
Transect 4	T4-T-OB	106-116	522	598	14.6	7.5	5.58	8.4	67	23	307	20	162	38.7	596	0.63	16	0.33	8	77.9	834	-	-	-	-
Transect 4	T4-T-OB	116-136	1090	1260	15.6	7.4	5.35	7.4	67	24.4	326	21.8	176	35.6	548	0.94	24	0.42	10	76.7	820	Clay	31	27	42
Transect 5	T5-C	0-13	241	323	34.0	7.5	0.98	0.8	87	7.06	123	2.17	23	1.65	33	0.17	6	0.56	17	4.95	69.1	-	-	-	-
Transect 5	T5-C	13-33	644	807	25.3	7.4	1.07	1.4	65	7.06	92.4	2.55	20.2	3.08	46	0.07	2	0.77	18	8.34	87.4	-	-	-	-
Transect 5	T5-C	33-53	821	969	18.0	7.6	1.57	2	58	10.6	123	4.62	32.3	5.4	72	0.08	2	0.8	16	13.5	125	-	-	-	-
Transect 5	T5-C	53-73	934	1100	17.8	7.7	3.29	4.1	54	26.5	288	11.9	77.8	17.9	223	<0.2	<5	1.43	28	51.3	445	Loam	45	29.4	25.6
Transect 5	T5-C	73-83	431	500	16.0	7.6	3.11	8.5	64	11.3	144	6.73	51.9	25.6	375	<0.2	<6	1.68	38	39.7	404	-	-	-	-
Transect 5	T5-C	83-93	492	564	14.6	7.8	3.24	9.7	59	8.94	105	6.02	42.9	26.5	359	<0.2	<6	1.93	40	39.1	368	-	-	-	-
Transect 5	T5-C-OB	93-103	572	666	16.4	7.5	6.38	10.6	71	22.3	315	21.3	182	49.6	808	1.1	30	1.54	38	89.8	1020	-	-	-	-
Transect 5	T5-C-OB	103-113	528	632	19.7	7.6	8.03	13.4	76	21.6	330	30.4	282	68.1	1200	1.4	43	2.12	58	120	1470	-	-	-	-
Transect 5	T5-C-OB	113-133	726	897	23.6	7.5	9.35	16	96	20.9	400	35	405	84.7	1860	1.7	64	2.41	82	138	2110	Clay	23	32.4	44.6
Transect 5	T5-U	0-16	297	414	39.4	6.6	1.75	2.6	89	9.35	167	5.36	58	7.16	147	0.16	6	0.53	17	1.75	25	-	-	-	-
Transect 5	T5-U	16-36	990	1180	19.2	7.2	4.84	6.5	57	24.2	278	15.4	107	29	382	<0.2	<6	1.08	22	65	596	-	-	-	-
Transect 5	T5-U	36-56	773	925	19.7	7.7	6.07	12.8	62	17.9	221	17.8	133	54.1	768	0.31	7	3.63	80	82.9	820	Clay Loam	38	26	36
Transect 5	T5-U	56-66	358	431	20.4	7.9	6.03	15.6	63	13	163	14.6	111	58	839	<0.2	<6	4.21	94	76.7	771	-	-	-	-
Transect 5	T5-U	66-76	368	442	20.1	7.8	6.92	14.3	61	21.1	259	20.7	154	65.5	926	0.34	8	4.38	95	94	924	-	-	-	-
Transect 5	T5-U-OB	76-86	513	646	25.9	7.5	8.38	14.5	79	24.8	393	33.1	318	78.1	1420	1.3	40	5.34	150	124	1570	-	-	-	-
Transect 5	T5-U-OB	86-96	545	678	24.4	7.4	8.62	13.6	85	24.2	410	33.4	341	72.8	1420	1.8	58	4.83	145	119	1610	-	-	-	-
Transect 5	T5-U-OB	96-116	984	1240	26.0	7.4	8.88	16.2	86	25	432	28	293	83.3	1660	1.7	58	6.52	200	122	1690	Silty Clay Loam	19	41.4	39.6
Transect 5	T5-M	0-14	474	569	20.0	7.4	1.62	1.8	62	11.3	141	3.99	30.1	5.06	73	0.25	6	0.7	15	14.5	144	-	-	-	-
Transect 5	T5-M	14-34	765	896	17.1	7.7	0.72	0.6	56	4.91	54.6	1.66	11.2	1.06	14	0.1	2	0.67	13	2.79	24.8	-	-	-	-
Transect 5	T5-M	34-54	784	932	18.9	7.7	0.67	1.6	57	3.07	35.1	1.69	11.7	2.54	33	0.06	1	0.46	9	2.51	22.9	Clay	34	23.4	42.6
Transect 5	T5-M	54-64	832	954	14.7	7.8	1.02	3.6	56	3.25	36.3	2.15	14.6	6	77	0.06	1	0.23	4	6.82	61	-	-	-	-
Transect 5	T5-M	64-74	438	496	13.2	7.8	1.43	5	56	4	44.6	3.03	20.4	9.3	119	0.1	2	0.2	4	12.6	113	-	-	-	-
Transect 5	T5-M-OB	74-84	448	514	14.7	7.4	4.32	4.3	68	26.6	365	19.2	159	20.7	326	1.1	29	0.23	6	61.8	677	-	-	-	-
Transect 5	T5-M-OB	84-94	428	495	15.7	7.4	4.91	5.1	72	26.2	379	24.3	212	25.5	423	1.4	39	0.22	6	70.6	816	-	-	-	-
Transect 5	T5-M-OB	94-114	1090	1270	16.5	6.5	5.65	5	68	26.6	364	39.4	326	29	457	1.2	33	0.3	7	87.7	960	Clay Loam	28	34.4	37.6
Transect 5	T5-L	0-8	333	410	23.1	7.6	1.43	1	68	10.8	146	3.8	31.2	2.8	44	0.8	21	0.8	19	5.52	60	-	-	-	-
Transect 5	T5-L	8-28	410	541	32.0	7.5	0.87	0.5	83	6.68	110	2.12	21.3	1.14	22	0.24	8	0.46	14	3.06	40.6	-	-	-	-
Transect 5	T5-L	28-48	486	579	19.1	7.6	0.55	0.9	57	2.95	33.9	1.2	8.4	1.37	18	0.13	3	0.31	6	1.79	16.5	Clay	38.6	19.8	41.6
Transect 5	T5-L	48-58	314	366	16.6	7.8	1.47	4.2	52	5.58	57.6	2.65	16.5	8.63	102	0.15	3	0.31	6	13.2	109	-	-	-	-
Transect 5	T5-L	58-68	323	382	18.3	7.7	2.31	8	57	6.95	79.3	3.98	27.4	18.7	246	<0.2	<6	0.35	7	25.8	236	-	-	-	-
Transect 5	T5-L-OB	68-78	347	441	27.1	7.5	6.86	11.5	84	24.6	413	24.1	244	57	1100	1.3	42	0.53	16	99.9	1340	-	-	-	-
Transect 5	T5-L-OB	78-88	510	652	27.8	6.2	8.45	12.7	90	24.8	447	41	447	72.9	1510	1.4	50	0.75	24	130	1880	-	-	-	-
Transect 5	T5-L-OB	88-108	769	975	26.8	7.2	9.34	14.6	95	23.6	449	40.6	468	82.9	1810	1.8	66	0.64	22	142	2170	Clay	23	25.4	51.6
Transect 5	T5-T	0-14	285	416	46.0	6.9	1.25	1	96	8.67	166	3.83	44.5	2.46	54	0.38	14	0.74	25	5.04	77.4	-	-	-	-
Transect 5	T5-T	14-34	754	891	18.2	7.3	2.7	1.8	52	29.9	313	11.5	72.6	8.35	100	<0.2	<5	0.74	14	46	385	-	-	-	-
Transect 5	T5-T	34-54	785	922	17.5	7.4	3.1	2.8	56	30.7	345	13.2	89.8	13.3	172	<0.2	<6	1.26	25	51.8	466	-	-	-	-
Transect 5	T5-T	54-74	1120	1250	11.6	7.4	3	2.9	54	29.2	314	11.4	74.1	13.1	162	0.39	8	0.62	12	49.6	427	-	-	-	-
Transect 5	T5-T	74-94	1200	1360	13.3	7.4	3.07	3.4	59	28.9	340	10.3	73.2	15	202	0.45	10	0.5	10	49.5	465	-	-	-	-
Transect 5	T5-T	94-114	1080	1260	16.7	7.4	2.85	3.8	62	23.2	288	7.76	58.3	15.1	216	0.27	6	0.72	16	41.8	415	-	-	-	-
Transect 5	T5-T	114-134	1270	1500	18.1	7.4	2.25	4.4	62	13.7	168	4.82	35.9	13.4	190	<0.2	<6	0.96	21	26.9	265	Clay Loam	38	24.4	37.6
Transect 5	T5-T	134-154	1180	1410	19.5	7.5	2.24	5.1	59	12.1	142	4.4	31.2	14.6	196	<0.2	<6	1.17	24	26.3	247	-	-	-	-
Transect 5	T5-T	154-174	802	984	22.7	7.7	2.49	7.2	66	8.94	119	3.39	27.3	17.8	272	<0.2	<7	1.2	28	26.3	280	Clay	36.6	22.4	41
Transect 5	T5-T	174-184	405	487	20.2	7.7	3	8	59	12.1	143	4.92	35.3	23.5	320	<0.2	<6	1.31	28	36.1	342	-	-	-	-
Transect 5	T5-T	184-194	336	409	21.7	7.7	2.92	8.9	61	9.92	122	4.5	33.5	23.9	338	<0.2	<6	1.18	26	33.7	332	-	-	-	-

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S	Texture	Sand 50µm - 2mm	Silt 2µm - 50µm	Clay <2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 5	**T5-T-OB**	**194-204**	718	888	23.7	7.7	4.29	8	66	18.7	248	9.47	76	29.9	455	0.8	21	1.04	24	53.6	568	-	-	-	-
Transect 5	**T5-T-OB**	**204-214**	605	691	14.2	7.8	3.45	7.1	46	19.3	179	8.24	46.3	26.2	280	0.48	9	0.97	16	49.8	370	-	-	-	-
Transect 5	**T5-T-OB**	**214-234**	1010	1140	12.9	7.7	4.57	6.6	40	26.1	207	10.6	50.6	28.5	259	0.52	8	0.92	13	60.9	385	Sandy Loam	66	18	16
Transect 6	**T6-C**	**0-9**	171	253	48.0	6	0.8	0.7	113	4.8	108	2.6	35.4	1.39	36	0.28	12	0.68	27	5.09	91.8	-	-	-	-
Transect 6	**T6-C**	**9-29**	843	1020	21.0	7	0.84	1.1	56	5.03	56.6	2.61	17.8	2.25	29	0.04	<1	0.47	9	4.27	38.4	-	-	-	-
Transect 6	**T6-C**	**29-49**	727	858	18.0	7.5	1.29	3	56	5.96	66.3	2.8	18.8	6.22	79	0.05	1	0.74	14	11	97.7	Clay	33	23	44
Transect 6	**T6-C**	**49-59**	408	503	23.3	7.4	2.68	6.4	72	12.2	174	6.28	54.3	19.4	319	<0.2	<7	1.32	34	32.2	369	-	-	-	-
Transect 6	**T6-C**	**59-69**	321	388	20.9	7.5	4.29	7.7	68	18.7	257	10.6	87.9	29.6	466	<0.2	<7	1.67	40	52.2	573	-	-	-	-
Transect 6	**T6-C**	**69-79**	608	706	16.1	7.7	5.14	8.7	55	20.8	229	13.5	89.9	36	456	0.29	6	1.81	35	65.7	579	-	-	-	-
Transect 6	**T6-C-OB**	**79-89**	351	445	26.8	7.6	7.69	12.2	91	23.5	429	30.4	336	63.5	1330	1.6	59	2.11	68	113	1650	-	-	-	-
Transect 6	**T6-C-OB**	**89-99**	364	461	26.6	7.6	7.94	12.4	89	23.7	424	32.8	354	66.2	1360	1.7	60	2.07	65	120	1710	-	-	-	-
Transect 6	**T6-C-OB**	**99-119**	829	1030	24.2	7.6	9.16	14.3	102	23.3	472	39.7	487	80.3	1870	2	81	1.95	70	144	2340	Clay	18	33.6	48.4
Transect 6	**T6-U**	**0-12**	225	292	29.8	6.2	0.99	0.8	83	6.22	103	3.29	33	1.8	34	0.37	12	0.72	21	6.77	89.8	-	-	-	-
Transect 6	**T6-U**	**12-32**	600	746	24.3	7.2	0.77	0.7	68	4.98	67.3	2.48	20.3	1.4	22	0.07	2	0.42	10	2.96	32.1	-	-	-	-
Transect 6	**T6-U**	**32-52**	855	995	16.4	7.5	0.83	1.9	41	3.85	31.9	2.15	10.8	3.35	32	0.06	1	0.31	4	5.11	33.9	Clay Loam	31	39	30
Transect 6	**T6-U**	**52-62**	613	720	17.5	7.4	1.62	3	58	8.03	93.3	4.69	33	7.66	102	0.1	2	0.26	5	16.3	151	-	-	-	-
Transect 6	**T6-U**	**62-72**	373	435	16.6	7.7	1.69	5.1	55	5.07	55.4	3.64	24.1	10.7	135	0.17	4	0.28	5	16.2	142	-	-	-	-
Transect 6	**T6-U-OB**	**72-82**	397	496	24.9	7.4	5.05	5.7	78	26.1	407	24.6	232	28.5	512	1.3	40	0.36	10	75.4	942	-	-	-	-
Transect 6	**T6-U-OB**	**82-92**	328	410	25.0	7.3	5.75	6.5	76	25.1	385	31.7	294	34.6	609	1.5	44	0.4	11	89.4	1090	-	-	-	-
Transect 6	**T6-U-OB**	**92-112**	1070	1320	23.4	7.4	6.59	8.3	78	24.9	387	36.6	343	45.8	818	1.2	37	0.49	14	104	1290	Clay	23	37	40
Transect 6	**T6-M**	**0-20**	87.2	167	91.5	5.6	1.35	1.9	264	6.7	354	4.66	149	4.44	270	0.6	62	0.55	51	12.8	541	-	-	-	-
Transect 6	**T6-M**	**20-40**	729	864	18.5	7.3	1.2	3.6	54	4.95	53.4	2.22	14.5	6.73	84	0.08	2	0.42	8	8.44	72.8	-	-	-	-
Transect 6	**T6-M**	**40-60**	899	1080	20.1	7.6	1.11	5.7	60	2.46	29.3	1.27	9.2	7.82	107	0.04	<1	0.4	8	7.36	70.1	-	-	-	-
Transect 6	**T6-M**	**60-80**	768	935	21.7	7.6	1.91	7	69	5.02	68.9	2.6	21.6	13.6	214	0.06	2	0.74	18	16.7	184	-	-	-	-
Transect 6	**T6-M**	**80-100**	1460	1630	11.6	7.6	2.85	10	37	7.5	55.6	4.51	20.2	24.5	209	<0.2	<4	0.58	8	32.2	191	Loam	39	34.6	26.4
Transect 6	**T6-M**	**100-110**	438	513	17.1	7.6	3.18	11.9	59	7.2	85.3	5.15	36.8	29.6	402	<0.2	<6	0.6	13	36	341	-	-	-	-
Transect 6	**T6-M**	**110-120**	325	400	23.1	7.7	4.34	14	71	7.82	111	6.96	59.6	38.1	621	<0.2	<7	0.87	22	48	544	-	-	-	-
Transect 6	**T6-M-OB**	**120-130**	438	551	25.8	7.6	7.37	13.1	79	23.8	377	24.5	235	64.5	1180	0.56	17	0.95	27	110	1400	-	-	-	-
Transect 6	**T6-M-OB**	**130-140**	299	382	27.8	7.6	8.43	14.7	93	24.4	451	29	326	75.9	1620	1.5	53	0.94	31	127	1880	-	-	-	-
Transect 6	**T6-M-OB**	**140-160**	584	768	31.5	7.6	8.54	15.7	105	23.7	497	27.4	348	79.3	1910	1.7	68	1.02	38	129	2170	Clay	18	32	50
Transect 6	**T6-L**	**0-4**	105	147	40.0	7.6	1.27	0.6	88	9.28	164	3.6	38.4	1.55	31	0.99	34	0.8	25	4.46	62.9	-	-	-	-
Transect 6	**T6-L**	**4-24**	656	768	17.1	7.6	0.69	0.6	51	4.28	43.4	1.81	11.1	1.05	12	0.1	2	0.93	17	2.92	23.7	-	-	-	-
Transect 6	**T6-L**	**24-44**	636	773	21.5	7.5	0.72	1	66	4.13	54.8	1.85	14.9	1.82	28	0.05	1	0.46	11	3.77	40	-	-	-	-
Transect 6	**T6-L**	**44-64**	398	471	18.3	7.6	0.92	1.7	54	4.93	53.3	2.29	15	3.21	40	0.06	1	0.51	10	6.71	58.1	-	-	-	-
Transect 6	**T6-L**	**64-84**	631	768	21.7	7.6	1.74	4.2	56	7.58	85.7	3.84	26.3	10.1	131	0.04	<1	0.7	14	17.1	155	-	-	-	-
Transect 6	**T6-L**	**84-104**	738	910	23.3	7.4	4.81	7.5	77	24.9	383	12.8	119	32.6	578	<0.2	<8	1.08	30	64.2	792	Clay	25	23	52
Transect 6	**T6-L**	**104-114**	525	622	18.5	7.4	6.17	12.8	59	23	270	12.2	86.4	53.6	724	<0.2	<6	1.02	21	82.9	779	-	-	-	-
Transect 6	**T6-L**	**114-124**	527	620	17.6	7.6	6.95	15.4	58	23.2	269	12	84.2	64.8	863	0.31	7	1.29	26	95.5	885	-	-	-	-
Transect 6	**T6-L-OB**	**124-134**	293	363	23.9	7.6	8.39	19.6	67	21.1	281	13.4	108	81.3	1250	0.79	20	1.55	37	112	1200	-	-	-	-
Transect 6	**T6-L-OB**	**134-144**	341	432	26.7	7.6	8.66	18.6	93	22.2	412	17.4	195	82.7	1770	1.3	46	1.03	34	123	1820	-	-	-	-
Transect 6	**T6-L-OB**	**144-164**	758	969	27.8	7.6	9.27	19.6	100	23.1	463	19.3	235	90.3	2080	1.5	58	1.15	41	132	2120	Clay	20	37	43
Transect 6	**T6-T**	**0-16**	104	223	114.4	6.6	1.74	2.4	227	10.2	465	4.92	135	6.48	339	0.68	60	1.17	94	13	474	-	-	-	-
Transect 6	**T6-T**	**16-36**	760	924	21.6	7.2	3.32	3.3	64	28.8	371	12.9	100	15.3	226	0.33	8	1.03	23	54	556	-	-	-	-
Transect 6	**T6-T**	**36-56**	806	941	16.7	7.4	3.63	4.6	54	26.7	286	13.7	88.6	20.6	253	0.29	6	0.79	15	58.7	502	Sandy Clay Loam	52	25	23
Transect 6	**T6-T**	**56-66**	771	897	16.3	7.6	3.18	5.3	50	16.8	167	9.07	54.5	19	217	0.16	3	0.76	13	40.4	321	-	-	-	-
Transect 6	**T6-T**	**66-76**	557	672	20.6	7.4	6.19	9.5	79	24.1	380	23.5	224	46.2	838	1.3	39	0.41	11	89.6	1130	-	-	-	-
Transect 6	**T6-T-OB**	**76-86**	536	623	16.2	7.5	3.92	7.8	58	14.6	169	9.32	65.2	27.1	361	<0.2	<6	0.77	16	47.1	436	-	-	-	-
Transect 6	**T6-T-OB**	**86-96**	386	479	24.1	7.5	7.69	12.6	87	23.4	406	29.7	312	64.9	1300	1.6	55	0.37	12	116	1620	-	-	-	-
Transect 6	**T6-T-OB**	**96-116**	878	1090	24.1	7.6	8.68	14.8	90	23	416	32.8	359	78.2	1630	1.8	65	0.38	12	133	1930	Silty Clay	15	40	45
Transect 7	**T7-P2**	**0-7**	203	298	46.8	5.2	1.18	1	98	8.13	159	3.8	44.9	2.36	53	0.47	18	0.96	33	10.3	160	-	-	-	-
Transect 7	**T7-P2**	**7-27**	725	860	18.6	7	2.47	0.7	56	29.5	333	7.73	52.8	2.9	38	<0.2	<6	0.53	11	36.6	331	-	-	-	-
Transect 7	**T7-P2**	**27-47**	635	737	16.1	7.3	2.56	1.1	53	31.2	329	9.66	61.6	4.98	60	<0.2	<5	0.29	5	41.4	349	-	-	-	-
Transect 7	**T7-P2**	**47-67**	1030	1180	14.6	7.2	2.76	1.7	58	30.2	350	10.4	73	7.51	100	<0.2	<6	0.26	5	43	398	-	-	-	-

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
																						Texture	Sand	Silt	Clay
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S		50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 7	T7-P2	67-87	961	1100	14.5	7.2	3.03	2.3	58	28.4	333	13.8	98	10.8	145	<0.2	<6	0.44	9	48.2	452	-	-	-	-
Transect 7	T7-P2	87-107	884	1020	15.4	7.2	3.16	2.9	64	26.5	338	13.5	104	12.8	189	<0.2	<6	0.62	14	47.1	482	Clay	28.6	21.4	50
Transect 7	T7-P2	107-117	87.4	109	24.7	6.9	3.85	5.2	130	26.3	682	13.2	206	23	684	0.29	15	0.99	46	53.4	1110	-	-	-	-
Transect 7	T7-P2	117-127	459	524	14.2	7.3	5.03	7.4	57	24.4	278	13.7	94.4	32.3	424	<0.2	<6	0.98	20	64.9	593	-	-	-	-
Transect 7	T7-P2-OB	127-137	704	832	18.2	7.4	7	10.9	79	23.3	369	25.3	243	53.9	984	1.3	41	0.69	19	98.1	1240	-	-	-	-
Transect 7	T7-P2-OB	137-147	517	614	18.8	7.4	7.91	12.9	81	22.6	366	27.4	268	64.6	1200	1.6	52	0.83	24	112	1450	-	-	-	-
Transect 7	T7-P2-OB	147-167	1060	1280	20.8	7.3	8.94	16	82	23	378	27.8	276	80.9	1530	1.8	57	0.96	28	131	1720	Clay	25	32.6	42.4
Transect 7	T7-P1	0-13	127	205	61.4	4.7	1.5	1	145	9.42	274	5.69	100	2.8	94	0.36	20	1.11	57	14.9	348	-	-	-	-
Transect 7	T7-P1	13-33	337	453	34.4	4.8	1.56	1.3	100	10.7	214	5.64	68.4	3.68	85	0.17	7	1.25	44	16.9	272	-	-	-	-
Transect 7	T7-P1	33-53	479	568	18.6	7.2	1.45	1.4	54	10.7	116	4.07	26.5	3.92	48	0.13	3	0.78	15	14	121	-	-	-	-
Transect 7	T7-P1	53-73	682	802	17.6	7.4	1.79	2.7	48	10.2	97.6	4.98	28.8	7.46	82	0.08	2	1.62	27	18.4	141	-	-	-	-
Transect 7	T7-P1	73-93	779	940	20.7	7.4	2.75	4.3	61	16	194	8.5	62.6	15.2	212	<0.2	<6	2.74	59	32.6	318	-	-	-	-
Transect 7	T7-P1	93-113	807	980	21.4	7.5	3.38	6.9	62	16.8	207	8.16	60.9	24.3	345	<0.2	<6	3.91	85	41.8	412	Clay Loam	39	24	37
Transect 7	T7-P1	113-123	473	588	24.3	7.4	5.52	9.3	62	24.8	307	12.8	95.8	40.4	576	<0.2	<6	4.68	103	68.5	679	-	-	-	-
Transect 7	T7-P1	123-133	310	390	25.8	7.5	5.75	9.7	57	24.5	278	12.8	88	42.1	549	0.26	6	4.34	87	70.9	644	-	-	-	-
Transect 7	T7-P1-OB	133-143	859	1030	19.9	7.4	7.3	11.1	62	24	299	28.8	218	57	818	1.3	31	4.35	96	101	1010	-	-	-	-
Transect 7	T7-P1-OB	143-153	709	810	14.2	7.5	8.51	13.9	55	21.2	234	30.4	202	70.5	893	1.4	29	4.08	80	120	1060	-	-	-	-
Transect 7	T7-P1-OB	153-173	1240	1420	14.5	7.7	9.73	22.4	60	18.5	221	17.4	126	94.8	1300	2.2	50	5.41	115	131	1250	Sandy Clay Loam	52	24	24
Transect 7	T7-C	0-10	82.7	130	57.2	6.4	1.76	2.2	146	8.9	260	5.36	94.7	5.9	198	0.74	42	0.72	37	17.4	407	-	-	-	-
Transect 7	T7-C	10-30	438	599	36.8	6.7	1.36	1	82	9.81	162	4.29	42.8	2.79	53	0.2	6	0.48	14	8.87	117	-	-	-	-
Transect 7	T7-C	30-50	666	789	18.5	7.2	2.52	0.9	53	29	307	10.1	64.8	4.1	50	<0.2	<5	0.77	14	38.9	330	-	-	-	-
Transect 7	T7-C	50-70	736	864	17.4	7.3	2.87	1.7	55	27.5	305	12.6	85	7.8	100	<0.2	<6	0.41	8	44	391	-	-	-	-
Transect 7	T7-C	70-90	778	890	14.4	7.4	3.46	3.3	53	27.9	296	12.8	82.5	14.9	182	<0.2	<5	0.78	15	51	433	Sandy Clay Loam	55	22	23
Transect 7	T7-C	90-100	491	543	10.6	7.6	2.42	6.4	50	9.06	89.9	4.4	26.4	16.6	189	0.18	3	1.03	18	25.3	201	-	-	-	-
Transect 7	T7-C	100-110	558	647	15.9	7.5	5.01	10.1	60	18.6	222	10.5	76.2	38.6	531	0.31	7	1.72	36	60	574	-	-	-	-
Transect 7	T7-C-OB	110-120	361	427	18.3	7.4	6.84	11.5	74	23.2	342	21.9	196	54.8	932	1.3	36	1.16	30	94.7	1120	-	-	-	-
Transect 7	T7-C-OB	120-130	494	598	21.1	7.4	8.46	14.2	77	23.3	359	29.9	279	73.3	1300	1.7	52	1.36	37	122	1500	-	-	-	-
Transect 7	T7-C-OB	130-150	736	886	20.4	7.5	9.5	15.5	81	22.6	367	37.4	366	84.8	1580	1.9	59	1.3	37	138	1800	Clay	19	37	44
Transect 7	T7-M	0-15	564	695	23.2	7.6	1.38	0.8	65	9.98	130	4.12	32.4	2.24	33	0.36	9	0.78	18	10.7	111	-	-	-	-
Transect 7	T7-M	15-35	687	818	19.1	7.4	2.54	0.7	56	29.2	324	11.5	77.6	3.4	43	<0.2	<6	0.31	6	39.6	352	-	-	-	-
Transect 7	T7-M	35-55	763	876	14.8	7.5	2.77	1.4	50	28.2	282	13.4	81.3	6.47	74	<0.2	<5	0.2	4	45.5	365	-	-	-	-
Transect 7	T7-M	55-75	1330	1540	15.8	7.7	1.8	2.6	54	9.99	108	6.6	43.2	7.53	94	0.1	2	0.16	3	21	182	-	-	-	-
Transect 7	T7-M	75-95	880	1010	14.8	7.8	1.88	3.3	54	9	97.7	6.33	41.6	9.09	114	0.17	4	0.17	3	21.7	188	Clay Loam	42	27.6	30.4
Transect 7	T7-M	95-105	500	586	17.2	7.7	2.12	4.3	52	8.8	92.1	6.46	40.9	11.9	144	0.14	3	0.22	4	24.1	202	-	-	-	-
Transect 7	T7-M	105-115	434	504	16.1	7.7	2.41	5.3	58	9.02	106	7.24	51.2	15.1	203	<0.2	<6	0.18	4	28	262	-	-	-	-
Transect 7	T7-M-OB	115-125	382	451	18.1	7.2	4.73	5.4	76	24.6	375	19.8	183	25.6	449	1	31	0.24	6	67	818	-	-	-	-
Transect 7	T7-M-OB	125-135	580	702	21.0	7.2	5.95	7.8	88	23.6	414	26.6	282	39.3	791	1.5	51	0.17	5	85.5	1200	-	-	-	-
Transect 7	T7-M-OB	135-155	834	1040	24.7	7.3	7.89	12.8	96	22.8	440	33.9	395	68.2	1510	1.8	68	0.23	8	112	1730	Clay	16.8	31.6	51.6
Transect 7	T7-T	0-15	123	220	78.9	6.9	1.26	1	140	8.01	224	2.7	45.5	2.41	77	0.96	52	1.11	55	6.07	135	-	-	-	-
Transect 7	T7-T	15-35	334	564	68.9	5.5	2.51	0.6	128	29.8	764	13.1	203	2.8	83	0.35	18	0.84	38	39.5	811	-	-	-	-
Transect 7	T7-T	35-55	287	409	42.5	5.3	2.98	2	124	28.4	705	16.6	250	9.27	265	<0.2	<10	0.58	25	46.6	928	-	-	-	-
Transect 7	T7-T	55-75	1040	1230	18.3	6.7	3.66	4.6	69	27.8	385	14.9	125	21.1	336	<0.2	<7	1.02	25	54	599	-	-	-	-
Transect 7	T7-T	75-95	684	791	15.6	7.2	3.51	7.7	64	15	192	9.63	74.6	27.1	400	<0.2	<6	1.06	24	44.5	456	Clay	30.4	28	41.6
Transect 7	T7-T	95-105	648	759	17.1	7.1	3.63	10.3	77	10.4	161	8.54	79.6	31.8	563	<0.2	<8	0.98	27	45.3	558	-	-	-	-
Transect 7	T7-T	105-110	135	163	20.7	7.4	6.19	10.2	80	23.2	372	21.2	206	48	884	0.45	14	1.28	36	85.4	1090	-	-	-	-
Transect 7	T7-T-OB	110-120	454	564	24.2	7.3	7.45	11.9	83	23.7	395	27.3	275	59.9	1150	1.1	36	1.47	43	107	1430	-	-	-	-
Transect 7	T7-T-OB	120-130	348	435	25.0	7.4	9.07	15	91	24	440	35.4	391	81.7	1720	1.7	61	1.94	63	128	1880	-	-	-	-
Transect 7	T7-T-OB	130-150	732	920	25.7	7.4	10.5	18.7	93	22.3	413	39	438	103	2210	1.9	70	2.4	79	156	2320	Clay	26.8	28.2	45
Transect 8	T8-P1	0-15	219	354	61.6	5.6	2.19	1.3	120	18.6	447	7.25	105	4.83	133	0.36	17	0.89	38	26.2	503	-	-	-	-
Transect 8	T8-P1	15-35	818	980	19.8	7.1	2.63	0.9	60	31.4	376	11.5	83.5	4.2	58	<0.2	<6	0.42	9	44.6	428	-	-	-	-
Transect 8	T8-P1	35-55	783	926	18.3	7.3	2.78	1.5	55	29.2	322	13	86.7	6.82	87	<0.2	<6	0.49	10	47.2	417	-	-	-	-
Transect 8	T8-P1	55-75	993	1160	16.8	7.3	3.1	2.9	51	27.4	278	13.4	82.3	13.2	154	<0.2	<5	0.8	14	49	399	-	-	-	-
Transect 8	T8-P1	75-95	748	871	16.4	7.1	3.66	5.3	65	24.6	319	14.1	111	23.4	349	<0.2	<6	1.12	26	57.5	597	Clay	32.4	21.2	46.4

			Moisture Content			Detailed Salinity (Saturated Paste)																	Particle Size Analysis		
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S	Texture	Sand	Silt	Clay
																							50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	Position	Detection Limit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 8	**T8-P1**	**95-105**	561	648	15.5	7.3	4.1	6.8	59	24.8	292	13.6	97.1	29.9	404	<0.2	<6	1.14	24	64.1	604	-	-	-	-
Transect 8	**T8-P1**	**105-115**	487	559	14.8	7.4	3.94	8.8	55	15.1	167	11.3	75.7	32	408	<0.2	<6	0.8	16	54.5	482	-	-	-	-
Transect 8	**T8-P1-OB**	**115-125**	562	692	23.1	7	7.12	9.8	78	23.7	372	34.7	330	52.8	954	1.3	39	0.79	22	108	1350	-	-	-	-
Transect 8	**T8-P1-OB**	**125-135**	466	572	22.7	7.1	7.56	10.9	85	22.1	375	34.6	354	57.9	1130	1.5	49	0.6	18	113	1530	-	-	-	-
Transect 8	**T8-P1-OB**	**135-155**	1020	1250	22.5	7.4	8.64	13.2	77	22.7	348	40.6	377	74.6	1320	1.9	58	0.58	16	136	1670	Clay	37.4	22.6	40
Transect 8	**T8-P2**	**0-12**	226	299	32.3	7.5	1.22	0.8	66	8.61	114	2.62	21	1.83	28	0.5	13	0.6	14	7.88	83.4	-	-	-	-
Transect 8	**T8-P2**	**12-32**	727	871	19.8	7.4	2.39	0.8	56	25.2	281	6.73	45.4	3.11	40	0.37	8	0.57	11	31.6	282	-	-	-	-
Transect 8	**T8-P2**	**32-52**	826	968	17.2	7.4	2.7	1.6	49	28.6	279	8.98	53	6.98	78	0.37	7	0.58	10	41.7	326	-	-	-	-
Transect 8	**T8-P2**	**52-72**	877	1070	22.0	7.5	3.14	3.4	54	28.1	305	9.55	62.6	14.9	185	0.29	6	0.9	17	49.1	425	-	-	-	-
Transect 8	**T8-P2**	**72-92**	912	1090	19.5	7.5	3.75	5.6	49	26.9	262	10.5	61.9	24.1	270	<0.2	<5	1.05	18	58.1	453	Loam	30.4	43.6	26
Transect 8	**T8-P2**	**92-102**	506	593	17.2	7.7	5.01	8.8	39	21.7	169	11.2	53	35.7	320	<0.2	<4	1.2	17	64.5	403	-	-	-	-
Transect 8	**T8-P2**	**102-112**	-	-	-	7.7	5.08	8.6	40	22.2	179	11.3	55.4	35.1	326	<0.2	<4	1.18	17	66.2	428	-	-	-	-
Transect 8	**T8-P2-OB**	**112-122**	-	-	-	7.4	6.86	11	63	24.4	307	23.9	182	54.1	783	1.2	29	1.08	24	101	1020	-	-	-	-
Transect 8	**T8-P2-OB**	**122-132**	388	470	21.1	7.1	7.45	11.7	68	24.4	329	31.4	257	62	963	1.5	40	0.99	24	113	1220	-	-	-	-
Transect 8	**T8-P2-OB**	**132-152**	652	798	22.4	7.2	7.42	13.4	77	22.7	351	20.3	189	62.3	1110	1.6	50	0.85	23	105	1300	Clay Loam	23.4	40.6	36
Transect 8	**T8-C**	**0-2**	474	600	26.6	7.4	0.96	0.4	69	6.74	93.2	1.84	15.4	0.88	14	0.69	19	0.54	13	4.16	46	-	-	-	-
Transect 8	**T8-C**	**2-22**	741	916	23.6	7.2	2.34	0.3	68	27	369	8.08	66.9	1.29	20	0.32	8	0.41	10	32.6	357	-	-	-	-
Transect 8	**T8-C**	**22-42**	710	831	17.0	6.5	2.36	0.7	59	21.7	257	12.5	89.4	2.76	38	0.05	1	0.5	10	34.7	329	-	-	-	-
Transect 8	**T8-C**	**42-62**	780	902	15.6	7.2	2.97	2.1	55	27.3	303	13.8	92.3	9.7	124	<0.2	<6	1.32	26	46.8	415	-	-	-	-
Transect 8	**T8-C**	**62-82**	784	914	16.6	7.4	3.8	6.5	56	21.3	241	11.3	77.1	26.3	342	<0.2	<6	1.77	35	55.6	502	Clay Loam	40.8	22.8	36.4
Transect 8	**T8-C**	**82-92**	544	634	16.5	7.4	5.77	9.9	53	23.3	246	15.4	98.1	43.5	528	0.27	6	2.18	41	77.1	651	-	-	-	-
Transect 8	**T8-C-OB**	**92-102**	709	869	22.6	7.5	9.44	14.5	70	23.7	334	35.2	301	78.9	1280	1.4	39	2.78	69	135	1530	-	-	-	-
Transect 8	**T8-C-OB**	**102-112**	512	631	23.2	7.6	10.5	16.8	85	22.8	387	44.4	456	97.7	1910	1.9	64	2.58	78	161	2190	-	-	-	-
Transect 8	**T8-C-OB**	**112-132**	971	1160	19.5	7.6	11.7	18.4	75	23	343	52.3	472	113	1940	2.2	64	3.11	82	182	2170	Clay	31.4	27.6	41
Transect 8	**T8-M**	**0-20**	186	323	73.7	7	0.99	0.4	140	6.42	180	2.48	42	0.89	29	0.8	44	0.82	41	2.6	58.2	-	-	-	-
Transect 8	**T8-M**	**20-40**	456	584	28.1	7.3	1.36	1	70	10.8	150	3.38	28.5	2.55	41	0.14	4	0.74	18	11.8	131	Clay Loam	35.4	26.2	38.4
Transect 8	**T8-M**	**40-52**	413	506	22.5	7.5	1.34	1.8	67	7.92	106	3.67	29.6	4.37	67	0.19	5	0.55	13	12	128	-	-	-	-
Transect 8	**T8-M-OB**	**52-62**	528	616	16.7	7.2	2.94	2.2	51	28	288	17.2	107	10.6	125	0.8	16	0.48	9	52.5	432	-	-	-	-
Transect 8	**T8-M-OB**	**62-72**	574	653	13.8	7.5	4.89	5.5	50	23.4	234	24.6	149	27.2	313	1	20	0.48	8	73.1	585	-	-	-	-
Transect 8	**T8-M-OB**	**72-92**	1150	1340	16.5	7.4	6.4	7.7	62	22.6	282	38.4	289	42.7	612	1.6	40	0.6	13	100	999	Sandy Clay Loam	54	25	21
Transect 8	**T8-T**	**0-17**	271	357	31.7	7.5	0.87	0.8	80	4.41	70.9	1.95	19	1.39	26	1.04	32	0.7	20	3.47	44.7	-	-	-	-
Transect 8	**T8-T**	**17-37**	545	726	33.2	6.8	2.74	2.8	87	24.1	419	9.33	98.2	11.4	229	<0.2	<9	2.96	91	37.6	524	-	-	-	-
Transect 8	**T8-T**	**37-57**	980	1140	16.3	7.3	3.65	5.2	58	26.9	311	11.2	78	22.6	301	<0.2	<6	2.09	43	55.5	513	Clay Loam	37	28.6	34.4
Transect 8	**T8-T**	**57-67**	448	523	16.7	7.4	4.76	7.3	60	23.2	280	14	102	31.4	436	<0.2	<6	1.98	42	64.1	617	-	-	-	-
Transect 8	**T8-T**	**67-77**	266	310	16.5	7.7	3.53	10.6	64	8.69	112	7.97	62	30.6	453	<0.2	<6	1.58	36	43	442	-	-	-	-
Transect 8	**T8-T-OB**	**77-87**	652	776	19.0	7.4	7.08	9.7	79	23.4	369	34.6	330	52.3	949	1.5	47	1.2	34	110	1380	-	-	-	-
Transect 8	**T8-T-OB**	**87-97**	513	612	19.3	7.4	7.98	10.8	76	23.3	357	45.2	418	63.1	1110	1.9	56	1.1	30	130	1590	-	-	-	-
Transect 8	**T8-T-OB**	**97-117**	987	1200	21.6	7.4	9.68	13.2	85	22.5	383	57.4	592	83.4	1640	2.2	74	1.02	31	160	2190	Clay	19	35	46
Transect 9	**T9-C**	**0-20**	232	330	42.2	6.1	1.47	0.7	169	11.8	399	4.18	85.6	1.95	76	0.4	26	0.88	52	11.4	309	-	-	-	-
Transect 9	**T9-C**	**20-40**	783	901	15.1	7.2	1.37	1.4	61	9.48	116	3.46	25.7	3.53	50	0.11	3	0.63	14	12.3	121	-	-	-	-
Transect 9	**T9-C**	**40-60**	1170	1300	11.1	7.2	2.23	3.2	50	13.8	139	5.95	36.3	10.1	117	0.16	3	0.5	9	26.4	213	-	-	-	-
Transect 9	**T9-C**	**60-80**	1230	1350	9.8	7.6	2.47	7.4	46	8.7	80.4	4.13	23.1	18.8	200	<0.2	<5	0.51	8	28.8	213	Sandy Clay Loam	51	26.6	22.4
Transect 9	**T9-C**	**80-90**	528	580	9.8	7.5	3.41	8.4	48	14.8	141	7.15	41.2	28	306	<0.2	<5	0.68	11	46.6	355	-	-	-	-
Transect 9	**T9-C**	**90-100**	578	642	11.1	7.6	3.51	11.2	45	10.4	93.2	5.91	32	32.1	330	<0.2	<4	0.96	15	43.3	310	-	-	-	-
Transect 9	**T9-C-OB**	**100-110**	566	654	15.5	7.4	6.42	11.2	62	23.3	289	19.3	145	51.8	738	0.93	22	1	22	90.6	898	-	-	-	-
Transect 9	**T9-C-OB**	**110-120**	518	601	16.0	7.3	7.35	12	69	23.4	322	26.9	224	60	950	1.4	38	0.98	24	106	1160	-	-	-	-
Transect 9	**T9-C-OB**	**120-140**	1210	1420	17.4	7.5	9.07	15.6	71	22.3	316	32.7	280	81.8	1330	1.8	50	1.1	28	136	1540	Clay Loam	38.6	28.4	33
Transect 9	**T9-U**	**0-8**	321	386	20.2	7.3	1.08	0.7	68	8.37	113	2.75	22.6	1.7	26	0.17	4	0.36	9	8.52	92.3	-	-	-	-
Transect 9	**T9-U**	**8-28**	638	767	20.2	7.4	2.27	0.6	59	28	331	7.15	51.1	2.53	34	0.23	5	0.3	6	36.8	348	-	-	-	-
Transect 9	**T9-U**	**28-48**	768	912	18.8	7.4	2.43	0.8	59	28	331	8.91	63.8	3.49	47	0.24	6	0.25	5	39	369	-	-	-	-
Transect 9	**T9-U**	**48-68**	875	1020	16.6	7.4	2.32	1.7	57	20.5	235	8.59	59.5	6.6	87	0.16	4	0.32	6	32.3	296	Clay Loam	37	27	36
Transect 9	**T9-U**	**68-78**	603	695	15.3	7.5	2.53	3.7	56	18.8	212	9.75	66.3	14	181	<0.2	<6	0.39	8	38.1	342	-	-	-	-
Transect 9	**T9-U**	**78-88**	491	574	16.9	7.6	2.99	6.4	61	13.2	162	9.44	70	21.6	305	<0.2	<6	0.46	10	41.6	408	-	-	-	-

			Moisture Content			Detailed Salinity (Saturated Paste)																Particle Size Analysis			
			Dry	Wet	%	pH	EC	SAR	Sat%	Calcium	Calcium	Magnesium	Magnesium	Sodium	Sodium	Potassium	Potassium	Chloride	Chloride	Sulfate-S	Sulfate-S	Texture	Sand	Silt	Clay
																							50µm - 2mm	2µm - 50µm	<2 µm
			g	g		pH	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg		% weight	% weight	% weight
Transect	**Position**	**Detection Limit**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.01	n/a	0.02	n/a	0.04	n/a	0.03	n/a	0.06	n/a	0.06	n/a	n/a	n/a	n/a	n/a
		Depth (cm)																							
Transect 9	**T9-U-OB**	**88-98**	368	432	17.4	7.4	5.35	6.8	72	24.8	356	25.7	224	34.1	565	1.2	34	0.41	10	82.6	951	-	-	-	-
Transect 9	**T9-U-OB**	**98-108**	487	577	18.5	7.4	6.08	7.9	80	24.4	391	35.8	346	43.3	797	1.7	52	0.43	12	98.1	1260	-	-	-	-
Transect 9	**T9-U-OB**	**108-128**	964	1110	15.1	7.5	7.36	10	78	22.9	359	42.8	404	57.3	1030	1.8	56	0.5	14	118	1470	Clay Loam	36	30	34
Transect 9	**T9-M**	**0-13**	421	547	29.9	7.1	1.24	1.4	88	7.6	134	3.57	38	3.41	69	0.23	8	0.88	28	6.77	95.4	-	-	-	-
Transect 9	**T9-M**	**13-33**	820	984	20.0	7.5	1.39	2.2	59	8.06	95.4	3.6	25.8	5.41	74	0.11	2	0.45	9	13.2	125	-	-	-	-
Transect 9	**T9-M**	**33-53**	958	1080	12.7	7.7	1.76	2.7	55	11	121	4.74	31.6	7.61	96	0.15	3	0.38	8	20.2	178	-	-	-	-
Transect 9	**T9-M**	**53-73**	1080	1250	15.7	7.5	2.16	4.6	64	10.2	130	5.32	41.4	12.8	190	0.14	3	0.51	12	25.3	260	Clay	33	26	41
Transect 9	**T9-M**	**73-83**	500	581	16.2	7.6	2.67	6.8	64	11.1	141	6.66	51.3	20.2	296	<0.2	<6	0.78	18	33.8	345	-	-	-	-
Transect 9	**T9-M**	**83-93**	598	693	15.9	7.4	3.98	6.4	65	25.9	336	16	126	29.4	437	0.46	12	0.88	20	65.9	683	-	-	-	-
Transect 9	**T9-M-OB**	**93-103**	438	508	16.0	7.4	5.78	8.1	70	24.6	346	25.3	216	40.6	658	1.3	36	0.84	21	86	968	-	-	-	-
Transect 9	**T9-M-OB**	**103-113**	459	542	18.1	7.5	7.13	10.9	66	23.5	310	31.8	254	57.4	871	1.6	41	1.26	30	106	1120	-	-	-	-
Transect 9	**T9-M-OB**	**113-133**	873	1070	22.6	7.5	7.72	13.5	77	23.8	367	30.7	287	70.5	1250	1.8	53	1.28	35	118	1450	Clay Loam	41	23	36
Transect 9	**T9-L**	**0-3**	38	73.8	94.2	5.8	0.99	0.6	355	4	284	2.73	117	1.01	82	1.62	225	1.24	156	3.26	185	-	-	-	-
Transect 9	**T9-L**	**3-23**	336	474	41.1	6	0.76	0.6	151	4.78	144	2.36	43.1	1.24	43	0.27	16	1.06	57	3.18	76.8	-	-	-	-
Transect 9	**T9-L**	**23-43**	791	909	14.9	7.3	1.39	2.4	45	7.99	71.8	3.47	18.9	5.73	59	0.07	1	0.92	15	12.8	92.2	-	-	-	-
Transect 9	**T9-L**	**43-63**	772	897	16.2	7.2	2.93	5.1	58	18.2	211	9.87	69.3	19	254	<0.2	<6	2.91	60	40	372	Clay	33	27	40
Transect 9	**T9-L**	**63-73**	467	556	19.1	7.3	6.23	11.2	68	23.7	321	19.1	156	51.7	806	<0.2	<7	5.83	140	83.4	904	-	-	-	-
Transect 9	**T9-L**	**73-83**	309	385	24.6	7.5	7.72	16.2	78	22.6	355	18.8	179	73.5	1330	0.38	12	7.87	219	102	1280	-	-	-	-
Transect 9	**T9-L-OB**	**83-93**	614	730	18.9	7.4	6.33	13	67	22.6	302	12.9	104	55	843	0.84	22	4.64	110	81.4	868	-	-	-	-
Transect 9	**T9-L-OB**	**93-103**	511	610	19.4	7.3	7.04	15.3	53	23.1	246	12.7	82.4	64.7	795	1	21	4.96	94	91.1	778	-	-	-	-
Transect 9	**T9-L-OB**	**103-123**	790	942	19.2	7.3	7.08	15.2	58	23.3	270	11	77.1	62.7	836	0.94	21	3.61	74	87.5	811	Loam	50	31	19
Transect 9	**T9-T**	**0-8**	194	255	31.4	6.8	1.44	4.6	94	4.49	84	2.41	27.3	8.54	184	0.22	8	2.58	86	8.01	120	-	-	-	-
Transect 9	**T9-T**	**8-28**	694	883	27.2	6.9	4.29	7	80	21.5	344	11	106	28.4	522	<0.2	<8	3.89	110	52.3	670	-	-	-	-
Transect 9	**T9-T**	**28-48**	798	944	18.3	7.5	5.62	8.8	51	26.1	264	14	86.1	39.7	462	0.28	5	10.4	188	66.9	542	-	-	-	-
Transect 9	**T9-T**	**48-68**	1050	1290	22.9	7.5	5.05	10.1	58	17.7	204	10.6	74.2	38	505	<0.2	<6	11.4	234	51.9	479	Sandy Clay Loam	45	21	34
Transect 9	**T9-T**	**68-78**	516	655	26.9	7.5	5.07	10	72	17.8	256	11.1	97.1	38	631	<0.2	<7	10.8	276	52.6	608	-	-	-	-
Transect 9	**T9-T**	**78-88**	194	245	26.3	7.5	4.75	9.9	78	16.1	250	10	94.5	35.7	638	0.34	10	8.94	246	50.2	625	-	-	-	-
Transect 9	**T9-T-OB**	**88-98**	580	745	28.4	7.4	5.81	9	92	24.9	460	17	190	41.2	875	1.1	38	8.13	266	72.6	1070	-	-	-	-
Transect 9	**T9-T-OB**	**98-108**	568	699	23.1	7.4	6.04	10.2	83	24.9	414	16.6	167	46.4	886	1	32	7.29	214	78.1	1040	-	-	-	-
Transect 9	**T9-T-OB**	**108-128**	969	1210	24.9	7.2	7.42	15.1	89	23.6	419	16.2	174	67.6	1380	1	37	5.94	187	97.8	1390	Clay	27	27	46

APPENDIX B

A 10-YEAR ASSESSMENT OF EVAPOTRANSPIRATION AND NET ECOSYSTEM EXCHANGE FROM SOUTH BISON HILL

SYNCRUDE CANADA LTD.

A 10 Year Assessment of Evapotranspiration and Net Ecosystem Exchange from South Bison Hill

Report Prepared For:

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Date: January 31, 2013

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1 Introduction

Syncrude Canada Ltd is undertaking an evaluation of the efficacy of prescribed cover thickness for reclamation covers over cretaceous overburden, much of which is saline/sodic shale. In support of this project, this report summarizes evapotranspiration and CO_2 fluxes from a long-term research site on South Bison Hill (SBH). Ten years of water growing season water, energy and CO_2 exchange have been measured atop SBH using the eddy covariance technique. The objectives of this technical report are to:

i. Compile 10 years of growing season evapotranspiration and CO_2 flux data.

ii. Report temporal patterns of these fluxes and associated hydrometric measurements and evaluate the link to the development of vegetation atop SBH.

iii. Compare values reported at SBH with those reported at other disturbed and undisturbed boreal forest aspen and mixed stands.

2 Background and Objectives

In the construction of reclaimed landforms, early successional ecosystems are created that bare little similarity to the undisturbed boreal forest that existed prior to mining. While reclamation sites vary based on parent material and construction strategies, all have a physiography, soil properties and vegetation that have been altered from the pre-mining landscape. Central to the performance of reclaimed soil covers is their water balance. With regards to plant functioning, sufficient moisture must be retained in the soil to support a range of successional species and a mature forest along with supplying water to wetlands and pit lakes. In the oil sands region, the largest loss of water is through evapotranspiration (ET), which is approximately equal to precipitation on an annual basis (Devito et al. 2005) and controls the near-surface movement of salts from oxidized sulphates in the carbonate-rich glacial tills that may result in soil salinization; and also influences the quantity of deep percolation.

Vegetation productivity, carbon, nutrient and water budgets are all influenced by ET. However, during the early stages of reclamation, ecosystems undergo a dramatic shift in species on an inter-annual basis. Unlike mature forests and agricultural crops, little biometeorological information is available for invasive species and juvenile vegetation that thrive on reclamation covers after establishment. In the sub-humid climate of northern Alberta, understanding ET losses of water and how this relates to cover evolution is critical in assessing the sustainability of the reclamation process.

In this report, growing season evapotranspiration and net ecosystem exchange (NEE) are reported from 2003 to 2012 atop SBH. During this period, the landform underwent dramatic shifts in vegetation along with considerable differences in growing season precipitation and temperature. The objective of this report is to summarize these findings and place them in the context of other boreal forest (primarily aspen) stands.

3 Materials and Methods

3.1 Site Description

The study site (57° 39' N, 111° 13' W), is a saline-sodic clay shale overburden landform informally termed South Bison Hill (SBH). The fluxes reported in this report are largely confined to the top flat part of the structure, which was capped with ~20 cm peat mineral mix overlying ~80 cm of till in the winter of 2002 (Figure 1). These areas were fertilized and seeded to agronomic barley in the summer of 2002 and then planted to white spruce (*Picea Glauca*) in the summer/fall of 2004. At the beginning of 2003, the major plant species atop SBH was foxtail barley (*Hordeum jubatum*). Minor species included fireweed (*Epilobium angustifolium*), sow thistle (*Sonchus arvense*), and white and yellow sweet clover (*Melilotus alba*, *Melilotus officinalis*). Beginning in 2006, the site has transitioned gradually to an ecosystem dominated by aspen (*Populus tremuloides* Michx.), which has grown as both planted and volunteer (invasive) and by fall 2012 was on average ~4 m in height (Figure 1; see report by Integral Ecology Group for details of current vegetation status).

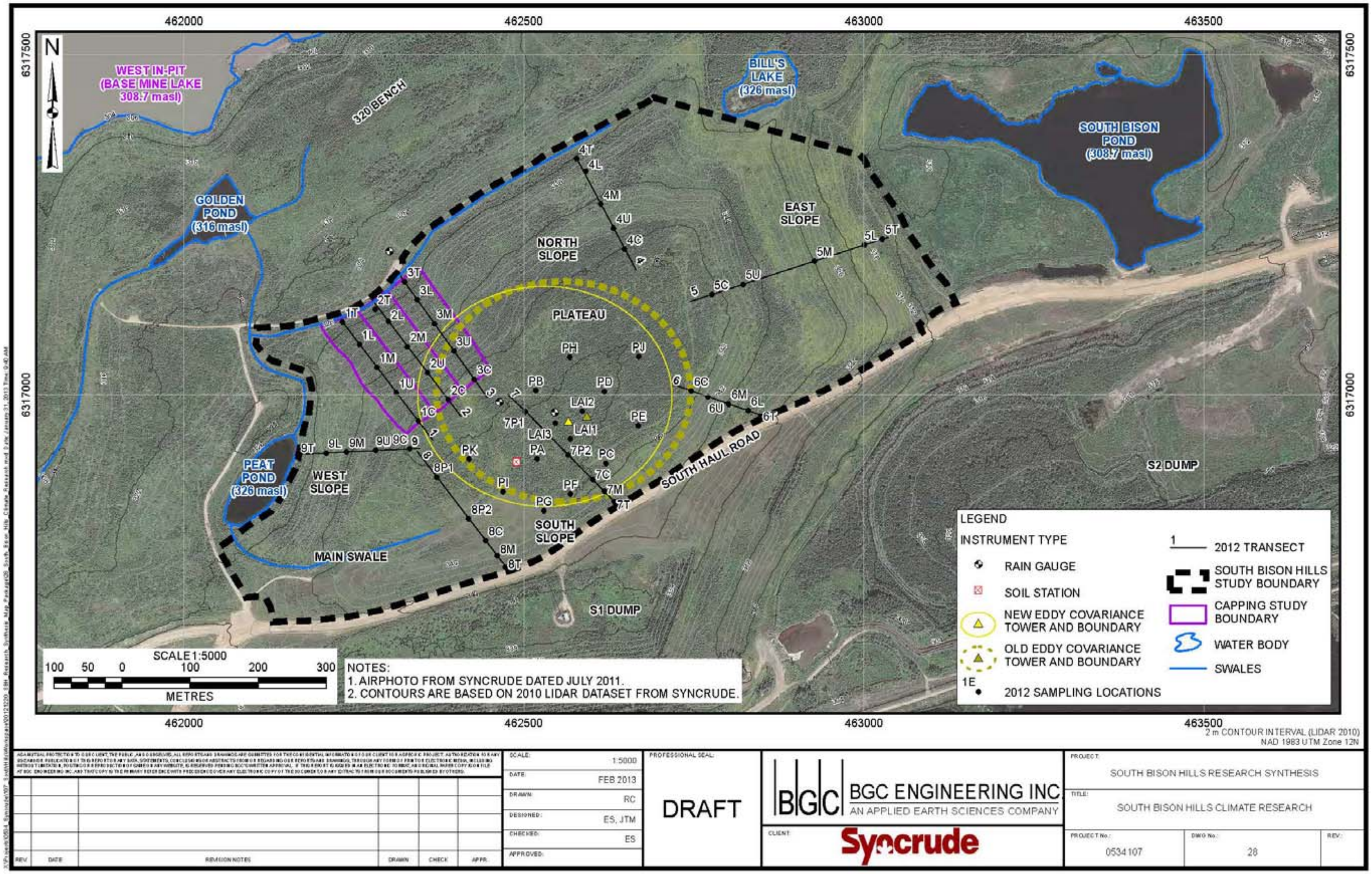

Figure 1. South Bison Hills eddy covariance technique instrument locations with approximate measurement radius.

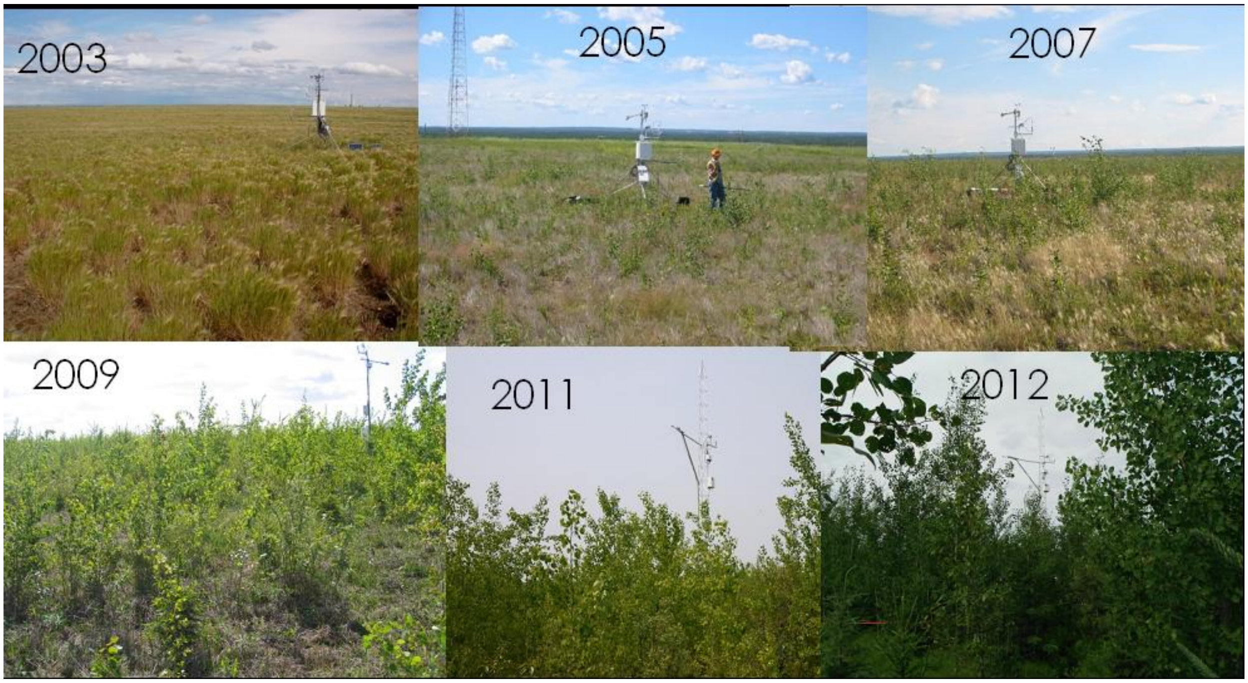

Figure 2. Site photographs for 2003, 2005, 2007, 2009, 2011 and 2012.

The climate is classified as a sub-humid continental, which is characterized by cold winters and warm summers. Thirty-year climate normals (1971 – 2000) for Fort McMurray indicate daily temperatures for January and July are -18.8^{o}C and +16.8^{o}C, respectively. Mean annual precipitation is 456 mm, of which 342 mm occurs as rainfall. The majority of rainfall (67 %) occurs from June to August and is delivered largely as convective storms of high intensity and short duration (Devito et al. 2005).

3.2 Continuous Measurements

The eddy covariance technique was used to measure fluxes of momentum, CO_2, sensible heat and latent heat on a continuous basis. A meteorological tower was placed in the approximate centre of SBH in 2003 with several hundred metres of fetch in each direction. The measurement system consisted of a three-dimensional sonic anemometer (CSAT3; Campbell Scientific), an open-path infrared gas analyser (LI-7500; Li-Cor), and a fine-wire thermocouple located in the approximate centre of the sonic head, which was located 2.9 m above the ground from 2003-2008, was raised to 5.1 m in 2009 and raised to 8.7 m in 2011. Both wind speed and gas concentration measurements and their fluctuations were obtained at a frequency of 20 Hz. Fluxes were calculated as the product of the mean covariance of the vertical wind speed fluctuations (w') and the scalar fluctuations in water vapour density (ρ_v'), temperature (T') and carbon dioxide (CO_2') as described by Webb et al. (1980). The CO_2 flux is a direct measurement of net ecosystem productivity (NEP), which in turn is the difference between gross ecosystem photosynthesis (GEP) and ecosystem respiration (ER). Positive NEP (upward CO_2 flux) indicates that the ecosystem is a CO_2 source, whereas negative indicates uptake.

At the tower with the eddy covariance instrumentation, down and up-welling long and short-wave radiation were measured using a CNR1 net radiometer (Kipp and Zonen). Air temperature and relative humidity were measured at 3 m. Soil heat flux, *G*, was measured using two heat flux plates, buried 0.5 m below the surface. Data was recorded at 1-minute intervals and recorded every 30 minutes on the CR23X datalogger until 2008 and then a CR3000 from 2009-2012. Supplemental data was collected at a second tower approximately 100 m from the eddy covariance tower, with an event-recording tipping rainfall gauge (TE-525, Texas Instruments). At depths of 0.05, 0.15, 0.25, 0.4, 0.95, 1.15, 1.25 and 1.80 m, soil moisture (CS615, Campbell Scientific), soil suction (229L, Campbell Scientific) and soil temperature were measured every four hours and recorded on a CR10X data-logger (Campbell Scientific).

3.3 Data corrections, gap filling and energy balance closure

Energy and CO_2 fluxes were corrected for energy balance closure and rejected during low wind speeds at night (Twine et al. 2000). Missing values were gap-filled using Fluxnet Canada protocols (Morgenstern et al. 2004; Humphreys et al. 2006) and the mean diurnal variation method (e.g. Falge et al. 2001; Moffat et al. 2007) with a 10-day moving window.

3.4 Periodic Measurements

To assess the growth of vegetation within and among growing season, leaf area index (LAI) was measured at approximately two-week intervals with an LAI-2000 (Li-Cor) plant canopy analyser at three permanent plots. Referenced site-photographs were also made at this time.

4 Results

Data is reported from 2003 to 2012. For the first three years of study, measurements were made May to August inclusive, and beginning 2006 were extended to the end of September and in 2010 into October.

4.1 Climate

Variation in climate for the 2003-2012 growing season (May – September) is summarized in Figure 2. There is considerable difference in the growing season rainfall among years, with 2012 having the greatest rainfall at 321 mm, whereas 2011 and 2007 were notably dry at 180 and 178 mm, respectively (Figure 2a). The climate normal (1971-2000) for Fort McMurray is 312 mm from May to September, and only 2012 had greater than normal rainfall. It is important to note that considerable intra-annual variability in rainfall occurs, and that wet years are not uniformly wet throughout. For example, 2012 had two extremely wet months (July and September) and a very dry August. There was some difference in growing season air temperature among the years (Figure 2b). 2004 was the coolest May - September (12.7°C) whereas 2011 was the warmest (15.7°C). There was no relationship between precipitation and temperature on a seasonal basis. With the exception of 2004 and 2005, most growing season months had temperature slightly greater than the 30-year climate normal.

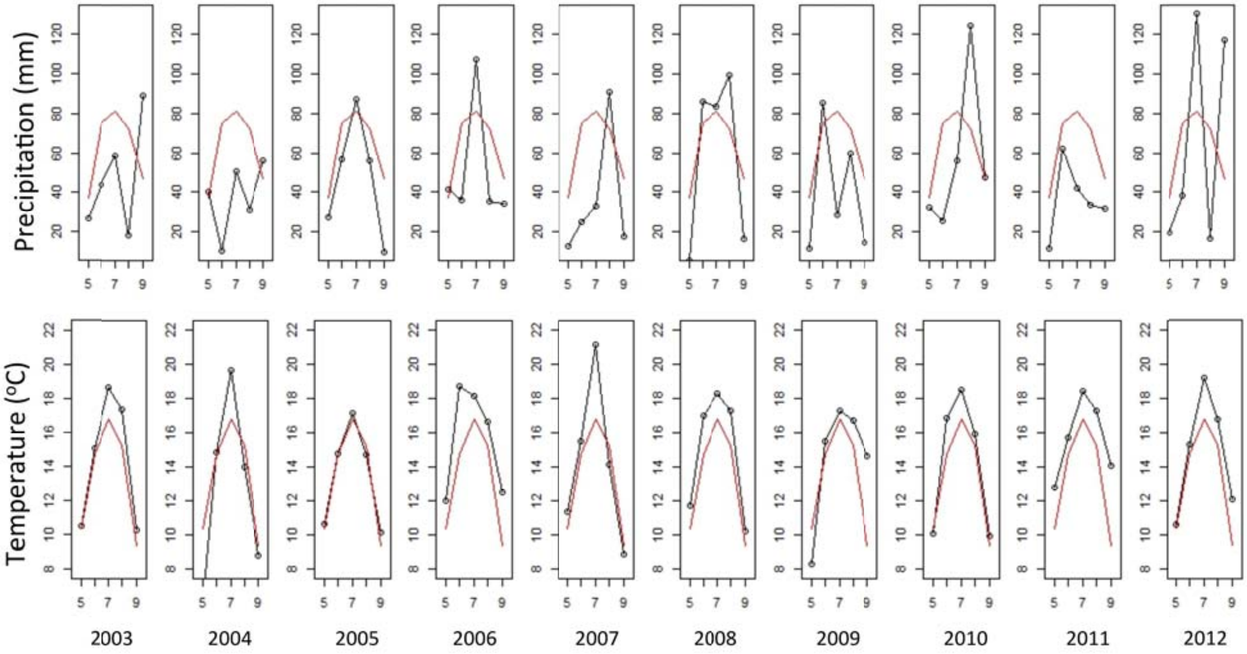

Figure 3. Mean monthly precipitation (a) and air temperature (b) for the 2003-2012 study period. Measured values are in black with circles, red line is the climate normal (1971-2000) for Fort McMurray. Month of year is on x-axis.

4.2 Soil Moisture and Suction

Near surface soil moisture exhibited little variability below 40 cm (data not shown), yet in the upper profile, water content varied both within and among years (Figure 3). Soil moisture was generally greatest at the beginning of May due to snowmelt recharge and declined thereafter due to evaporation with rainfall acting to recharge the soils. There are several trends that can be observed in the soil moisture data before and after 2006, the year aspen began to emerge on the plateau of SBH. 2004 was a notably dry year and a long period of summer soil moisture recession in the near-surface zone. However, soil moisture at 25 cm did not show a large decline. In contrast, beginning 2007 and increasing thereafter, soil moisture deficits became much greater at both surface and depth as the growing aspen root mass drew increasing amounts of water from the rooting zone. Soil moisture at 25 cm began declining from near-saturation to ~20% by volume in late summer.

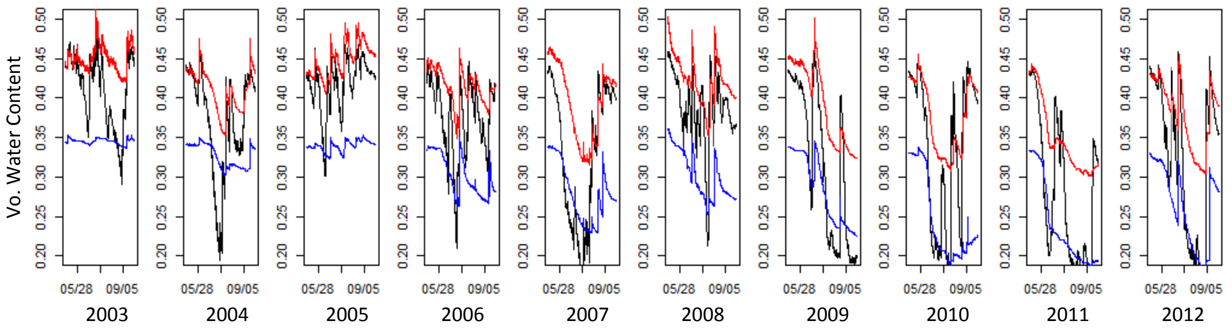

Figure 4. Soil moisture in the upper 25 cm of the profile from 1 May to 30 September for all years. Black line is 5 cm, red line is 15 cm and blue line 25 cm depth.

Much like soil moisture, suction in the top 25 cm showed the variability within and among seasons (Figure 4). During the first three years of the study, soil suctions did not exceed 400 kPa despite a very dry 2004. Beginning 2007, soil suctions became markedly greater, and in all years following (except 2008) exceeded 500 kPa as soil moisture levels dropped below 0.3. Typically, suction increases by the end of August due to a decline in ET and late-season rain. There are two general states of soil suction: those that occurred prior to and after 2007 and the establishment of the aspen vegetation. Post 2007, water use from near-surface soils is much greater to sustain ET and productivity in the aspen stand, whereas prior to this, emergent and perennial vegetation was less effective in utilizing the near-surface water store.

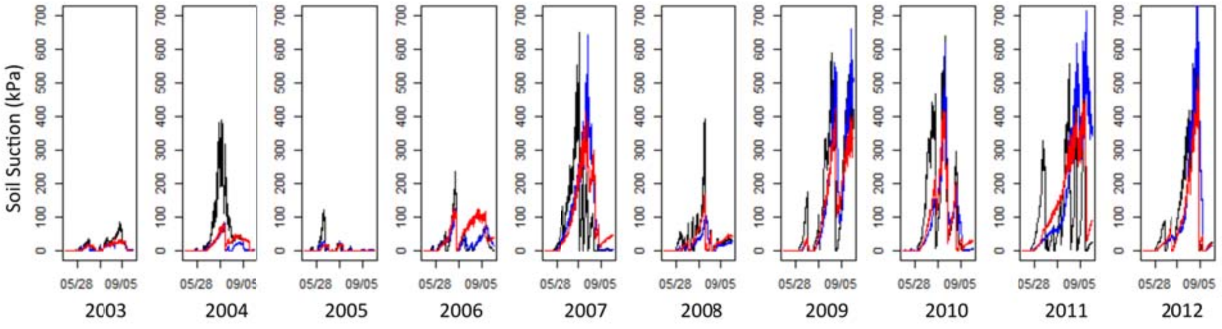

Figure 5. Soil suction in the upper 25 cm of the profile from 1 May – 30 September for all years. Black line is 5 cm, red line is 15 cm and blue line 25 cm depth.

4.3 Leaf Area Index and Vegetation

Leaf area index (LAI) began increasing rapidly in early June in all years, typically peaked in July and declined gradually thereafter depending upon the vegetation type that predominated the site (Figure 5). Note that September LAI values are reported beginning 2006. At the onset of reclamation in 2003, the dominant species throughout the growing season was foxtail barley, which has a very short growing season and accounted for the rapid rise and fall of LAI by early August. In contrast, peak LAI was greater approximately three weeks later in 2004, and values were sustained by a second flowering of sweet clover that was not apparent in 2003. The lowest LAI occurred in 2005, when values increased quickly but slowly declined as no single species was abundant compared with earlier years. Beginning in 2006, there was an increase in plant diversity and aspen. Once established, aspen became the predominant species, increasing in height and in 2008 rapidly increased its foliar area (as expressed by LAI). Beginning in 2008, LAI at SBH was largely controlled by the bud-burst and senescence of an aspen stand in its early stages of establishment, and values were approximately 3 times greater than those observed at the beginning of the study in 2003. Values of LAI appear to have reached a maximum of ~3 to 3.5 during July after 2008, which corresponds to the period of enhanced evapotranspiration (see section 4.4) and increased soil water withdrawal (Figure 4).

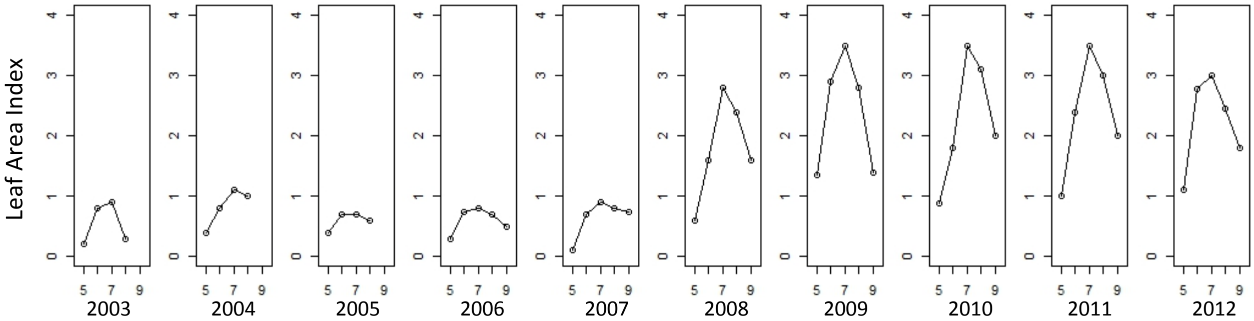

Figure 6. Growing season leaf area index (LAI) for the 2003-2012 study period. Month of year is on x- axis.

4.4 Evapotranspiration

Average monthly evapotranspiration (ET) rates expressed in millimetres per day follow a trend of increasing rates throughout the growing season followed by a steep decline, particularly in September during the years recorded (2006-2012) (Figure 6). May to September values ranged from ~1 to 4 mm per day, with monthly and inter-annual differences due to the variability in available energy and climate, vegetation and soil water availability. Peak growing season ET was smallest in 2004 at 2.3 mm d^{-1} and greatest in 2010 at ~3.9 mm d^{-1}. ET rates showed a marked increase in 2008 corresponding with the increase in LAI attributed to the aspen cover. Since 2008, the pattern and magnitude of ET has been consistent at SBH, with inter-annual variability due largely to differences in climate and moisture availability. In all cases, ET values are greater than seasonal rainfall, relying on soil water recharge during snowmelt to sustain ET and plant growth.

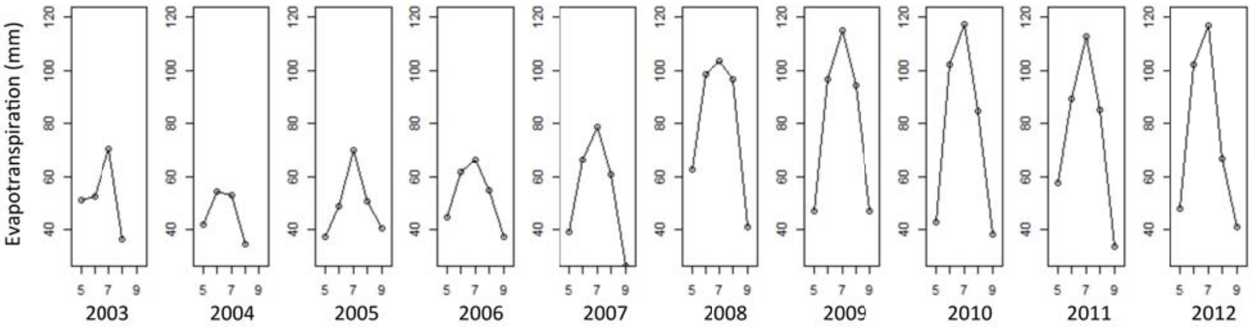

Figure 7. Monthly evapotranspiration (ET) for the 2003-2012 study period. Month of year is on x-axis.

4.5 Net Ecosystem Exchange

Since the establishment of a surface cover and vegetation in 2003, SBH has been a growing season sink for CO_2 (Figure 7). Values of NEE follow similar patterns to those of ET, with values gradually becoming more negative (greater carbon uptake) as the aspen forest establishes. Both the values of uptake and the variability in monthly fluxes increases after the establishment of aspen, mirroring the bud-burst to senescence cycle. Values of growing season NEE from 2003-2012 are similar to those reported for other boreal aspen forests (Barr et al. 2007; Hogg et al. 2008; Brummer et al. 2012)

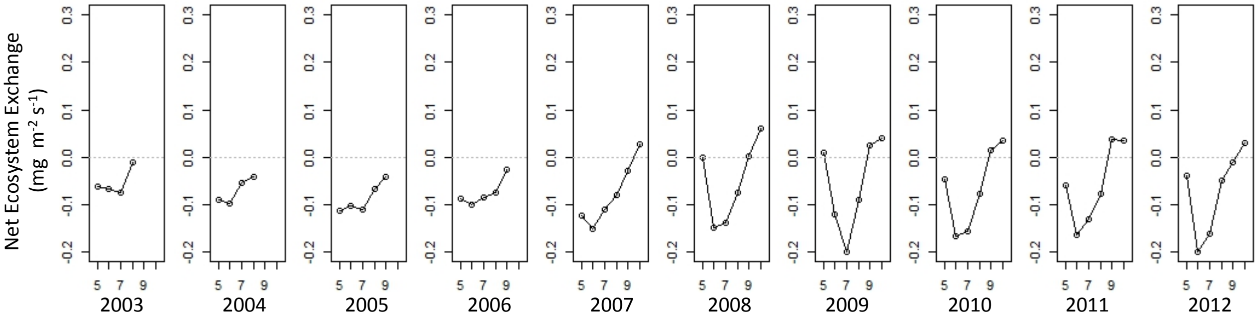

Figure 8. Monthly net ecosystem exchange (NEE) for the 2003-2012 study period. Negative values indicate carbon uptake (sink), positive values indicate carbon loss (source). Month of year is on x-axis.

5 Discussion

Since the onset of a soil and vegetation cover atop SBH, the site has undergone dramatic changes in vegetation properties and water balance fluxes. Evapotranspiration is the greatest loss of water from SBH, as the water budget is largely vertical where inputs in precipitation are returned to the atmosphere, with small amounts of runoff and percolation comparatively.

ET is a complex process, with atmospheric drivers such as net radiation, vapour pressure deficit (dryness of the air), air temperature and wind are all moderated by plant photosynthetic capacity, stomatal regulation, soil moisture and suction. Previous work (Carey 2008; 2011) has summarized controlling factors of water and energy partitioning atop SBH from 2003-2009. This report extends on this work to 2012 and shows that since the establishment of a growing aspen-dominated stand in 2007-2008, growing season ET has reached a new ‘steady state’, despite inherent differences in climate among years. Since 2008, ET rates have plateaued at ~4 mm d^{-1}, which is similar to those reported for mature aspen stands in the boreal forest (Blanken et al., 2001, Brummer et al. 2012). Other metrics of comparison such as NEE and stomatal conductance (data not show) also support the position that the aspen stand atop SBH is, with regards to its growing season water and carbon fluxes, similar to young and mature boreal stands (Barr et al., 2007).

Several factors are likely responsible for the increase in ET following the establishment of the aspen stand. The first is that the increase in LAI and root biomass provides a more effective means of transferring water from the near-surface rooting zone to the atmosphere. The other primary factor to explain the increase in ET is the increase in canopy interception with greater LAI. With increased foliage, more precipitation is intercepted by the canopy and directly evaporated from the vegetation surface. In addition, less water is able to reach the surface as throughfall, and soil moisture declines. The lower soil moisture levels and higher soil suctions post 2008, despite 2008 and 2012 being wet years, are partly attributed to declines in precipitation reaching the soil and increased ET from direct precipitation on the canopy. Carey (2011) after reviewing data up to 2009 postulated that if soil water is lowered sufficiently, soil suctions will become large enough to inhibit ET and photosynthesis causing tree stress. Based on subsequent years of data (2010-2012), it does not appear that aspen atop SBH are exhibiting stress, and that despite large differences in summer precipitation, the trees are able to sufficiently utilize soil moisture reservoirs to promote growth, store carbon and evaporate at levels comparable to undisturbed systems.

6 Conclusion

The plateau of SBH has undergone dramatic vegetation change since 2003 when water and carbon flux measurements began at the site. In the early stages of reclamation, there were large changes in species composition and density as expressed by LAI, and ET and NEE was lower reflecting the lack of mature vegetation on the site. Since 2007, aspen has begun to dominate the overstory vegetation and LAI as a fraction of total vegetation. Since this time, ET and NEE values have increased to sustain vigorous aspen growth. There exists considerable data from mature and recovering boreal stands to suggest that this site appears to have water and carbon fluxes that are now similar to those observed elsewhere. As the water balance of aspen stands is largely controlled by variations in climate and the stand continues to mature, it is important that long-term monitoring of this site be continued as it is the only example of an oil sands reclamation site that has been monitored using the eddy covariance technique for this duration (10 years) since the onset of revegetation.

Acknowledgements

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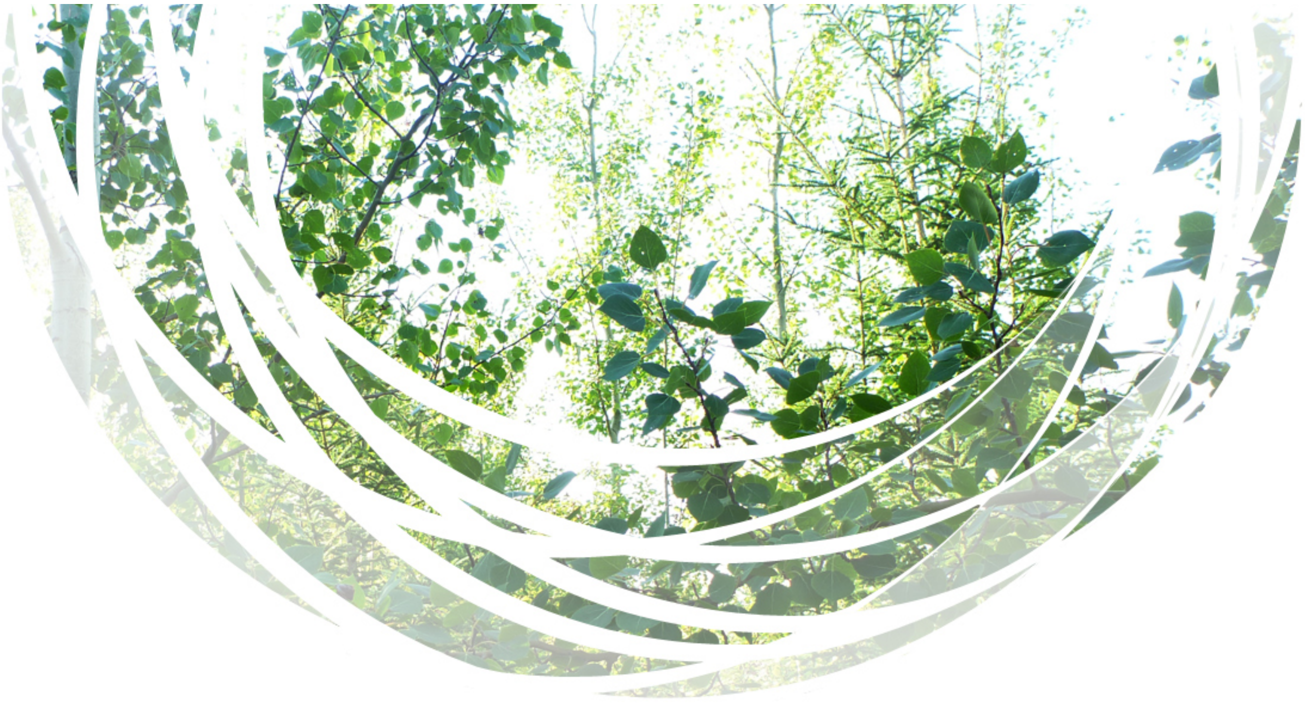
APPENDIX C
SOUTH BISON HILL RESEARCH SYNTHESIS – VEGETATION OVERSTORY RESPONSE TO RECLAMATION COVER DEPTH

SYNCRUDE CANADA LTD.



INTEGRAL ECOLOGY GROUP LTD.

South Bison Hill research synthesis – vegetation overstory response to reclamation cover depth

Prepared for: Syncrude Canada Limited

Prepared by: Katherine Garrah, Gyula Gulyas, Justin Straker,
and Jim Thrower

February 25, 2013
Project No. SCL30D-12

Distribution:
- Syncrude Canada Ltd. – e-copy
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February 25, 2013
File: SCL30D-12

Syncrude Canada Limited

ATTENTION: MARTY YARMUCH

REFERENCE: SOUTH BISON HILL RESEARCH SYNTHESIS – VEGETATION OVERSTORY RESPONSE TO RECLAMATION COVER DEPTH

Dear Marty:

Please find following the Integral Ecology Group's draft report on above-ground vegetation characteristics on the South Bison Hill study area in 2012. This report is meant to contribute to a larger research program, and to the synthesis document being prepared by Syncrude Canada Ltd. and BGC Engineering.

We trust this information meets your requirements at this time, and thank you for the Integral Ecology Group's continuing involvement in Syncrude Canada Ltd.'s reclamation programs.

Yours sincerely,

Justin Straker, M.Sc., P.Ag.
Integral Ecology Group Ltd.
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1% FOR THE PLANET | MEMBER

EXECUTIVE SUMMARY

Syncrude Canada Limited initiated a study to examine the effects of reclamation cover depth on reclamation outcomes on saline-sodic overburden, on the reclaimed South Bison Hill landform. Reclamation treatments on this landform consisted of placing mineral and organic cover materials to a target depth of 1 m. A portion of the landform was devoted to a cover-depth trial, where cover materials were placed at nominal 0.35-, 0.5-, and 1.0-m depths. In 1999, white spruce and aspen trees were planted in the trial area, with the remainder of the landform revegetated from 2002-2004.

The primary objectives of this study were to measure tree growth attributes on the study site and to use resulting data to (i) advance understanding of reclamation performance on covered upland saline-sodic overburden structures; and (ii) identify any effects of reclamation-cover thickness on response variables.

In 2012, trees were measured in 80 systematically located sample plots throughout the approximately 49-ha study site. Measurements included tree height and age to estimate site index, leaf area index, capping depth at each sample point, and laboratory analysis of foliar nutrients.

The results showed good tree growth in all sampled areas. The site index (height of site trees at 50 years breast-height age) of white spruce trees ranged from about 17-25 m with an overall average of 21 m. Aspen site index ranged from about 16-22 m with an overall average of 20 m. Although these estimates from early height growth may over-estimate site index at older ages, they are higher than the means of 17-18 m that are commonly observed for natural stands in the surrounding areas of north-east Alberta (Feng *et al*. 2006, Beckingham and Archibald 1996). The average site indexes for white spruce in this study are also comparable to estimates reported for planted white spruce stands in other similar areas of Alberta that are regenerated after logging using standard forest management practices.

There are some statistical limitations to how the data were collected and analyzed in this study, due to a lack of replication within and outside the study area. However, we do not believe that these factors significantly impact the general trends or results of the study, and expect that similar results would be observed in other reclaimed oil sands areas that are treated similarly.

We believe that the data and interpretations included in this report support the following conclusions:

1. all covers on the SBH study area, regardless of thickness, are supporting above-ground vegetation characteristics that meet or exceed relevant equivalent-capability targets;
2. increases in tree growth performance may be observed with increasing cover thickness, with the rate of increase being greater at thicknesses from 10-50 cm, and lower as thicknesses increase past 50 cm. However, these trends, where they exist, are generally weak, and are based on

measurements conducted on young trees, which emphasizes the importance of continued monitoring as these stands develop. It is important to recognize that the SBH reclamation objective is not to achieve maximum tree growth performance, but to achieve performance consistent with equivalent-capability targets. This study shows that thicker covers are not necessary for this achievement.

3. Evapotranspiration and leaf-area index data collected by McMaster University on the SBH plateau show that evapotranspiration has reached an approximate steady state, and should not be expected to increase in the future beyond inter-annual variation driven by climatic variation. Thus, we believe that the validity of conclusions from this study will be maintained in the future, and will not be substantially affected by maturation of the SBH forest stands. In particular, we do not expect substantial decreases in site index as these stands age. As above, this premise should be tested through future monitoring.
4. Site-index and soil salinity/sodicity values suggest a minimum reclamation-cover depth of 50 cm. Modelling of performance over longer climatic cycles indicates that cover depths of up to 75 cm may be required to meet vegetation water demands over extended drought periods.

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1 INTRODUCTION

In the summer of 2012, Syncrude Canada Limited (SCL) initiated a study to examine the effects of reclamation cover (capping) depth on reclamation outcomes on saline-sodic overburden (SSOB, or Clearwater shale). SCL selected the South Bison Hill (SBH) site for this study because:

1. this location is the site of a controlled cover-depth trial initiated in 1999, making it one of the few sites where the effects of depth of cover placement can be isolated from confounding variables;
2. the SBH landform has hosted intensive reclamation research (using Syncrude's "instrumented watershed" approach) since cover placement, providing a long-standing quantitative record of reclamation development and performance over time; and
3. the majority of reclamation on this site was conducted from 1999-2003, making it some of the oldest reclamation on SSOB on the Mildred Lake mine. This allows examination of longer-term responses to cover depth.

In support of the larger study initiated by SCL, the Integral Ecology Group (Integral Ecology) was requested to conduct a field survey and sampling campaign to examine the relationship between reclamation-cover depth and the growth of trees and other vegetation on the SBH site.

1.1 STUDY OBJECTIVES

The primary objectives of this study were to measure tree growth attributes on the study site and to use resulting data to (i) advance understanding of reclamation performance on covered upland SSOB structures; and (ii) identify any effects of reclamation-cover thickness on response variables. Secondary objectives were to use the information and trends to help address the larger questions of how tree growth on reclaimed sites compares to measures of equivalent capability and if the trends indicated in early stages of stand development might be maintained in the future.

1.2 STUDY TEAM

This project was completed for Marty Yarmuch of Syncrude Canada Ltd. in Edmonton, Alberta. The Integral Ecology Group team included Justin Straker MSc, PAg (project leader), and Katherine Garrah MSc, and Jeff Anderson, MSc can. (field ecologists). Gyula Gulyas MSc, Guillaume Therien, PhD, and Jim Thrower, PhD, RPF assisted in data analysis and reporting. Julian McGreevy of BGC Engineering assisted in presentation of spatial data, and in preparation of maps. NorthWind Land Resources completed associated soil surveys (NorthWind Land Resources Inc. 2012), and data on soil salinity and sodicity were generated and shared by Joel Hilderman of Klohn Crippen Berger. Data and interpretations on vegetation leaf-area index and evapotranspiration were provided by Sean Carey, PhD, of McMaster University (Carey 2013).

2 STUDY SITE

2.1 RECLAMATION HISTORY

2.1.1 Soil placement

Several soil cover designs were adopted for soil placement activities in the SBH study area (Figure 3-1). The soil cover design varied in soil material types and configurations, but the target capping depth remained 100 cm except portions of the South Bison Hill capping study (see below).

Soil placement activities in the South Bison Hill study area occurred in phases, predominantly from 1999 to 2003, with a portion of the east slope reclaimed in 1996. Four types of soil material were placed throughout this period:

- Direct placement – material containing a suitable balance of organic (Muskeg) and mineral (Secondary), salvaged from the approximate surface 0.5 m of the pre-disturbance salvage area. This material was salvaged and placed without a further coversoil layer.
- Peat-mineral mix – predominantly organic material generally containing little to no mineral material and placed as a coversoil layer over mineral subsoil (Secondary).
- Secondary – mineral soil material containing little to no organic materials. This material is suitable (Good to Fair soil quality) for use as subsoil (AAFRD, 1987) and is overlain by a cover-soil layer.
- Non-sodic – mineral soil material that is similar to Secondary, except it does not meet all Good to Fair soil suitability requirements. Generally, these materials exceeded the % clay fraction and/or soil pH ratings.

The majority of the soil placement in the study area consists of 0.20 m of Muskeg over 0.30 m Secondary over 0.50 m of non-sodic soil. Soil cover design varied in soil material types and configuration across SBH. Aside from portions of the South Bison Hill capping study, SBH soil placement maintained a consistent soil placement target capping depth of 100 cm. For more information on landform design, construction and reclamation, including depth of reclamation material placement and soil survey methods, please see the Syncrude SBH Research Synthesis Report (2013).

2.1.2 Revegetation

Revegetation at the site consisted of seeding barley with fertilizer application (10:30:15:4, N:P:K:S) prior to tree planting. Barley seeding rates were generally 20-25 kg/ha and the fertilizer application rate was 326-363 kg/ha. Generally barley seeding and fertilization took place the year following soil reclamation placement and the year before tree planting. The east slope (1997) was the only area not seeded to barley. Slip failures occurred on the slope in the spring following soil placement of the direct-placement material (0.5 m), so a pasture seed mix was selected for slope stabilization. The seed mix consisted of wheatgrass (slender and intermediate), Russian wild rye, birdsfoot trefoil, alsike clover and timothy, with fertilizer applied at 570 kg/ha.

Reforestation activities within the study area predominantly took place in 2002 and 2003. The only exceptions include the capping study (1999), a small area directly west of the capping study (2004), as well as understory-shrub (green alder) planting on the plateau and east slope (upper-crest and toe positions). Planted tree species generally consisted of a trembling aspen-white spruce mix in variable proportions (0.3:1 to 1:1 trembling aspen: white spruce). Tree planting densities also varied across the site, ranging from 1,411 to 2,383 stems/ha, with alder planting densities from 622 to 857 stems/ha. Further detail on planting dates, seed lots and suppliers is provided in Appendix A.

2.2 CAPPING DEPTH TRIAL

The trial area is located on the northern slope of the SBH landform, and is comprised of 3 strips with target capping depths of:

1. 1.0 m (80 cm secondary overlain by 20 cm of peat-mineral mix),
2. 0.50 m (30 cm of secondary overlain by 20 cm of peat-mineral mix), and
3. 0.35 m (20 cm of secondary overlain by 15 cm of peat-mineral mix).

Observed cover depths in this trial ranged from 0.15 to 1.48 m. Seeding and fertilization of this area of SBH were as discussed above, with white spruce and aspen planted in the fall of 1999 at 800 stems per hectare per species (1600 total stems per hectare).

3 METHODS

3.1 PRIMARY RESPONSE ATTRIBUTE

In this study we used tree site index as the primary measure of vegetation response. This is because trees form the majority of above-ground vegetation biomass on the site and place the greatest demand on site resources. There is also an established history (e.g., Alberta Environment, 2010) of using tree site index as a proxy metric for net primary productivity (which is more difficult to measure), and the capability of forested sites to support upland vegetation. Site index is also widely used and accepted as the most appropriate measure of tree productivity in Canada and throughout the world.

We believe that the composition of understory vegetation species will be more related to revegetation history (both in artificial introduction and pattern of stand development) than site potential productivity or equivalent capability. Data were collected on foliar chemistry and understory vegetation community composition; however, we consider them as supplemental and they were collected to check for unexpected influences on vegetation response (in the case of foliar sampling) and as additional data for future use (understory composition). Please see Appendix B for understory species composition, and Appendix C for foliar chemistry.

3.2 SAMPLE POINTS

We established 80 sample plots in the study site from Sept. 9-17, 2012. Forty-five (45) plots were located at sample points established for other study components (five plots along nine different transects) (Figure 3-1). The additional 35 plots were located along or near these transects to increase sample size and the ability to detect trends. The total number of installed plots includes 36 plots within the capping trial (12 plots in each depth treatment) and 44 plots outside the trial area.

The additional 35 plots were established using GPS to identify target locations. On the plateau area additional plots were located on rounded UTM eastings and northings, to approximate even spacing. On the capping depth trial, additional plots were placed to provide approximately equal down-slope spacing. Additional points were shifted to the east or west of the main transect to intersect areas of historic tree measurements. Coordinates for the three LAI points were provided by Sean Carey. Coordinates for all plots are provided in Appendix D.

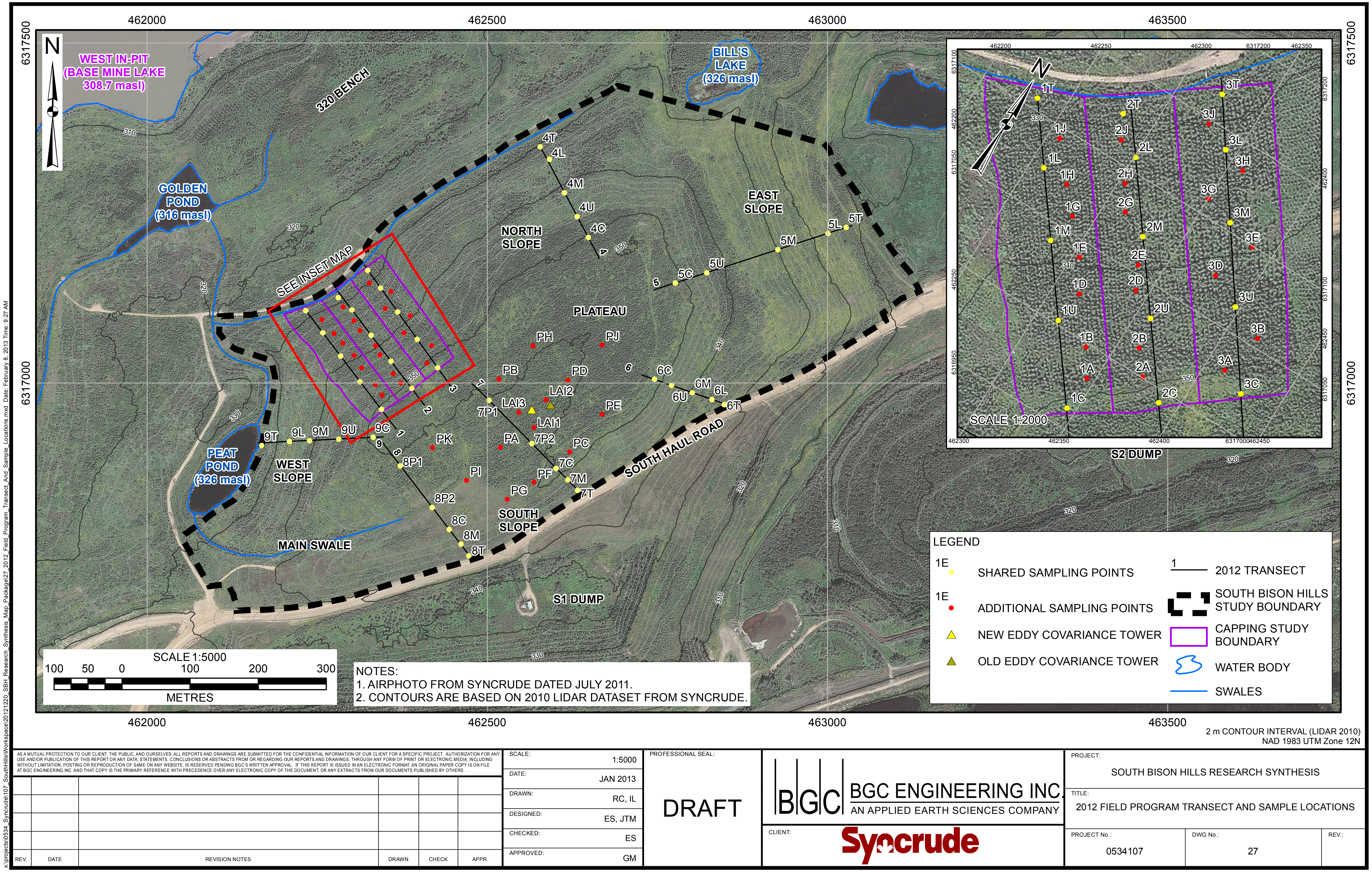

Figure 3-1. 2012 shared (yellow) and additional (red) sampling points in the SBH study area. Transects are numbered, plateau plots are indicated with a ‘P’, and the capping trial area is expanded in the inset.

3.3 SAMPLE PLOTS

Two different fixed-area (circular) plots were centered at each sample point (Figure 3-2):

1. main plot (100 m²) to sample stand density, site index, and leaf-area index; and
2. subplot (10 m²) to sample total stem density and stocking.

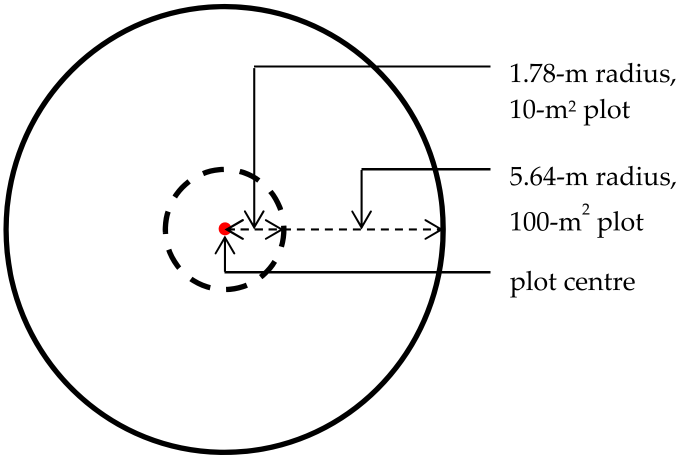

Figure 3-2. Sample plot configuration.

3.4 PLOT MEASUREMENTS

3.4.1 Plot descriptors

Descriptors for each plot included transect number, plot number, and UTM coordinate. Slope position was also noted: crest (C), upper (U), middle (M), lower (L), toe (T), and plateau (P).

3.4.2 Capping depth

The depth of capping material (observable reclamation material type[s] and depth to SSOB) was measured at each plot by NorthWind Land Resources, using a 5-cm diameter combination soil auger.

3.4.3 Tree attributes

All trees within main plots that met tagging limits were tagged with plastic numbered tree tags, attached with wire to lateral branches. The tagging limit for conifer trees was a stem height >30 cm and for deciduous trees was a diameter at breast height (DBH) of >4.0 cm. We did not remove or replace tags from previous research efforts, but previously tagged trees within this study's main plots were given new tags, and the previous tag numbers were recorded. All newly tagged trees were measured for height and diameter, with height measured using a graduated height pole and diameter using steel rulers. Notes were made on the presence of leader damage, malformation, or multiple leaders, if any, and on poor tree conditions and chlorosis.

The only measurement in subplot was a tally of tree stems. The tally height threshold was 30 cm for coniferous trees and 130 cm for deciduous trees.

3.4.4 Site trees

For calculation of GYPSY-based site-index estimates, site or top-height trees were selected during the data-analysis phase as the largest-diameter eligible (i.e., healthy, undamaged, dominant or co-dominant in canopy position, unsuppressed) tree in each 100-m^2 main plot. The heights of these trees were extracted from plot data, and total age determined from planting records. Age was not taken from increment cores to avoid physical damage on trees with small diameter stems and to avoid introducing pathogens (which might compromise future measurements). For the purposes of collecting growth-intercept (GI) data for spruce, a site tree was field-selected, and GI data (height and whorl count for 3-5 years above breast height) were collected. These GI site trees were selected as the tallest[1] eligible spruce per main plot. These trees were selected as an approximation of top height which is defined as the average height of the 100 largest diameter trees/ha and is used to estimate site index.

3.4.5 Leaf-area index

Leaf-area index (LAI) was measured in four cardinal directions from the center of each main plot using a LI-COR LAI-2200 Plant Canopy Analyzer with a 30° view cap to restrict shade interference from slopes. The first observation was taken above canopy height to calibrate the sensor. Sixteen (16) measurements were taken at each plot, four in each cardinal direction at 1 ,2, 3, and 4 m from plot centre. The observations were averaged by the instrument to provide one LAI value for each plot.

3.4.6 Understory vegetation

Characteristic species were measured for absolute percent cover in the main plot by visual assessment.

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[1] Total height was used as the selection parameter in these young stands (provided all other selection criteria were met) as it is possible to determine relative top and crown position, and select the dominant site tree. In older/larger stands, this is not possible, and DBH is generally used as the selection parameter. Selecting trees using height is more appropriate in young stands where trees are mostly of small diameter; however, measurements of these trees at older ages should revert to the diameter-based method of site tree selection.

Species not characteristic of a particular ecosite or site type were recorded if their presence was greater than 1%. Specimens for all species unidentifiable in the field were collected for later identification in the lab. Species of interest were those listed as characteristic for upland ecosites and site types according to the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (Alberta Environment, 2010).

3.4.7 Density and stocking

Stand density and plot stocking were calculated for each plot. These measures are more related to revegetation practice and history than to inherent site quality; however, substantial soil moisture limitations due to inadequate reclamation cover thickness could result in seedling mortality and corresponding low stand-density and stocking. For this reason, these parameters were examined as part of this study.

3.4.8 Foliar chemistry

We sampled spruce and aspen trees for foliar chemistry at each of the 45 previously established plots for which soil chemistry data was collected. For each species, three dominant/co-dominant healthy trees were selected, and a sample taken of the current year's foliage from a lateral shoot in the upper third quarter of the live crown (Ballard and Carter 1986). Care was taken during tree selection to avoid obvious top-height trees. Samples were combined to form a single composite per species in each plot. Samples were placed in paper bags, labeled, and placed in a cooler with ice for shipment to Pacific Soils Analysis in Richmond, BC. Foliar samples were analyzed for concentrations of macro and micronutrients (including nitrogen (N), phosphorus (P), calcium, magnesium, potassium, sulphur (S), and sulphate sulphur, copper, zinc, iron, manganese, and boron), and for weight of 100 leaves.

The results for N, P, and S are reported in this paper. Nitrogen is of primary interest because it is a significant determinant of tree growth, and there is potential for atmospheric deposition of N from industrial fuel combustion in the area. Phosphorus is of interest because it is a macronutrient studied in soil-capping research in the oil sands region (Barbour *et al.*, 2010), while sulphur is of interest because it has been identified as often being co-deficient with nitrogen in boreal forest ecosystems.

3.4.9 Soil salinity and sodicity

Samples for analysis of soil salinity and sodicity were collected by O'Kane Consultants and NorthWind Land Resources at the 45 transect plots. Results of laboratory analyses (for electrical conductivity [EC] and sodium absorption ratio [SAR]) of these samples were provided by Joel Hilderman, geoenvironmental engineer at Klohn Crippen Berger. These results were arithmetically composited to generate EC and SAR values for the topsoil (TS, 0-20 cm), upper-subsoil (US, 20-50 cm) and lower-subsoil (50-100 cm) layers. These layers are based on designations found in the current *Land Capability Classification System* (Alberta Environment, 2006).

3.5 SITE INDEX ESTIMATION

We estimated spruce site index using GYPSY (Alberta's Growth and Yield Projection System). The GYPSY site-index value is the average height of site trees at 50 years of age at breast height, which is estimated from total height and total age. The Alberta definition of site index is based on the average height of the three largest diameter trees in a 300 m^2 plot, where our sample is based on the largest on tree in a 100 m^2 plot. We also tested site index estimated from GI measurements and the equations developed for Alberta (Huang 1996). The estimates of site index from the two methods were very similar, thus we chose to use the GYPSY estimate for the majority of analyses.

We also estimated the site index of aspen using GYPSY. For aspen that were clearly of planted origin, we estimated total tree age from planting records. Where aspen trees were of natural origin, we estimated age from anecdotal evidence and historic photographs to help determine time of ingress. This second method applied primarily to aspen on the plateau area of the site.

Growth intercept was calculated as the average annual height growth increment for the greatest of the first three, four, or five years growth above breast height. A GI measurement was not taken on 13 of the plots because there was not at least three years growth above breast height or the plot did not contain a suitable site tree. Plots that did not contain a suitable site tree were considered as a null plot for both GYPSY and GI site index. More discussion of site index methods is presented in Appendix E.

3.6 CAPPING DEPTH TRIAL

For the comparison of attributes between the three capping depths (transects 1-3) we did not include toe and crest plots, as they were highly influenced by edge effects, and in many cases were outside the original trial area.

4 RESULTS

Site index and associated results and analysis are provided in the following sections. The full site index and tree measurement data sets are provided in Appendix B.

4.1 SITE INDEX

4.1.1 Spruce

Site index of 14-year-old planted white spruce trees in the capping-depth trial ranged from approximately 17-25 m. Average site indices by capping treatment were from 20.7-21.6 m (Table 4-1), and statistical testing indicates no significant differences in site index by treatment ($\alpha = 0.05$). It is possible that more intensive sampling would be capable of revealing a statistically identifiable trend, but the absolute differences in observed site indices between capping treatments are likely smaller than errors associated with tree measurements and site index estimation.

Table 4-1. White spruce average site index in the capping depth trial.

Capping Depth	Number of Plots	Average (m)	Standard Deviation (m)	Standard Error (m)	95% Confidence Interval (m)
0.35 m	10	20.7	1.6	0.5	19.7–21.6
0.50 m	10	21.6	1.5	0.5	20.7–22.4
1.00 m	10	21.3	1.9	0.6	20.2–22.4

When all plots in the trial are considered together, a linear regression of site index with observed (rather than nominal) capping depth at each sample plot shows no significant relationship between cover depth and tree growth (Figure 4-1). If testing of significance is ignored, over the range of capping depths in the trial, the slope of the trend line suggests that each 1.0-m increase in capping depth over the observed range is associated with a 1.0-m increase in site index.

The data sampled in areas outside the capping-depth trial show increasing site index with increasing capping depth (Figure 4-2). The trend is weak ($R^2 \cong 0.2$) but is statistically significant ($\alpha = 0.05$). These plots did not contain the shallower depths included in the trial area, and show somewhat lower site indexes in the range of 0.6-0.8 m of capping depth. This trend line suggests that each 0.26-m increase in capping depth over the observed range is associated with a 1.0-m increase in site index.

When all plots (in and outside the trial area) are combined, the results are similar, showing no significant relationship between reclamation cover depth and site index (Figure 4-3 – this trend line suggests that each 0.83-m increase in capping depth over the observed range is associated with a 1.0-m increase in site index.

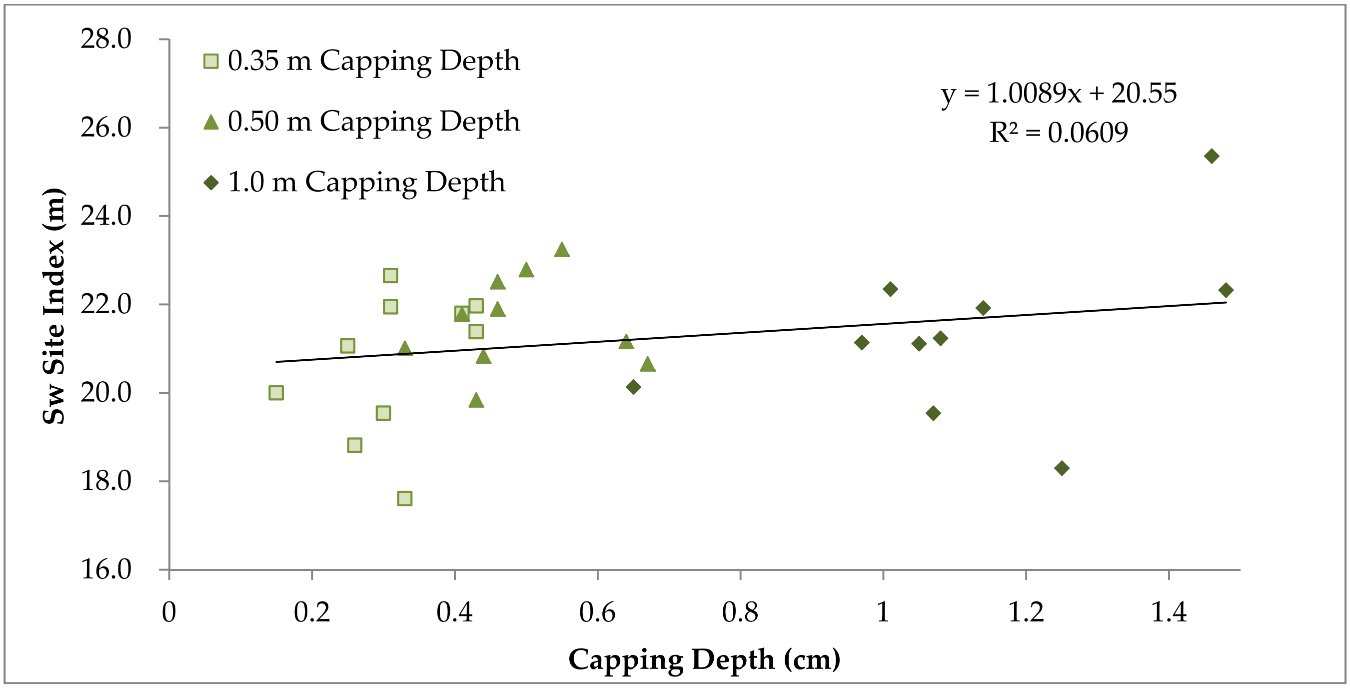

Figure 4-1. Relationship between spruce site index and capping depth in the trial area. Capping depth trial is indicated by squares (T1 - 0.35m), triangles (T2 - 0.5m) and diamonds (T3 - 1.0m).

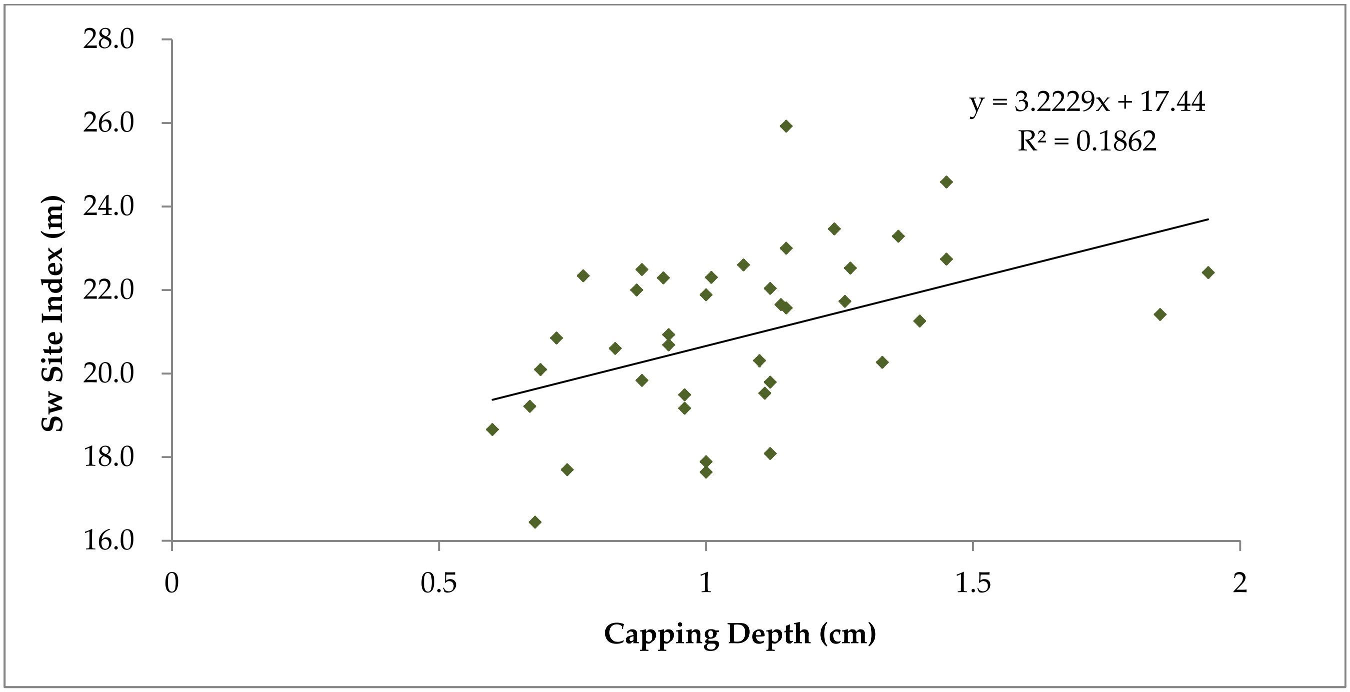

Figure 4-2. Relationship between spruce site index and capping depth outside the trial area.

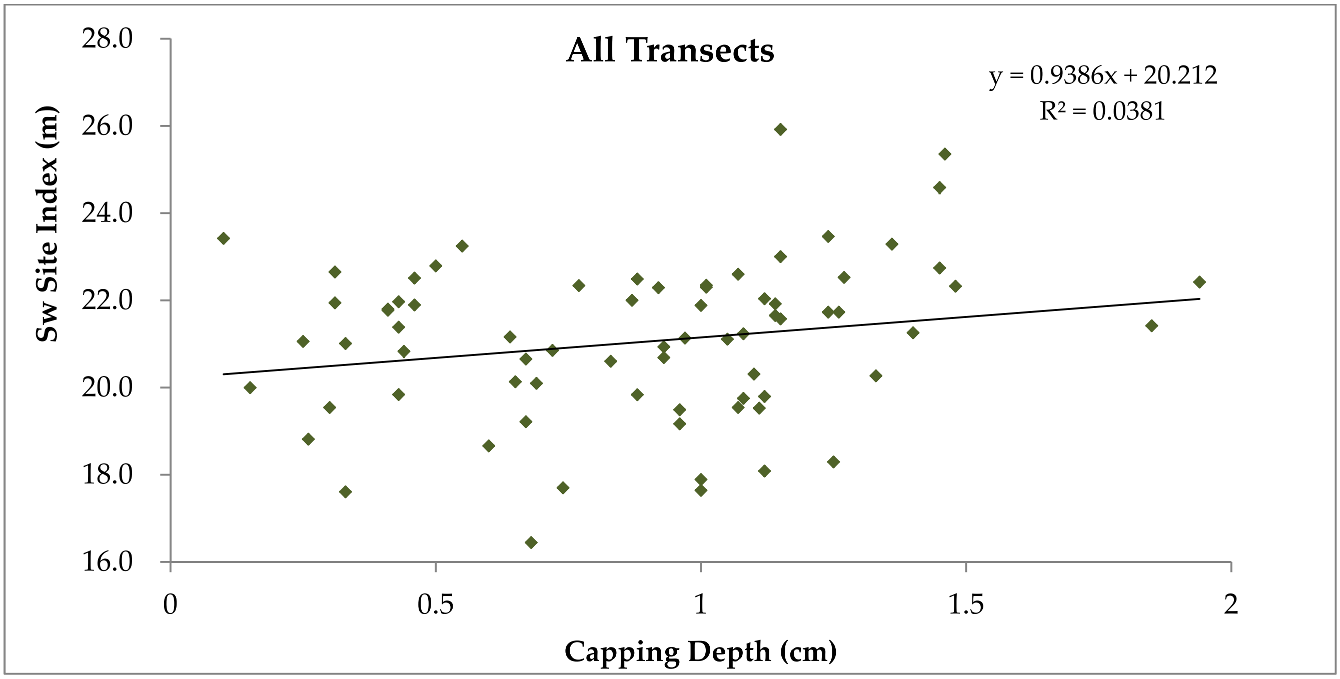

Figure 4-3. Relationship between spruce site index and capping depth for all areas.

4.1.2 Aspen

The site index of aspen trees in the trial ranged from approximately 16-22 m and averaged 17-19 m (not statistically different, $\alpha = 0.05$) among the three capping depths (Table 4-2, Figure 4-4). As with spruce, these small differences are likely due to sampling error, and are neither statistically nor biologically significant.

Table 4-2. Aspen average site index in the capping depth trial.

Capping Depth	Number of Plots	Average (m)	Standard Deviation (m)	Standard Error (m)	95% Confidence Interval (m)
0.35 m	10	18.2	1.73	0.55	17.2–19.2
0.50 m	10	17.5	1.35	0.43	16.7–18.3
1.0 m	10	19.1	1.01	0.32	18.5–19.7

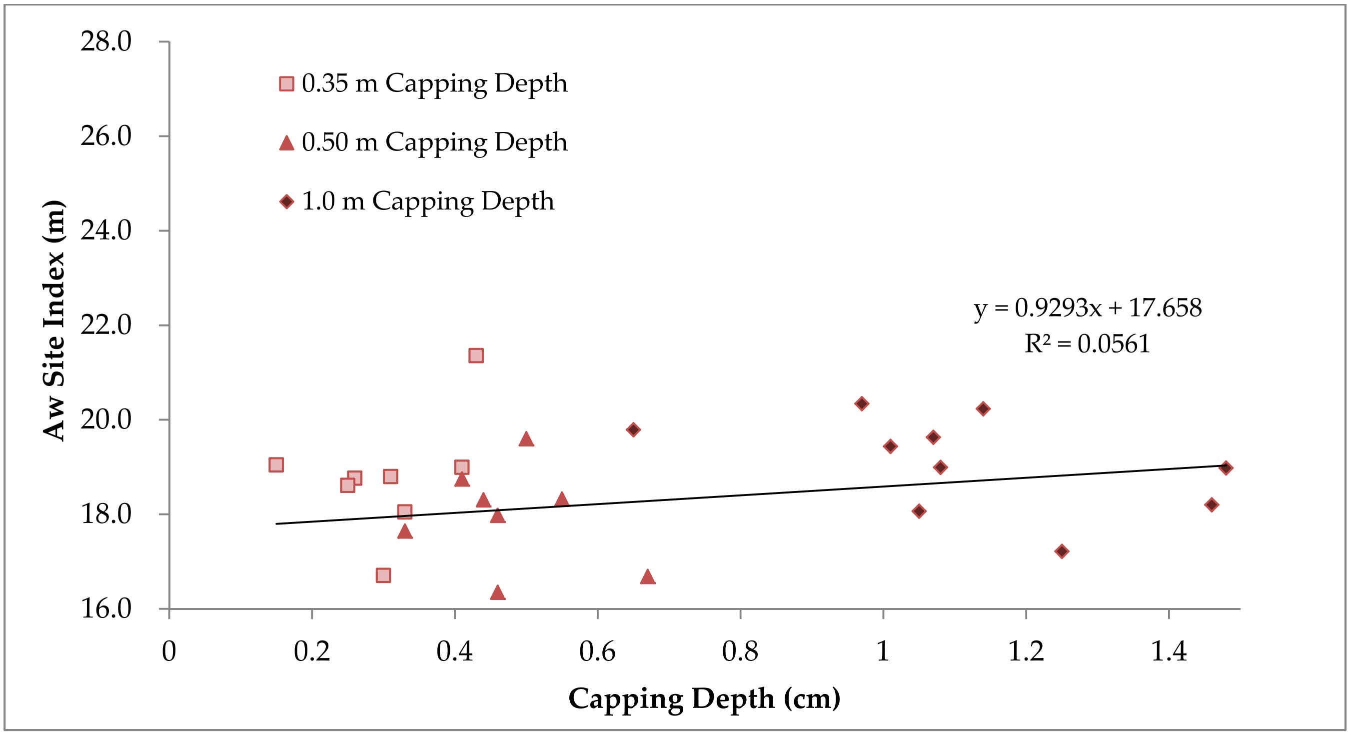

Figure 4-4. Relationship between aspen site index and capping depth in the trial area. Capping depth trial is indicated by squares (T1 - 0.35m), triangles (T2 - 0.5m) and diamonds (T3 - 1.0m).

The data sampled from areas outside the trial area showed no relationship between aspen site index and capping depth (Figure 4-5), however, overall the average site index was higher in the non-trial areas (22.0 m) compared to the trial area (18.3 m). One possible explanation for this difference may be related to the aspen in the trial area being largely of planted origin where those in the other areas were natural ingress. There could also be confounding of site characteristics (most likely moisture) in the plateau area, which was primarily naturally regenerated by aspen.

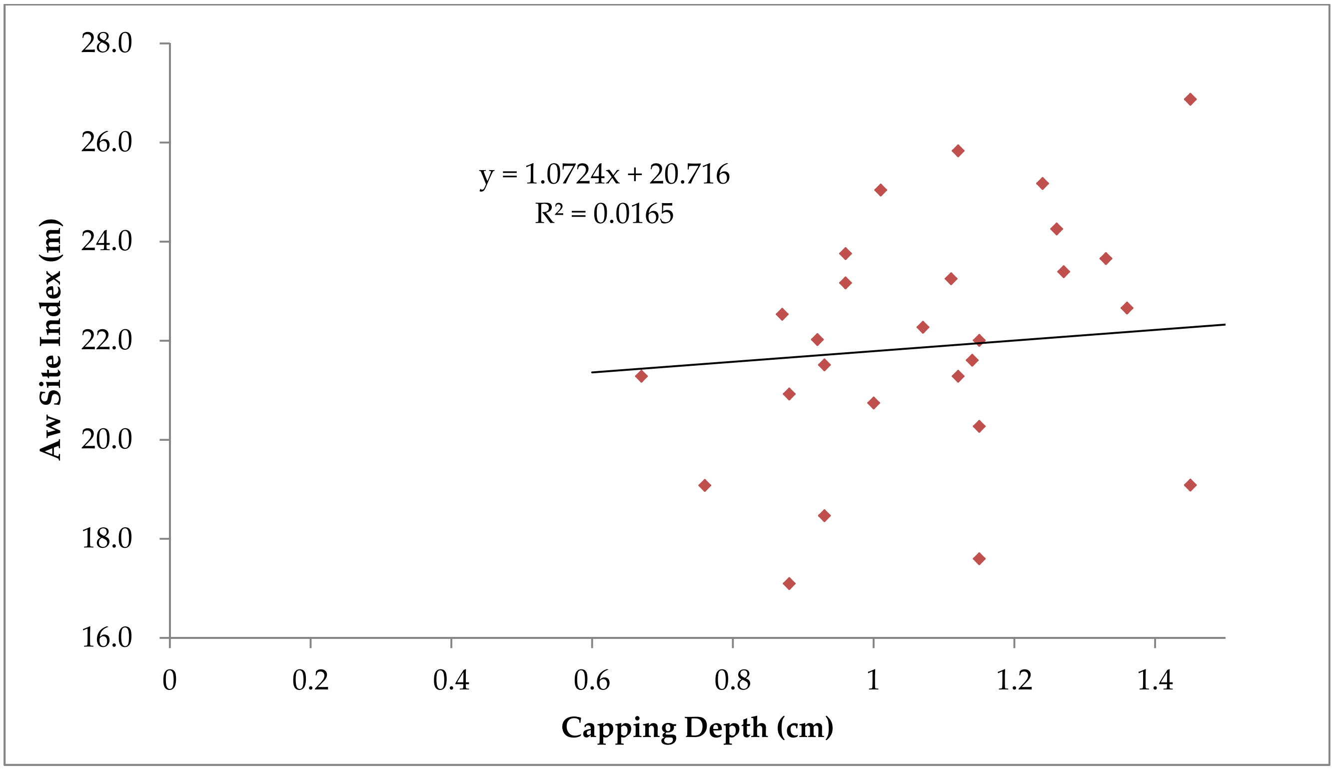

Figure 4-5. Relationship between aspen site index and capping depth outside the trial area.

When all aspen data are combined, there is a statistically significant trend of increasing site index with increasing capping depth; however, this is likely an artefact of the different overall averages and ranges of capping depth in and outside the trial area (Figure 4-6). This trend line suggests that each 0.3-m increase in capping depth over the observed range is associated with a 1.0-m increase in site index.

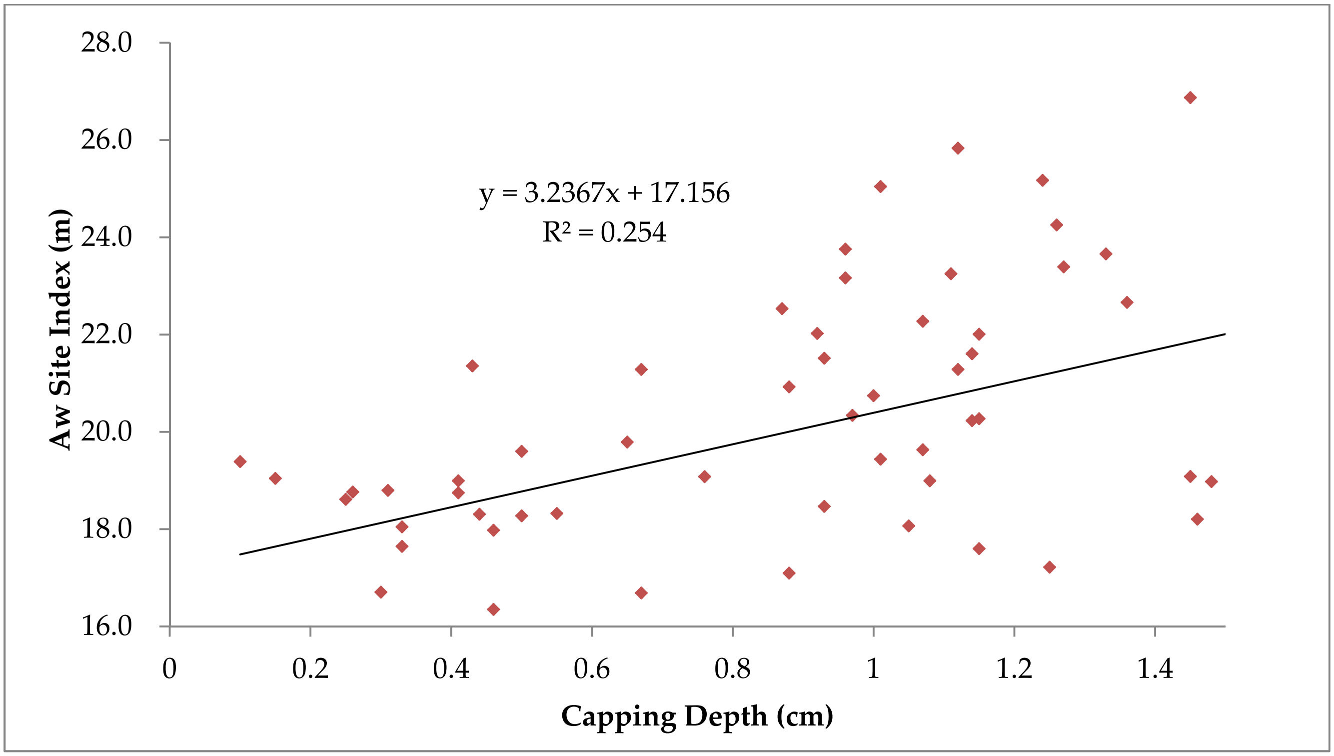

Figure 4-6. Relationship between aspen site index and capping depth for all areas.

4.2 HEIGHT DISTRIBUTION

We examined the distribution of tree heights in the capping depth trial in an attempt to detect differences that might not be evident in site index. The majority of spruce trees in all three capping depths are in the 4.0-5.0-m height class; and there are no clear trends in the small changes in proportions within height classes as capping depth increases (Figure 4-7). The 1.0-m capping depth has the tallest trees, but they are so few that a strong trend is not evident. This lack of a clear trend by height with capping depth is consistent with the site index results.

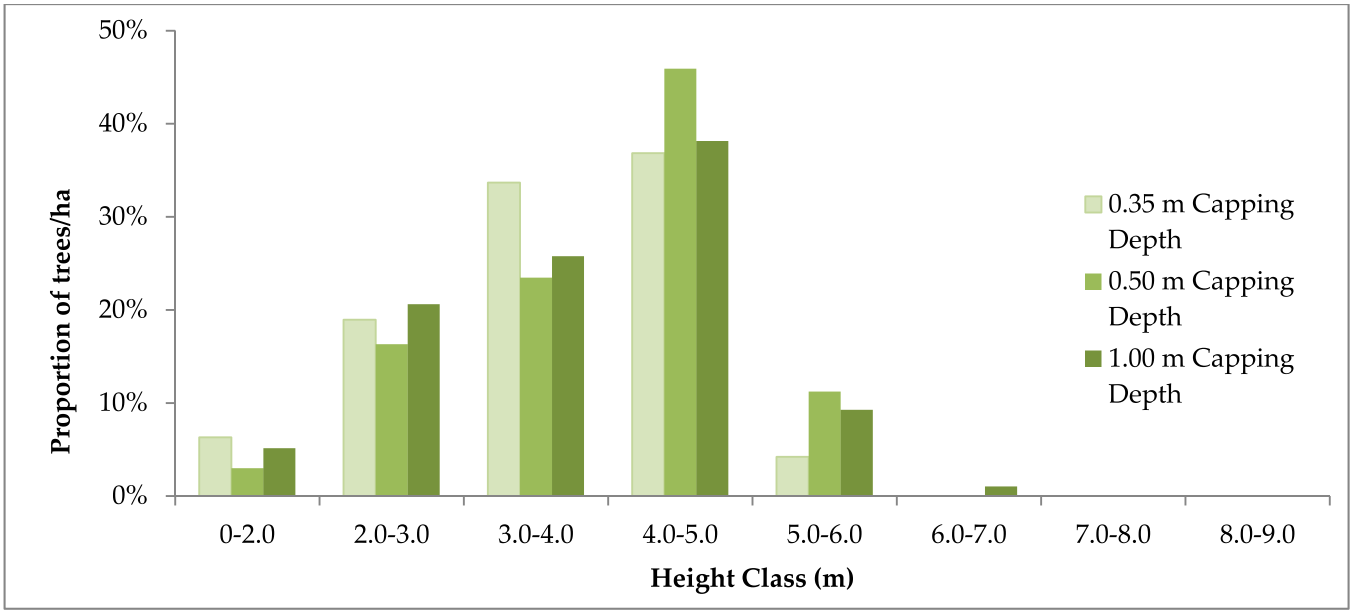

Figure 4-7. Distribution of spruce tree heights in the capping depth trial.

The distribution of aspen tree heights showed a higher proportion of taller trees in the 1.0-m capping depth; however, the general trend was not strong as the tallest trees (8-9 m) were found only in the 0.35 m and 0.5 m depths (Figure 4-8). Overall, the heights of aspen trees were taller than spruce, which did not exceed 7 m.

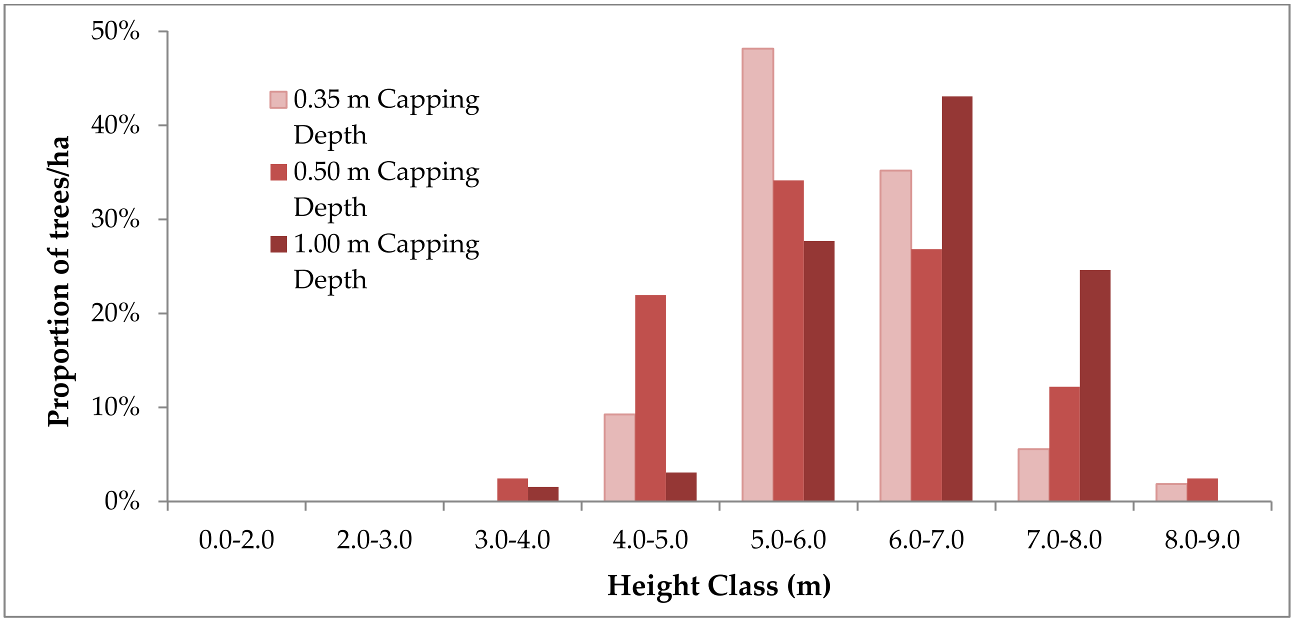

Figure 4-8. Distribution of aspen tree heights in the capping depth trial.

4.3 DENSITY AND STOCKING

The data showed no notable pattern of reduced density levels, with the majority of plots having >1,000 stems/ha. Consistent with the mixedwood “d2” reclamation designation of this site, the largest number of plots (49%) are found in the “CD” stocking class, or stocked with both a conifer and deciduous stem, with 36% of plots stocked with a deciduous stem only, 10% of plots stocked with a coniferous stem only, and only 5% of plots being non-stocked. This gives an overall stocking percentage of 95%, well above the conventional 80% target for successful commercial reforestation. All potential strata are sufficiently stocked – even the warm-aspect slopes (sloped sections of transects 6-9) have a stocking level of 81%. As with the data on stand density, these stocking values confirm adequate forest regeneration on the study site.

Table 4-3. Proportion of stocked sample plots.

Status	Composition	Number of Plots	Proportion of Plots
Stocked	Coniferous (C)	8	10%
	Deciduous (D)	29	36%
	Coniferous-Deciduous (CD)	39	49%
Non-stocked		4	5%
Total		80	100%

4.4 FOLIAR NUTRIENTS

Foliar-nutrient results and analysis are provided in the following sections. The full data set of foliar results in provided in Appendix C.

4.4.1 Spruce

Laboratory analyses show a consistent concentration of foliar nitrogen (N) throughout the study area with an overall average of 1.33% (Table 4-4). There is no statistically significant difference among the averages in the capping depth trial or with other areas in the site. Interpretive values suggested by Ballard and Carter (1986) for white spruce in British Columbia indicate nitrogen "adequacy" at foliar concentrations above 1.55%, and slight-moderate deficiencies at concentrations from 1.30-1.55%. (Note that these interpretations are largely inferred from observed growth responses to nutrient additions, and should not be taken as indicating abnormal nutrient status, as nitrogen deficiencies in forests are endemic throughout western North America.) The foliar N concentrations observed in this study are slightly higher than those reported by Brockley and Simpson (2004) for control plots in a white spruce fertilization trial in B.C., and in the middle of the range of their N-fertilized plots. They are also generally higher than the values reported by Chang *et al.* (2010) for 6 natural stands in the oil sands region (mean = 1.10%), and those reported by reported by Wang (1995) for 102 sampled white spruce stands in sub-boreal B.C (mean = 1.17%).

As with N, lab analyses show a consistent level of foliar phosphorus (P) throughout the trial, with no significant differences between areas, and an overall average of 0.16%, at the adequacy threshold suggested by Ballard and Carter. Analyses for sulphur (S) are likewise consistent, with no significant differences by area, and an overall average of 0.09%. According to Ballard and Carter's interpretive values, these concentrations, along with data on inorganic foliar S (SO_4-S) concentrations, suggest possible sulphur deficiencies. Examination of data on additional macro- and micro-nutrients (Ca, K, Mg, B, Cu, Fe, Mn, Zn – Appendix C) indicate no nutrient deficiencies, with the possible exception of B, for which the majority of observations fall into Ballard and Carter's probable and possible deficiency categories. However, current growth data indicate that it is unlikely that supply of sulphur or boron is limiting ecosystem establishment on the South Bison Hill study area.

Table 4-4. Statistics for foliar nutrients (N, P, S) for spruce and aspen.

Nutrient/ Species	**Transect/ Cap Depth**	**Trees Sampled**	**Average (%)**	**Std. Dev. (%)**	**Std. Error (%)**	**Lower CI (%)**	**Upper CI (%)**
Nitrogen							
Spruce	2 (0.35 m)	4	1.31	0.13	0.063	1.11	1.51
	1 (0.50 m)	5	1.34	0.07	0.031	1.26	1.43
	3 (1.00 m)	3	1.39	0.05	0.027	1.27	1.50
	Others	25	1.33	0.13	0.026	1.27	1.38
	All	37	1.33	0.12	0.019	1.29	1.37
Aspen	2 (0.35 m)	5	1.94	0.14	0.061	1.77	2.11
	1 (0.50 m)	5	1.92	0.10	0.043	1.80	2.04
	3 (1.00 m)	5	2.00	0.14	0.063	1.82	2.17
	Others	24	1.89	0.21	0.042	1.80	1.98
	All	39	1.91	0.18	0.029	1.85	1.97
Phosphorus							
Spruce	2 (0.35 m)	4	0.15	0.01	0.006	0.13	0.17
	1 (0.50 m)	5	0.16	0.01	0.004	0.15	0.18
	3 (1.00 m)	3	0.17	0.01	0.003	0.15	0.18
	Others	25	0.16	0.03	0.005	0.15	0.18
	All	37	0.16	0.02	0.004	0.16	0.17
Aspen	2 (0.35 m)	5	0.18	0.02	0.011	0.15	0.21
	1 (0.50 m)	4	0.17	0.01	0.006	0.15	0.19
	3 (1.00 m)	5	0.16	0.02	0.008	0.14	0.18
	Others	22	0.16	0.03	0.006	0.15	0.17
	All	36	0.16	0.03	0.004	0.16	0.17
Sulphur							
Spruce	2 (0.35 m)	4	0.10	0.01	0.003	0.09	0.10
	1 (0.50 m)	5	0.10	0.00	0.002	0.09	0.10
	3 (1.00 m)	3	0.09	0.00	0.002	0.08	0.10
	Others	25	0.09	0.01	0.001	0.09	0.09
	All	37	0.09	0.01	0.001	0.09	0.09
Aspen	2 (0.35 m)	5	0.37	0.32	0.144	-0.03	0.77
	1 (0.50 m)	4	0.37	0.10	0.051	0.21	0.53
	3 (1.00 m)	5	0.21	0.03	0.015	0.17	0.25
	Others	22	0.22	0.04	0.009	0.20	0.23
	All	36	0.25	0.14	0.023	0.21	0.30

4.4.2 Aspen

There is little published data or interpretive standards for foliar nutrition in aspen; thus, it is difficult to make the same kinds of comparisons as made above for white spruce. Comparison of values observed in this study to published data indicate that foliar nitrogen concentrations in aspen on the reclaimed South Bison Hill are below the mean (2.61%) and range (2.00-2.94%) of concentrations observed in 8 natural sites in the oil sands region (Chang *et al.* 2010), and below the mean concentration of 2.26% measured by Chen *et al.* (1998) at 60 sites in boreal British Columbia, but within the range of 1.57-2.89% observed by these authors. In part, the lower values reported in this study may be attributable to timing of sample collection: foliar samples in this study were collected on Sept. 9, and were likely affected to N translocation prior to leaf-drop, whereas cited data were from samples collected in August, which would be less affected by this nutrient translocation. Data published by Maynard *et al.* (1994) indicate that the mean aspen foliar sulphur concentration reported in this study (0.25%) is similar to the mean observed by these authors (0.23%) in aspen in a low-sulphur-deposition site in west-central Alberta.

4.5 SOIL SALINITY AND SODICITY

Results of depth-weighted calculations for electrical conductivity (EC) and sodium absorption ratio (SAR) are presented in Table 4-5 (with the full dataset presented in Appendix C). In general, there are expected trends of higher values on thinner covers, and of increasing values with increasing depths.

An examination of data and discussions presented by Close *et al.* (2007) indicates the following thresholds with respect to salinity:

- topsoil EC >4 dS/m is associated with inability to establish typical (non-saline) boreal forest communities. These authors observed that, provided topsoil EC remained <4 dS/m, typical boreal forest communities could exist even in the presence of highly saline conditions at depth (subsoil EC >20 dS/m); and
- topsoil EC >2 dS/m and/or upper subsoil EC >4 dS/m are associated with declining forest productivity.

Comparison of data from this study to these thresholds indicates the following:

- no topsoil EC values >4 dS/m are observed. The highest observed value is 3.93 dS/m, on the toe-slope position of the 35-cm cover trial.
- Mean values for topsoil and upper subsoil exceed the 2- and 4-dS/m forest-productivity thresholds on the 35-cm cover, and these thresholds are also exceeded individually at plots 1M, 5U, 6T, 7P2, 8C, 8P1, and 9T.)

As with EC, SAR is higher in the subsoil layers than in the topsoil layer, with the site-wide mean in the topsoil layer being less than 2.

Table 4-5. Statistics for EC and SAR by soil-cover layer.

Parameter/ Layer	Transect/ Cap Depth	n	Average (dS/m)	Std. Dev. (dS/m)	Std. Error (dS/m)	Lower CI (dS/m)	Upper CI (dS/m)
EC							
TS (0-20 cm)	2 (0.35 m)	5	**2.44**	1.43	1.09	-0.59	5.47
	1 (0.50 m)	5	0.92	0.49	0.41	-0.22	2.06
	3 (1.00 m)	5	1.02	0.34	0.46	-0.25	2.28
	Others	30	1.44	0.57	0.26	0.90	1.98
	All	45	1.45	0.77	0.22	1.01	1.88
US (20-50 cm)	2 (0.35 m)	5	**5.50**	2.88	2.46	-1.33	12.33
	1 (0.50 m)	5	1.66	1.73	0.74	-0.40	3.72
	3 (1.00 m)	5	1.80	1.06	0.81	-0.44	4.04
	Others	30	2.04	1.21	0.37	1.28	2.80
	All	45	2.36	1.84	0.35	1.65	3.07
LS (50-100 cm)	2 (0.35 m)	4	6.26	3.49	3.13	-3.70	16.23
	1 (0.50 m)	5	4.38	3.22	1.96	-1.06	9.82
	3 (1.00 m)	5	3.91	2.47	1.75	-0.95	8.77
	Others	30	3.84	1.54	0.70	2.41	5.28
	All	44	4.13	2.11	0.62	2.88	5.39
SAR (no units)							
TS (0-20 cm)	2 (0.35 m)	5	5.11	3.26	2.29	-1.24	11.46
	1 (0.50 m)	5	1.29	1.29	0.58	-0.31	2.90
	3 (1.00 m)	5	1.74	0.81	0.78	-0.42	3.90
	Others	30	1.23	1.11	0.23	0.77	1.69
	All	45	1.73	1.87	0.26	1.21	2.25
US (20-50 cm)	2 (0.35 m)	5	10.26	5.20	4.59	-2.48	23.00
	1 (0.50 m)	5	3.63	3.14	1.62	-0.88	8.13
	3 (1.00 m)	5	3.24	1.91	1.45	-0.78	7.26
	Others	30	2.25	2.04	0.41	1.41	3.09
	All	45	3.40	3.56	0.51	2.38	4.42
LS (50-100 cm)	2 (0.35 m)	4	11.26	5.58	5.63	-6.66	29.17
	1 (0.50 m)	5	7.51	5.13	3.36	-1.81	16.84
	3 (1.00 m)	5	7.74	3.95	3.46	-1.87	17.34
	Others	30	6.34	3.07	1.16	3.97	8.71
	All	44	7.08	3.81	1.07	4.93	9.23

Bolded values exceed levels associated with declining forest productivity in Close *et al.* (2007)

Analysis of site index values by soil salinity and sodicity reveals no relationships for spruce, but weak, statistically significant negative relationships for the upper subsoil (SAR) and lower subsoil (EC and SAR) for aspen – see Appendix F. No aspen site indices above 21.5 m were observed with subsoil EC values >4 dS/m, and no aspen site indices above 20.0 m were observed with subsoil SAR values >12.

Mean spruce site index on the plots exceeding the above 2- and 4-dS/m forest-productivity thresholds is 21.1 m, just slightly above the site-wide mean of 21.0 m. Mean aspen site index on these plots is 19.1 m, just under 1 m less than the site-wide mean of 20.0 m.

Lilles *et al.* (2012) report that white spruce and aspen growing on high-salinity sites in northern Alberta had normal growth rates in juvenile stand phases, but showed evidence of declining growth rates as stands aged – these decreases were manifested as stands exceeded ages of approximately 15-40 years. Consequently, these authors state that where "revegetation has occurred over soils with salinity at depth, stands should be watched carefully as they age, because growth limitations associated with salinity may not be evident in juvenile trees". However, the average subsoil salinity and sodicity of these authors' "high-salinity" sites was 13.2 dS/m and 35, respectively, compared to values in this study of 4.1 dS/m for EC and 7.1 for SAR. EC and SAR values from Lilles *et al.*'s low-salinity sites, at which trees generally did not show unexpected growth reductions with increasing age, were 4.0 dS/m and 17.1, respectively, which are similar (EC) or substantially higher (SAR) than the values reported in this study. We recommend continued monitoring of tree growth performance on the SBH site to confirm persistence of trends observed to date, but do not expect to see decreases in growth performance over time such as those reported by Lilles *et al*. on saline-sodic sites.

4.6 SPATIAL PRESENTATION OF SELECTED DATA

Data for a number of parameters measured in this study – including site index, stem density, stocking, and LAI – are presented spatially, by plot, in Appendix G.

5 DISCUSSION

5.1 MINIMUM RECLAMATION-COVER DEPTH

Data reported in Section 4 of this report for GYPSY-derived site index indicated no significant relationships, or weakly significant positive relationships, between increasing reclamation-cover depth and increasing site index. GYPSY site-index estimates, however, generate data with a greater spread, due to errors in estimating age to breast height and subsequent growth above breast height. Use of growth-intercept site-index estimates for white spruce may be a more direct measure of growth performance on the site, and suggests that there may be a significant positive relationship between capping depth and site index, as illustrated in Figure 5-1.

This information suggests substantial increases in site indices as cover depths increase from 15-50 cm (an approximate 1.7-m increase along the regression line in this range), followed by decreasing response as cover depths increase from 50-150 cm.

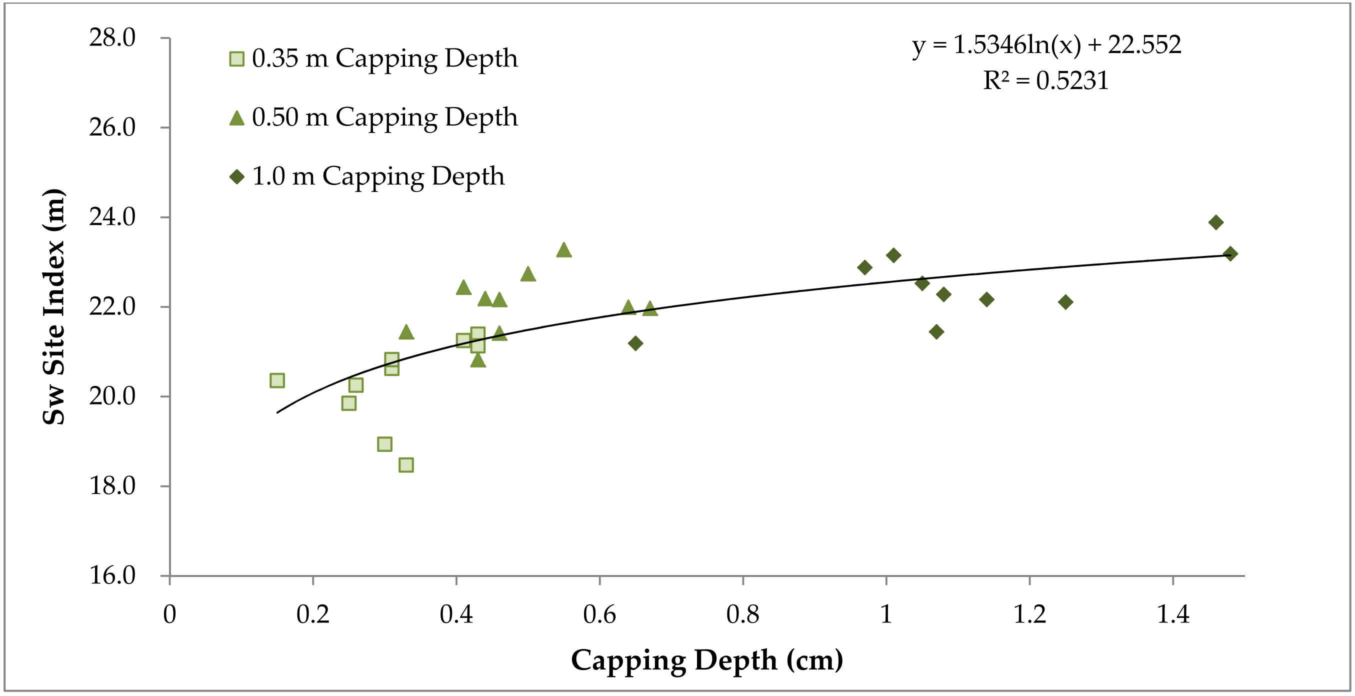

Figure 5-1. Comparison of white spruce GI-based site-index estimates to measured total capping depth across the SBH capping trials (toe and crest plots removed).

These data, combined with those on topsoil and upper-subsoil salinity and sodicity, which show mean values on the 35-cm cover exceeding inferred productivity thresholds, suggest that a minimum reclamation-cover depth would be 50 cm.

5.2 EQUIVALENT CAPABILITY

It is important to view the study results in the context of what should be expected in a regenerating forest stand in Alberta's northeast boreal forest – that is, within an "equivalent capability" context. It may be that greater reclamation cover depths can support greater tree growth performance (as weakly suggested by some data in this study), but that increased growth may not be required, normal, appropriate, or desired. In order to provide this context, we examine three different approaches to understanding equivalent capability as it relates to tree growth performance:

1. How do results relate to expectations for target ecosites?
2. How do results relate to threshold values contained in *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* ("The Revegetation Manual" – Alberta Environment, 2010)? And,
3. How do results compare to data for the pre-disturbance Mildred Lake lease area?

5.2.1 Target ecosites

The dominant target ecosite for the study site is a "d", with the ecosite phase corresponding to leading overstory species (primarily "d2", or a mixture of aspen and white spruce). Data on site index published in the *Field Guide to Ecosites of Northern Alberta (*Beckingham and Archibald, 1996) is compared to data collected in this study in Table 5-1. This information indicates that mean site indices on the reclaimed SBH site exceed those measured on non-mined forest stands across the region.

Table 5-1. Site index from the study site compared to expected values for d ecosites.

	Ecosite Guide		Study Site	
	n	mean	n	mean
White spruce	502	16.8 ± 0.2	73	21.0 ± 0.2
Aspen	397	18.2 ± 0.2	62	20.0 ± 0.3

5.2.2 Site index from the Revegetation Manual

The 2010 version of the Revegetation Manual does not necessarily have regulatory applicability to this study site, as this site was reclaimed prior to this version's development. However, this document represents current thinking and approaches to evaluation of oil sands reclamation revegetation. This manual uses site index as one indicator of successful reclamation for sites designated as having a commercial forestry end land use. Two threshold values (minimum values to be achieved) per species are presented in the Revegetation Manual, based on: 1) site index required for entry into the "Fair" Timber Productivity Rating (TPR) class; and 2) mean site index in the Fair TPR class. These thresholds are compared to data collected in this study in Table 5-2. These data show that both mean and minimum site indices for both species meet the higher (Top Height ½ Fair) criteria[2].

Table 5-2. Site index from the study site compared to the Revegetation Manual.

	Revegetation Manual		Study Site	
	Top Height Fair (m)	Top Height ½ Fair (m)	Mean (m)	Minimum (m)
White spruce	7.1	9.3	21.0	15.6
Aspen	11.6	13.5	20.0	15.3

5.2.3 Site index on the pre-disturbance Mildred Lake lease

Vegetation data compiled for the submission of SCL's 2011 Mine Reclamation Plan and Life of Mine Closure Plan were examined to collect data on vegetation conditions and estimated site-index values for the pre-disturbance landscape. These data are based on Alberta Vegetation Inventory (AVI) mapping of historic (pre-development) air photos. The following comparisons are made to the entirety of the pre-disturbance lease area, and to upland portions of this area, rather than to the pre-disturbance SBH area. The rationale for this approach is that SCL is not required to reproduce equivalent capability with spatial fidelity to pre-disturbance conditions, but only to achieve equivalent-capability objectives on a lease-wide basis.

Figure 5-2 displays the frequency distribution of TPR classes on the forested pre-development Mildred Lake lease (this area is not equivalent to the total lease area due to the presence of non-forested ecosystems). Approximately 37% of the area is in the unproductive class due to a corresponding proportion of wetland ecosystems in the landscape. Of interest for this comparison are the Fair, Medium, and Good TPR classes that are predominantly populated by upland ecosystems, and comprise approximately 63% of the lease area.

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[2] The Revegetation Manual assumes comparison of threshold site-index values to top-height, growth-intercept site index estimates. For reasons discussed in this report, these are not available for aspen, and so GYPSY-derived site index estimates are presented here for both species. Growth-intercept site-index estimates for spruce from the study site are higher than the GYPSY-derived estimates presented in Table 5-2, for both mean and minimum values.

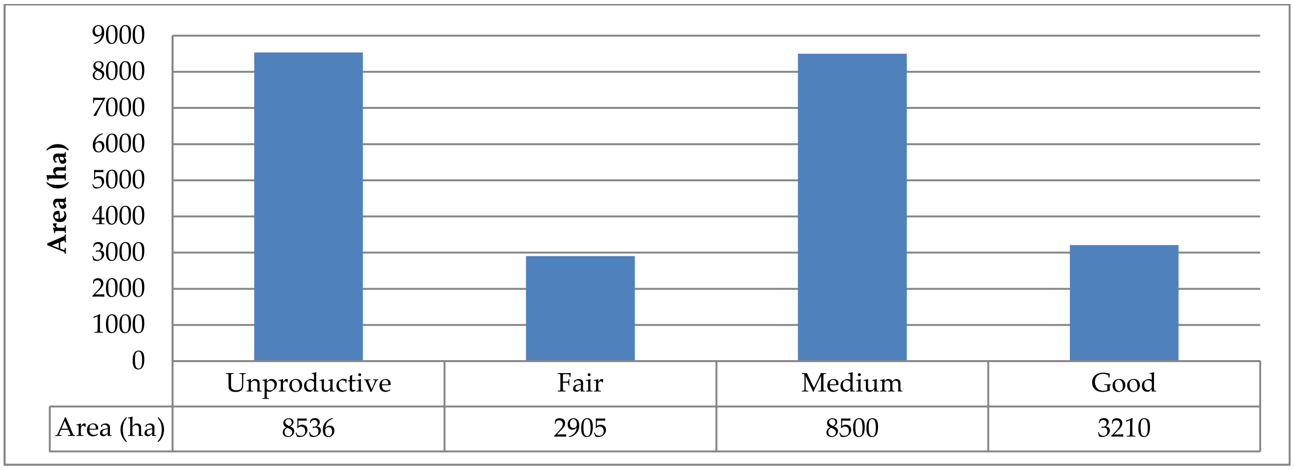

Figure 5-2. Frequency distribution of area of TPR classes on the pre-disturbance Mildred Lake lease (total 23 151 ha).

Figure 5-3 shows a similar frequency distribution for leading overstory species on the pre-development Mildred Lake lease. Relevant to this study are the approximately 10 000 ha, or 46% of the pre-disturbance landscape, on which either white spruce or aspen was the leading overstory species in the time period directly prior to mine development. The discrepancy between total areas reported in Figure 5-2 and Figure 5-3 are due to some polygons with assigned TPR values lacking data on overstory species.

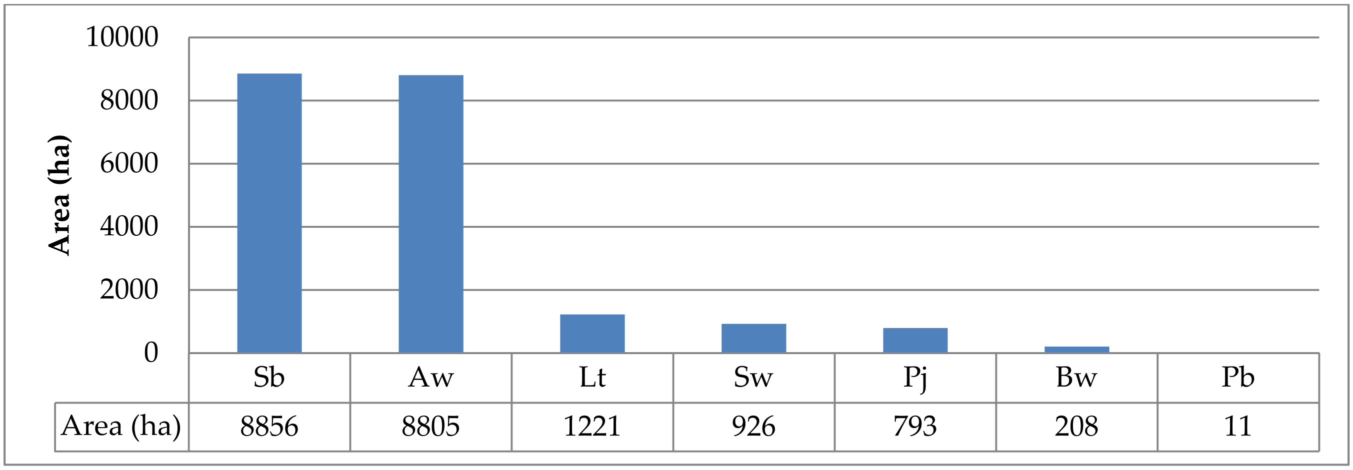

Figure 5-3. Frequency distribution of area of leading overstory species on the pre-disturbance Mildred Lake lease (total 20 820 ha). Species codes: Sb=black spruce; Aw=aspen; Lt=larch (tamarack); Sw=white spruce; Pj=jack pine; Bw=white birch; and Pb=balsam poplar.

Based on the above data, frequency distributions of pre-development TPR classes were generated for the total area on which aspen was identified as the leading species (8805 ha) and where white spruce was identified as the leading species (926 ha). These distributions were then attributed with site-index values using data published in Version 2.1.1 of the Alberta Vegetation Inventory Interpretation Standards (Alberta Sustainable Resource Development, 2006), and compared to frequency distributions of approximate 1-m site-index classes from data collected in this study on the SBH site. These comparisons are presented in Figure 5-4 and Figure 5-5, and summarized in Table 5-3.

These comparisons of all site index data from the SBH study site to pre-disturbance estimates of site index from AVI show "overachievement" of equivalent capability for these parameters, regardless of reclamation cover depth.

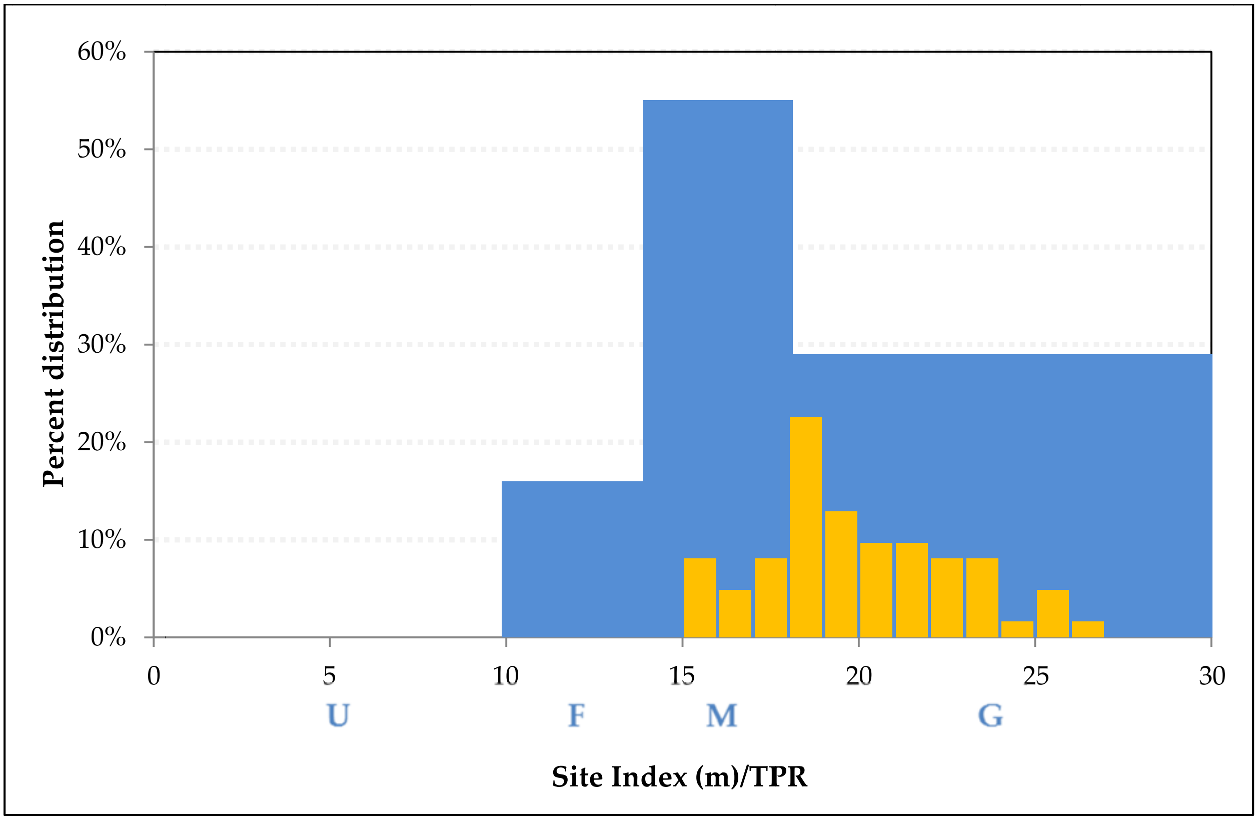

Figure 5-4. Frequency distribution of aspen timber productivity rating (TPR) on the pre-development landscape (blue bars) in comparison to observed data from the SBH study site (yellow bars), using GYPSY-based site-index estimates and corresponding TPR classes (U = Unproductive; F = Fair; M = Medium; G = Good).

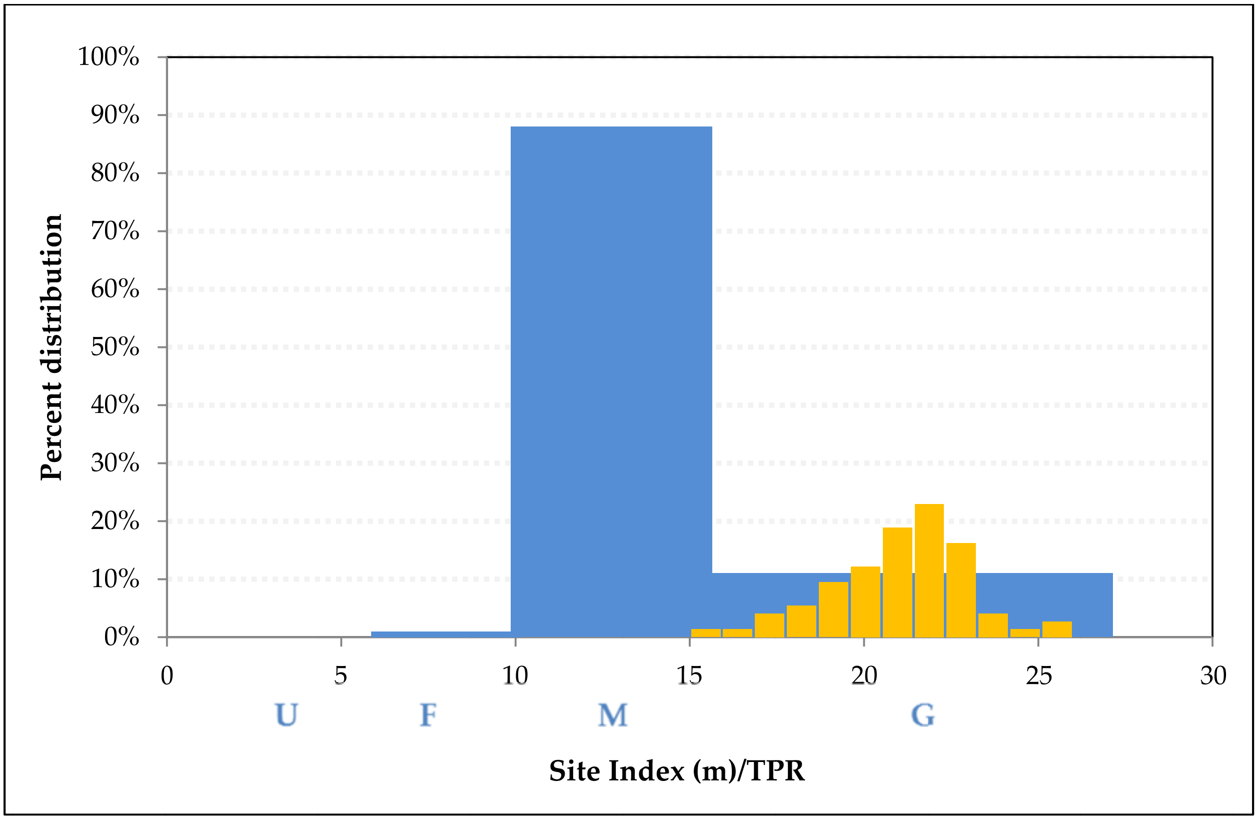

Figure 5-5. Frequency distribution of white spruce timber productivity rating (TPR) on the pre-development landscape (blue bars) in comparison with observed data from the SBH study site (yellow bars), using GYPSY-based site-index estimates and corresponding TPR classes (U = Unproductive; F = Fair; M = Medium; G = Good).

Table 5-3. Proportion (percentage of area [pre-development] or plot observations [SBH]) of TPR class by species and area.

		TPR Class			
Species	**Area**	**Unproductive (%)**	**Fair (%)**	**Medium (%)**	**Good (%)**
Aspen	Pre-development	0	16	55	29
	SBH reclaimed	0	0	21	79
White spruce	Pre-development	0	1	88	11
	SBH reclaimed	0	0	1	99

5.3 WILL EARLY GROWTH TRENDS BE MAINTAINED IN THE FUTURE?

When trying to draw conclusions on vegetation performance based on data from relatively young stands, there is always a question as to whether currently observed performance will persist as the stand ages. The most plausible site-based mechanisms (i.e., factors inherent to the site, as opposed to disturbance agents such as insect outbreaks) for declining performance would be increased demand for soil water and nutrient resources by stands entering the inter-tree competition phase. As discussed above, the nutritional status of overstory species on the SBH study site does not suggest that nutrient supply is likely to limit future performance.

Our best understanding of vegetation demand for soil water on the SBH site comes from the multi-year study conducted by Sean Carey of McMaster University (Carey 2013), in which actual evapotranspiration (AET, which is equivalent to the combined "demand" for soil water from vegetation transpiration and soil-surface evaporation) has been measured through eddy-covariance techniques on the SBH plateau since 2003. This study demonstrated an increase in AET from 2003 to 2009, due initially to shifts in vegetation composition (from a forb and graminoid-dominated community in 2003 and 2004 to a tree-dominated community in subsequent years), and then to development of the vegetation overstory. Average AET values have been generally maintained since 2009, with peak monthly levels occurring mid-growing-season (July), reaching values of ~115-120 mm, and total growing-season values approaching 400 mm. These values and the trajectory of their recovery are consistent with data (Amiro *et al*. 2006a, Amiro *et al*. 2006b, Arain *et al*., 2002, Baldocci 2000, Barr *et al*., 2007, Devito 2005, Nijssen 2002, Pomeroy *et al.* 1997, Swanson and Rothwell 2001) from naturally regenerated mixedwood stands in northern Alberta (although the recovery-and-plateau trajectory is more rapid in natural regeneration), and are evidence that soil-water demand from vegetation has reached an approximate steady-state maximum, and should not be expected to increase further as the SBH forests mature beyond normal inter-annual variation. AET values and corresponding values for leaf-area index are presented in Figure 5-6 (the LAI values in this figure were measured at the locations labelled "LAI1", "LAI2", and "LAI3" in this study. See Figure 3-1).

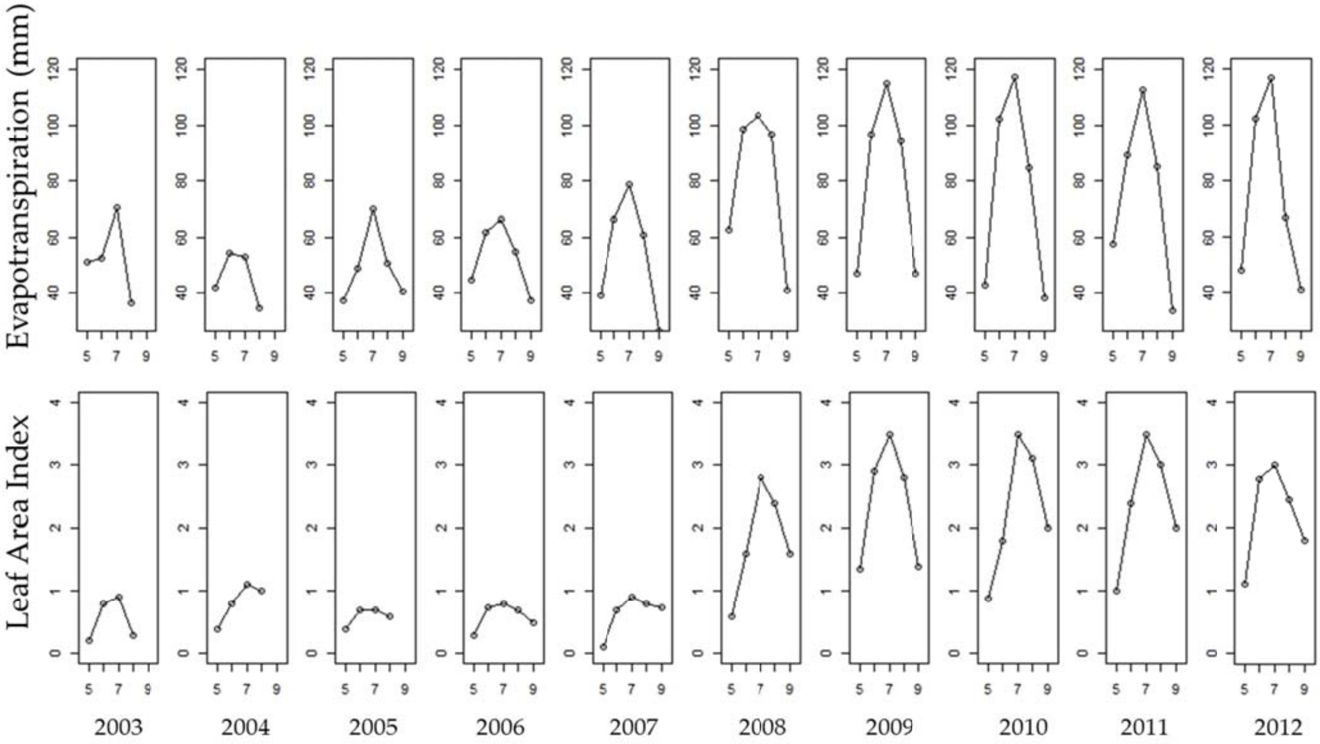

Figure 5-6. Evapotranspiration and leaf-are index on the SBH study site from 2003 to 2012 (x-axis labels refer to months of the year, where 5=May, etc.) – data and figures courtesy Dr. Sean Carey, McMaster University.

As the vast majority of transpiration is water-vapour loss from leaf stomata, LAI can be used as a surrogate for measures of transpiration (direct measurements of transpiration require far more equipment and effort, and are not available for the non-plateau areas of the SBH study site). The LAI data presented in Figure 5-6 follow a similar pattern to that presented for AET, with an increase in peak LAI values up to 2009, and similar annual LAI maxima of approximately 3.0-3.5 since then. Although we do not have direct AET measurements for the SBH study site, we can equate LAI to AET, and infer vegetation water demand across the study site by comparing measured LAI for areas where AET is unknown to the LAI-AET relationship established on the SBH plateau. This comparison is presented in Figure 5-7, with the "LAI" and "Plateau" values representing approximate extent of vegetation currently measured by the McMaster eddy-covariance installation. (Note for sake of comparison between Figure 5-6 and Figure 5-7 that the average of LAI values measured in this study at the McMaster LAI-measurement locations is 1.88, which is similar to the value of 1.8 measured by McMaster at the same locations [though using slightly different methods] in September 2012). For more details on the McMaster evapotranspiration work, please refer to Carey, 2013. All LAI data collected for this study are presented in Appendix H.

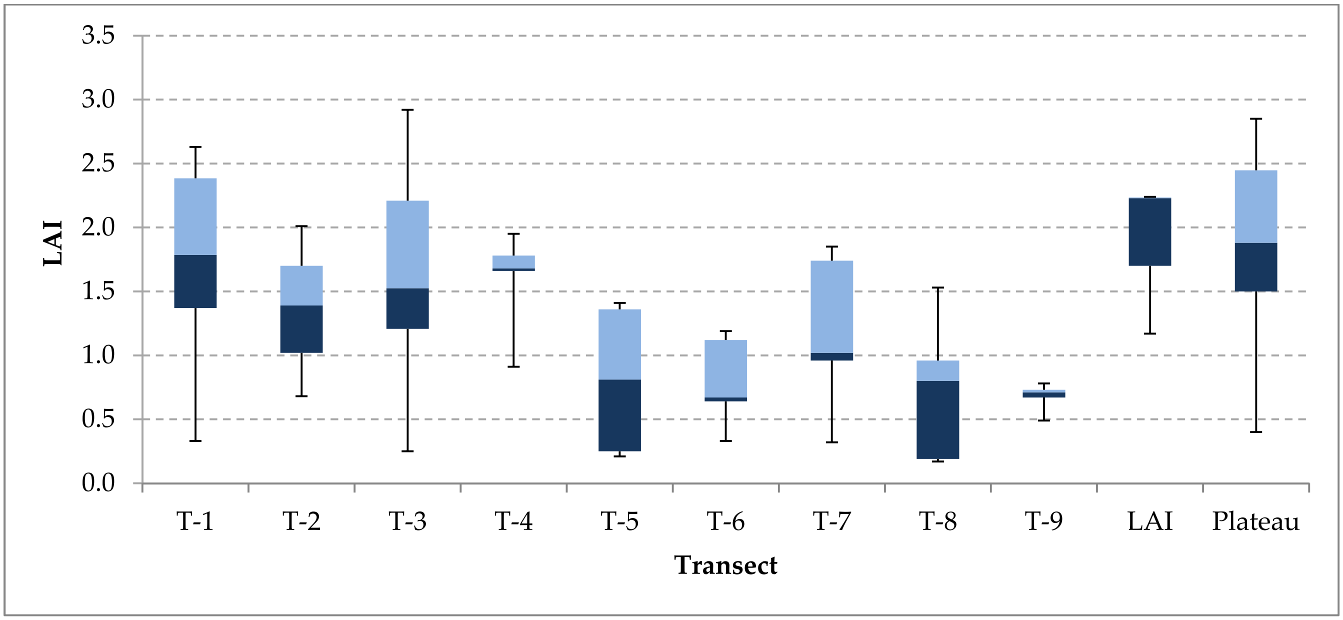

Figure 5-7. LAI by transect and area on the study site. Metrics of the box plots are 25th, 50th, and 75th percentiles; whiskers denote minimum and maximum values; mean values are at box mid-points.

The comparison shown in Figure 5-7 indicates that LAI on the plateau is approximately equivalent to that measured on transects 1 through 4, but is substantially greater than that measured on transects 5 through 9. Probable reasons for this measured difference are:

- differences in composition of vegetation communities – natural regeneration of aspen is much greater on the plateau, due possibly to higher initial surface soil moisture conditions on the plateau, or possibly to greater production and catch of aspen seed on the plateau in the years immediately following cover placement. The reduction in aspen abundance on transects 5-9 results in a reduction in leaf area. And,
- differences in development trajectories – it appears that a combination of aspect effects (reduced surface-soil moisture due to increased solar radiation) and grass competition initially retarded the regeneration trajectory on transects 5 through 9, which means that the overstory canopy, and hence leaf area, has developed more slowly on the plateau. This reduction in development rate is generally not reflected in site-index estimates, indicating that it is largely historic, occurring only in the initial years after revegetation.

The implication of reduced LAI values on transects 5 through 9 in comparison to the plateau is that evapotranspirative demand on these transects has not yet reached the level measured on the plateau. This demand is likely to increase somewhat as the stands on these transects develop, but will likely remain lower than the levels measured on the plateau, as these south-aspect stands would be expected to be less productive than those on the plateau, and thus photosynthesize and transpire less.

Because of the importance in this study of the cover-trial areas in reaching conclusions on the effects of capping depth, the LAI comparison between these areas and the plateau area is presented in Figure 5-8. Data used in this figure for the cover-trial transects are derived from the same plots used for the earlier site-index figures (i.e., crest and toe plots have been removed). The plateau values are derived from the approximate area currently measured by the McMaster eddy-covariance tower, and composed of measurements from all additional "P" plots, the "LAI" plots, and plots "7P" and "7P1". Note that this approach differs from that used in Figure 5-7, where the "Plateau" category includes only the additional "P" plot.

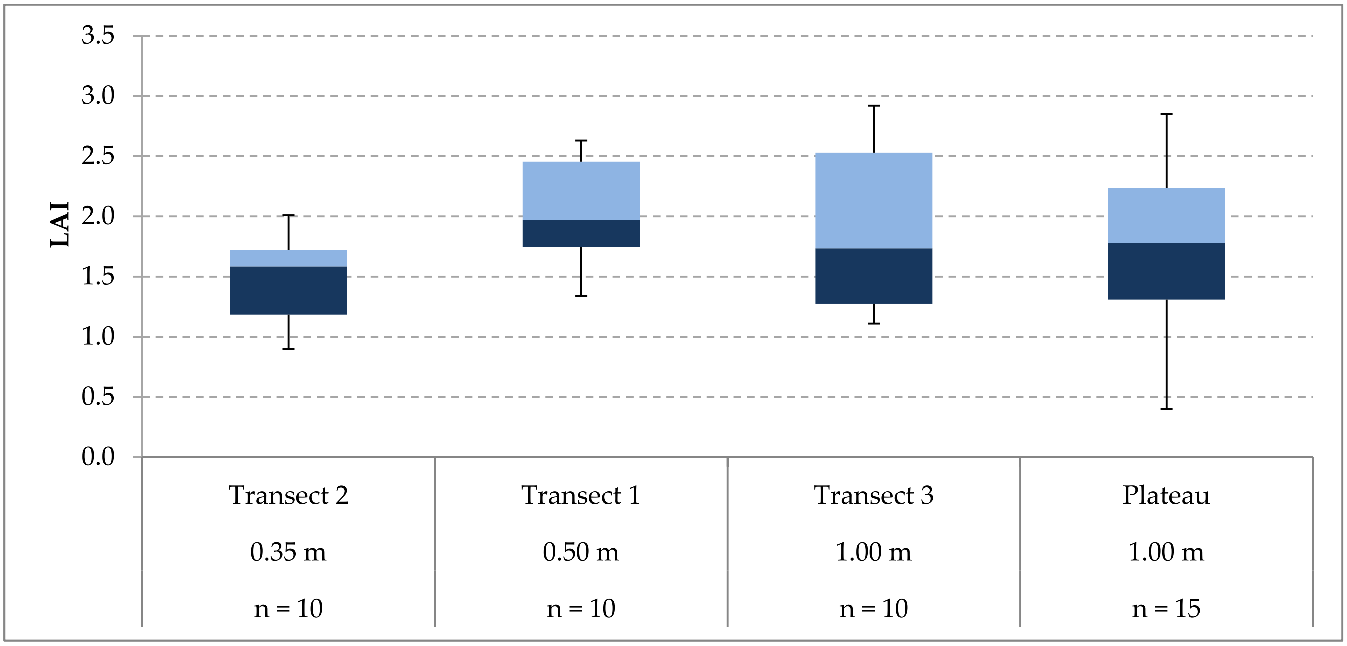

Figure 5-8. LAI in the capping depth trial and plateau area of the study site. Metrics of the box plots are 25th, 50th, and 75th percentiles; whiskers denote minimum and maximum values; mean values are at box mid-points .

The LAI data shown in Figure 5-8 indicates no significant differences in LAI by surveyed area, although the mean value on the 35-cm cover-trial area is approximately 20% less than that of the plateau. As previously discussed, this reflects the more moisture-constrained conditions on the thin-cover area, which will likely not support the same canopy density and LAI as the thicker covers found on the other two cover-trial transects and the plateau.

Based on the comparisons presented in Figure 5-7 and Figure 5-8, we can infer that evapotranspirative demand on the cover-trial transects is at or very close to its maximum, and should not be expected to increase (beyond normal inter-annual variation) in future years. Therefore, we believe that the discussion of growth performance results to date is indicative of what should be expected on this site to maturity.

5.4 HIGH GROWTH RATES

The observed growth in this study is seemingly higher than what is observed in natural stands in the surrounding areas of northern Alberta, and is also seemingly as high as, or possibly slightly higher than, what is observed in post-harvest regeneration in this region. However, this assessment is based only on site index at an early stage of stand development. Site index is a very commonly used measure of growth and inherent site potential in traditional forestry practice. One of the main assumptions is that site index, as measured by tree height growth, is relatively stable over time. Numerous empirical studies over many years in many areas of the world have shown this to be largely true; however, some researchers now speculate that this may not be true under conditions of climate change, and may also not be true for reconstructed sites. This is a compelling reason to continue carefully monitoring the growth of trees on reclaimed soil conditions over time.

Some possible reasons for this seemingly higher growth rates in these areas compared to surrounding natural areas include improved soil aeration and drainage, improved soil nutrition (especially N), higher soil temperatures, and decreased vegetative competition in the establishment phase.

5.5 SITE-INDEX ESTIMATION METHODS

Our site-index estimation procedures were slightly different from Government of Alberta standards. We do not believe that our methods impact the results in a significant way or change the general trends or results shown in this study.

We estimated site index from one tree in a 100-m^2 plot, while the standard in Alberta is to use the average of three trees in a 300-m^2 plot. This discrepancy could result in a slight under-estimation of site index on the SBH study site. In addition, where growth-intercept site-index is reported, it is based on the visually identified tallest tree in the plot, rather than on the largest-diameter tree, which could result in a small over-estimation of site index (although the majority of the time the two selection methods identified the same tree).

Because we did not perform destructive sampling in this program, total age values for GYPSY-based site-index estimates are derived from planting records. This approach introduces some uncertainty for aspen, which has substantial natural colonization on the study site. Because of this uncertainty, we performed some sensitivity analyses, where we increased the estimated age of volunteer aspen by one year. This approach reduced site indices for applicable trees by less than 10% (approximately 1.4 m), and did not have an appreciable effect on overall study results and interpretations.

There is some evidence that estimating site index in young white spruce stands can overestimate site index due to "dominance switching" (Feng *et al*. 2006). To acknowledge this issue, we tested the correction methods of Feng *et al*. 2006 in this analysis. The results showed that the overall average site index did not change, but the variation was greatly increased and included estimates that we believe are unrealistic. We therefore chose to not use the correction and to retain the GYPSY estimates. This is an issue that we believe needs further investigation by growth-and-yield researchers and is beyond the scope of this study. A carefully designed monitoring program in reclaimed oil sands areas will quantify this phenomenon if it occurs. This issue is addressed in more detail in Appendix E.

5.6 STATISTICAL LIMITATIONS

There are theoretical and statistical limitations to inferring the results of this trial to other areas. These are associated with the lack of replication of capping treatments within the study site and across other reclaimed areas. Theoretically, the interpretation of the results reported here are limited to the treatment plots/landform from which they were collected. However, we believe that these statistical limitations will not change the general trends observed here and that it is reasonable to expect that tree growth on other areas treated in a similar manner would respond in a similar way.

We understand these limitations and understood them prior to beginning this study. We believe that due to the efforts in detailed instrumentation and research on this site, the processes governing major phenomena influencing tree response, such as surface-water movement and storage, are well understood. This provides some justification for extrapolating the results to other landforms reclaimed in similar ways. However, we also acknowledge that replication in the form of additional study sites and additional installations within sites would improve statistical confidence in the trends and results shown in this study.

6 CONCLUSIONS

The above-ground vegetation data collected in this study indicate adequate establishment and growth of vegetation across the SBH study site, including on the thinner capping depths found on the cover-trial transects. No nutritional deficiencies in trees were identified or are expected to manifest in the future, and height-growth parameters on all plots meet or exceed comparative values from a range of sources. Site-index values on the SBH site, including those on the thinnest cover (35 cm), generally show higher site productivity than that indicated by pre-disturbance mapping of the Mildred Lake lease area.

Examination of tree growth performance by cover depth indicates some significant positive relationships – these relationships are strongest for white spruce (using GI-based site-index estimates) as cover thickness increases from 10-50 cm, with less rapid gains in site index with additional increases in cover depth.

Data collected on evapotranspiration and leaf-area index demonstrate that vegetation demand for water has increased over the period of stand development, and then levelled off as the overstory reaches crown closure. This indicates that the SBH site is at or nearing a steady-state with respect to vegetation use of soil water for transpiration, and should not be expected to continue increasing its demand in the future. This finding in turn means that we can expect the validity of the conclusions reached in this study to be maintained as the SBH forest stands age – in particular, there is no reason to expect declining site index over time (although our site-index estimates will become more accurate if repeated on older trees).

It is important to note that the growth performance documented in this study is based largely on a relatively short period from approximately 2005 onward where growing-season precipitation has been similar to the long-term climate record (Carey 2013). Substantial deviations from mean conditions, including drought periods, are to be expected over the lifespan of a forest stand, and extended drought periods would result in reductions to the growth performance measured in this study. For this reason it would be prudent to be cautious or conservative with management interpretations of data collected in this study. The modelling report conducted by Huang and Barbour for this study supports this conservatism, showing that over a longer simulated climatic record of 60 years, cover depths of up to 75 cm may be required to meet vegetation water demands over extended drought periods, whereas this study indicates little benefit in cover depths of greater than 50 cm.

In synthesis, we believe that the data and interpretations included in this report support the following conclusions:

1. all covers on the SBH study area, regardless of thickness, are supporting above-ground vegetation characteristics that meet or exceed relevant equivalent-capability targets;
2. increases in tree growth performance may be observed with increasing cover thickness, with the rate of increase being greater at thicknesses from 10-50 cm, and lower as thicknesses increase past 50 cm. However, these trends, where they exist, are generally weak, and are based on measurements conducted on young trees, which emphasizes the importance of continued monitoring as these stands develop. It is important to recognize that the SBH reclamation objective is not to achieve maximum tree growth performance, but to achieve performance consistent with equivalent-capability targets. This study shows that thicker covers are not necessary for this achievement.
3. Evapotranspiration and leaf-area index data collected by McMaster University on the SBH plateau show that evapotranspiration has reached an approximate steady state, and should not be expected to increase in the future beyond inter-annual variation driven by climatic variation. Thus, we believe that the validity of conclusions from this study will be maintained in the future, and will not be substantially affected by maturation of the SBH forest stands. In particular, we do not expect substantial decreases in site index as these stands age. As above, this premise should be tested through future monitoring.
4. Site-index and soil salinity/sodicity values suggest a minimum reclamation-cover depth of 50 cm. Modelling of performance over longer climatic cycles indicates that cover depths of up to 75 cm may be required to meet vegetation water demands over extended drought periods.

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South Bison Hill research synthesis – vegetation overstory response to reclamation cover depth

– Appendices –

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February 22, 2013

Project No. SCL30D-12

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APPENDIX A – INFORMATION ON SEEDLINGS PLANTED AT SBH

1999 – Planting started on Sept 10 and was completed Nov 5 by Fort McKay Environment Services (subcontracted out). Seedling production was sub-contracted to K&C Silviculture in Red Deer and Smoky Lake Forest Nursery.

2002 – Planting started on Aug 26 and was completed Sept 18 by Fort McKay Environment Services (sub-contracted out to Forest Tree Consultants Ltd.). Seedling production was sub-contracted to K&C Silviculture for the white spruce; Smoky Lake for aspen and jack pine.

Seed lots

Aspen:	SYN 10-93-11-4-1995	Provincial Registration # - 3380
Spruce:	SYN 16-93-10-4-1990	Provincial Registration # - 3421
Pine:	SYN 95-10-4-1990	Provincial Registration # - 3616

2003 – Planting was from Aug 14-23 by Ft. McKay (sub-contracted out to Forest Tree Consultants Ltd.) Seedling production was sub-contracted to K&C Silviculture for the white spruce; Smoky Lake for aspen and jack pine and shrubs.

Seed lots

Aspen – same as previous (SAP)

Spruce:	SYN 4-93-10-4-1995	Provincial Registration # - 3513
Pine:	SAP	

Shrubs collected in locations:
Green Alder – R11 TP94 W of 4th
Prickly Rose – R10 TP89 W of 4
Common Rose – R9 TP89 W of 4

2004 – Planting was from June 25 to July 12, and from August 18-29 by Fort McKay. Seedling production was sub-contracted to K&C Silviculture for the white spruce; Smoky Lake for aspen and jack pine and shrubs.

Seed lots

Aspen:	SYN 10-93-11-4-1995	Provincial Registration # - 3380 AND
	SYN 19-93-10-4-1997	Provincial Registration # - 3381
Spruce:	SYN 4-93-10-4-1995	Provincial Registration # - 3513
	SYN 22-92-11-4-1996	Provincial Registration # - 3514
	SYN 28-92-11-4-1998	Provincial Registration # - 3515

Shrubs collected:

Green Alder, Red-osier dogwood and pin cherry – R11 TP94 W 0f 4
Choke cherry – R10 TP92 W of 4
Saskatoon – R10 TP93 W of 4

APPENDIX B – VEGETATION DATA

Table 1. White Spruce Growth Intercept Data.

PLOT	UNIQUEID	SPEC	HTCM	DIAMM	INTCM	INTNO	BHAGE	GI	SI_GI
1A	SW30-1A-20	SW	416	54	253	5	7	0.51	21.97
1B	SW30-1B-44	SW	416	56	212	5	7	0.42	20.82
1C	SW30-1C-10	SW	244	19	130	3	3	0.43	20.97
1D	SW30-1D-76	SW	535	74	287	5	7	0.57	22.74
1E	SW30-1E-90	SW	486	69	262	5	7	0.52	22.19
1G	SW30-1G-14	SW	523	64	232	5	7	0.46	21.42
1H	SW30-1H-28	SW	555	69	315	5	7	0.63	23.28
1J	SW30-1J-73	SW	461	65	233	5	7	0.47	21.45
1L	SW30-1L-53	SW	492	65	273	5	7	0.55	22.44
1M	SW30-1M-1	SW	497	64	261	5	8	0.52	22.17
1U	SW30-1U-59	SW	467	63	254	5	7	0.51	22.00
2A	SW30-2A-527	SW	338	42	152	5	6	0.30	18.47
2B	SW30-2B-541	SW	404	50	195	5	6	0.39	20.25
2C	SW30-2C-516	SW	292	29	157	3	4	0.52	22.08
2D	SW30-2D-560	SW	493	68	226	5	8	0.45	21.25
2E	SW30-2E-578	SW	422	55	198	5	6	0.40	20.36
2G	SW30-2G-607	SW	499	75	206	5	8	0.41	20.63
2H	SW30-2H-633	SW	529	73	212	5	8	0.42	20.82
2J	SW30-2J-658	SW	500	67	231	5	7	0.46	21.39
2L	SW30-2L-645	SW	463	62	184	5	7	0.37	19.85
2M	SW30-2M-603	SW	476	63	222	5	7	0.44	21.13
2T	SW30-2T-674	SW	563	62	270	5	7	0.54	22.37
2U	SW30-2U-553	SW	404	59	162	5	7	0.32	18.94
3A	SW30-3A-745	SW	361	43	211	4	5	0.53	22.11
3B	SW30-3B-763	SW	654	72	352	5	7	0.70	23.89
3D	SW30-3D-803	SW	516	58	308	5	7	0.62	23.15
3E	SW30-3E-815	SW	470	61	266	5	7	0.53	22.28
3G	SW30-3G-38	SW	498	62	261	5	7	0.52	22.17
3H	SW30-3H-64	SW	421	56	233	5	7	0.47	21.45
3J	SW30-3J-90	SW	447	54	277	5	6	0.55	22.53
3L	SW30-3L-81	SW	427	64	224	5	7	0.45	21.19
3M	SW30-3M-7	SW	523	61	294	5	7	0.59	22.88
3U	SW30-3U-795	SW	559	64	310	5	7	0.62	23.19
4C	SW30-4C-73	SW	238	17	100	3	4	0.33	19.27
4L	SW30-4L-29	SW	371	34	194	3	4	0.65	23.21
4M	SW30-4M-45	SW	357	39	216	3	4	0.72	23.74
4T	SW30-4T-4	SW	298	23	165	3	4	0.55	22.36
4U	SW30-4U-57	SW	284	29	145	3	4	0.48	21.62

PLOT	UNIQUEID	SPEC	HTCM	DIAMM	INTCM	INTNO	BHAGE	GI	SI_GI
5L	SW30-5L-25	SW	208	18	95	3	3	0.32	18.93
5M	SW30-5M-34	SW	234	22	116	3	3	0.39	20.25
5T	SW30-5T-10	SW	310	29	172	3	4	0.57	22.58
5U	SW30-5U-50	SW	254	22	146	3	3	0.49	21.66
7C	SW30-7C-72	SW	257	25	120	3	4	0.40	20.47
7M	SW30-7M-8	SW	326	44	190	3	5	0.63	23.11
7P	SW30-7P-82	SW	312	35	137	3	4	0.46	21.29
7P1	SW30-7P1-55	SW	326	30	178	3	4	0.59	22.77
7T	SW30-7T-24	SW	433	49	298	5	6	0.60	22.96
8M	SW30-8M-20	SW	220	22	77	3	4	0.26	17.45
8P	SW30-8P-56	SW	288	26	164	3	3	0.55	22.32
8P1	SW30-8P1-42	SW	234	21	111	3	3	0.37	19.97
8T1	SW30-8T1-6	SW	308	36	156	4	5	0.39	20.21
9C	SW30-9C-82	SW	296	33	175	3	4	0.58	22.68
9L	SW30-9L-38	SW	264	24	126	3	4	0.42	20.78
9M	SW30-9M-45	SW	272	24	164	3	3	0.55	22.32
9T	SW30-9T-27	SW	312	30	158	3	4	0.53	22.12
9U	SW30-9U-77	SW	246	22	142	3	3	0.47	21.50
LAI1	SW30-LAI1-684	SW	314	29	150	3	4	0.50	21.82
LAI2	SW30-LAI2-713	SW	334	31	177	3	4	0.59	22.74
LAI3	SW30-LAI3-742	SW	239	21	128	3	3	0.43	20.87
PA	SW30-PA-826	SW	292	27	155	3	4	0.52	22.01
PB	SW30-PB-15	SW	312	28	165	3	4	0.55	22.36
PD	SW30-PD-963	SW	227	22	110	3	3	0.37	19.91
PE	SW30-PE-984	SW	372	33	230	4	5	0.58	22.61
PF	SW30-PF-856	SW	258	23	122	3	4	0.41	20.57
PH	SW30-PH-7	SW	361	30	197	3	4	0.66	23.29
PJ	SW30-PJ-89	SW	307	25	151	3	4	0.50	21.86
PK	SW30-PK-82	SW	290	29	154	3	4	0.51	21.97

Table 2. White Spruce & Aspen Site Tree Data.

PLOT	UNIQUEID	SPEC	HT CM	DIA MM	PLANT YEAR	PLANT SEAS	PLUG AGE	TOT AGE	Y2BH	SI GYPSY	SI FENG
1A	SW30-1A-22	SW	447	67	1999	Fall	1	14	6.63	20.65	21.59
1A	SW30-1A-28	AW	581	65	1999	Fall	1	14	3.60	16.69	
1B	SW30-1B-46	AW	519	60	1999	Fall	1	14	4.00	15.50	
1B	SW30-1B-44	SW	416	56	1999	Fall	1	14	6.92	19.84	19.96
1C	SW30-1C-10	SW	244	19	2003	Fall	1	10	6.95	19.75	17.10
1D	SW30-1D-76	SW	535	74	1999	Fall	1	14	5.97	22.79	26.20
1D	SW30-1D-71	AW	750	66	1999	Fall	1	14	2.82	19.60	
1E	SW30-1E-97	SW	454	74	1999	Fall	1	14	6.57	20.83	21.96
1E	SW30-1E-99	AW	672	69	1999	Fall	1	14	3.14	18.31	
1G	SW30-1G-14	SW	523	64	1999	Fall	1	14	6.05	22.51	25.57
1G	SW30-1G-17	AW	653	50	1999	Fall	1	14	3.23	17.98	
1H	SW30-1H-28	SW	555	69	1999	Fall	1	14	5.84	23.24	27.25
1H	SW30-1H-32	AW	673	55	1999	Fall	1	14	3.13	18.32	
1J	SW30-1J-73	SW	461	65	1999	Fall	1	14	6.51	21.01	22.32
1J	SW30-1J-56	AW	634	57	1999	Fall	1	14	3.32	17.65	
1L	SW30-1L-53	SW	492	65	1999	Fall	1	14	6.27	21.78	23.95
1L	SW30-1L-52	AW	698	57	1999	Fall	1	14	3.03	18.75	
1M	SW30-1M-1	SW	497	64	1999	Fall	1	14	6.23	21.90	24.21
1M	SW30-1M-100	AW	563	56	1999	Fall	1	14	3.71	16.35	
1T	SW30-1T-74	AW	670	48	1999	Fall	1	14	3.15	18.27	
1U	SW30-1U-59	SW	467	63	1999	Fall	1	14	6.46	21.16	22.64
1U	SW30-1U-53	AW	536	56	1999	Fall	1	14	3.88	15.83	
2A	SW30-2A-526	AW	657	77	1999	Fall	1	14	3.21	18.05	
2A	SW30-2A-527	SW	338	42	1999	Fall	1	14	7.82	17.61	15.88
2B	SW30-2B-545	SW	379	62	1999	Fall	1	14	7.31	18.82	18.03
2B	SW30-2B-539	AW	699	60	1999	Fall	1	14	3.02	18.76	
2C	SW30-2C-516	SW	292	29	2003	Fall	1	10	6.28	21.73	21.02
2D	SW30-2D-560	SW	493	68	1999	Fall	1	14	6.26	21.80	24.00
2D	SW30-2D-568	AW	713	62	1999	Fall	1	14	2.97	19.00	
2E	SW30-2E-574	AW	716	79	1999	Fall	1	14	2.95	19.05	
2E	SW30-2E-578	SW	422	55	1999	Fall	1	14	6.86	20.00	20.28
2G	SW30-2G-607	SW	499	75	1999	Fall	1	14	6.22	21.94	24.31
2G	SW30-2G-622	AW	701	67	1999	Fall	1	14	3.01	18.80	
2H	SW30-2H-633	SW	529	73	1999	Fall	1	14	6.01	22.65	25.88
2H	SW30-2H-636	AW	537	60	1999	Fall	1	14	3.88	15.85	
2J	SW30-2J-661	AW	864	83	1999	Fall	1	14	2.45	21.36	
2J	SW30-2J-658	SW	500	67	1999	Fall	1	14	6.21	21.97	24.36
2L	SW30-2L-645	SW	463	62	1999	Fall	1	14	6.49	21.06	22.43
2L	SW30-2L-656	AW	690	58	1999	Fall	1	14	3.06	18.61	

PLOT	UNIQUEID	SPEC	HT CM	DIA MM	PLANT YEAR	PLANT SEAS	PLUG AGE	TOT AGE	Y2BH	SI GYPSY	SI FENG
2M	SW30-2M-603	SW	476	63	1999	Fall	1	14	6.39	21.38	23.11
2M	SW30-2M-601	AW	522	60	1999	Fall	1	14	3.98	15.56	
2T	SW30-2T-674	SW	563	62	1999	Fall	1	14	5.79	23.42	27.66
2T	SW30-2T-672	AW	737	47	1999	Fall	1	14	2.87	19.39	
2U	SW30-2U-546	SW	405	67	1999	Fall	1	14	7.03	19.54	19.39
2U	SW30-2U-548	AW	582	57	1999	Fall	1	14	3.60	16.71	
3A	SW30-3A-753	AW	610	54	1999	Fall	1	14	3.44	17.22	
3A	SW30-3A-745	SW	361	43	1999	Fall	1	14	7.52	18.30	17.08
3B	SW30-3B-763	SW	654	72	1999	Fall	1	14	5.31	25.36	32.43
3B	SW30-3B-776	AW	666	67	1999	Fall	1	14	3.17	18.20	
3D	SW30-3D-807	AW	740	83	1999	Fall	1	14	2.86	19.44	
3D	SW30-3D-803	SW	516	58	1999	Fall	1	14	6.09	22.35	25.20
3E	SW30-3E-815	SW	470	61	1999	Fall	1	14	6.44	21.24	22.79
3E	SW30-3E-820	AW	713	60	1999	Fall	1	14	2.97	19.00	
3G	SW30-3G-40	AW	790	68	1999	Fall	1	14	2.68	20.23	
3G	SW30-3G-38	SW	498	62	1999	Fall	1	14	6.22	21.92	24.26
3H	SW30-3H-59	AW	752	68	1999	Fall	1	14	2.82	19.63	
3H	SW30-3H-57	SW	405	56	1999	Fall	1	14	7.03	19.54	19.39
3J	SW30-3J-87	AW	658	68	1999	Fall	1	14	3.20	18.07	
3J	SW30-3J-84	SW	465	61	1999	Fall	1	14	6.48	21.11	22.53
3L	SW30-3L-66	AW	762	67	1999	Fall	1	14	2.78	19.79	
3L	SW30-3L-81	SW	427	64	1999	Fall	1	14	6.81	20.13	20.54
3M	SW30-3M-8	SW	466	65	1999	Fall	1	14	6.47	21.14	22.58
3M	SW30-3M-9	AW	797	60	1999	Fall	1	14	2.66	20.34	
3T	SW30-3T-96	AW	509	46	1999	Fall	1	14	4.08	15.30	
3U	SW30-3U-777	AW	712	69	1999	Fall	1	14	2.97	18.98	
3U	SW30-3U-789	SW	515	66	1999	Fall	1	14	6.10	22.32	25.15
4C	SW30-4C-70	AW	500	40	2004	Ingress	0	8	2.47	21.28	
4C	SW30-4C-71	SW	232	19	2003	Fall	1	10	7.15	19.22	16.12
4L	SW30-4L-24	AW	570	43	2002	Fall	1	11	2.94	19.08	
4L	SW30-4L-29	SW	371	34	2002	Fall	1	11	5.98	22.74	24.22
4M	SW30-4M-46	AW	730	63	2002	Fall	1	11	2.33	22.02	
4M	SW30-4M-45	SW	357	39	2002	Fall	1	11	6.11	22.29	23.22
4T	SW30-4T-18	AW	836	74	2002	Fall	1	11	2.04	23.76	
4T	SW30-4T-1	SW	278	24	2002	Fall	1	11	7.04	19.49	17.52
4U	SW30-4U-67	AW	493	44	2004	Ingress	0	8	2.50	21.12	
4U	SW30-4U-57	SW	284	29	2003	Fall	1	10	6.38	21.42	20.37
5C	SW30-5C-74	AW	510	42	2004	Ingress	0	8	2.43	21.51	
5C	SW30-5C-73	SW	266	26	2003	Fall	1	10	6.62	20.69	18.90
5L	SW30-5L-23	SW	206	19	2002	Fall	1	11	8.37	16.45	12.33
5M	SW30-5M-34	SW	234	22	2002	Fall	1	11	7.78	17.70	14.35

PLOT	UNIQUEID	SPEC	HT CM	DIA MM	PLANT YEAR	PLANT SEAS	PLUG AGE	TOT AGE	Y2BH	SI GYPSY	SI FENG
5T	SW30-5T-6	AW	566	49	2003	Fall	1	10	2.71	20.09	
5T	SW30-5T-10	SW	310	29	2003	Fall	1	10	6.08	22.42	-
5U	SW30-5U-50	SW	254	22	2004	Fall	1	9			20.59
6C	SW30-6C-929	SW	252	29	2003	Fall	1	10	6.82	20.10	17.75
6L	SW30-6L-883	SW	189	13	2004	Fall	1	9			14.48
6M	SW30-6M-888	SW	204	19	2003	Fall	1	10	7.69	17.89	13.83
6T1	SW30-6T1-995	AW	518	48	2003	Fall	1	9	2.94	19.08	
6U	SW30-6U-908	SW	270	30	2003	Fall	1	10	6.56	20.85	19.22
7C	SW30-7C-72	SW	257	25	2003	Fall	1	10	6.75	20.31	18.16
7M	SW30-7M-8	SW	326	44	2003	Fall	1	10	5.91	23.00	23.80
7M	SW30-7M-9	AW	452	43	2003	Fall	1	10	3.33	17.60	
7P	SW30-7P-83	AW	610	56	2004	Ingress	0	8	2.06	23.66	
7P	SW30-7P-80	SW	256	20	2003	Fall	1	10	6.76	20.27	18.08
7P1	SW30-7P1-35	AW	597	49	2004	Ingress	0	8	2.10	23.39	
7P1	SW30-7P1-41	SW	313	31	2003	Fall	1	10	6.04	22.53	22.74
7T	SW30-7T-100	AW	575	61	2003	Fall	1	10	2.67	20.27	
7T	SW30-7T-22	SW	414	51	2003	Fall	1	10	5.18	25.92	31.00
8C	SW30-8C-26	SW	160	9	2003	Fall	1	10	8.85	15.55	10.23
8M	SW30-8M-20	SW	220	22	2003	Fall	1	10	7.37	18.66	15.13
8P	SW30-8P-62	AW	532	49	2004	Ingress	0	8	2.33	22.01	
8P	SW30-8P-56	SW	288	26	2003	Fall	1	10	6.33	21.57	20.69
8P1	SW30-8P1-50	SW	245	29	2003	Fall	1	10	6.93	19.80	17.18
8T1	SW30-8T1-6	SW	308	36	2003	Fall	1	10	6.10	22.34	22.33
9C	SW30-9C-82	SW	296	33	2003	Fall	1	10	6.23	21.89	21.35
9L	SW30-9L-38	SW	264	24	2003	Fall	1	10	6.65	20.61	18.73
9M	SW30-9M-48	AW	490	41	2003	Fall	1	10	3.10	18.47	
9M	SW30-9M-45	SW	272	24	2003	Fall	1	10	6.54	20.93	19.39
9T	SW30-9T-31	AW	608	51	2003	Fall	1	10	2.54	20.92	
9T	SW30-9T-27	SW	312	30	2003	Fall	1	10	6.05	22.49	22.66
9U	SW30-9U-78	AW	431	40	2003	Fall	1	10	3.48	17.10	
9U	SW30-9U-77	SW	246	22	2003	Fall	1	10	6.92	19.84	17.26
LAI1	SW30-LAI1-683	AW	688	56	2004	Ingress	0	8	1.84	25.17	
LAI1	SW30-LAI1-685	SW	339	35	2003	Fall	1	10	5.78	23.47	24.86
LAI2	SW30-LAI2-710	AW	562	59	2004	Ingress	0	8	2.22	22.66	
LAI2	SW30-LAI2-713	SW	334	31	2003	Fall	1	10	5.83	23.29	24.46
LAI3	SW30-LAI3-731	AW	590	45	2004	Ingress	0	8	2.12	23.25	
LAI3	SW30-LAI3-742	SW	239	21	2003	Fall	1	10	7.03	19.53	16.69
PA	SW30-PA-836	AW	640	45	2004	Ingress	0	8	1.97	24.26	
PA	SW30-PA-826	SW	292	27	2003	Fall	1	10	6.28	21.73	21.02
PB	SW30-PB-30	AW	724	63	2004	Ingress	0	8	1.75	25.83	
PB	SW30-PB-18	SW	300	29	2003	Fall	1	10	6.19	22.04	21.68

PLOT	UNIQUEID	SPEC	HT CM	DIA MM	PLANT YEAR	PLANT SEAS	PLUG AGE	TOT AGE	Y2BH	SI GYPSY	SI FENG
PC	SW30-PC-860	AW	500	43	2004	Ingress	0	8	2.47	21.28	
PC	SW30-PC-863	SW	208	20	2003	Fall	1	10	7.61	18.09	14.15
PD	SW30-PD-955	AW	586	48	2004	Ingress	0	8	2.14	23.17	
PD	SW30-PD-959	SW	231	24	2003	Fall	1	10	7.17	19.17	16.03
PE	SW30-PE-975	AW	783	68	2004	Ingress	0	8	1.62	26.87	
PE	SW30-PE-984	SW	372	33	2003	Fall	1	10	5.49	24.59	27.56
PF	SW30-PF-843	AW	556	46	2004	Ingress	0	8	2.24	22.53	
PF	SW30-PF-852	SW	299	26	2003	Fall	1	10	6.20	22.00	21.59
PG	SW30-PG-61	AW	477	44	2004	Ingress	0	8	2.58	20.74	
PG	SW30-PG-57	SW	199	12	2003	Fall	1	10	7.80	17.64	13.42
PH	SW30-PH-1	AW	544	47	2004	Ingress	0	8	2.29	22.27	
PH	SW30-PH-3	SW	315	31	2003	Fall	1	10	6.02	22.60	22.90
PI	SW30-PI-94	SW	280	28	2003	Fall	1	10	6.43	21.26	20.04
PJ	SW30-PJ-947	AW	681	54	2004	Ingress	0	8	1.86	25.04	
PJ	SW30-PJ-89	SW	307	25	2003	Fall	1	10	6.11	22.30	22.25
PK	SW30-PK-84	AW	514	45	2004	Ingress	0	8	2.41	21.60	
PK	SW30-PK-82	SW	290	29	2003	Fall	1	10	6.31	21.65	20.86

Table 3. Full dataset of height and DBH of all trees surveyed across SBH. Indications in the single asterisk column (*) indicate a GYPSY site index tree on which more information can be obtained in Table 2; Indications in the double asterisk column (**) indicate a growth intercept site index tree on which more information can be obtained in Table 1.

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
1A	1A-16	AW		6.02	5.7		
1A	1A-17	AW		5.85	5.6		
1A	1A-18	AW		5.9	5.4		
1A	1A-19	SW		4.6	5.1		
1A	1A-20	SW		4.16	5.4		Y
1A	1A-21	AW		5.95	5.6		
1A	1A-22	SW		4.47	6.7	Y	
1A	1A-23	SW		2.98	2.6		
1A	1A-24	AW		4.97	5.4		
1A	1A-25	SW	a	2.75	2.3		
1A	1A-26	SW	a	2.6	1.9		
1A	1A-27	SW		4.37	6.1		
1A	1A-28	AW		5.81	6.5	Y	
1A	1A-29	AW		4.86	4.3		
1A	1A-30	SW	b	2.8	1.9		
1A	1A-31	SW	b	2.25	1.6		
1A	1A-32	SW	b	2.83	2.7		
1A	1A-33	SW	b	2.42	1.6		
1A	1A-34	SW	b	2.15	1.3		
1A	1A-35	SW		2.45	2.6		
1B	1B-36	SW	a	3.7	4.4		
1B	1B-37	SW	a	2.67	2.2		
1B	1B-38	SW		3.74	4.1		
1B	1B-39	SW		3.59	3.8		
1B	1B-40	AW		5.38	4.5		
1B	1B-41	AW		4.55	4.1		
1B	1B-42	SW	b	1.95	1.1		
1B	1B-43	SW	b	2.72	2.7		
1B	1B-44	SW		4.16	5.6	Y	Y
1B	1B-46	AW		5.19	6	Y	
1B	1B-47	SW		4.31	4.3		
1B	1B-48	SW		4.1	4.9		
1B	1B-52	AW		4.56	4.3		
1C	1C-1	SW		1.77	1.1		
1C	1C-10	SW		2.44	1.9	Y	Y
1C	1C-11	SW		1.52	0.8		
1C	1C-12	SW		1.8	1.1		
1C	1C-13	SW		1.75	1		
1C	1C-14	SW		1.85	1.1		
1C	1C-15	SW		2.08	1.6		
1C	1C-2	SW		1.79	1.2		
1C	1C-3	SW		1.99	1.6		
1C	1C-4	SW		1.84	1.3		
1C	1C-5	SW		1.74	1.3		
1C	1C-6	SW		1.88	1		
1C	1C-7	SW		1.58	0.8		
1C	1C-8	SW		1.44	0.7		
1C	1C-9	SW		1.64	0.9		
1D	1D-71	AW		7.5	6.6	Y	
1D	1D-72	AW		5.89	4.8		
1D	1D-73	AW		6.92	6.3		
1D	1D-74	SW		2.1	1.5		
1D	1D-75	AW		6.61	4.9		
1D	1D-76	SW		5.35	7.4	Y	Y
1D	1D-77	SW		0.44	0		
1D	1D-78	SW		4.09	3.7		
1D	1D-79	SW		3.47	3		
1D	1D-80	AW		6.52	6.3		
1D	1D-81	AW		6.13	4.2		
1D	1D-82	SW		4.85	6.5		
1D	1D-83	SW		3.62	3.4		
1D	1D-84	AW		6.78	5.9		
1D	1D-85	AW		5.81	6		
1D	1D-86	AW		7.8	6.5		
1D	1D-87	SW		4.33	5.3		
1D	1D-88	SW		5.18	7		
1D	1D-89	SW		4.85	5.9		
1E	1E-90	SW		4.86	6.9		Y

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
1E	1E-91	AW		5.8	5.1		
1E	1E-92	SW		3.16	3.8		
1E	1E-93	SW		4.8	6		
1E	1E-94	SW		3.53	4.1		
1E	1E-95	SW		4.73	6		
1E	1E-96	SW		4.04	4.4		
1E	1E-97	SW		4.54	7.4	Y	
1E	1E-98	AW		4.98	4.1		
1E	1E-99	AW		6.72	6.9	Y	
1G	1G-14	SW		5.23	6.4	Y	Y
1G	1G-15	AW		5.5	4.4		
1G	1G-16	SW		5	5.4		
1G	1G-17	AW		6.53	5	Y	
1G	1G-18	SW		4.37	5.6		
1G	1G-19	SW		4.12	5.1		
1G	1G-20	AW		5.69	4.4		
1G	1G-21	SW		5.2	6.7		
1G	1G-22	SW		5.35	7.1		
1G	1G-23	SW	a	5	4.2		
1G	1G-24	SW	a	2.9	4.6		
1G	1G-25	SW		4.98	5.3		
1H	1H-28	SW		5.55	6.9	Y	Y
1H	1H-29	SW		4.98	5.7		
1H	1H-30	AW		5.83	5.1		
1H	1H-31	AW		6.35	4		
1H	1H-32	AW		6.73	5.5	Y	
1H	1H-33	AW		6.38	5		
1H	1H-34	SW		4.68	5.7		
1H	1H-35	SW		5.51	6.8		
1H	1H-36	AW		8.04	5.4		
1H	1H-37	AW		7.03	5		
1H	1H-38	SW		4.32	5.8		
1H	1H-39	SW		5.68	6.2		
1H	1H-40	SW		4.65	6.5		
1H	1H-41	SW		5	6.1		
1H	1H-42	AW		5.43	4.3		
1J	1J-56	AW		6.34	5.7	Y	
1J	1J-57	AW		6.55	4.3		
1J	1J-58	SW		4.02	3.5		
1J	1J-59	SW		4.34	4.7		
1J	1J-60	AW		6.3	4.2		
1J	1J-61	SW		4.62	4.3		
1J	1J-62	SW		4.35	5.6		
1J	1J-63	SW		4.53	5.1		
1J	1J-64	AW		5.84	5.2		
1J	1J-65	AW		6.35	4.6		
1J	1J-66	SW		4.67	5.5		
1J	1J-67	SW	a	3.61	3.5		
1J	1J-68	SW	a	3.2	3		
1J	1J-70	AW		5	4.4		
1J	1J-71	SW		2.53	2.7		
1J	1J-72	SW		4.55	5.9		
1J	1J-73	SW		4.61	6.5	Y	Y
1L	1L-42	SW		2.9	3.3		
1L	1L-43	SW	a	3	3.1		
1L	1L-44	SW	a	2.76	2.4		
1L	1L-45	AW		5.45	4		
1L	1L-46	SW		4.94	5.7		
1L	1L-47	SW		4.46	4.6		
1L	1L-48	AW		5.63	4.1		
1L	1L-49	SW		0.64	0		
1L	1L-50	SW		4.28	5.7		
1L	1L-51	AW		6.29	5.2		
1L	1L-52	AW		6.98	5.7	Y	
1L	1L-53	SW		4.92	6.5	Y	Y
1L	1L-54	SW		4.71	5.2		
1L	1L-55	AW		5.1	4		
1M	1M-1	SW		4.97	6.4	Y	Y
1M	1M-10	SW		3.82	5.3		
1M	1M-100	AW		5.63	5.6	Y	
1M	1M-11	AW		5.54	4.4		
1M	1M-12	SW		4.72	5.4		
1M	1M-13	SW		3.43	5.7		
1M	1M-2	SW		3.85	5.7		
1M	1M-3	AW		5.5	4.9		
1M	1M-4	SW		3.77	5.4		
1M	1M-5	SW		3.92	4.6		
1M	1M-6	SW		3.87	4.4		
1M	1M-7	AW		6.13	4.3		
1M	1M-8	SW		4.58	5.5		
1M	1M-9	SW		4.29	5.3		
1T	1T-74	AW		6.7	4.8	Y	

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
1T	1T-75	AW		6.6	4.5		
1T	1T-77	AW		5.72	4.5		
1T	1T-78	AW		5.46	4.2		
1T	1T-79	AW		5.55	4.1		
1U	1U-53	AW		5.36	5.6	Y	
1U	1U-54	AW	a	5.84	4.6		
1U	1U-55	AW	a	5.13	4		
1U	1U-56	SW		3.35	4.3		
1U	1U-57	SW	b	3.98	3.8		
U	1U-58	SW	b	4.06	3.2		
1U	1U-59	SW		4.67	6.3	Y	Y
1U	1U-60	AW		5.59	5.2		
1U	1U-61	SW		3.96	4.4		
1U	1U-62	SW		3.2	3		
1U	1U-63	SW		4.32	5.7		
1U	1U-64	AW		5.7	5		
1U	1U-65	AW		6	5.2		
1U	1U-66	SW		4.35	5.5		
1U	1U-67	SW		4.34	5.8		
1U	1U-68	SW		3.9	4		
1U	1U-69	SW		3.81	5.4		
1U	1U-70	SW		3.14	4.4		
2A	2A-521	AW		3.86	3.7		
2A	2A-522	SW	a	1.64	0.7		
2A	2A-523	SW	a	2.74	2.7		
2A	2A-524	SW		2.32	1.8		
2A	2A-525	AW		5.81	6.5		
2A	2A-526	AW		6.57	7.7	Y	
2A	2A-527	SW	b	3.38	4.2	Y	Y
2A	2A-528	SW	b	2.96	2.8		
2A	2A-530	SW	c	3.15	3.7		
2A	2A-531	SW	c	2.05	1.1		
2A	2A-532	AW		4.84	4.2		
2A	2A-533	SW	d	2.48	2.4		
2A	2A-534	SW	d	2.26	1.5		
2A	2A-535	SW		3.26	3.5		
2A	2A-536	AW		4.72	4		
2B	2B-537	AW		6.21	5.8		
2B	2B-538	SW		2.42	2.6		
2B	2B-539	AW		6.99	6	Y	
2B	2B-540	AW		4.62	5.3		
2B	2B-541	SW		4.04	5		Y
2B	2B-542	SW		3	4.5		
2B	2B-543	AW		6.27	5.3		
2B	2B-544	SW		4.06	5		
2B	2B-545	SW		3.79	6.2	Y	
2C	2C-501	SW		1.51	0.9		
2C	2C-502	SW		2.45	2.2		
2C	2C-503	SW		1.84	1.3		
2C	2C-504	SW		2.32	2.2		
2C	2C-505	SW		1.09	0		
2C	2C-506	SW		2.03	1.3		
2C	2C-507	SW		2.24	1.9		
2C	2C-508	SW		1.15	0		
2C	2C-509	SW		2.16	1.3		
2C	2C-510	SW		1.08	0		
2C	2C-511	SW		2.06	1.3		
2C	2C-512	SW		2.72	2.3		
2C	2C-513	SW		2.93	2.7		
2C	2C-514	SW		2.52	2.1		
2C	2C-515	SW		2.17	1.8		
2C	2C-516	SW		2.92	2.9	Y	Y
2C	2C-517	SW		2.7	2.3		
2C	2C-518	SW		2.09	1.4		
2C	2C-519	SW		2.35	1.9		
2C	2C-520	SW		1.45	0.7		
2D	2D-559	AW		4.1	4.1		
2D	2D-560	SW		4.93	6.8	Y	Y
2D	2D-561	AW		3.4	2.6		
2D	2D-562	SW		3.48	5		
2D	2D-563	SW		4.23	5		
2D	2D-564	AW		4.12	2.7		
2D	2D-565	AW		4.86	3.9		
2D	2D-566	SW		3.48	3.8		
2D	2D-567	AW		5.56	4.3		
2D	2D-568	AW		7.13	6.2	Y	
2D	2D-569	AW		7.09	6		
2D	2D-570	AW		5.82	4.3		
2D	2D-571	SW		4.15	4.5		
2D	2D-572	SW		3.96	5.3		
2E	2E-574	AW		7.16	7.9	Y	
2E	2E-575	SW	a	3	3.3		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
2E	2E-576	SW	a	2.5	1.8		
2E	2E-577	SW		4.38	5.2		
2E	2E-578	SW		4.22	5.5	Y	Y
2E	2E-579	SW		3.62	4.7		
2E	2E-580	SW	b	2.86	2.3		
2E	2E-581	SW	b	3.3	3		
2E	2E-582	SW	b	3.13	2.7		
2E	2E-583	AW		3.98	4.3		
2E	2E-584	AW		5.66	5.1		
2E	2E-585	SW	c	2.52	2		
2E	2E-586	SW	c	1.98	1.2		
2E	2E-587	SW		4.1	4.9		
2E	2E-589	AW		2.2	1.1		
2E	2E-590	AW		5.34	3.9		
2E	2E-591	AW		6.07	4.1		
2E	2E-592	AW		6.18	5.3		
2G	2G-607	SW		4.99	7.5	Y	Y
2G	2G-608	SW		4.6	6.1		
2G	2G-609	AW		3.9	3.9		
2G	2G-611	SW		3.24	3.4		
2G	2G-612	SW		2.48	2.2		
2G	2G-613	SW		3.34	3.7		
2G	2G-614	AW		6.69	6		
2G	2G-615	SW		4.2	6		
2G	2G-616	AW		5.61	4.2		
2G	2G-617	SW		3.54	5.1		
2G	2G-618	SW		3.28	4.8		
2G	2G-619	SW		2.38	1.9		
2G	2G-620	SW		4.01	5.6		
2G	2G-621	SW		4.47	6.2		
2G	2G-622	AW		7.01	6.7	Y	
2H	2H-623	SW		4.83	6.4		
2H	2H-624	SW		1.98	1.4		
2H	2H-625	SW		5.28	6.9		
2H	2H-626	AW		4.96	3.6		
2H	2H-627	SW	a	1.54	0.5		
2H	2H-628	SW	a	1.56	0.7		
2H	2H-629	AW		6.53	5.1		
2H	2H-630	AW		5.63	4.2		
2H	2H-631	AW		5.63	4.3		
2H	2H-632	SW		1.62	0.7		
2H	2H-633	SW		5.29	7.3	Y	Y
2H	2H-634	SW	b	2.28	1.4		
2H	2H-635	SW	b	2.6	2.2		
2H	2H-636	AW		5.37	6	Y	
2H	2H-637	AW		5.52	4.9		
2H	2H-638	AW		5.59	5.1		
2H	2H-639	SW		4.46	2.8		
2J	2J-657	SW		4.72	6.2		
2J	2J-658	SW		5	6.7	Y	Y
2J	2J-659	AW		4.92	4.6		
2J	2J-660	SW		3.91	4.8		
2J	2J-661	AW		8.64	8.3	Y	
2J	2J-662	SW		2.94	3.8		
2J	2J-663	SW		3.48	2.2		
2J	2J-664	SW		3.33	3.9		
2J	2J-665	SW		4.27	6.4		
2J	2J-666	AW		4.74	4.3		
2J	2J-667	SW		3.02	2.9		
2J	2J-668	SW		3.33	2.9		
2J	2J-669	SW		4.47	5.8		
2L	2L-640	SW	a	4.5	5		
2L	2L-641	SW	a	4.5	4.7		
2L	2L-642	SW		3.2	3.9		
2L	2L-643	AW		4.8	4.6		
2L	2L-644	SW		3.95	5.2		
2L	2L-645	SW		4.63	6.2	Y	Y
2L	2L-646	AW		6.22	5		
2L	2L-647	SW	b	4.55	5.4		
2L	2L-648	SW	b	3.8	3.2		
2L	2L-649	SW		4.45	5.8		
2L	2L-650	AW		7.03	5.3		
2L	2L-651	SW		4.57	4.8		
2L	2L-652	SW		4.85	5.5		
2L	2L-653	AW		5.22	4.6		
2L	2L-654	SW		4.02	5.5		
2L	2L-655	SW		5.17	6		
2L	2L-656	AW		6.9	5.8	Y	
2M	2M-593	SW		3.92	4.1		
2M	2M-594	SW	a	3.11	2.3		
2M	2M-595	SW	a	3.12	2.7		
2M	2M-596	AW		4.17	4		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
2M	2M-597	SW		4.2	5.5		
2M	2M-598	SW		3.98	6.1		
2M	2M-599	SW		3.87	4.8		
2M	2M-600	SW		4.82	6.1		
2M	2M-601	AW		5.22	6	Y	
2M	2M-602	SW		4.35	5.9		
2M	2M-603	SW		4.76	6.3	Y	Y
2M	2M-604	SW	b	3.96	3.7		
2M	2M-605	SW	b	3.31	2.5		
2M	2M-606	AW		4.7	4.2		
2T	2T-670	AW		6.11	4.4		
2T	2T-671	AW		5.35	4.3		
2T	2T-672	AW		7.37	4.7	Y	
2T	2T-673	AW		6.11	4.6		
2T	2T-674	SW		5.63	6.2	Y	Y
2T	2T-675	SW		4.22	4.7		
2T	2T-676	AW		4.48	4.3		
2U	2U-546	SW		4.05	6.7	Y	
2U	2U-547	SW		4.08	5.7		
2U	2U-548	AW		5.82	5.7	Y	
2U	2U-549	SW		2.93	3.2		
2U	2U-550	SW		3.69	4.2		
2U	2U-551	SW		2.72	3.7		
2U	2U-552	AW		5.27	5.3		
2U	2U-553	SW		4.04	5.9		Y
2U	2U-554	SW		2.94	3.3		
2U	2U-555	AW		4.39	3.7		
2U	2U-556	SW		4.75	5.7		
2U	2U-557	SW		4.4	4.7		
2U	2U-558	AW		6.42	5.3		
3A	3A-745	SW		3.61	4.3	Y	Y
3A	3A-746	SW		3.54	3.9		
3A	3A-747	SW		1.98	1.3		
3A	3A-748	SW		1.88	1.3		
3A	3A-749	AW		5.2	4.2		
3A	3A-750	SW		2.42	2.4		
3A	3A-751	SW		2	1.6		
3A	3A-752	AW		5.71	4.5		
3A	3A-753	AW		6.1	5.4	Y	
3A	3A-754	AW		5.42	4.2		
3A	3A-755	AW		5.45	3.3		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
3A	3A-756	AW		4.6	3.3		
3B	3B-757	AW		5.99	4.8		
3B	3B-758	AW		6.05	4.5		
3B	3B-759	SW	a	2.14	1.8		
3B	3B-760	SW	a	4.31	4		
3B	3B-761	SW	a	2.32	1.5		
3B	3B-762	AW		6.53	4.6		
3B	3B-763	SW		6.54	7.2	Y	Y
3B	3B-764	AW		6.01	4.2		
3B	3B-765	AW		5.96	5.7		
3B	3B-766	SW	b	4.02	4.3		
3B	3B-767	SW	b	3.82	2.6		
3B	3B-768	SW		5.3	6.2		
3B	3B-769	AW		6.26	4.1		
3B	3B-770	AW		6.18	4.5		
3B	3B-771	AW		7.09	6.6		
3B	3B-772	SW		5.42	5.7		
3B	3B-773	SW	c	2.44	1.6		
3B	3B-774	SW	c	3.22	3.1		
3B	3B-775	SW		3.98	3.5		
3B	3B-776	AW		6.66	6.7	Y	
3C	N/A			N/A	N/A		
3D	3D-796	AW		7.57	6.5		
3D	3D-797	AW		7.85	6.9		
3D	3D-798	SW		3.75	4.1		
3D	3D-799	AW		6.44	5		
3D	3D-800	SW		4.81	4.9		
3D	3D-801	SW	a	2.23	2.1		
3D	3D-802	SW	a	2.4	2.1		
3D	3D-803	SW		5.16	5.8	Y	Y
3D	3D-804	AW		7.29	6.4		
3D	3D-805	SW	b	4.38	5.6		
3D	3D-806	SW	b	3.2	2.3		
3D	3D-807	AW		7.4	8.3	Y	
3D	3D-808	SW		3.91	5		
3D	3D-809	AW		5.54	5.9		
3D	3D-810	SW		3.86	5.7		
3D	3D-811	AW		6.99	7.9		
3D	3D-812	SW		4.41	4.6		
3E	3E-1	AW		6.66	4.9		
3E	3E-2	SW		4.67	4.7		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
3E	3E-3	SW		4.27	4.8		
3E	3E-813	AW		6	7.6		
3E	3E-814	SW		2.7	2.4		
3E	3E-815	SW		4.7	6.1	Y	Y
3E	3E-816	AW		4.6	4.8		
3E	3E-817	AW		4.86	5		
3E	3E-818	SW		3.62	3.9		
3E	3E-819	SW		4	5		
3E	3E-820	AW		7.13	6	Y	
3E	3E-821	SW		3.75	5.4		
3G	3G-37	AW		5.89	4.4		
3G	3G-38	SW		4.98	6.2	Y	Y
3G	3G-39	SW		3.9	4.8		
3G	3G-40	AW		7.9	6.8	Y	
3G	3G-41	SW		4.72	5.8		
3G	3G-43	SW	a	2.49	1.3		
3G	3G-44	SW	a	2.84	4.6		
3G	3G-45	SW	a	3.42	4.2		
3G	3G-46	SW	a	3.55	4.1		
3G	3G-47	SW	b	4.62	4.6		
3G	3G-48	SW	b	5.25	5.8		
3G	3G-49	SW		4.41	4.7		
3H	3H-50	AW		6.98	5.6		
3H	3H-51	AW		6.93	5.7		
3H	3H-52	SW		3.06	5.5		
3H	3H-53	AW		6.88	4.9		
3H	3H-54	SW		3.67	4.2		
3H	3H-55	SW		4.66	5.3		
3H	3H-56	AW		5.81	4.3		
3H	3H-57	SW		4.05	5.6	Y	
3H	3H-58	AW		5.12	5.1		
3H	3H-59	AW		7.52	6.8	Y	
3H	3H-60	SW		4.22	4.6		
3H	3H-61	SW		3.92	4.4		
3H	3H-62	AW		6.86	6		
3H	3H-63	SW		3.9	3.9		
3H	3H-64	SW		4.21	5.6		Y
3H	3H-65	AW		6.15	6		
3J	3J-82	AW		7.04	6.5		
3J	3J-83	AW		7.8	6.6		
3J	3J-84	SW		4.65	6.1	Y	
3J	3J-85	AW		6.83	5.1		
3J	3J-86	SW		2.44	1.2		
3J	3J-87	AW		6.58	6.8	Y	
3J	3J-88	SW		2.71	3.1		
3J	3J-89	SW		4.32	4.8		
3J	3J-90	SW		4.47	5.4		Y
3J	3J-91	SW		1.47	0.4		
3J	3J-92	AW		5.55	4.5		
3J	3J-93	AW		6.98	5.7		
3J	3J-94	SW		4.44	5.2		
3J	3J-95	SW		2.53	1.6		
3L	3L-66	AW		7.62	6.7	Y	
3L	3L-67	SW		4.67	5.5		
3L	3L-68	SW		4.85	6.1		
3L	3L-69	AW		6.9	6.2		
3L	3L-70	SW		4.52	4.6		
3L	3L-71	SW		4.29	5.4		
3L	3L-72	SW		4.24	4.7		
3L	3L-73	SW		3.64	3.8		
3L	3L-74	SW		3.39	3.9		
3L	3L-75	SW		4.12	4.4		
3L	3L-76	SW		1.94	1.5		
3L	3L-77	AW		6.7	6.2		
3L	3L-78	AW		3.96	4.4		
3L	3L-79	SW		4.27	4.2		
3L	3L-80	SW		4.33	6.3		
3L	3L-81	SW		4.27	6.4	Y	Y
3M	3M-10	PB		5.1	4.2		
3M	3M-11	SW		2.86	4		
3M	3M-12	PB		5.5	4.2		
3M	3M-13	AW		7.9	5.9		
3M	3M-14	SW	a	2.69	3.3		
3M	3M-15	SW	a	2.08	1.6		
3M	3M-16	SW	a	2.81	2.5		
3M	3M-17	SW		5	5.8		
3M	3M-19	AW		5.61	5		
3M	3M-20	AW		7.37	5.9		
3M	3M-21	AW		6.61	4.7		
3M	3M-22	AW		6.85	6		
3M	3M-23	SW		3.85	5.3		
3M	3M-24	AW		6.74	4		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
3M	3M-25	AW		6.6	5.6		
3M	3M-26	SW	b	2.59	2.3		
3M	3M-27	SW	b	3.41	3		
3M	3M-36	SW		4.48	6.1		
3M	3M-4	AW		5	4.7		
3M	3M-5	BP		5.43	4.4		
3M	3M-6	SW		4.44	6		
3M	3M-7	SW		5.23	6.1		Y
3M	3M-8	SW		4.66	6.5	Y	
3M	3M-9	AW		7.97	6	Y	
3T	3T-96	AW		5.09	4.6	Y	
3T	3T-97	AW		4.46	4.5		
3U	3U-699	SW		3.82	5.4		
3U	3U-777	AW		7.12	6.9	Y	
3U	3U-778	AW		6.9	5.1		
3U	3U-779	SW		4.38	5.1		
3U	3U-780	AW		7.33	6.4		
3U	3U-781	SW		3.83	5.6		
3U	3U-782	SW		4.43	6.1		
3U	3U-783	AW		5.86	5.3		
3U	3U-784	SW		1.85	1.7		
3U	3U-785	AW		5.94	4.6		
3U	3U-786	AW		5.89	4.4		
3U	3U-787	AW		6.23	4.9		
3U	3U-788	SW		5.08	6.4		
3U	3U-789	SW		5.15	6.6	Y	
3U	3U-790	SW		4.15	5		
3U	3U-791	SW		2.92	1.6		
3U	3U-792	SW		4.11	6.1		
3U	3U-793	SW		3.01	3.3		
3U	3U-794	SW		2.8	3.4		
3U	3U-795	SW		5.59	6.4		Y
4C	4C-68	SW		1.45	0.8		
4C	4C-70	AW		5	4	Y	
4C	4C-71	SW		2.32	1.9	Y	
4C	4C-72	SW		1.55	0.6		
4C	4C-73	SW		2.38	1.7		Y
4C	4C-74	SW		1.94	1.4		
4C	4C-75	SW	a	1.54	0.6		
4C	4C-76	SW	a	1.62	0.7		
4C	4C-77	SW		2.1	1.3		
4C	4C-78	SW		2.24	1.9		
4C	4C-79	SW	b	1.58	0.7		
4C	4C-80	SW	b	1.62	0.7		
4C	4C-81	SW		1.14	0		
4C	4C-82	SW		1.65	1.1		
4C	4C-83	SW		1.5	0.8		
4C	4C-84	SW		1.38	0.4		
4C	4C-85	SW		1.99	1.2		
4C	4C-86	SW		1.98	1		
4C	4C-87	SW		1.84	0.9		
4C	4C-88	SW		2.1	1.7		
4C	4C-89	SW		2.05	1.3		
4L	4L-22	SW		2.07	1.7		
4L	4L-23	SW		2.6	2.8		
4L	4L-24	AW		5.7	4.3	Y	
4L	4L-25	AW		5.45	4		
4L	4L-26	SW		1.5	1.1		
4L	4L-27	AW		5.5	4.3		
4L	4L-28	SW		3.18	2.9		
4L	4L-29	SW		3.71	3.4	Y	Y
4L	4L-30	SW	a	3.05	2.6		
4L	4L-31	SW	a	2.05	0.7		
4L	4L-32	SW		2.18	1		
4L	4L-33	SW		2.15	1.6		
4M	4M-34	SW		2.85	3.6		
4M	4M-35	AW		4.92	4.6		
4M	4M-36	AW		5.05	4		
4M	4M-37	SW		3.21	3		
4M	4M-38	SW		2.44	2.1		
4M	4M-39	AW		6.19	5.1		
4M	4M-40	AW		6.32	4.6		
4M	4M-41	AW		6.25	5.6		
4M	4M-42	SW		2.99	3		
4M	4M-43	AW		6.75	6.3		
4M	4M-44	SW		2.03	1.2		
4M	4M-45	SW		3.57	3.9	Y	Y
4M	4M-46	AW		7.3	6.3	Y	
4M	4M-47	AW		5.88	5.6		
4M	4M-48	AW		5.76	5		
4M	4M-49	SW		3.05	2.9		
4M	4M-50	SW		1.96	1.3		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
4M	4M-51	AW		6.19	5.4		
4M	4M-52	SW		2.13	1.3		
4T	4T-1	SW		2.78	2.4	Y	
4T	4T-10	SW		2.22	1.5		
4T	4T-11	SW		1.89	0.9		
4T	4T-12	SW		2.85	2.2		
4T	4T-13	AW		6.87	5.1		
4T	4T-14	AW		7.17	4.8		
4T	4T-15	AW		5.99	4.2		
4T	4T-16	AW		6.19	4.5		
4T	4T-17	SW		2.9	2.3		
4T	4T-18	AW		8.36	7.4	Y	
4T	4T-19	AW		6.92	4		
4T	4T-2	AW		6.92	6		
4T	4T-20	AW		6.87	4.2		
4T	4T-3	AW	h2	7.09	6.1		
4T	4T-4	SW		2.98	2.3		Y
4T	4T-5	SW		2.27	1.7		
4T	4T-6	AW		6.55	5.5		
4T	4T-7	AW	h2	7.05	5.3		
4T	4T-8	AW		5.8	4.7		
4T	4T-9	AW		6.98	5.3		
4U	4U-53	SW		1.59	0.6		
4U	4U-54	SW		1.72	1.1		
4U	4U-55	SW		1.95	1.1		
4U	4U-56	SW		1.15	0		
4U	4U-57	SW		2.84	2.9	Y	Y
4U	4U-58	SW		3.27	3.6		
4U	4U-59	SW		1.84	0.8		
4U	4U-60	SW		1.99	1.1		
4U	4U-62	SW		1.54	0.6		
4U	4U-63	SW		1.9	1		
4U	4U-64	SW		1.75	1		
4U	4U-65	SW		2.44	2.2		
4U	4U-66	SW		2.29	2.1		
4U	4U-67	AW		4.93	4.4	Y	
5C	5C-14	SW	b	0.94	0		
5C	5C-58	SW		2.19	1.7		
5C	5C-59	SW		1.84	1.2		
5C	5C-60	SW		1.04	0		
5C	5C-61	SW		1	0		
5C	5C-62	SW	b	2.24	1.6		
5C	5C-63	SW		1.41	0.4		
5C	5C-64	SW		1.66	0.8		
5C	5C-65	SW		1.74	1.1		
5C	5C-66	SW	a	1.83	0.9		
5C	5C-67	SW	a	1.71	0.8		
5C	5C-68	SW		2.22	1.9		
5C	5C-69	AW		5.15	4.1		
5C	5C-70	SW		2.22	1.8		
5C	5C-71	SW		2.03	1.7		
5C	5C-72	SW		2.11	1.5		
5C	5C-73	SW		2.66	2.6	Y	
5C	5C-74	AW		5.1	4.2	Y	
5C	5C-75	SW		2.11	1.5		
5C	5C-76	SW		1.94	1.2		
5C	5C-77	SW		1.64	1.1		
5C	5C-78	SW		2.37	2.4		
5C	5C-79	SW		2.17	1.7		
5C	5C-80	SW		1.69	0.9		
5C	5C-81	SW		1.45	0.4		
5C	5C-82	SW		2.32	1.8		
5C	5C-83	SW		2.05	1.4		
5C	5C-84	SW		0.36	0		
5L	5L-19	SW		1.18	0		
5L	5L-21	SW		0.81	0		
5L	5L-23	SW		2.06	1.9	Y	
5L	5L-24	SW		1.86	1.8		
5L	5L-25	SW		2.08	1.8		Y
5L	5L-26	SW		1.83	1.4		
5L	5L-27	SW		1.32	0.5		
5L	5L-28	SW		1.86	1.6		
5L	5L-29	SW		1.16	0		
5L	5L-30	SW		1.45	0.5		
5M	5M-31	SW		1.59	1		
5M	5M-32	SW		1.18	0		
5M	5M-33	SW		2.02	1.4		
5M	5M-34	SW		2.34	2.2	Y	Y
5M	5M-35	SW		1.94	1.6		
5M	5M-36	SW		1.33	0.5		
5M	5M-37	SW		1.32	0.4		
5M	5M-38	SW		1.55	0.8		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
5M	5M-39	SW		1.76	1.4		
5T	5T-1	SW		2.3	1.8		
5T	5T-10	SW		3.1	2.9	Y	Y
5T	5T-11	SW		1.98	1.2		
5T	5T-12	SW		1.18	0		
5T	5T-13	SW		2.22	1.7		
5T	5T-15	SW		2.2	1.8		
5T	5T-16	SW		1.8	0.9		
5T	5T-17	SW		1.98	1.4		
5T	5T-18	SW		2.4	2		
5T	5T-2	SW		1.62	1		
5T	5T-20	SW		1.66	1.3		
5T	5T-22	SW		1.9	1.8		
5T	5T-3	SW		1.78	1.2		
5T	5T-4	SW		2.02	1		
5T	5T-5	SW		1.7	1.6		
5T	5T-6	AW		5.66	4.9	Y	
5T	5T-7	SW		2.44	2.4		
5T	5T-8	SW		1.74	1.1		
5T	5T-9	SW		2.04	1.4		
5U	5U-40	SW		1.75	1.3		
5U	5U-41	SW		1.8	1.4		
5U	5U-42	SW		1.88	1.5		
5U	5U-43	SW		1.6	0.7		
5U	5U-44	SW		1.76	1.2		
5U	5U-45	SW		1.7	0.9		
5U	5U-46	SW		0.2	0		
5U	5U-47	SW		1.54	0.6		
5U	5U-48	SW		1.59	0.6		
5U	5U-49	SW		2.06	1.8		
5U	5U-50	SW		2.54	2.2	Y	Y
5U	5U-51	SW		1.27	0		
5U	5U-52	SW		2.32	2.2		
5U	5U-53	SW		1.6	0.9		
5U	5U-54	SW		1.65	0.8		
5U	5U-55	SW		2	1.4		
5U	5U-56	SW		1.35	0.4		
5U	5U-57	SW		2	1.5		
6C	6C-916	SW		1.19	0		
6C	6C-917	SW		1.08	0		
6C	6C-918	SW		1.04	0		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
6C	6C-919	SW		1.24	0		
6C	6C-920	SW		1.25	0		
6C	6C-921	SW		2.05	1.4		
6C	6C-922	SW		1.92	1.6		
6C	6C-923	SW		1.72	1		
6C	6C-924	SW		2.67	2.4		
6C	6C-925	SW		2.26	2.2		
6C	6C-926	SW		2.43	2.7		
6C	6C-927	SW		1.1	0		
6C	6C-928	SW		1.45	0.7		
6C	6C-929	SW		2.52	2.9	Y	
6C	6C-930	SW		1.51	0.7		
6C	6C-931	SW		1.61	0.9		
6C	6C-932	SW		1.55	0.9		
6L	6L-1000	SW		1.65	0.6		
6L	6L-881	SW		1.42	0.5		
6L	6L-882	SW		1.65	0.8		
6L	6L-883	SW		1.89	1.3	Y	
6L	6L-884	SW		1.85	1		
6L	6L-885	SW		2.07	1.2		
6L	6L-886	SW		1.74	1.1		
6L	6L-887	SW		1.81	1.2		
6L	6L-997	SW		1.5	0.6		
6L	6L-998	SW		1.65	0.7		
6L	6L-999	SW		1.53	0.6		
6M	6M-888	SW		2.04	1.9	Y	
6M	6M-889	SW		1.91	1.5		
6M	6M-890	SW		1.84	1.6		
6M	6M-891	SW		2.02	1.8		
6M	6M-892	SW		1.46	0.4		
6M	6M-893	SW		1.16	0		
6M	6M-894	SW		1.5	0.5		
6M	6M-895	SW		1.67	1.4		
6M	6M-896	SW		1.95	1.2		
6M	6M-897	SW		0.98	0		
6T1	6T1-995	AW		5.18	4.8	Y	
6T1	6T1-996	SW		0.44	0		
6U	6U-898	SW		1.82	1.2		
6U	6U-899	SW		2.22	2.1		
6U	6U-900	SW		1.52	0.6		
6U	6U-901	SW		2.23	2		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
6U	6U-902	SW		1.6	1.1		
6U	6U-903	SW		1.75	1.3		
6U	6U-904	SW		2.38	2.3		
6U	6U-905	SW		1.99	2.1		
6U	6U-906	SW		2.14	1.4		
6U	6U-907	SW		1.83	1.4		
6U	6U-908	SW		2.7	3	Y	
6U	6U-909	SW		2.35	2.2		
6U	6U-910	SW		2.2	2.5		
6U	6U-911	SW		1.91	1.6		
6U	6U-912	SW		1.99	2		
6U	6U-913	SW		1.95	1.9		
6U	6U-914	SW		1.66	1.1		
6U	6U-915	SW		1.92	1.6		
7C	7C-65	SW		1.83	1.1		
7C	7C-66	SW	a	1.89	1.3		
7C	7C-67	SW	a	1.25	0		
7C	7C-68	SW		1.99	1.4		
7C	7C-69	SW		2.12	1.7		
7C	7C-70	SW		1.96	1.1		
7C	7C-71	SW		2.7	2.1		
7C	7C-72	SW		2.57	2.5	Y	Y
7C	7C-73	SW	b	2.21	1.3		
7C	7C-74	SW	b	1.85	0.8		
7C	7C-75	SW		2.5	2.3		
7C	7C-76	SW		0.44	0		
7C	7C-77	SW		0.55	0		
7C	7C-78	SW		1.55	0.9		
7M	7M-1	SW		1.8	1.6		
7M	7M-10	SW		1.45	0.7		
7M	7M-11	SW		1.46	0.7		
7M	7M-2	SW		1.65	0.9		
7M	7M-3	SW		1.1	0		
7M	7M-4	SW		1.76	1.2		
7M	7M-5	SW		3	3.7		
7M	7M-6	SW		3	3.1		
7M	7M-7	SW		1.65	0.9		
7M	7M-8	SW		3.26	4.4	Y	Y
7M	7M-9	AW		4.52	4.3	Y	
7P2	7P1-31	SW		2.43	1.7		
7P2	7P1-32	SW		1.89	1.2		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
7P2	7P1-33	SW		1.66	0.8		
7P2	7P1-34	SW		3.24	2.4		
7P2	7P1-35	AW		5.97	4.9	Y	
7P2	7P1-37	SW		2.84	2.4		
7P2	7P1-38	AW		5.42	4.5		
7P2	7P1-39	SW		2.45	2		
7P2	7P1-40	SW		2.42	1.7		
7P2	7P1-41	SW		3.13	3.1	Y	
7P2	7P1-42	AW		6.36	4.6		
7P2	7P1-43	AW		5.7	4.7		
7P2	7P1-44	SW		2.52	2.2		
7P2	7P1-45	SW		1.16	0		
7P2	7P1-46	SW		1.74	0.8		
7P2	7P1-47	AW		6.15	4.1		
7P2	7P1-48	SW		1.98	1.1		
7P2	7P1-49	SW		0.4	0		
7P2	7P1-50	SW		1.9	1		
7P2	7P1-51	SW		2.05	1		
7P2	7P1-52	SW		2.73	2.5		
7P2	7P1-53	SW		2.14	1.3		
7P2	7P1-54	AW		5.4	4.2		
7P2	7P1-55	SW		3.26	3		Y
7P1	7P-79	SW		2	1.1		
7P1	7P-80	SW		2.56	2	Y	
7P1	7P-81	SW		1.95	1.2		
7P1	7P-82	SW		3.12	3.5		Y
7P1	7P-83	AW		6.1	5.6	Y	
7P1	7P-84	SW		1.4	0.5		
7P1	7P-85	AW		5.82	4.4		
7P1	7P-86	SW		2.24	1.4		
7P1	7P-87	AW		5.1	4.3		
7P1	7P-88	SW		1.86	1.9		
7P1	7P-89	AW		5.51	4.4		
7P1	7P-90	AW		6.15	4.2		
7P1	7P-91	SW		2.38	1.6		
7P1	7P-92	SW		1.8	0.9		
7P1	7P-93	AW		5.66	4		
7P1	7P-94	SW		1.18	0		
7P1	7P-95	SW		1.96	1.1		
7P1	7P-96	SW		1.17	0		
7P1	7P-97	SW		1.6	0.9		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
7P1	7P-98	SW		1.65	0.9		
7P1	7P-99	SW		1.8	1.2		
7T	7T-100	AW		5.75	6.1	Y	
7T	7T-12	AW		6.24	5.4		
7T	7T-13	SW		3.3	3.9		
7T	7T-14	SW		3.26	3.4		
7T	7T-15	SW		4.04	4.5		
7T	7T-16	AW		5.32	4.1		
7T	7T-17	AW		5	4.4		
7T	7T-18	SW		3.52	3.7		
7T	7T-19	SW		4.12	4		
7T	7T-20	SW		3.21	3.8		
7T	7T-21	SW		3.37	4.4		
7T	7T-22	SW		4.14	5.1	Y	
7T	7T-23	AW		6.07	5.8		
7T	7T-24	SW		4.33	4.9		Y
8C	8C-22	SW		1.05	0		
8C	8C-23	SW		1.28	0		
8C	8C-24	SW		1.53	0.9		
8C	8C-25	SW		1.61	0.7		
8C	8C-26	SW		1.6	0.9	Y	
8C	8C-27	SW		0.84	0		
8C	8C-28	SW		0.72	0		
8C	8C-29	SW		0.68	0		
8C	8C-30	SW		1.24	0		
8C	8C-31	SW		0.82	0		
8C	8C-32	SW		1.1	0		
8C	8C-33	SW		1.46	0		
8C	8C-34	SW		1.16	0		
8C	8C-35	SW		1.25	0		
8C	8C-36	SW		0.5	0		
8M	8M-12	SW		1.03	0		
8M	8M-13	SW		0.81	0		
8M	8M-14	SW		1.22	0		
8M	8M-15	SW		0.93	0		
8M	8M-16	SW		1.1	0		
8M	8M-17	SW		1.69	0.1		
8M	8M-18	SW		1.04	0		
8M	8M-19	SW		1.55	0.6		
8M	8M-20	SW		2.2	2.2	Y	Y
8M	8M-21	SW		0.81	0		
8P2	8P1-37	SW		0.85	0		
8P2	8P1-38	SW		2.55	2.5		
8P2	8P1-39	SW		1.77	1.1		
8P2	8P1-40	SW		1.48	0.8		
8P2	8P1-41	SW		2.19	1.9		
8P2	8P1-42	SW		2.34	2.1		Y
8P2	8P1-43	SW		1.25	0		
8P2	8P1-44	SW		2.33	2.6		
8P2	8P1-45	SW		1.94	1.4		
8P2	8P1-46	SW		1.14	0		
8P2	8P1-47	SW		2.22	2.3		
8P2	8P1-48	SW		0.98	0		
8P2	8P1-49	SW		2.12	2.4		
8P2	8P1-50	SW		2.45	2.9	Y	
8P2	8P1-51	SW		2.17	2.4		
8P2	8P1-52	SW		1.88	1.3		
8P1	8P-53	SW		2.01	1.5		
8P1	8P-54	SW		1.89	1.2		
8P1	8P-55	SW		1.75	0.7		
8P1	8P-56	SW		2.88	2.6	Y	Y
8P1	8P-57	SW		2.14	1.4		
8P1	8P-58	AW		5.14	4.5		
8P1	8P-59	SW		1.96	1.2		
8P1	8P-60	AW		5.42	4.4		
8P1	8P-61	SW		3.36	1.9		
8P1	8P-62	AW		5.32	4.9	Y	
8P1	8P-63	AW		5.68	4.4		
8P1	8P-64	AW		6.14	4.6		
8P1	8P-65	SW		2.32	2		
8P1	8P-66	AW		5.59	4.5		
8P1	8P-67	SW		2.06	1.6		
8P1	8P-677	SW		2.44	1.6		
8P1	8P-68	SW		1.99	1.4		
8P1	8P-69	SW		1.61	0.6		
8P1	8P-70	SW		1.82	1.2		
8P1	8P-71	SW		1.54	0.7		
8P1	8P-72	SW		2.14	1.5		
8T1	8T1-1	SW		2.88	3		
8T1	8T1-10	SW		2.18	2.3		
8T1	8T1-11	SW		2.23	2.4		
8T1	8T1-2	SW		2.67	2.8		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
8T1	8T1-3	SW		2.95	3.2		
8T1	8T1-4	SW		2.19	1.9		
8T1	8T1-5	SW		1.84	1.3		
8T1	8T1-6	SW		3.08	3.6	Y	Y
8T1	8T1-7	SW		3.35	3.4		
8T1	8T1-8	SW		1.79	1.7		
8T1	8T1-9	SW		1.62	0.9		
8T1	8T1-933	SW		1.76	2.1		
8T1	8T1-934	SW		1.9	1.7		
8T1	8T1-935	SW		2.25	2.4		
8T1	8T1-936	SW		1.5	1.5		
8T1	8T1-937	SW		2.57	2.2		
8T1	8T1-938	SW		3.07	3.2		
8T1	8T1-939	SW		2.35	2.1		
8T1	8T1-940	SW		2.28	2.4		
8T1	8T1-941	SW		2.24	2		
9C	9C-79	SW		2.9	2.7		
9C	9C-80	SW		2.4	2.1		
9C	9C-81	SW		2.91	3.1		
9C	9C-82	SW		2.96	3.3	Y	Y
9C	9C-83	SW		2.24	2.1		
9C	9C-84	SW		2.75	3.1		
9C	9C-85	SW		2.41	2.2		
9C	9C-86	SW		1.84	1.1		
9C	9C-87	SW		2.33	2.3		
9C	9C-88	SW		2.06	1.7		
9C	9C-89	SW		1.77	1		
9C	9C-90	SW		1.86	1.2		
9C	9C-91	SW	a	2.22	1.8		
9C	9C-92	SW	a	2.97	3.2		
9C	9C-93	SW		2.91	2.7		
9C	9C-94	SW		1.84	1.2		
9C	9C-95	SW		2.68	2.2		
9C	9C-96	SW		2.88	2.7		
9C	9C-97	SW		2.3	2		
9L	9L-35	SW		1.92	1		
9L	9L-36	SW		2.39	1.8		
9L	9L-37	SW		2.43	1.8		
9L	9L-38	SW		2.64	2.4	Y	Y
9L	9L-39	SW		2.04	2		
9L	9L-40	SW		1.85	1.2		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
9L	9L-41	SW		1.92	1.9		
9M	9M-42	SW		2.35	1.9		
9M	9M-43	SW		1.64	0.7		
9M	9M-44	SW		2.25	1.7		
9M	9M-45	SW		2.72	2.4	Y	Y
9M	9M-46	SW		1.7	1.1		
9M	9M-47	SW		1.64	0.9		
9M	9M-48	AW		4.9	4.1	Y	
9M	9M-49	SW		1.8	1		
9M	9M-50	SW		1.7	1.2		
9M	9M-51	SW		1.92	1.4		
9M	9M-52	SW		1.7	1.1		
9M	9M-53	SW		2.24	1.6		
9M	9M-54	SW		1.34	0.4		
9M	9M-55	SW		1.53	0.8		
9M	9M-56	SW		1.68	1.2		
9M	9M-57	SW		1.74	1		
9M	9M-58	SW		1.53	0.6		
9M	9M-59	SW		1.95	1.6		
9M	9M-60	SW		0.74	0		
9M	9M-61	SW		1.91	1		
9T	9T-27	SW		3.12	3	Y	Y
9T	9T-28	SW		2.5	1.8		
9T	9T-29	SW		2.15	1.1		
9T	9T-30	SW		1.9	1		
9T	9T-31	AW		6.08	5.1	Y	
9T	9T-32	SW		3.21	2.8		
9T	9T-33	SW		2.39	1.9		
9T	9T-34	SW		2.56	1.9		
9U	9U-62	SW		1.68	0.7		
9U	9U-63	SW		2.05	1.8		
9U	9U-64	SW		1.94	1.4		
9U	9U-65	SW		1.47	0.6		
9U	9U-66	SW		1.49	0.7		
9U	9U-67	SW		1.15	0		
9U	9U-68	SW		2.12	1.8		
9U	9U-69	SW		2.03	1.7		
9U	9U-70	SW		1.35	0.6		
9U	9U-71	SW		0.91	0		
9U	9U-72	SW		1.39	0.5		
9U	9U-73	SW		1.51	0.6		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
9U	9U-74	SW		1.52	0.4		
9U	9U-75	SW		1.74	1.1		
9U	9U-76	SW		1.37	0.6		
9U	9U-77	SW		2.46	2.2	Y	Y
9U	9U-78	AW		4.31	4	Y	
LAI1	LAI1-674	SW		0.91	0		
LAI1	LAI1-675	AW		5.85	5		
LAI1	LAI1-676	AW		6.47	4.9		
LAI1	LAI1-677	SW		2.42	1.5		
LAI1	LAI1-678	SW		2.54	2.4		
LAI1	LAI1-679	AW		5.7	4		
LAI1	LAI1-680	SW		2.38	2.4		
LAI1	LAI1-681	SW		2.22	1.8		
LAI1	LAI1-682	AW		6.78	5.1		
LAI1	LAI1-683	AW		6.88	5.6	Y	
LAI1	LAI1-684	SW		3.14	2.9		Y
LAI1	LAI1-685	SW		3.39	3.5	Y	
LAI1	LAI1-686	SW		3.21	2.5		
LAI1	LAI1-687	SW		2.7	1.9		
LAI1	LAI1-688	AW		6.24	4.5		
LAI1	LAI1-689	AW		6.99	4.6		
LAI1	LAI1-690	SW		2.08	1.1		
LAI1	LAI1-691	SW		2.38	1.4		
LAI1	LAI1-692	AW		5.98	5		
LAI1	LAI1-693	AW		6.25	4.8		
LAI1	LAI1-694	SW		2.76	2.3		
LAI1	LAI1-695	SW		1.31	0.7		
LAI1	LAI1-696	AW		5.51	4.9		
LAI1	LAI1-697	AW		6	4		
LAI1	LAI1-698	AW		6.88	5.3		
LAI2	LAI2-700	SW		2.22	1.9		
LAI2	LAI2-701	SW		1.84	1.2		
LAI2	LAI2-702	SW		2.64	2		
LAI2	LAI2-703	SW		3.02	2.4		
LAI2	LAI2-704	SW		2.32	1.8		
LAI2	LAI2-705	SW		2.67	2.3		
LAI2	LAI2-706	SW		2.92	3.1		
LAI2	LAI2-707	AW		6.65	5.2		
LAI2	LAI2-708	SW		2.85	1.8		
LAI2	LAI2-709	AW		6.46	5.5		
LAI2	LAI2-710	AW		5.62	5.9	Y	

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
LAI2	LAI2-711	AW		5.78	4.5		
LAI2	LAI2-712	SW		3.19	2.5		
LAI2	LAI2-713	SW		3.34	3.1	Y	Y
LAI2	LAI2-714	AW		5.99	5.6		
LAI2	LAI2-715	SW		2.75	2.1		
LAI2	LAI2-716	SW		3.04	2.9		
LAI2	LAI2-717	SW		2.64	1.8		
LAI2	LAI2-718	SW		1.49	0.4		
LAI2	LAI2-719	SW		2.3	2.9		
LAI2	LAI2-720	SW		2.35	2.3		
LAI2	LAI2-721	SW		1.6	0.7		
LAI2	LAI2-722	SW		2.6	2.4		
LAI2	LAI2-723	SW		2.66	2.4		
LAI3	LAI3-724	SW		1.64	0.7		
LAI3	LAI3-725	SW		1.97	1.1		
LAI3	LAI3-726	AW		5.83	4.3		
LAI3	LAI3-727	SW		2.44	2		
LAI3	LAI3-729	SW		2.29	1.4		
LAI3	LAI3-730	AW		4.85	4.2		
LAI3	LAI3-731	AW		5.9	4.5	Y	
LAI3	LAI3-732	SW		2.12	1.4		
LAI3	LAI3-733	SW		2.11	1.1		
LAI3	LAI3-734	SW		1.9	1		
LAI3	LAI3-735	SW		0.96	0		
LAI3	LAI3-736	SW		2.31	1.9		
LAI3	LAI3-737	SW		2.21	1.7		
LAI3	LAI3-738	SW		1.71	0.8		
LAI3	LAI3-739	SW		2.07	1.5		
LAI3	LAI3-740	SW		1.03	0		
LAI3	LAI3-741	SW		1.86	1.1		
LAI3	LAI3-742	SW		2.39	2.1	Y	Y
LAI3	LAI3-743	SW		1.44	0.6		
LAI3	LAI3-744	SW		1.16	0		
PA	PA-826	SW		2.92	2.7	Y	Y
PA	PA-827	SW		1.62	0.7		
PA	PA-828	AW		6.1	4		
PA	PA-829	SW		2	1		
PA	PA-830	SW		2.21	1.3		
PA	PA-831	SW		1.26	0		
PA	PA-832	SW		1.48	0.6		
PA	PA-833	SW		1.02	0		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
PA	PA-834	SW		1.63	0.7		
PA	PA-835	SW		2.38	1.5		
PA	PA-836	AW		6.4	4.5	Y	
PA	PA-837	AW		6.14	4.4		
PA	PA-838	SW		1.84	0.9		
PA	PA-839	SW		0.87	0		
PA	PA-840	SW		1.64	0.4		
PB	PB-15	SW		3.12	2.8		Y
PB	PB-16	AW	a	5.97	4.8		
PB	PB-17	AW	a	6.74	5.2		
PB	PB-18	SW		3	2.9	Y	
PB	PB-19	SW		1.9	1.7		
PB	PB-20	SW		2.26	2		
PB	PB-21	SW		1.26	0		
PB	PB-22	SW		2.21	1.7		
PB	PB-23	SW		2.81	2.4		
PB	PB-24	AW		5.26	4.8		
PB	PB-25	SW		2.24	1.7		
PB	PB-26	SW		2.25	1.6		
PB	PB-27	AW		6.39	4.5		
PB	PB-28	SW		2.55	2.3		
PB	PB-29	AW		5.88	4.6		
PB	PB-30	AW		7.24	6.3	Y	
PB	PB-31	SW		2.72	2.5		
PC	PC-857	SW		1.65	0.9		
PC	PC-858	SW		1.76	0.8		
PC	PC-859	SW		2	0.9		
PC	PC-860	AW		5	4.3	Y	
PC	PC-861	SW		2.18	1.8		
PC	PC-862	SW		1.84	0.9		
PC	PC-863	SW		2.08	2	Y	
PC	PC-864	SW		1.98	1.4		
PC	PC-865	SW		1.68	1		
PC	PC-866	SW		1.39	0.4		
PC	PC-867	SW		1.9	1.1		
PC	PC-868	SW		1.48	0.4		
PC	PC-869	SW		1.36	0.4		
PC	PC-870	SW		1.51	0.5		
PC	PC-871	SW		1.84	1		
PC	PC-872	SW		1.18	0		
PC	PC-873	SW		1.5	0.6		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	* *
PD	PD-949	SW		1.98	1.6		
PD	PD-950	SW		1.34	0.4		
PD	PD-951	SW		2.21	2.3		
PD	PD-952	SW		1.42	0.6		
PD	PD-953	SW		1.81	0.8		
PD	PD-954	SW		1.18	0		
PD	PD-955	AW		5.86	4.8	Y	
PD	PD-956	SW		1.88	0.9		
PD	PD-957	SW		2.36	1.9		
PD	PD-958	SW		1.38	0.4		
PD	PD-959	SW		2.31	2.4	Y	
PD	PD-960	SW		1.97	1.1		
PD	PD-961	SW		1.94	1.3		
PD	PD-962	SW		1.93	1		
PD	PD-963	SW		2.27	2.2		Y
PD	PD-964	SW		2.19	1.9		
PD	PD-965	SW		1.4	0.6		
PE	PE-966	SW		2.67	2.2		
PE	PE-967	SW		3.27	3.5		
PE	PE-968	AW		6.92	5.8		
PE	PE-969	SW		2.16	1.7		
PE	PE-970	AW		6.32	4.4		
PE	PE-971	SW		2.15	1.4		
PE	PE-972	SW		1.34	0.4		
PE	PE-973	AW		5.78	4.6		
PE	PE-974	SW		2.11	1.1		
PE	PE-975	AW		7.83	6.8	Y	
PE	PE-976	SW		2.31	1.4		
PE	PE-977	SW		2.42	1.6		
PE	PE-978	AW		6.92	5.4		
PE	PE-979	SW		2.5	1.7		
PE	PE-980	AW		6.74	4.9		
PE	PE-982	SW		2.7	2.5		
PE	PE-983	AW		6.28	5.8		
PE	PE-984	SW		3.72	3.3	Y	Y
PE	PE-985	SW		2.56	2.6		
PE	PE-986	SW		2.69	1.9		
PE	PE-987	SW		2.47	1.9		
PE	PE-988	AW		5.96	5.2		
PE	PE-989	AW		6.06	5		
PE	PE-990	AW		6.82	5.2		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
PE	PE-991	SW		2.99	2.8		
PE	PE-992	SW		2.82	2.6		
PE	PE-993	SW		2.69	1.9		
PE	PE-994	AW		5.61	5.6		
PF	PF-841	SW		2.29	1.8		
PF	PF-842	SW		1.75	0.2		
PF	PF-843	AW		5.56	4.6	Y	
PF	PF-844	SW		2.78	2.1		
PF	PF-845	SW		2.37	2.6		
PF	PF-846	SW		2.81	2.6		
PF	PF-847	SW		1.83	1.2		
PF	PF-848	SW		2.22	2.1		
PF	PF-849	SW		2.2	1.6		
PF	PF-850	SW		2.35	1.6		
PF	PF-851	SW		2.37	2.5		
PF	PF-852	SW		2.99	2.6	Y	
PF	PF-853	SW		2.53	2.2		
PF	PF-854	SW		2.15	1.9		
PF	PF-855	SW		2.26	1.9		
PF	PF-856	SW		2.58	2.3		Y
PG	PG-56	SW		1.32	0.5		
PG	PG-57	SW		1.99	1.2	Y	
PG	PG-58	SW		0.8	0		
PG	PG-59	SW		1.79	0.9		
PG	PG-60	SW		1.64	0.9		
PG	PG-61	AW		4.77	4.4	Y	
PG	PG-62	AW		5.59	4.1		
PG	PG-63	SW		1.45	0.5		
PG	PG-64	SW		1.25	0		
PH	PH-1	AW		5.44	4.7	Y	
PH	PH-10	SW		2.21	1.6		
PH	PH-100	SW		2.25	2.2		
PH	PH-11	AW		6.53	4.4		
PH	PH-12	SW		3.04	3		
PH	PH-13	SW		1.74	0.9		
PH	PH-14	SW		1.8	1		
PH	PH-2	SW		1.6	0.8		
PH	PH-3	SW		3.15	3.1	Y	
PH	PH-4	SW		2.8	2		
PH	PH-5	SW		2.89	2.8		
PH	PH-6	SW		2.55	1.6		
PH	PH-7	SW	a	3.61	3		Y
PH	PH-8	SW	a	1.85	0.9		
PH	PH-9	SW		2.34	1.7		
PH	PH-90	SW		2.1	1.2		
PH	PH-91	AW		5.8	4.2		
PH	PH-92	SW		2.53	2.2		
PH	PH-93	SW		1.91	1.7		
PH	PH-94	AW		5.65	4.2		
PH	PH-95	SW		1.48	0.9		
PH	PH-96	SW		2.6	2.1		
PH	PH-97	SW		0.9	0		
PH	PH-98	SW		2.13	1.1		
PH	PH-99	SW		2.7	2.1		
PI	PI-100	SW		2.46	1.9		
PI	PI-822	SW		1.14	0		
PI	PI-823	SW		2.42	2.4		
PI	PI-824	SW		1.72	1.3		
PI	PI-91	SW		2.39	1.8		
PI	PI-92	SW		1.83	1		
PI	PI-93	SW		2.01	1.6		
PI	PI-94	SW		2.8	2.8	Y	
PI	PI-95	SW		1.7	1.2		
PI	PI-96	SW		1.54	0.6		
PI	PI-97	SW		1.66	0.9		
PI	PI-98	SW		2.46	2.2		
PI	PI-99	SW		2.32	2.4		
PJ	PJ-100	SW		1.48	0.4		
PJ	PJ-85	AW		5.08	4.3		
PJ	PJ-86	SW		2.22	1.4		
PJ	PJ-87	SW		2.72	2.3		
PJ	PJ-88	SW		2.49	1.9		
PJ	PJ-89	SW		3.07	2.5	Y	Y
PJ	PJ-90	SW		2.18	1.5		
PJ	PJ-91	SW		2.39	1.4		
PJ	PJ-92	SW		1.91	1.4		
PJ	PJ-93	SW		2.32	2		
PJ	PJ-94	SW		2.14	1.6		
PJ	PJ-942	AW		7.35	5.1		
PJ	PJ-943	SW		0.45	0		
PJ	PJ-944	AW		6.44	4.9		
PJ	PJ-945	SW		1.22	0		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
PJ	PJ-947	AW		6.81	5.4	Y	
PJ	PJ-948	SW		2.72	2.2		
PJ	PJ-95	SW		2.52	1.8		
PJ	PJ-96	AW		5.35	4.5		
PJ	PJ-97	SW		2.79	2.3		
PJ	PJ-98	AW		6.55	4.6		
PJ	PJ-99	SW		1.83	1.2		
PK	PK-73	SW		1.24	0		
PK	PK-74	SW		1.97	1.3		
PK	PK-75	SW		1.53	0.5		
PK	PK-76	SW		2.11	1.9		
PK	PK-77	SW		1.9	1.2		
PK	PK-78	SW		1.94	1.2		

Plot	Unique ID	Species	Shared Stem	Height (m)	DIA (cm)	*	**
PK	PK-79	SW		2.04	1.4		
PK	PK-80	SW		2.26	1.7		
PK	PK-81	SW		2.13	1.5		
PK	PK-82	SW		2.9	2.9	Y	Y
PK	PK-83	SW		1.68	1.3		
PK	PK-84	AW		5.14	4.5	Y	
PK	PK-85	SW		1.75	0.9		
PK	PK-86	SW		1.89	1		
PK	PK-87	SW		1.86	1.2		
PK	PK-89	SW		2.29	1.9		
PK	PK-90	SW		1.75	0.7		

Table 4. Vegetation data for characteristic plant species observed at sampling locations on SBH, as per the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (2009).

Tree Stratum	**1A**	**1B**	**1C**	**1D**	**1E**	**1G**	**1H**	**1J**	**1L**	**1M**	**1T**	**1U**
Betula papyrifera									0.1			
Picea glauca	16	17	8	18	10	11	16	9	14	18	0	18
Pinus banksiana												
Populus balsamifera			0.1				0.1	1	0.1	0.1	1.5	
Populus tremuloides	16	13	7	22	12	25	16	15	20	12	13	12
Forb Stratum												
Cornus canadensis												
Epilobium angustifolium	1				0.1	1	2		3	1	1	
Equisetum arvense			0.1				*		3		2	
Fragaria virginiana	*	1	0.1				*			0.1		
Lathyrus ochroleucus			0.1									
Lycopodium annotinum												
Petasites frigidus var. palmatus	0.1											
Pyrola asarifolia							0.1	0.1			0.1	
Calamagrostis canadensis	7	10	14	3	4	3	*	1	1	1.5		7
Moss Stratum												
Hylocomium splendens				0.1								
Pleurozium schreberi												
Ptilium crista-castrensis												
Shrub Stratum												
Alnus viridis			1									
Amelanchier alnifolia												
Arctostaphylos uva-ursi										0.1		
Cornus stolonifera	0.1											
Ledum groenlandicum												
Linnaea borealis												
Ribes triste									0.1			
Rosa acicularis	0.1	0.1	0.1	0.1	0.1				0.1			
Rubus idaeus	2	2	0.1	3	1	*	4		1	0.1	1	3
Rubus pubescens											0.1	
Salix bebbiana				3	2	4	4	2	4	7	6	
Salix discolor												
Salix drummondiana												
Salix glauca												
Salix spp.			0.1	4	6	8	10	5	3			6
Shepherdia canadensis												
Vaccinium myrtilloides												
Vaccinium vitis-idaea						0.1	0.1					

Tree Stratum	**2A**	**2B**	**2C**	**2D**	**2E**	**2G**	**2H**	**2J**	**2L**	**2M**	**2T**	**2U**
Betula papyrifera												
Picea glauca	5	10	10	10	10	11	8	10	10	14	4	13
Pinus banksiana												
Populus balsamifera			1	2	2	1	0.1	3	0.1			
Populus tremuloides	16	8	5	16	18	9	9	18	9	18		15
Forb Stratum												
Cornus canadensis												
Epilobium angustifolium							2	1.5	0.1	1	3	
Equisetum arvense			4	1			0.1					0.1
Fragaria virginiana			2									0.1
Lathyrus ochroleucus			0.1								1	
Lycopodium annotinum												
Petasites frigidus var. palmatus											1	
Pyrola asarifolia							0.1					
Calamagrostis canadensis	2		1	4	4		4	2	2		*	2
Moss Stratum												
Hylocomium splendens							0.1					0.1
Pleurozium schreberi												
Ptilium crista-castrensis												
Shrub Stratum												
Alnus viridis												
Amelanchier alnifolia												
Arctostaphylos uva-ursi				3								
Cornus stolonifera						0.1						
Ledum groenlandicum			1									
Linnaea borealis												
Ribes triste												
Rosa acicularis							0.1					
Rubus idaeus						2						
Rubus pubescens	1	2			1	2	0.1	1				*
Salix bebbiana			1		4	4	6	5	4	3	11	2
Salix discolor				0.1								
Salix drummondiana												
Salix glauca					0.1							
Salix spp.						2	3	1			1	
Shepherdia canadensis												
Vaccinium myrtilloides												
Vaccinium vitis-idaea												

Tree Stratum	**3A**	**3B**	**3C**	**3D**	**3E**	**3G**	**3H**	**3J**	**3L**	**3M**	**3T**	**3U**
Betula papyrifera										2		
Picea glauca	5	9		14	15	16	18	10	20	15		20
Pinus banksiana												
Populus balsamifera	1		0.1					0.1		3.5		1
Populus tremuloides	12	20	4	10	8	13	20	14	14	17	4	18
Forb Stratum												
Cornus canadensis												
Epilobium angustifolium				1	3		2	3	2	1		0.1
Equisetum arvense							0.1	1		0.1		
Fragaria virginiana	2							1	1			
Lathyrus ochroleucus												
Lycopodium annotinum												
Petasites frigidus var. palmatus												
Pyrola asarifolia	0.1									1		
Calamagrostis canadensis	0.1	4	R	6	4			3	5	2	3	5
Moss Stratum												
Hylocomium splendens												
Pleurozium schreberi												
Ptilium crista-castrensis				0.1								
Shrub Stratum												
Alnus viridis			0.1									
Amelanchier alnifolia												
Arctostaphylos uva-ursi									0.1			
Cornus stolonifera												
Ledum groenlandicum												
Linnaea borealis												0.1
Ribes triste												
Rosa acicularis		0.1			0.1	0.1				0.1		0.1
Rubus idaeus	2	4.5	1	0.1	2	4	7	4	4	2	3	3
Rubus pubescens										0.1		
Salix bebbiana		2			1	2		3		2	10	1
Salix discolor												
Salix drummondiana												
Salix glauca												
Salix spp.	3	4				2		4	3	6	1	6
Shepherdia canadensis												
Vaccinium myrtilloides									0.1			
Vaccinium vitis-idaea		0.1								0.1		

Tree Stratum	**4C**	**4L**	**4M**	**4T**	**4U**	**5C**	**5L**	**5M**	**5T**	**5U**
Betula papyrifera	1				5	0.1				
Picea glauca	8	8	9	5	11	6	5	6	9	8
Pinus banksiana										
Populus balsamifera	20	1			2	4		4	3	1
Populus tremuloides	16	12	14	13	8	9	1		17	
Forb Stratum										
Cornus canadensis										
Epilobium angustifolium	*	3		1	2	2	1	0.1	1	1
Equisetum arvense	6			1	4	20			3	1
Fragaria virginiana								0.1		
Lathyrus ochroleucus	0.1			0.1	0.1					0.1
Lycopodium annotinum										
Petasites frigidus var. palmatus										
Pyrola asarifolia	0.1									
Calamagrostis canadensis		5	10	6		15		2	2	3
Moss Stratum										
Hylocomium splendens										
Pleurozium schreberi								0.1		
Ptilium crista-castrensis										
Shrub Stratum										
Alnus viridis	3				4				3	3
Amelanchier alnifolia										
Arctostaphylos uva-ursi										
Cornus stolonifera										
Ledum groenlandicum	0.1								0.1	
Linnaea borealis										
Ribes triste			0.1							
Rosa acicularis		0.1	0.1						0.1	
Rubus idaeus		6	3.5	5	*					
Rubus pubescens	0.1		0.1		0.1					
Salix bebbiana	4	2	3		2	*	0.1	*	6	*
Salix discolor										
Salix drummondiana										
Salix glauca										
Salix spp.	2		5	6						
Shepherdia canadensis						*				
Vaccinium myrtilloides										
Vaccinium vitis-idaea	0.1									0.1

Tree Stratum	**6C**	**6L**	**6M**	**6T**	**6U**	**7C**	**7L**	**7M**	**7P1**	**7P2**	**7T**	**7U**
Betula papyrifera						0.1				2		
Picea glauca	9	4	4.5		11	7		15	11	12	16	
Pinus banksiana												
Populus balsamifera	0.1	1	0.1	0.1		2		5	3	4	0	
Populus tremuloides	4		4	16		13			20	25	6	
Forb Stratum												
Cornus canadensis												
Epilobium angustifolium		2	1	1		1			2	2	2	
Equisetum arvense	3	12	3	10		2			5	15		
Fragaria virginiana	1.5		0.1		1.5	0.1		3	1			
Lathyrus ochroleucus			0.1	0.1								
Lycopodium annotinum												
Petasites frigidus var. palmatus												
Pyrola asarifolia									0.1			
Calamagrostis canadensis	15	2	10	1	50	2		6	6			
Moss Stratum												
Hylocomium splendens												
Pleurozium schreberi												
Ptilium crista-castrensis												
Shrub Stratum												
Alnus viridis	1	6	2	5		1		0.1		1		
Amelanchier alnifolia												
Arctostaphylos uva-ursi		0.1	0.5						0.1			
Cornus stolonifera								0.1	0.1			
Ledum groenlandicum									0.1	2		
Linnaea borealis												
Ribes triste												
Rosa acicularis								2.5			12	
Rubus idaeus	3				1.5						0.1	
Rubus pubescens			0.1									
Salix bebbiana	1	4	2	2	0.8	1			1	1		
Salix discolor												
Salix drummondiana												
Salix glauca	0.1											
Salix spp.	1		4	2		2			1			
Shepherdia canadensis								1				
Vaccinium myrtilloides												
Vaccinium vitis-idaea												

Tree Stratum	**8C**	**8M**	**8P1**	**8P2**	**8T1**	**8U**	**9C**	**9L**	**9M**	**9T**	**9U**
Betula papyrifera							0.1				
Picea glauca	4	4	9	7.5	13		12	7	14	8	9
Pinus banksiana											
Populus balsamifera			3	0.1			2.5	0.1	2	1	0.1
Populus tremuloides			20	0.1			7	6	9	10	9
Forb Stratum											
Cornus canadensis											
Epilobium angustifolium								1			1
Equisetum arvense			10	0.1			1	3	5	8	0.1
Fragaria virginiana		1	1		0.5		2				
Lathyrus ochroleucus		0.1	0.1					0.1			
Lycopodium annotinum											
Petasites frigidus var. palmatus											
Pyrola asarifolia			0.1								
Calamagrostis canadensis	4	1		20			1.5	9	10	15	5
Moss Stratum											
Hylocomium splendens											
Pleurozium schreberi											
Ptilium crista-castrensis											
Shrub Stratum											
Alnus viridis			3				0.1		1	1	
Amelanchier alnifolia			0.1								
Arctostaphylos uva-ursi		0.1									
Cornus stolonifera	0.1										0.1
Ledum groenlandicum											
Linnaea borealis											
Ribes triste											
Rosa acicularis	0.1	3						0.1		1	3
Rubus idaeus	1.5		1					2			
Rubus pubescens								0.1			
Salix bebbiana									0.1		
Salix discolor											
Salix drummondiana											
Salix glauca											
Salix spp.							1	1	1		1.5
Shepherdia canadensis			*				1.3				
Vaccinium myrtilloides											
Vaccinium vitis-idaea			0.1						0.1		

Tree Stratum	**PA**	**PB**	**PC**	**PD**	**PE**	**PF**	**PG**	**PH**	**PI**	**PJ**	**PK**
Betula papyrifera	2	1		3	1.5	3	2	1		1	0.1
Picea glauca	3.5	12	8	7	12	9	2.5	16.5	5.5		
Pinus banksiana											7
Populus balsamifera		4	3	1	1.5	2	3	1		2	2
Populus tremuloides	19	10	16		23	25	16	17		40	6
Forb Stratum											
Cornus canadensis											
Epilobium angustifolium		4		3		0.1	2	4	1.5		
Equisetum arvense		20		40/50	0.1		4	6	0.1	10	*
Fragaria virginiana			1	0.1			0.1	0.1		0.5	
Lathyrus ochroleucus			0.1				1				
Lycopodium annotinum											
Petasites frigidus var. palmatus											
Pyrola asarifolia											
Calamagrostis canadensis	3	4	3	0.1	1		4	2	60		
Moss Stratum											
Hylocomium splendens											
Pleurozium schreberi											
Ptilium crista-castrensis											
Shrub Stratum											
Alnus viridis	0.1					1	3	4		*	1
Amelanchier alnifolia											
Arctostaphylos uva-ursi											
Cornus stolonifera											
Ledum groenlandicum	0.1			0.5	*		1	0.25		0.1	0.1
Linnaea borealis											
Ribes triste											
Rosa acicularis			0.1								
Rubus idaeus											
Rubus pubescens											
Salix bebbiana	1	3		2	*	2		3		6	
Salix discolor											
Salix drummondiana											
Salix glauca					*						
Salix spp.	3	2	5	4		2		3			2
Shepherdia canadensis											
Vaccinium myrtilloides					0.1						
Vaccinium vitis-idaea				1			0.1	0.1		1	

Tree Stratum	**LAI1**	**LAI2**	**LAI3**
Betula papyrifera	1	1	0.1
Picea glauca	12	13	10.5
Pinus banksiana			
Populus balsamifera	2	2	3.5
Populus tremuloides	21	18	9
Forb Stratum			
Cornus canadensis		2	
Epilobium angustifolium	2	30	
Equisetum arvense	4		60
Fragaria virginiana		1	1
Lathyrus ochroleucus			
Lycopodium annotinum		0.1	
Petasites frigidus var. palmatus			
Pyrola asarifolia			
Calamagrostis canadensis	5		
Moss Stratum			
Hylocomium splendens			
Pleurozium schreberi			
Ptilium crista-castrensis			
Shrub Stratum			
Alnus viridis			2
Amelanchier alnifolia			
Arctostaphylos uva-ursi			
Cornus stolonifera			
Ledum groenlandicum			0.1
Linnaea borealis			
Ribes triste			
Rosa acicularis			
Rubus idaeus			
Rubus pubescens			
Salix bebbiana	1.5	1	
Salix discolor			
Salix drummondiana			
Salix glauca			
Salix spp.			3
Shepherdia canadensis			
Vaccinium myrtilloides			
Vaccinium vitis-idaea			0.1

APPENDIX C – CHEMISTRY DATA

Table 1. Foliar chemistry data for white spruce and aspen on SBH.

	TOTAL												
Sample Label	N	P	Ca	Mg	K	S	Cu	Zn	Fe	Mn	B	AVAIL SO4-S	100 Leaf Weight
	%						ppm	ppm	ppm	ppm	ppm	ppm	(g)
1C-SW	1.35	0.15	0.72	0.10	0.41	0.094	5	77	111	52	8	30	0.250
1L-SW	1.45	0.15	0.80	0.11	0.56	0.093	6	47	118	185	20	39	0.299
1M-SW	1.15	0.13	0.52	0.07	0.33	0.103	5	46	121	130	9	175	0.332
1U-SW	1.28	0.16	0.64	0.11	0.56	0.092	3	50	123	107	15	38	0.441
2C-SW	1.42	0.17	0.80	0.08	0.63	0.095	7	59	119	568	13	32	0.336
2L-SW	1.37	0.15	0.61	0.09	0.46	0.099	4	46	128	169	21	92	0.327
2M-SW	1.27	0.17	0.64	0.11	0.46	0.093	4	47	117	69	9	97	0.285
2T-SW	1.39	0.16	0.79	0.11	0.66	0.100	9	53	143	212	17	140	0.330
2U-SW	1.27	0.17	0.85	0.11	0.59	0.104	5	60	170	151	19	218	0.404
3L-SW	1.35	0.16	0.68	0.11	0.61	0.094	5	53	111	64	13	44	0.333
3M-SW	1.37	0.17	0.59	0.09	0.60	0.094	6	43	107	66	19	56	0.391
3U-SW	1.44	0.17	0.75	0.10	0.52	0.087	6	42	117	229	11	22	0.379
4C-SW	1.28	0.14	0.64	0.11	0.47	0.083	9	39	80	316	9	44	0.276
4L-SW	1.37	0.17	0.81	0.10	0.57	0.096	6	54	97	46	19	28	0.272
4M-SW	1.45	0.17	0.77	0.10	0.49	0.091	4	52	118	56	8	35	0.368
4T-SW	1.31	0.18	0.65	0.10	0.64	0.087	4	51	101	40	8	51	0.375
4U-SW	1.34	0.16	0.61	0.11	0.55	0.095	9	52	114	60	8	38	0.230
5C-SW	1.35	0.14	0.91	0.11	0.47	0.087	4	45	103	153	8	31	0.272
5L-SW	1.32	0.13	0.56	0.08	0.58	0.099	9	52	219	30	10	37	0.271
5M-SW	1.33	0.19	0.66	0.09	0.56	0.092	5	47	167	29	10	53	0.362
5T-SW	1.39	0.14	0.72	0.12	0.48	0.081	5	48	158	294	12	39	0.266
5U-SW	1.35	0.15	0.76	0.11	0.45	0.088	4	64	117	244	13	29	0.221
6C-SW	1.46	0.18	0.61	0.11	0.61	0.091	4	59	168	119	10	51	0.272
6L-SW	1.45	0.22	0.82	0.15	0.48	0.100	4	67	447	107	10	68	0.280
6M-SW	1.38	0.17	0.64	0.11	0.60	0.099	4	58	373	201	14	38	0.305
6U-SW	1.41	0.18	0.72	0.12	0.51	0.094	4	58	345	124	13	60	0.404
7C-SW	1.37	0.20	0.68	0.13	0.57	0.095	3	50	210	156	10	55	0.269
7M-SW	1.50	0.17	1.02	0.13	0.68	0.100	4	69	318	76	15	74	0.260
7P1-SW	1.35	0.16	0.66	0.09	0.58	0.094	4	48	120	232	10	42	0.320
7P2-SW	1.18	0.17	0.70	0.11	0.48	0.083	4	32	98	783	11	50	0.247
7T-SW	1.51	0.16	0.83	0.11	0.55	0.094	4	64	476	203	23	41	0.350
8C-SW	1.05	0.13	0.61	0.09	0.37	0.080	5	66	292	25	10	49	0.259
8M-SW	1.39	0.17	0.67	0.13	0.44	0.099	3	60	370	40	11	81	0.210
8P1-SW	1.33	0.20	0.81	0.12	0.59	0.092	5	52	129	516	11	58	0.279
8P2-SW	0.96	0.11	0.68	0.08	0.45	0.081	4	81	230	13	16	117	0.179
8T-SW	1.24	0.15	1.14	0.15	0.52	0.087	4	62	694	32	23	85	0.327
9C-SW	1.36	0.15	0.76	0.10	0.46	0.091	5	63	176	226	12	43	0.344
9L-SW	1.20	0.17	0.46	0.10	0.47	0.084	4	41	139	93	14	22	0.271
9M-SW	1.30	0.15	0.52	0.09	0.34	0.087	3	42	185	82	11	49	0.265
9U-SW	1.13	0.18	0.63	0.09	0.47	0.082	3	52	156	419	16	74	0.250

	TOTAL												
Sample Label	N	P	Ca	Mg	K	S	Cu	Zn	Fe	Mn	B	AVAIL SO4-S	100 Leaf Weight
			%				ppm	ppm	ppm	ppm	ppm	ppm	(g)
1C-AW	1.73	0.20	1.29	0.41	0.73	0.226	6	134	311	79	44	1596	6.443
1L-AW	2.01	0.14	0.88	0.36	0.98	0.278	7	57	294	102	138	2261	7.714
1M-AW	2.09	0.20	1.63	0.52	1.10	0.944	5	83	376	134	59	5996	5.545
1T-AW	1.90	0.18	1.94	0.51	0.84	0.194	8	87	232	67	87	1626	10.078
1U-AW	1.99	0.19	1.48	0.49	0.88	0.216	5	90	324	78	54	988	8.186
2C-AW	1.92	0.17	1.13	0.36	0.70	0.160	5	103	277	132	40	730	8.291
2L-AW	1.99	0.18	1.34	0.45	1.23	0.335	6	90	330	128	87	3142	6.450
2M-AW	1.94	0.17	1.25	0.44	0.90	0.280	5	194	301	89	75	3691	6.364
2T-AW	1.75	0.15	1.29	0.36	0.97	0.351	10	78	234	101	64	3876	8.460
2U-AW	1.98	0.17	1.45	0.48	0.91	0.517	5	69	318	109	59	3039	8.352
3C-AW	1.79	0.14	1.58	0.41	0.68	0.170	11	127	196	107	62	798	5.130
3L-AW	2.04	0.15	1.56	0.39	1.05	0.256	11	76	138	86	82	1754	6.611
3M-AW	2.14	0.18	1.18	0.44	1.03	0.209	6	38	210	74	52	1416	7.016
3T-AW	1.93	0.15	1.31	0.31	1.00	0.226	6	156	252	83	39	1841	9.506
3U-AW	2.09	0.18	1.52	0.33	0.87	0.193	11	71	198	144	45	755	5.619
4C-AW	1.49	0.12	1.29	0.32	0.80	0.215	6	80	188	139	54	1527	6.282
4L-AW	2.09	0.16	1.37	0.37	0.76	0.204	8	172	231	74	40	682	8.015
4M-AW	2.02	0.18	2.02	0.40	0.69	0.194	4	140	355	94	63	1255	7.562
4T-AW	1.92	0.17	1.44	0.34	1.00	0.192	10	75	182	67	53	842	6.103
4U-AW	1.62	0.13	1.46	0.29	0.70	0.324	4	99	210	124	37	1529	5.497
5C-AW	1.91	0.12	1.05	0.26	1.26	0.303	10	89	454	66	45	1221	6.891
5M-AW	2.20	0.22	1.59	0.33	0.72	0.190	6	179	390	46	63	843	6.804
5T-AW	1.92	0.14	1.29	0.32	0.74	0.192	10	109	389	119	40	576	7.343
5U-AW	1.75	0.16	1.31	0.39	0.93	0.244	10	159	334	99	49	1772	5.243
6C-AW	1.93	0.18	1.93	0.41	0.75	0.182	7	214	541	147	60	857	6.419
6L-AW	1.93	0.20	1.52	0.52	0.95	0.171	10	114	583	83	25	528	15.736
6M-AW	1.76	0.16	1.48	0.39	0.74	0.202	6	186	691	83	51	1026	9.814
6T-AW	1.95	0.14	1.47	0.41	0.92	0.233	10	127	1644	125	49	1547	5.865
7C-AW	1.97	0.19	1.69	0.38	0.80	0.182	5	134	536	126	39	1362	7.016
7M-AW	1.93	0.12	1.20	0.31	0.75	0.236	4	203	535	58	51	1438	6.519
7P1-AW	2.20	0.18	1.79	0.37	0.98	0.228	5	130	407	136	75	1438	7.016
7P2-AW	2.07	0.18	1.40	0.36	0.85	0.245	10	191	330	197	34	1402	6.063
7T-AW	2.32	0.12	1.40	0.34	1.19	0.256	9	315	694	76	55	1584	12.926
8P1-AW	1.80	0.15	1.33	0.33	0.90	0.213	10	107	304	126	46	1657	6.775
9C-AW	1.66	0.14	1.45	0.32	0.80	0.183	3	216	286	180	46	1084	5.958
9L-AW	1.90	0.18	1.94	0.57	1.02	0.194	3	183	312	125	69	1525	6.336
9M-AW	1.73	0.17	1.73	0.46	0.81	0.172	3	134	300	86	64	1300	6.002
9T-AW	1.62	0.16	1.86	0.40	0.91	0.216	6	269	280	150	43	2309	4.826
9U-AW	1.61	0.17	1.42	0.42	0.77	0.172	6	113	484	159	69	1751	6.724

Analyses completed for J. Straker of The Integral Ecology Group, November 2012, by Pacific Soils Analysis, Richmond BC.

Table 2. Summarized foliar chemistry data for white spruce and aspen on SBH, for elements not summarized in the main report.

Nutrient/ Species	Mean	Std. Dev.	Minimum	Maximum
Calcium (%)				
Spruce (n=40)	0.71	0.13	0.46	1.14
Aspen (n=39)	1.47	0.25	0.88	2.02
Magnesium (%)				
Spruce	0.11	0.02	0.07	0.15
Aspen	0.39	0.07	0.26	0.57
Potassium				
Spruce	0.52	0.08	0.33	0.68
Aspen	0.89	0.15	0.68	1.26
Copper (mg/kg)				
Spruce	5	2	3	9
Aspen	7	2	3	11
Zinc (mg/kg)				
Spruce	54	10	32	81
Aspen	133	60	38	315
Iron (mg/kg)				
Spruce	192	129	80	694
Aspen	376	248	138	1644
Manganese (mg/kg)				
Spruce	168	163	13	783
Aspen	108	35	46	197
Boron (mg/kg)				
Spruce	13	4	8	23
Aspen	57	20	25	138
SO4-S (mg/kg)				
Spruce	61	41	22	218
Aspen	1656	1060	528	5996
100-leaf weight (g)				
Spruce	0.303	0.059	0.179	0.441
Aspen	7.269	2.095	4.826	15.736

Table 3. Per-plot depth weighted (up to 100 cm) soil chemistry data for pH, electrical conductivity, and sodium adsorption ratio.

	pH			EC			SAR		
Plot	**TS**	**US**	**LS**	**TS**	**US**	**LS**	**TS**	**US**	**LS**
1C	7.12	7.47	6.97	0.89	0.93	2.65	0.92	2.27	5.52
1L	6.00	7.35	7.21	0.55	0.73	2.70	0.50	1.07	1.89
1M	5.77	6.89	7.26	1.77	4.70	7.24	3.57	8.23	10.61
1T	7.30	7.63	7.68	0.64	0.54	0.97	0.55	1.10	4.78
1U	5.95	7.41	7.29	0.75	1.41	8.34	0.92	5.47	14.75
2C	5.96	7.27	7.67	0.85	0.71	1.09	0.38	1.14	3.58
2L	6.88	7.45	7.50	3.08	6.66	7.56	6.98	12.65	15.10
2M	6.60	7.43	7.54	3.38	6.52	8.79	4.40	11.72	15.65
2T	7.55	7.50		3.93	8.28		9.10	14.13	
2U	6.40	7.43	7.20	0.96	5.31	7.61	4.70	11.67	10.70
3C	7.26	7.56	7.74	1.19	2.56	4.21	1.80	4.48	9.03
3L	7.25	7.58	7.70	1.47	2.36	7.01	2.48	4.45	12.63
3M	6.52	7.07	7.26	0.70	0.64	1.30	1.06	1.19	4.96
3T	7.36	7.61	7.57	1.09	2.78	5.46	2.58	4.95	9.44
3U	6.74	7.52	7.60	0.65	0.68	1.58	0.80	1.13	2.62
4C	6.62	7.08	7.34	0.95	2.21	6.30	0.67	1.47	9.85
4L	7.03	7.45	7.60	1.05	0.72	1.24	0.58	1.33	2.36
4M	6.92	7.34	7.58	1.12	1.18	3.98	0.74	1.04	6.27
4T	7.24	7.35	7.50	1.43	0.60	1.97	0.86	1.71	4.71
4U	7.58	7.30	7.04	0.58	1.63	2.47	1.18	1.93	2.40
5C	7.50	7.49	7.67	0.98	1.30	3.57	0.80	1.68	6.88
5L	7.54	7.59	7.26	1.09	0.70	6.00	0.70	1.01	10.62
5M	7.49	7.70	7.48	1.35	0.69	3.07	1.44	1.13	4.33
5T	7.02	7.35	7.40	1.69	2.91	3.02	1.24	2.33	3.20
5U	6.72	7.43	7.64	2.37	5.41	7.43	3.38	9.44	14.43
6C	6.55	7.35	7.56	0.82	1.20	5.68	0.92	2.54	9.64
6L	7.60	7.53	7.54	0.81	0.76	2.49	0.60	1.09	4.56
6M	5.60	7.40	7.60	1.35	1.17	2.13	1.90	4.30	7.94
6T	6.72	7.29	7.50	2.06	3.46	5.33	2.58	3.91	8.78
6U	6.60	7.38	7.44	0.90	0.81	3.91	0.76	1.42	5.46
7C	6.55	7.03	7.40	1.56	2.13	3.02	1.60	0.93	3.28
7M	7.55	7.45	7.72	1.67	2.66	1.96	0.78	1.05	2.93
7P1	4.74	6.16	7.40	1.52	1.50	2.38	1.11	1.36	3.85
7P2	6.37	7.22	7.20	2.02	2.56	2.97	0.81	1.07	2.25
7T	6.55	5.40	6.80	1.57	2.75	3.53	0.90	1.30	6.15
8C	7.22	6.73	7.37	2.20	2.52	4.90	0.31	1.05	7.40
8M	7.00	7.37	7.38	0.99	1.35	4.98	0.40	1.27	5.59
8P1	5.98	7.20	7.22	2.30	2.71	3.39	1.20	1.20	4.11
8P2	7.50	7.40	7.53	1.22	2.65	3.67	0.80	1.47	5.07
8T1	7.40	7.02	7.45	1.15	3.13	5.76	1.10	3.84	9.20
9C	6.10	7.20	7.50	1.47	1.66	2.82	0.70	2.00	7.52
9L	5.97	7.15	7.33	0.79	1.69	5.80	0.60	2.85	11.55
9M	7.24	7.61	7.50	1.29	1.60	3.11	1.68	2.48	5.78
9T	6.86	7.34	7.48	3.15	5.23	5.19	6.04	8.41	9.82
9U	7.36	7.40	7.46	1.79	2.38	3.25	0.64	0.81	4.31

APPENDIX D – COORDINATES FOR ALL POINTS

Table 1. UTM coordinates for all plots surveyed for vegetation on SBH.

Plot	Northing	Easting
1A	6316982.4000	462345.5660
1B	6316997.7980	462335.3150
1C	6316961.3585	462344.8225
1D	6317022.3490	462315.3820
1E	6317040.5500	462303.9030
1G	6317058.8430	462287.8480
1H	6317072.9430	462274.9800
1J	6317093.7680	462257.2200
1L	6317074.0296	462258.4052
1M	6317039.9099	462284.4234
1T	6317106.7660	462233.4418
1U	6317002.3752	462313.0458
2A	6317000.6760	462372.8200
2B	6317013.9510	462362.1440
2C	6316992.5686	462388.9542
2D	6317041.6440	462342.5150
2E	6317055.2810	462335.7780
2G	6317077.4660	462312.8200
2H	6317091.7940	462303.8110
2J	6317112.2960	462288.2910
2L	6317107.7670	462300.8620
2M	6317070.5561	462329.2325
2M[a]	6317075.0000	462333.0000
2T	6317125.6933	462281.0952
2U	6317032.0746	462358.5716
3A	6317029.6030	462411.6440
3B	6317055.6380	462418.2210
3C	6317022.6322	462426.9885
3D	6317073.9860	462377.5990
3E	6317099.3280	462387.0310
3G	6317109.8920	462350.0290
3H	6317134.6530	462358.4190
3J	6317147.4210	462326.9340
3L	6317139.7473	462343.4306
3M	6317104.7567	462368.3192
3T	6317166.1639	462324.4700
3U	6317064.3195	462397.1944
4C	6317214.1326	462648.4513
4L	6317328.9764	462591.2654
4M	6317280.3308	462613.5130
4T	6317347.4843	462577.7394
4U	6317245.2227	462631.9653
5C	6317147.2967	462776.5358
5L	6317220.2383	463000.9913
5M	6317196.2344	462927.1268
5T	6317229.0417	463027.4655
5U	6317162.2679	462822.6053
6C	6317005.4762	462746.0958
6L	6316976.1751	462830.0338
6M	6316986.1016	462801.4654
6T	6316969.0000	462848.0000
6T[a]	6316968.0000	462845.0000
6U	6316996.7952	462770.9049
7C	6316874.7171	462601.3622
7M	6316857.3503	462618.6816
7P1	6316974.8359	462502.6534
7P2	6316911.0871	462565.5044
7T	6316842.7906	462632.8390
8C	6316784.9254	462443.9293
8M	6316762.2507	462461.3231
8P1	6316878.6396	462372.0414
8P2	6316817.3546	462419.0530
8T	6316746.0000	462473.0000
8T[a]	6316746.0000	462467.0000
9C	6316920.6241	462332.3153
9L	6316914.1358	462209.2226
9M	6316915.5835	462238.9807
9T	6316908.0000	462169.0000
9U	6316917.6741	462281.9540
PA	6316905.8010	462519.4870
PB	6317006.1430	462517.4740
PC	6316898.9010	462621.1950
PD	6317004.8500	462618.6960
PE	6316954.3370	462668.7080
PF	6316853.9330	462568.5860
PG[b]	6317110.0000	462346.0000
PH	6317055.0430	462567.3950
PI	6316857.0560	462469.6520
PJ	6317055.8430	462668.8340
PK	6316905.1520	462419.7750
LAI1	6316934.7560	462568.4760
LAI2	6316975.3330	462586.2300
LAI3	6316957.4750	462546.5960

a. Plot centres for plots 2M, 6T, and 8T were relocated by Integral Ecology to avoid straddling transitioning vegetation communities affected by discrete and non-regenerated features such as a fenced-in area (2M) and an active roadway (6T and 8T). Plot centres were only sufficiently relocated to permit a 5.64 m radius plot in a homogenous vegetation community type. Coordinates for plots denoted with an 'a' are of the relocated plot centre; those not denoted 'a' are the original plot centre coordinates.

b. Plot 'PG' was not located in the high accuracy survey. Coordinates provided are from a handheld GPS device and are accurate within 3m.

APPENDIX E – CALCULATING SITE INDEX FOR WHITE SPRUCE AND ASPEN IN THE SYNCRUDE SOUTH BISON HILL CAPPING DEPTH TRIAL

Memorandum

TO: JUSTIN STRAKER

FROM: GYULA GULYAS (THEXLWIZ CONSULTING LTD.)

SUBJECT: CALCULATING SITE INDEX FOR WHITE SPRUCE AND ASPEN IN THE SYNCRUDE SOUTH BISON HILL CAPPING DEPTH TRIAL

DATE: DECEMBER 7, 2012

CC: KATHERINE GARRAH

Introduction

In October 2012 Justin Straker of the Integral Ecology Group requested the calculation of site index for white spruce and aspen based on the field work completed as part of the Syncrude South Bison Hill Science Synthesis Capping Depth Trial.

The purpose of this memo is to document the methods and results of the site index calculations. The description of the data collection protocols and the analysis of the results will be presented in the study report.

Methods

Site index measures the capacity of the land to grow trees of a given species. It represents the average height of eligible site trees (usually represented by the 100 largest DBH trees per hectare) of one species at 50 years breast height (BH) age. Accurate site index estimates are crucial to adequately describe site quality, formulate silviculture prescriptions, schedule treatments and predict stand growth and yield (Martin 1995).

1.1.1.1 White Spruce

Site trees of white spruce were identified in a 5.64 m radius plot (area=100 m^2) in the field. Growth intercept of 3-5 years above BH were measured based on the annual branch whorls. One spruce site tree in each plot was identified as the tallest[1] tree that is healthy, undamaged, located in the dominant or co-dominant canopy position and have not been overtopped by other trees or brush competition (i.e. no impediment to height growth due to a damaged leader or broken top). Age at BH was also determined based on annual whorl count.

Growth intercept models for predicting site index in young white spruce stands were developed by Alberta Environmental Protection (Huang 1996). The observed site index values were expressed as a function of average annual height growth intercept in 3-5 years above a reference height.

[Eq. 1] $SI = \frac{b_0 * GI}{b_1 + GI}$

where:

SI = Site index (m), which is the height at 50 years BH age

b_0-b_1 = Estimated coefficients

GI = Average annual growth intercept (m/year) in t years above the reference height (h_0).

All growth intercept measurements were based on growth above h_0=1.3 m[2]. The estimated coefficients for white spruce at 1.3 m base height are presented in Table 1.

Table 1. Growth intercept model for white spruce

t (years)	Coefficients (h_0=1.3 m)	
	b_0	b_1
3	29.659821	0.179620
4	30.149753	0.191800
5	30.739549	0.201934

Growth intercept techniques are difficult to implement in white spruce from data collected in operational surveys. Whorl count could be unreliable to estimate height increments due to Lammas growth, fake or hidden whorls and terminal bud scars are difficult to detect if the trees have more than three years of growth above BH. Growth intercept methods also rely on individual site tree stem

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[1] The largest DBH eligible tree is generally selected for site tree. However, in younger stands using the growth intercept method it is also required to select a tree that has a minimum of three years' growth above BH.

[2] A few GI measurements dipped below BH to the next whorl down if that resulted in measuring 3 years of growth (3 full internodes) so long as the next whorl down was within 20 cm.

analysis based site index estimates which may be biased due to dominance switching among juvenile trees (Dahms 1963, Magnussen and Penner 1996). Trees that are selected as site trees at a young age may not be the site trees at 50 years BH age in white spruce stands; which could result in an overestimate of site index.

In order to address the potential issue of site tree replacement, we calculated site index based on the latest published equations for white spruce in Alberta using the Growth and Yield Projection System – GYPSY (Huang *et al*. 2009). The GYPSY model attempts to remove the height bias due to site tree replacement by using permanent sample plot (PSP) based stand top height trajectories rather than individual site tree height growth. The basic premise of the approach is that by reselecting the site trees at each measurement of the PSP, the site tree replacement due to dominance switching is directly built into the models.

Top height is defined as the average height of the 100 largest DBH trees per hectare. Therefore one white spruce site tree in each 100 m^2 plot was identified based on the largest DBH tree that is healthy, undamaged, located in the dominant or co-dominant canopy position and have not been overtopped by other trees or brush competition (i.e. no impediment to height growth due to a damaged leader or broken top).

Total age from germination was determined based on careful examination of planting records. We determined the exact number of growing seasons based on the year and month of planting, the year and month of the survey and the age of the planted stock[3]. Given that the majority of the spruce was planted, we feel that the planting information is likely more reliable than whorl counts.[4]

The GYPSY site index model for white spruce has the following form:

[Eq. 2]

$$H_{top} = SI_t \times \left(\frac{1+\exp(b_1 + b_2\sqrt{\ln(1+50^2)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})}{1+\exp(b_1 + b_2\sqrt{\ln(1+totage^2)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})} \right)$$

where:

Htop = Top height (m), i.e., average height of the 100 largest DBH trees per ha

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[3] Tree seedlings were generally sown in February for fall planting thus most plugs would have one growing season.

[4] In an ideal situation, the selected site trees should be cored or similar site trees should be destructively sampled in the plot buffer and the rings counted in the lab.

SIt = Total age-based site index, i.e., top height at 50 years total age
totage = Total age from the point of germination (number of growing season)
b1-b4 = Estimated coefficients (b1= 12.14943, b2= -3.77051, b3= -0.28534 and b4= 0.165483)

For white spruce of approximately 15 years total age, it was found that the height of top height trees was approximately 14% greater than the height of the top height trees that would be selected closer to breast height age 50 years (Feng *et al*. 2006). We decided to employ the juvenile site index equation developed by Feng *et al*. using data from 168 white spruce trees that were longitudinally sectioned along the pith, selected from juvenile (age 6–15) stands in Alberta.

[Eq. 3] $SI = \frac{Ht-0.3}{a*Age^{b}}$

where

SI = Site index (m), which is the height at 50 years BH age

Ht = Corrected tree height (m) - (0.86*height)
Age = Time since planting in years
a-b = Estimated coefficients (a = 0.005, b = 1.323)

1.1.1.2 Aspen

Field identification of site trees and measurement of age and growth intercept were not conducted for aspen. Therefore one aspen site tree in each 100 m^2 plot was identified from the collected data based on the largest DBH tree that is healthy, undamaged, located in the dominant or co-dominant canopy position and have not been overtopped by other trees or brush competition (i.e. no impediment to height growth due to a damaged leader or broken top).

Total age from germination was determined based on careful examination of planting records. However, the major challenge for aspen was the large number of ingress (volunteer) that emerged on site after planting. For example, there were many young aspen on the crest and plateau sites where no aspen was planted according to records. Anecdotal evidence and photographs helped us determine the approximate age when aspen ingress started to emerge (Figure 1). The assigned total ages on these sites will likely result in conservative site index estimates as some of the selected site trees could be a couple of years younger.[5]

Figure 1. The emergence of aspen volunteers on the plateau sites (courtesy of Sean Carey)[6]

In the case of planted aspen, total age from germination was determined based on careful examination of planting records. We determined the exact number of growing seasons based on the year and month of planting, the year and month of the survey and the age of the planted stock.

The GYPSY site index model for aspen has the following form:

[Eq. 4]

$$H_{top} = SI_t \times \left(\frac{1+\exp(b_1 + b_2\sqrt{\ln(1+50)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})}{1+\exp(b_1 + b_2\sqrt{\ln(1+totage)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})} \right)$$

where:

Htop = Top height (m), i.e., average height of the 100 largest DBH trees per ha
SIt = Total age-based site index, i.e., top height at 50 years total age
totage = Total age from the point of germination (number of growing season)
b1-b4 = Estimated coefficients (b1= 9.908888, b2= -3.92451, b3= -0.32778 and b4= 0.134376)

Results

The site index calculation details for white spruce and aspen are listed in Appendix C. Only some basic

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[5] Unfortunately aspen is a fast-growing species and the site index model is the steepest at the younger ages which may result in larger underestimates of aspen site index. Only collecting aspen site tree age data directly in the field (preferably coring and ring counting in the lab) would mitigate this issue.

[6] Associate Professor, School of Geography & Earth Sciences, McMaster University

statistics are presented in this memo. Detailed analysis of the results with regards to capping depth will be discussed in the study report.

1.1.1.3 White Spruce

There were 67 white spruce site trees where growth intercept was measured in the field. There were no suitable site trees on 13 plots due to the absence of white spruce or the trees were too short and did not have the minimum of 3 years of growth above BH. Descriptive statistics are presented in Table 2. The average white spruce site index for the entire study area was 21.6 m based on the growth intercept measurements.

Table 2. Descriptive statistics of growth intercept data for white spruce

Statistics	Height (cm)	DBH (mm)	GI (m/year)	Site Index (m)
Average	378	43	0.49	21.60
St Dev	110	19	0.10	1.30
CV%	29%	43%	20%	6%
Minimum	208	17	0.26	17.45
Maximum	654	75	0.72	23.89
N	67	67	67	67

There were 76 white spruce site trees that we identified based on the data using the largest DBH eligible tree in each plot. There were no suitable site trees on 4 plots due to the absence of spruce or the trees have not reached BH yet. We calculated the GYPSY based site index and also the juvenile site index using the corrected height as per Feng *et al* (2006). The GYPSY model also enabled us to calculate the average time to reach BH (Y2BH).

Descriptive statistics are presented in Table 3. The average white spruce site index for the entire study area was 21.0 m based on both GYPSY and the juvenile site index model.

Table 3. Descriptive statistics of site tree data for white spruce

Statistics	Height (cm)	DBH (mm)	Years to BH	SI (m) GYPSY	SI (m) FENG
Average	357	42	6.6	21.0	21.0
St Dev	113	20	0.7	1.9	4.2
CV%	32%	47%	10%	9%	20%
Minimum	160	9	5.2	15.5	10.2
Maximum	654	75	8.9	25.9	32.4
N	76	76	73	73	76

Note: There were 3 site trees with total age below the 9.5 years minimum for GYPSY

The results suggest that the site index estimates obtained for white spruce are very similar regardless of the method used. There were 45 site trees in the data set that were also measured for growth intercept, indicating a generally good agreement (45/67=67%) between selecting the tallest versus the largest DBH suitable tree.

Comparing the site index values based on growth intercept with GYPSY (Figure 2) also reveals that there is a very good agreement in both range and also trend between the two methods. The 45-degree red line in the figure would indicate a perfect correlation (slope=1).

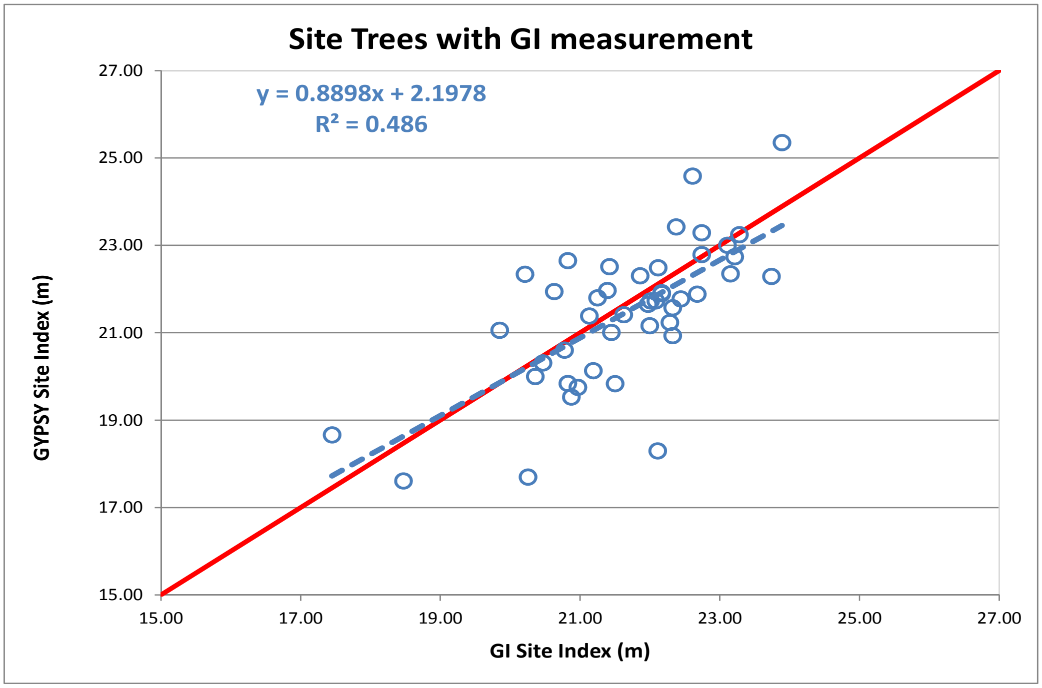


Figure 2. Comparing growth intercept and GYPSY based site index estimates for white spruce

1.1.1.4 Aspen

There were 62 aspen site trees that we identified based on the data using the largest DBH eligible tree in each plot. There were no suitable site trees on 18 plots due to the absence of aspen or suitable site trees. We calculated the GYPSY based site index only as no growth intercept data were collected as models developed using the GI method for aspen are generally poor.

Descriptive statistics are presented in Table 4. The average aspen site index for the entire study area was 20.0 m based on the GYPSY model.

Table 4. Descriptive statistics of site tree data for aspen

Statistics	Height (cm)	DBH (mm)	Years to BH	SI (m) GYPSY
Average	628	57	2.8	20.0
St Dev	102	11	0.6	2.7
CV%	16%	19%	21%	14%
Minimum	431	40	1.6	15.3
Maximum	864	83	4.1	26.9
N	62	62	62	62

Discussion

The Syncrude South Bison Hill study site appears to have planted white spruce trees that grow exceptionally well (Figure 3). The average site index did not change appreciably regardless of the calculation method we used for estimation. The average white spruce site index in post-harvest regenerated (PHR) mixedwood stands is around 18 m (Feng *et al* 2006) which is about 15% less than the observed values in our study (~21 m). The height-age scatter plot in Figure 3 shows that at 14 years of age the average height of white spruce site trees is around 4.7 m that is well above the range of regenerated stands created by traditional forestry methods.

The study site is located on an overburden dump which is a man-made, engineered structure. The area is capped with stockpiled soil and is subjected to fertilization treatments. Nitrogen deposition due to atmospheric pollution from fossil fuel consumption may also be a contributing factor.

The site index models developed in forestry attempt to model height growth patterns of site trees under normal stand development scenarios. It is not known if the observed growth on the SCL South Bison Hill study site and on other reclaimed areas of the mineable oil sands can be sustained or if it is a growth spurt that will eventually slow down.

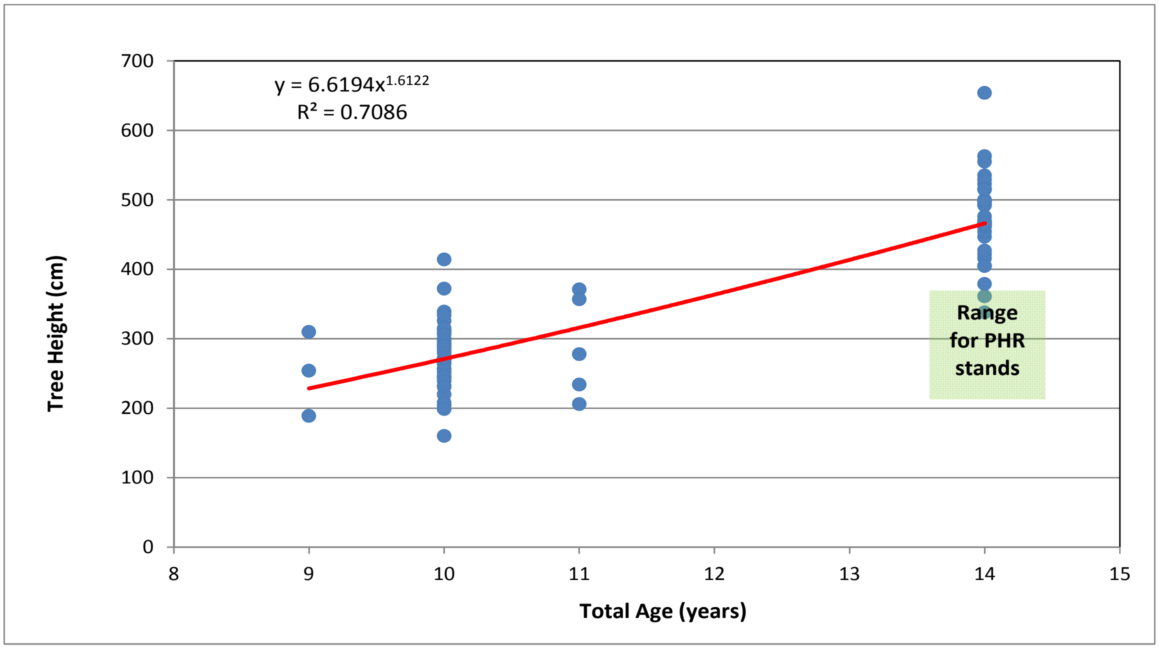


Figure 3. Height-age scatter plots for white spruce site trees

By applying traditional forestry site index equations, we are making the assumption that the site trees in the reclaimed areas will follow a similar height growth trajectory as their forestry counterparts of the same age and height. This assumption must be tested via long term observation of time series data using permanent sample plots where trees are tagged and site tree replacement over time can be tracked. New site index equations may be developed that are calibrated to stand development and growth patterns observed under reclaimed conditions. These models will need to consider soil and site factors that are specific to engineered structures and synthetic soils on the mineable oil sands.

References

Dahms,W.G. 1963. Correction for a possible bias in developing site index curves from sectioned tree data. J. For. 61: 25–27.

Feng, Z., K.J. Stadt, V.J. Lieffers and S. Huang. 2006. Linking juvenile growth of white spruce with site index. The Forestry Chronicle, 82(6): 819-824.

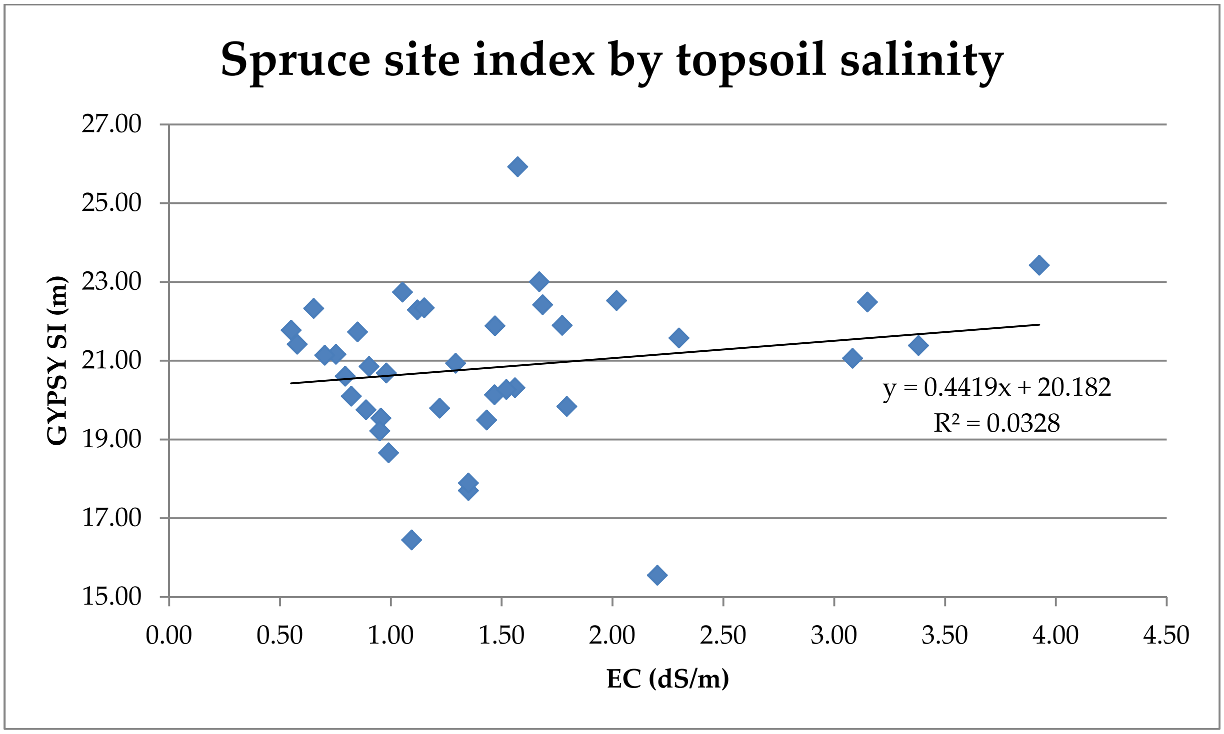
Huang, S. 1996. Interim Growth Intercept Models for Predicting Site Index in Young Spruce, Pine and Aspen stands. Technical Report, Pub. No.T/338. Alberta Environmental Protection, Land and Forest Service, Forest Management Division. Edmonton, Alberta. 14 pp.

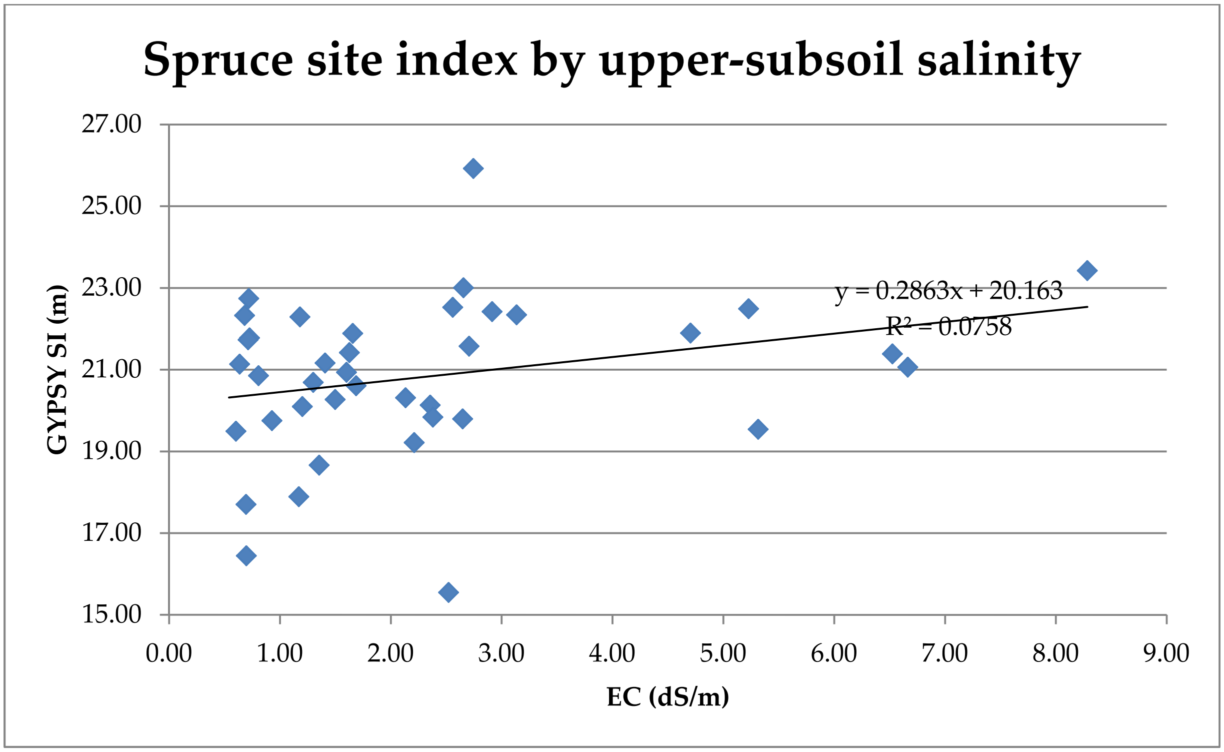
Huang, S., S.X. Meng, and Y. Yang. 2009. A Growth and Yield Projection System (GYPSY) for Natural and Post-harvest Stands in Alberta. Technical Report, Pub. No.T/216. Alberta Sustainable Resource Development, Forest Management Branch. Edmonton, Alberta.

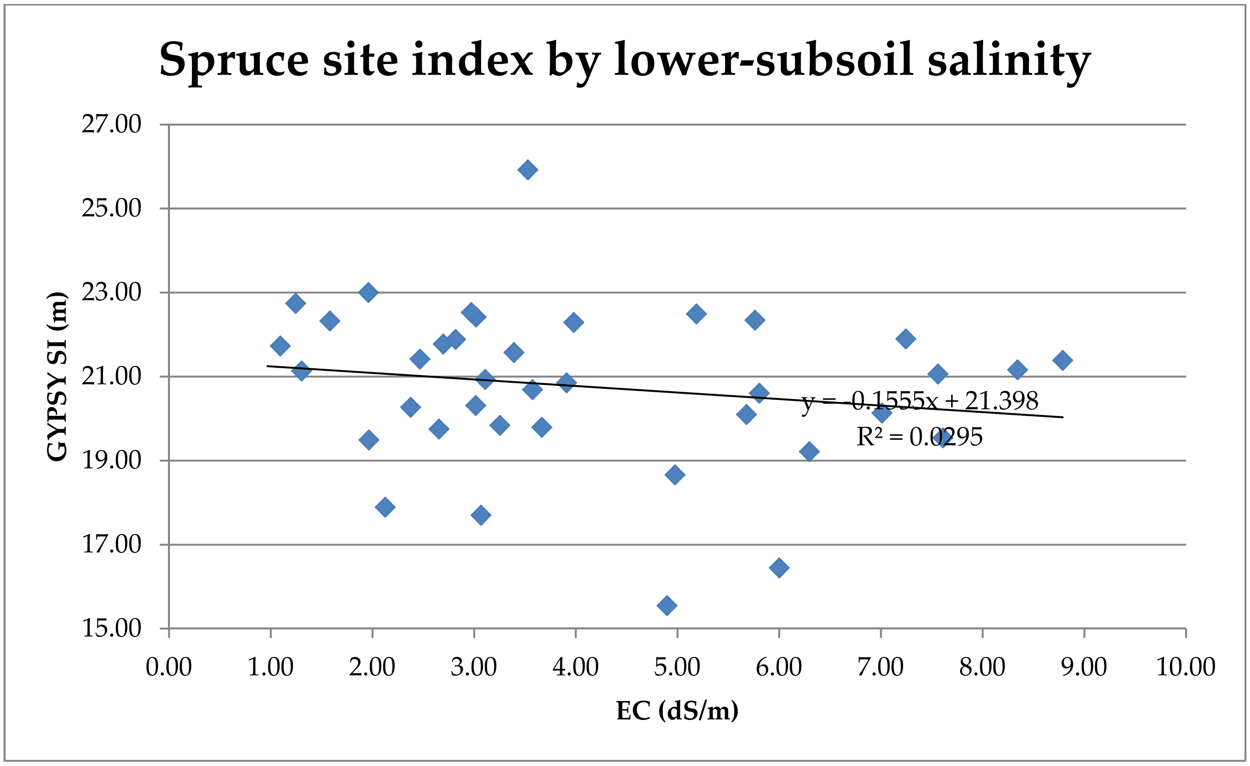
Magnussen, S. and M.Penner. 1996. Recovering time trends in dominant height from stem analysis. Can. J. For. Res. 26: 9–22.

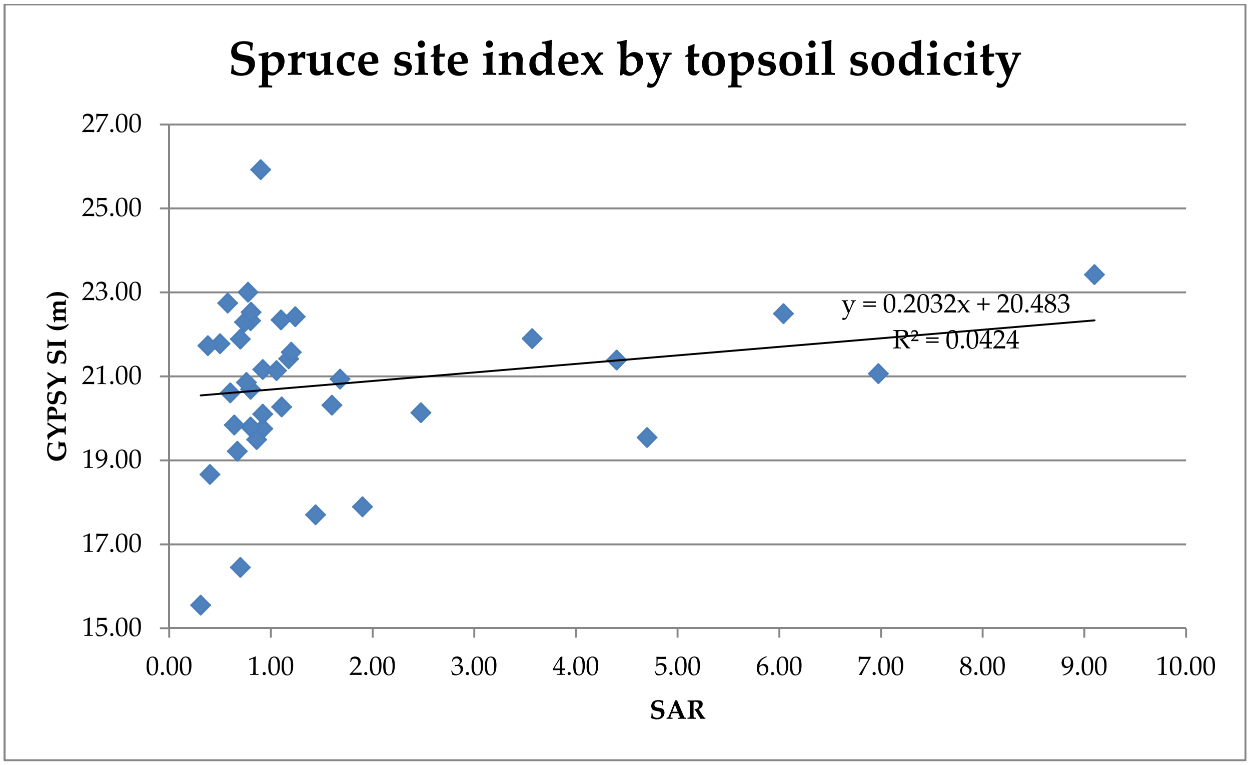
Martin, P. 1995. Growth intercept method for silviculture surveys. BC Ministry of Forests, Silviculture Practices Branch. 36 pp.

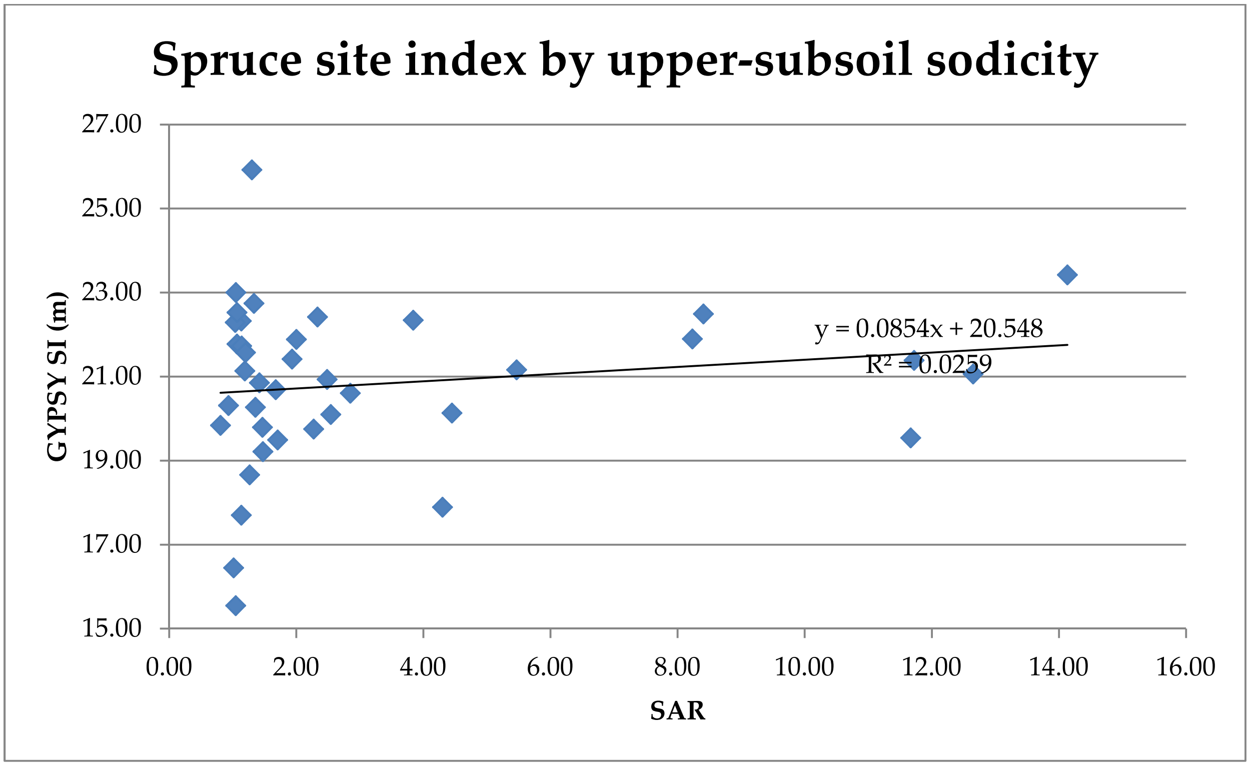
APPENDIX F – SOIL SALINITY/SODICITY RELATIONSHIPS WITH TREE PRODUCTIVITY






Spruce site index by lower-subsoil salinity
GYPSY SI (m)
27.00
25.00
23.00
21.00
19.00
17.00
15.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
EC (dS/m)
y = -0.1555x + 21.398
R² = 0.0295


Spruce site index by topsoil sodicity
GYPSY SI (m)
27.00
25.00
23.00
21.00
19.00
17.00
15.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
SAR
y = 0.2032x + 20.483
R² = 0.0424


Spruce site index by upper-subsoil sodicity
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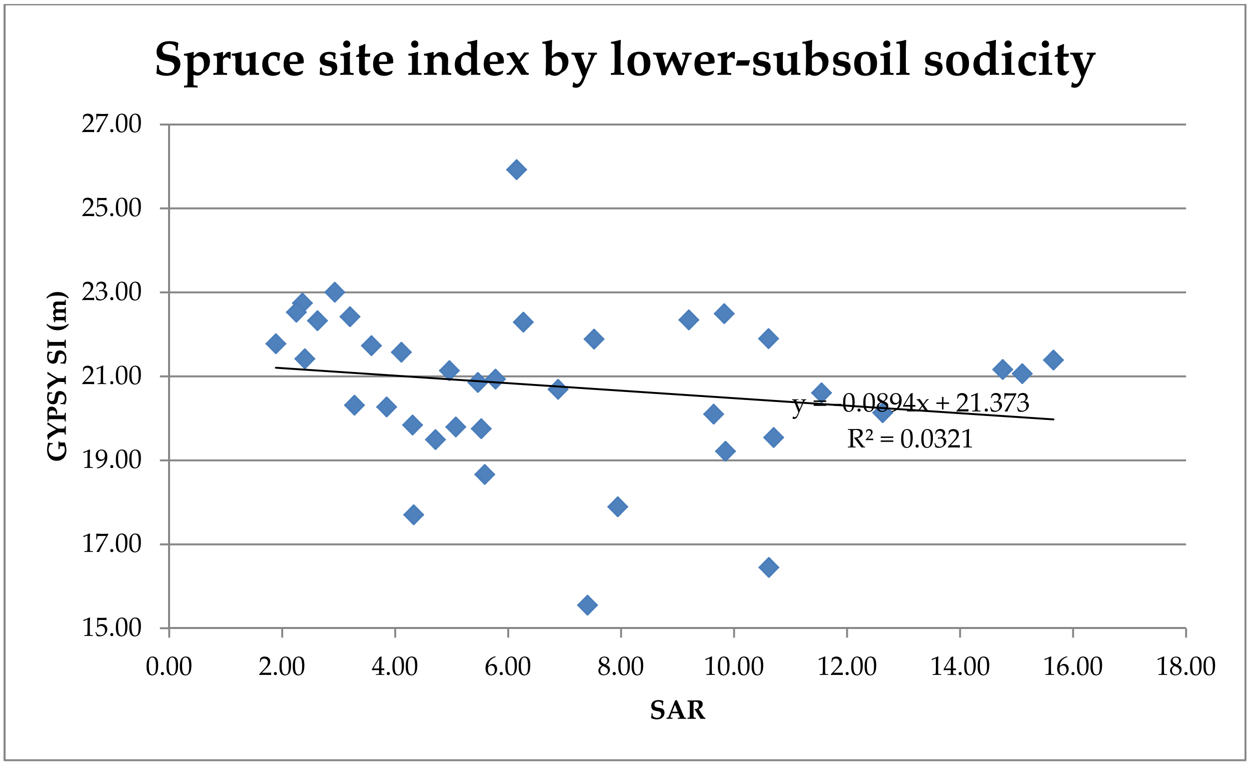
25.00
23.00
21.00
19.00
17.00
15.00
GYPSY SI (m)
y = 0.0854x + 20.548
R² = 0.0259
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
SAR


Spruce site index by lower-subsoil sodicity
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25.00
23.00
21.00
19.00
17.00
15.00
GYPSY SI (m)
y = -0.0894x + 21.373
R² = 0.0321
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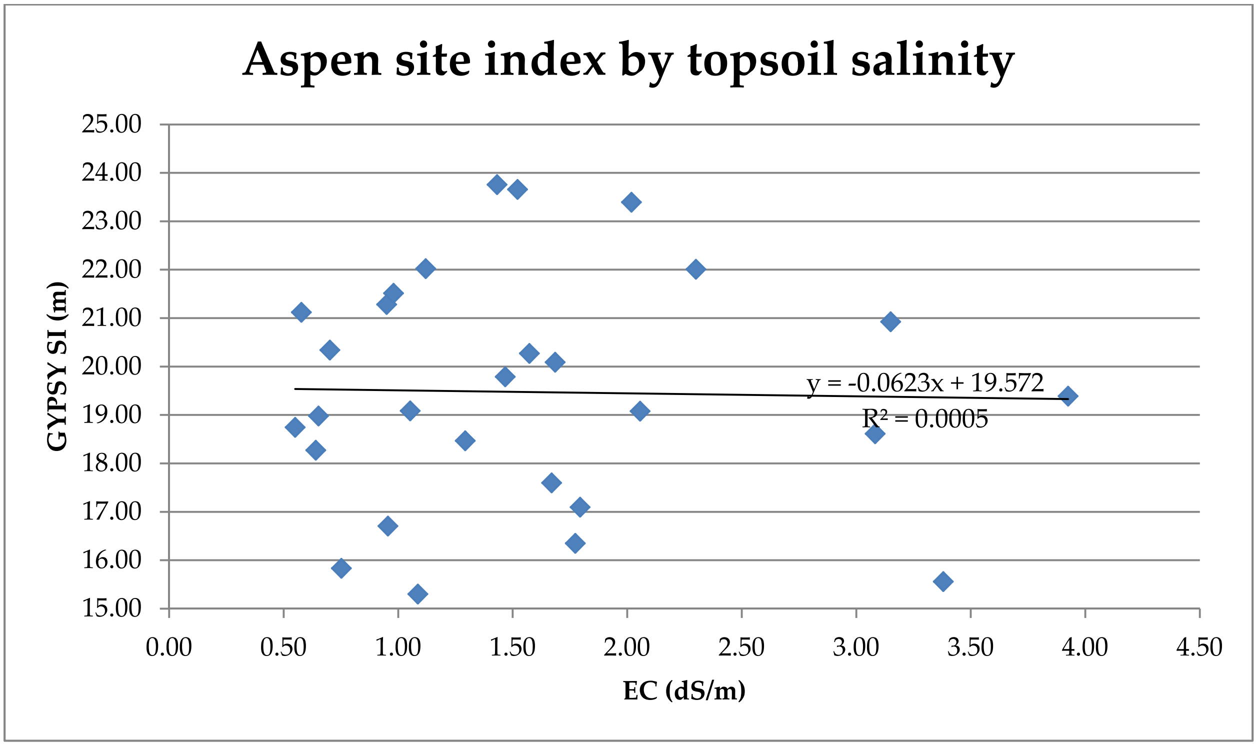
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SAR


Aspen site index by topsoil salinity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
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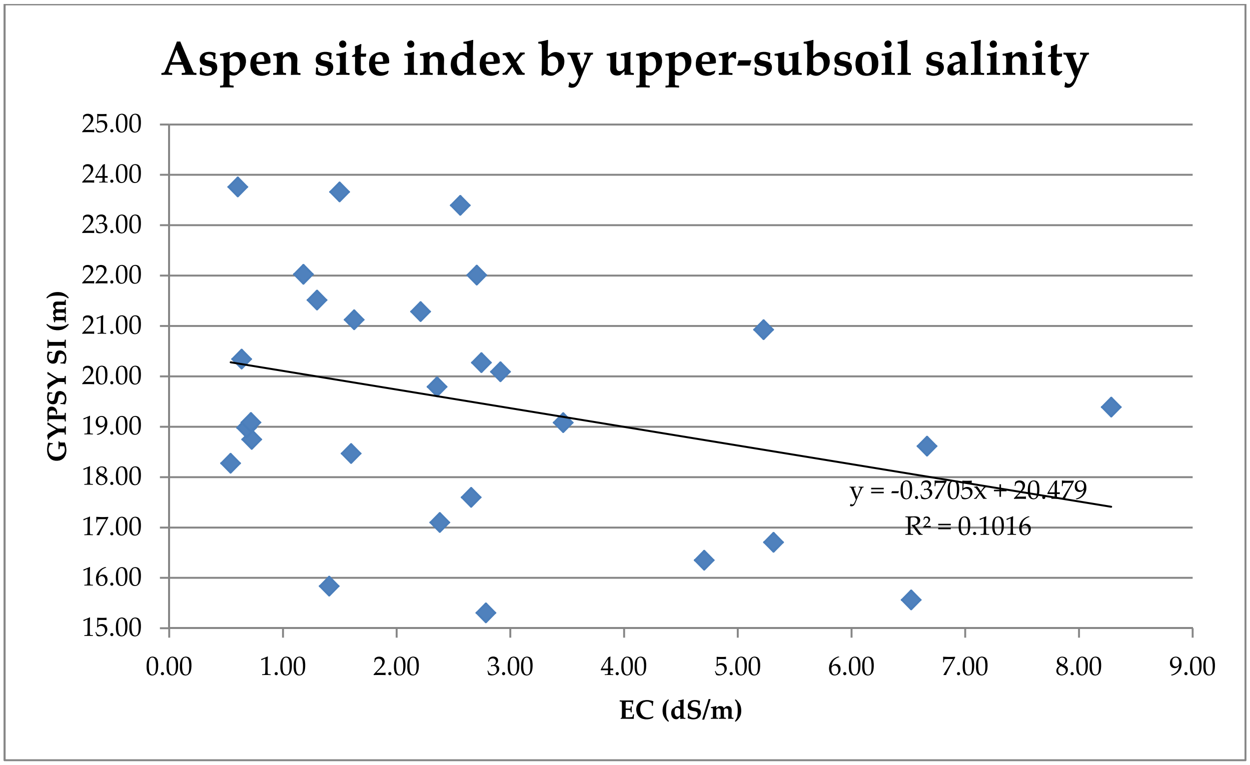
R² = 0.0005


Aspen site index by upper-subsoil salinity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
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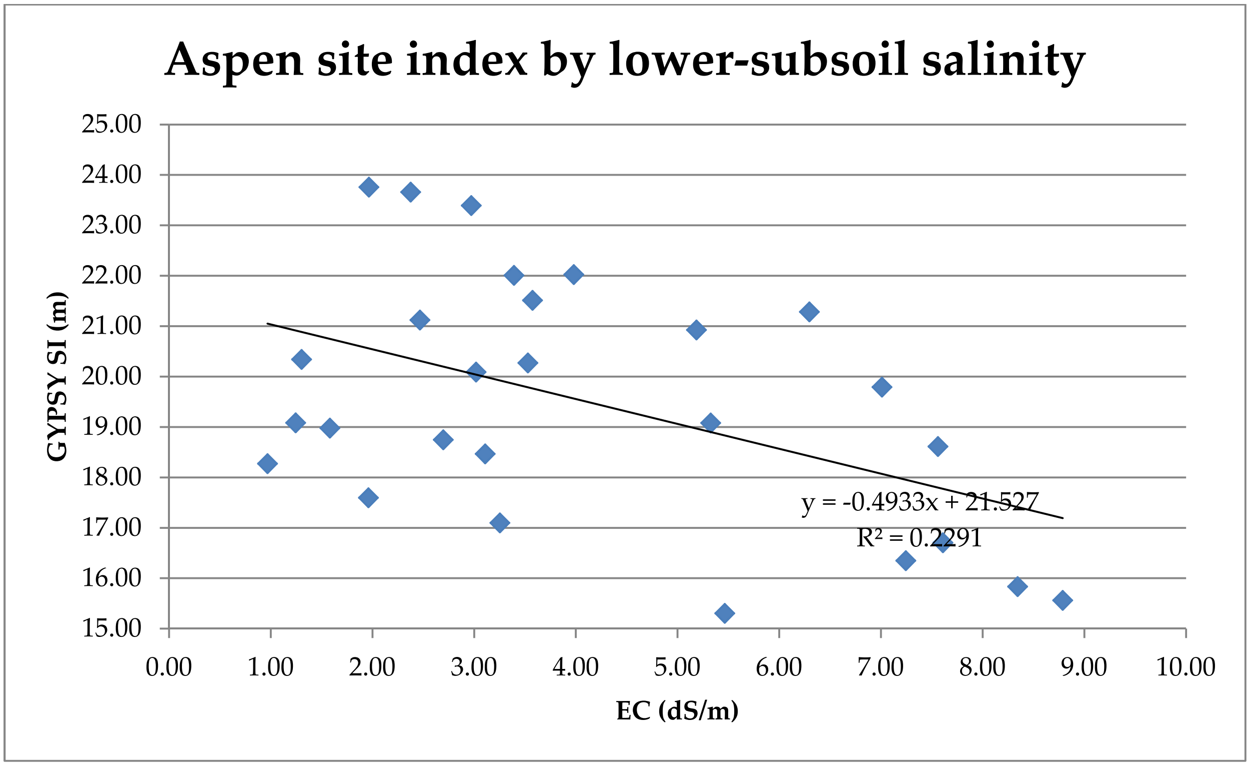
R² = 0.1016


Aspen site index by lower-subsoil salinity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
EC (dS/m)
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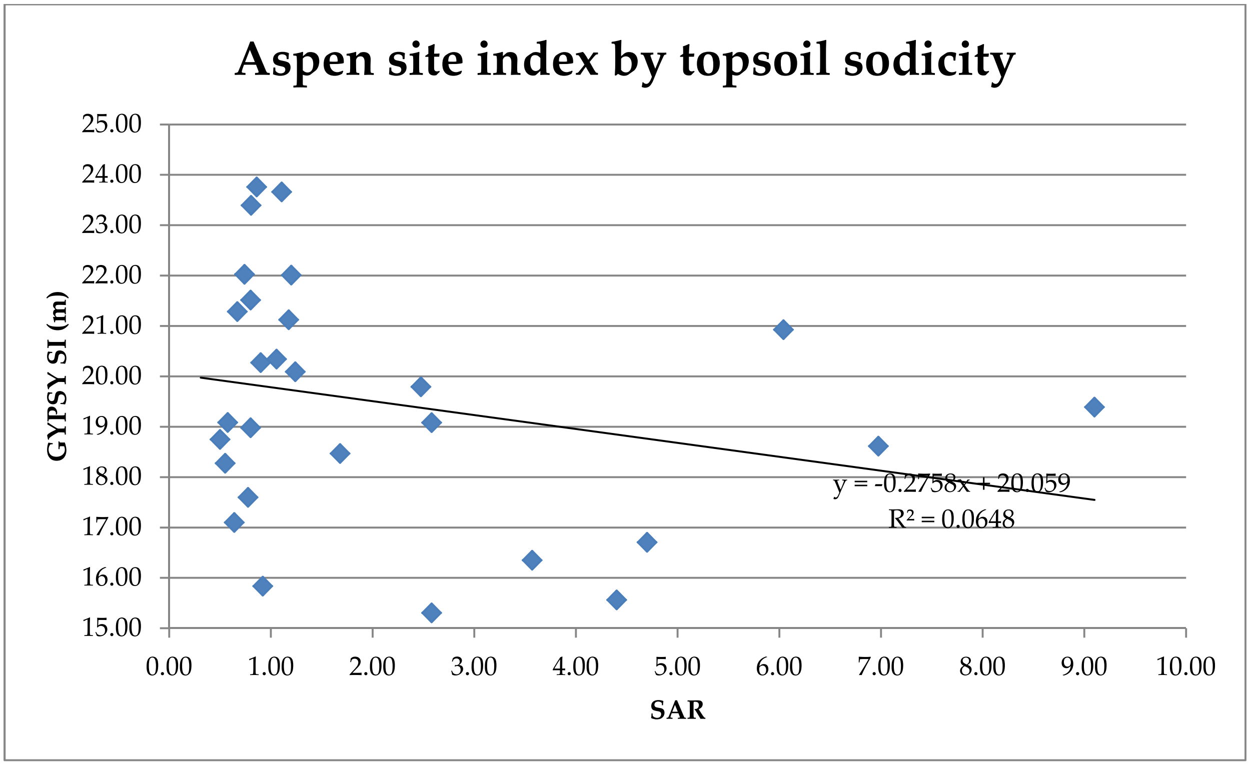
R² = 0.2291


Aspen site index by topsoil sodicity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
SAR
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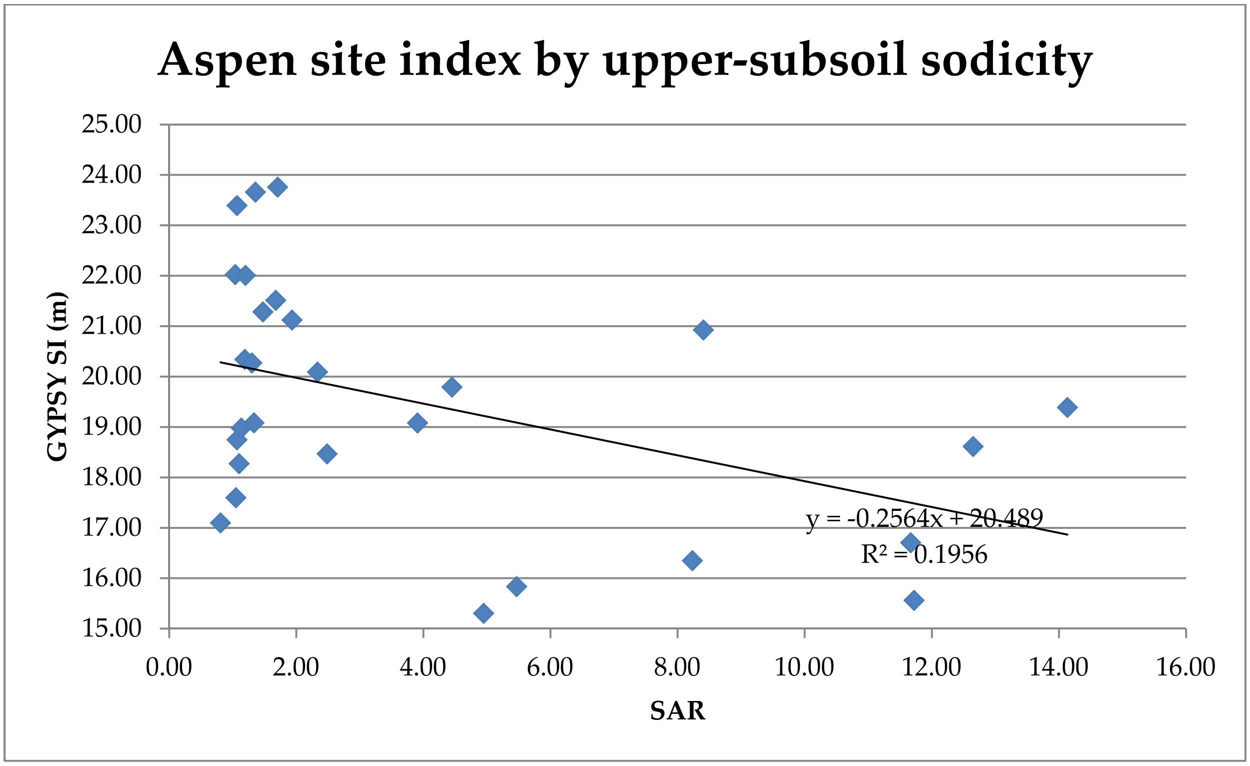
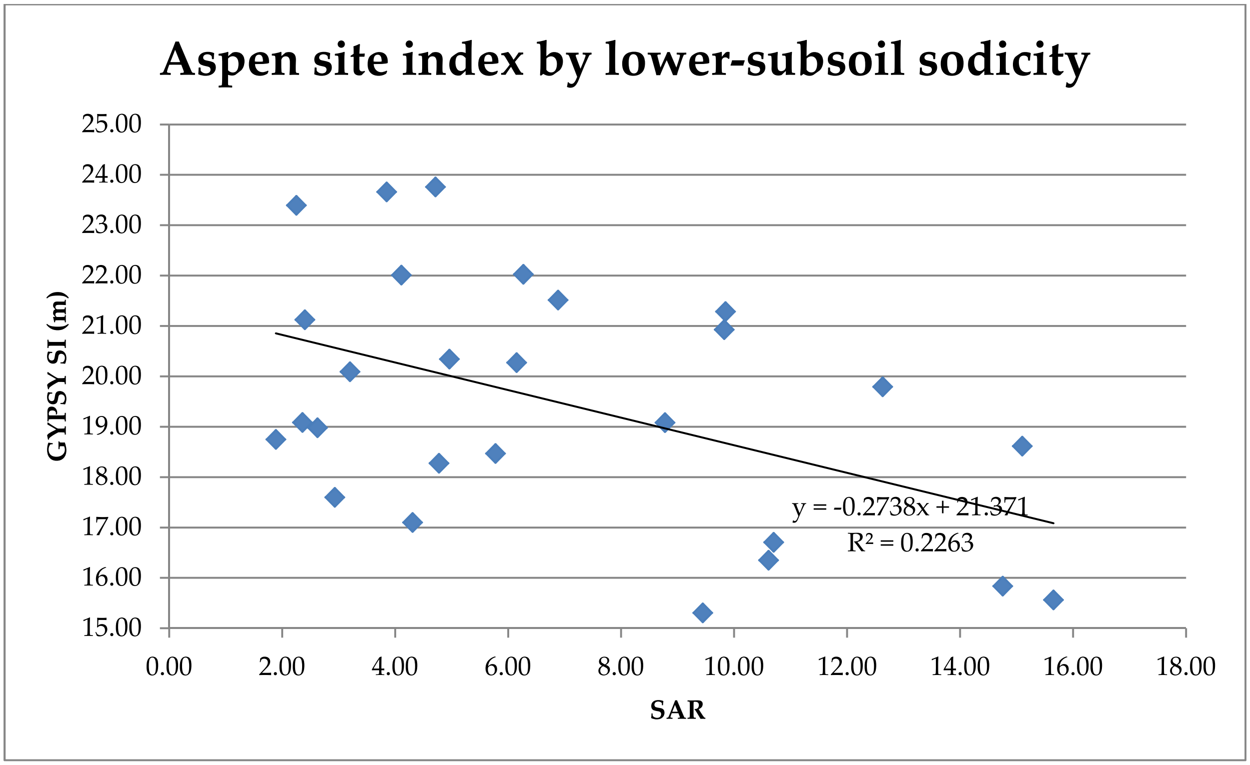
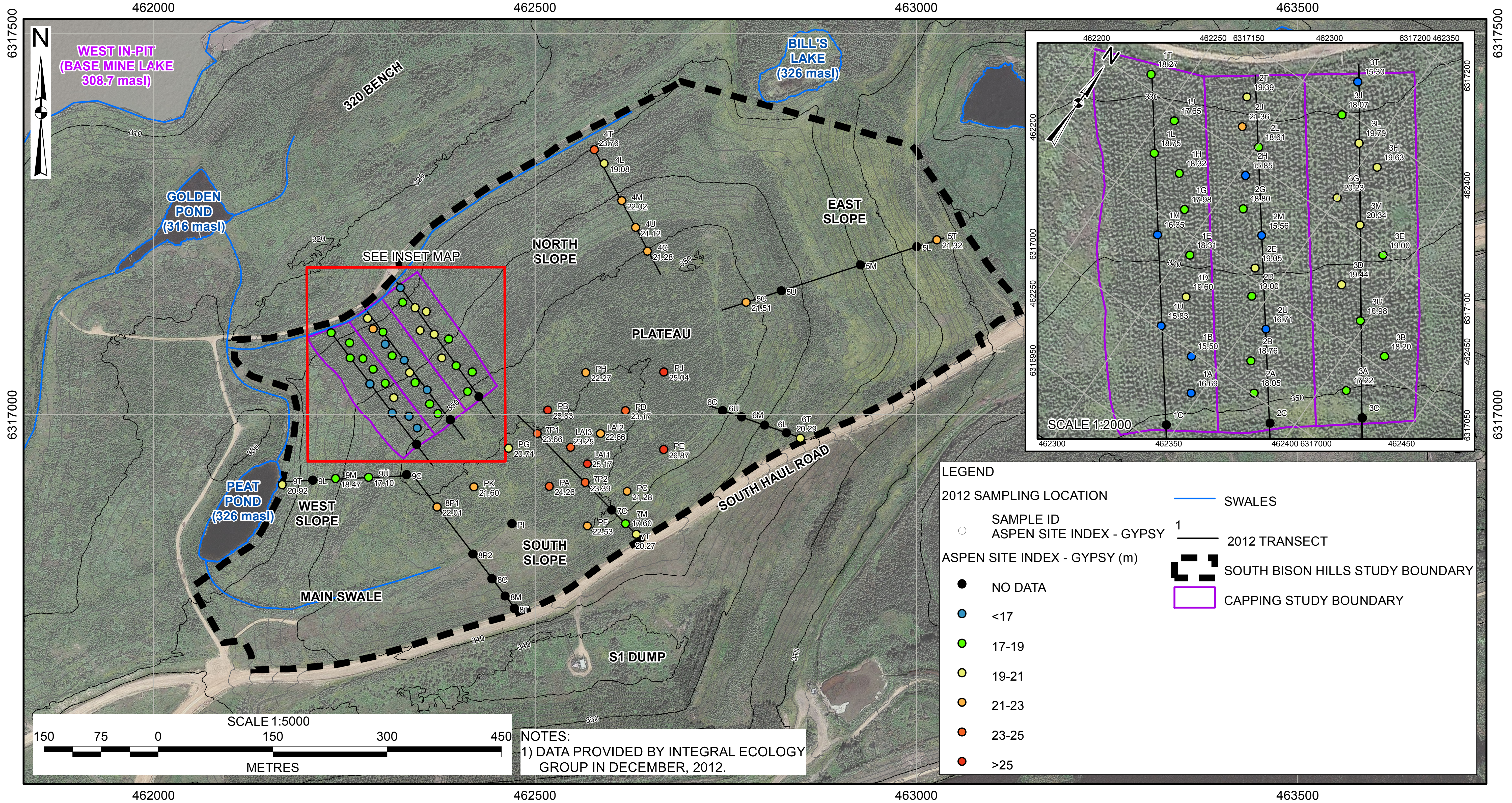
R² = 0.0648


Aspen site index by upper-subsoil sodicity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
SAR
y = -0.2564x + 20.489
R² = 0.1956


Aspen site index by lower-subsoil sodicity
GYPSY SI (m)
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
SAR
y = -0.2738x + 21.371
R² = 0.2263

APPENDIX G – SPATIAL PLOTS PREPARED BY BGC

Figure 1. Aspen GYPSY-based site index by plot on the SBH study area.



NOTES:
1) DATA PROVIDED BY INTEGRAL ECOLOGY GROUP IN DECEMBER, 2012.

NAD 1983 UTM Zone 12N

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REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: DEC 2012
DRAWN: RC
DESIGNED: JM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

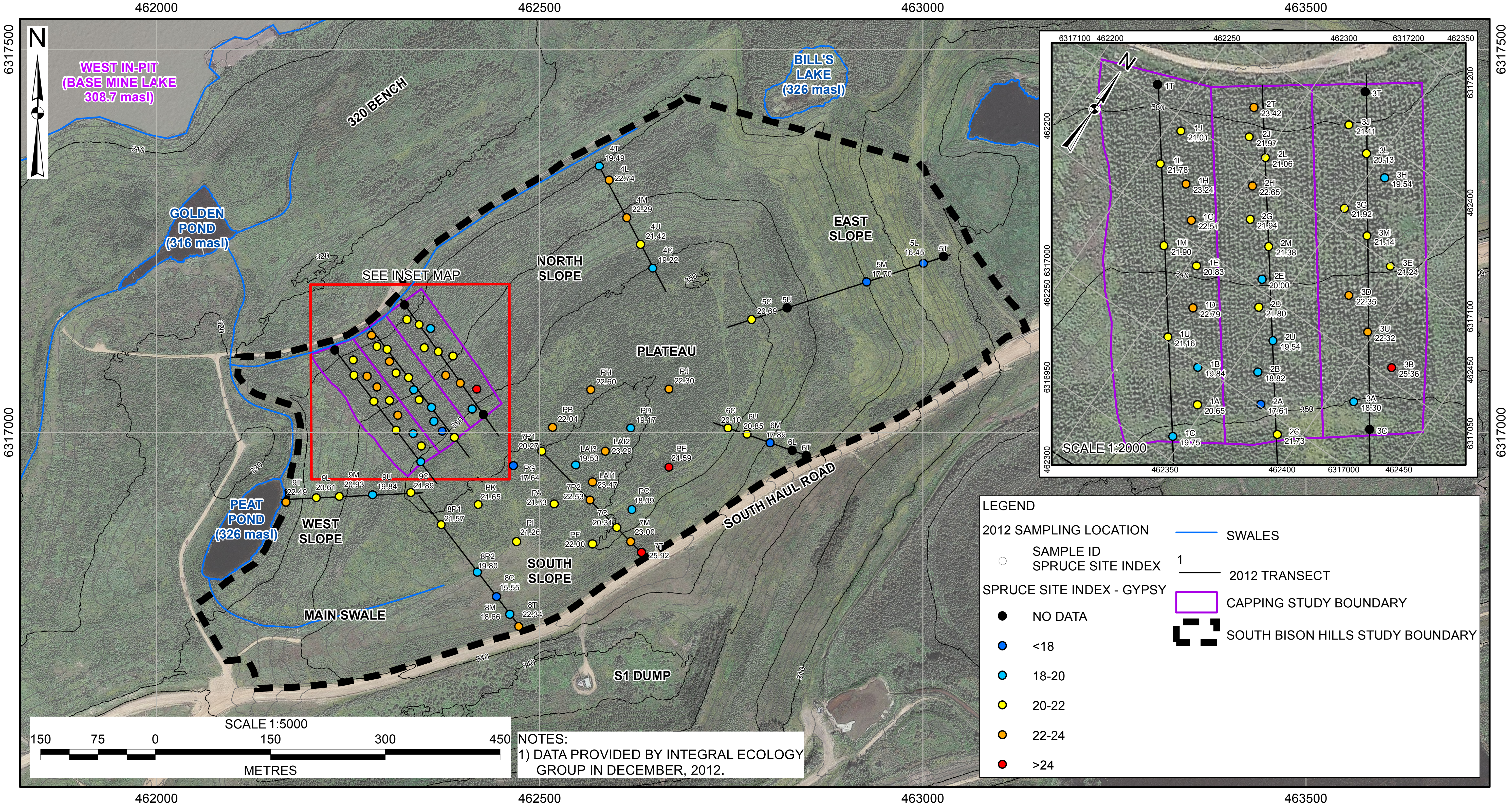
CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
ASPEN SITE INDEX - GYPSY

PROJECT No.: 0534107
DWG No.: 22
REV.:

Figure 2. Spruce GYPSY-based site index by plot on the SBH study area.



LEGEND

2012 SAMPLING LOCATION

○ SAMPLE ID
SPRUCE SITE INDEX

SPRUCE SITE INDEX - GYPSY

- ● NO DATA
- ● <18
- ● 18-20
- ● 20-22
- ● 22-24
- ● >24

SWALES

2012 TRANSECT

CAPPING STUDY BOUNDARY

SOUTH BISON HILLS STUDY BOUNDARY

NOTES:
1) DATA PROVIDED BY INTEGRAL ECOLOGY GROUP IN DECEMBER, 2012.

NAD 1983 UTM Zone 12N

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	DEC 2012
DRAWN:	RC
DESIGNED:	JM
CHECKED:	ES
APPROVED:	

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
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CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
SPRUCE SITE INDEX - GYPSY

PROJECT No.:	DWG No.:	REV.:
0534107	20	

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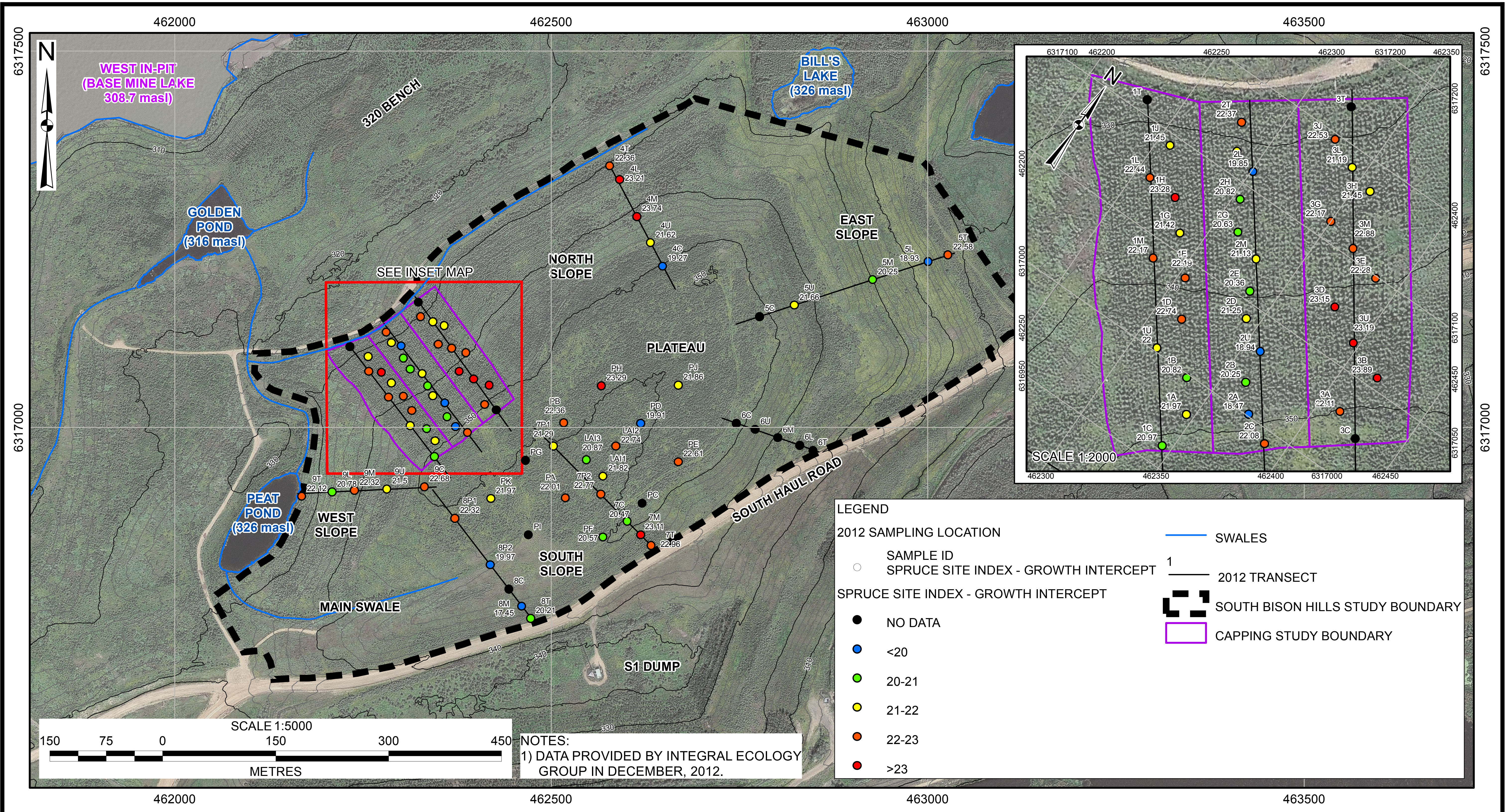
Figure 3. Spruce GI-based site index by plot on the SBH study area.



LEGEND

2012 SAMPLING LOCATION

○ SAMPLE ID
SPRUCE SITE INDEX - GROWTH INTERCEPT

SPRUCE SITE INDEX - GROWTH INTERCEPT

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- ● <20
- ● 20-21
- ● 21-22
- ● 22-23
- ● >23

— SWALES

1 — 2012 TRANSECT

▬ ▬ SOUTH BISON HILLS STUDY BOUNDARY

☐ CAPPING STUDY BOUNDARY

NOTES:
1) DATA PROVIDED BY INTEGRAL ECOLOGY GROUP IN DECEMBER, 2012.

NAD 1983 UTM Zone 12N

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: DEC 2012
DRAWN: RC
DESIGNED: JM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

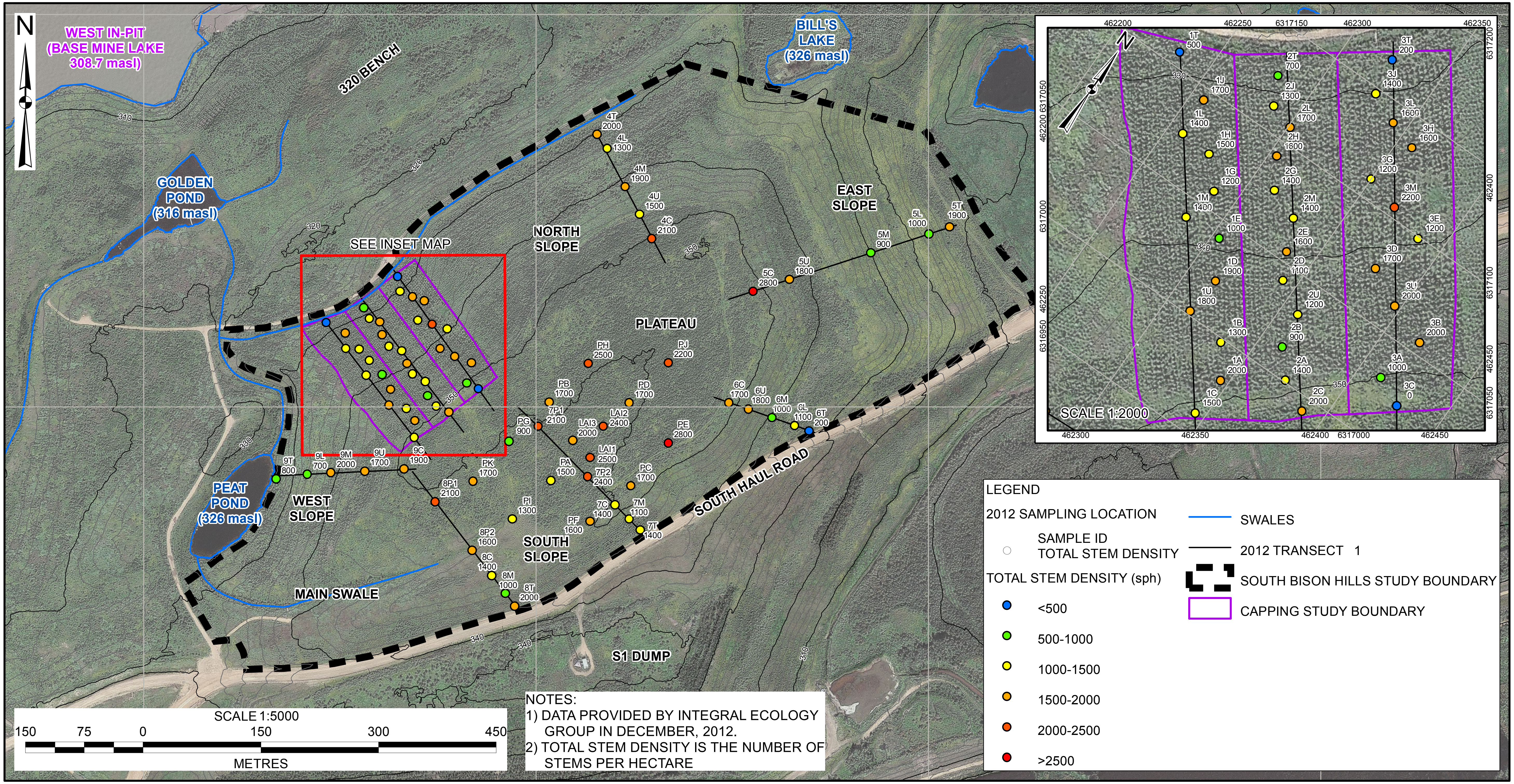
CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
SPRUCE SITE INDEX - GROWTH INTERCEPT

PROJECT No.: 0534107
DWG No.: 21
REV.:

Figure 4. Stand density by plot location on the SBH study area.



LEGEND

2012 SAMPLING LOCATION

○ SAMPLE ID
TOTAL STEM DENSITY

TOTAL STEM DENSITY (sph)

- ● <500
- ● 500-1000
- ● 1000-1500
- ● 1500-2000
- ● 2000-2500
- ● >2500

SWALES

2012 TRANSECT 1

SOUTH BISON HILLS STUDY BOUNDARY

CAPPING STUDY BOUNDARY

NOTES:
1) DATA PROVIDED BY INTEGRAL ECOLOGY GROUP IN DECEMBER, 2012.
2) TOTAL STEM DENSITY IS THE NUMBER OF STEMS PER HECTARE

NAD 1983 UTM Zone 12N

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DRAWN: RC
DESIGNED: JM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

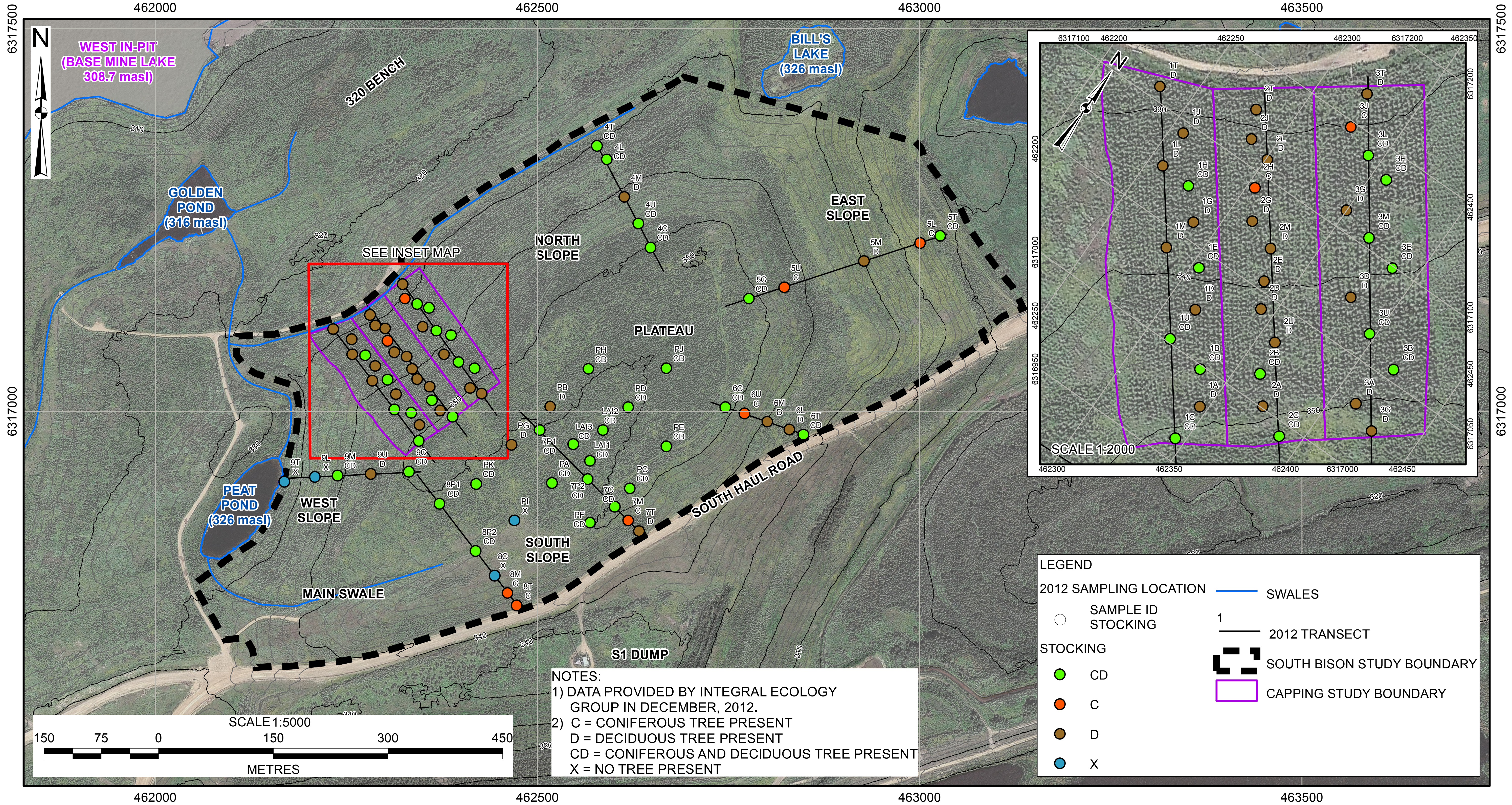
CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
TOTAL STEM DENSITY (sph)

PROJECT No.: 0534107
DWG No.: 23
REV.:

Figure 5. Plot stocking by location on the SBH study site.



NOTES:
1) DATA PROVIDED BY INTEGRAL ECOLOGY GROUP IN DECEMBER, 2012.
2) C = CONIFEROUS TREE PRESENT
D = DECIDUOUS TREE PRESENT
CD = CONIFEROUS AND DECIDUOUS TREE PRESENT
X = NO TREE PRESENT

LEGEND

2012 SAMPLING LOCATION
○ SAMPLE ID STOCKING

STOCKING
- 🟢 CD
- 🔴 C
- 🟤 D
- 🔵 X

SWALES
1 2012 TRANSECT
SOUTH BISON STUDY BOUNDARY
CAPPING STUDY BOUNDARY

NAD 1983 UTM Zone 12N

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: DEC 2012
DRAWN: RC
DESIGNED: JM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
STOCKING DENSITY CONIFEROUS AND DECIDUOUS

PROJECT No.: 0534107
DWG No.: 25
REV.:

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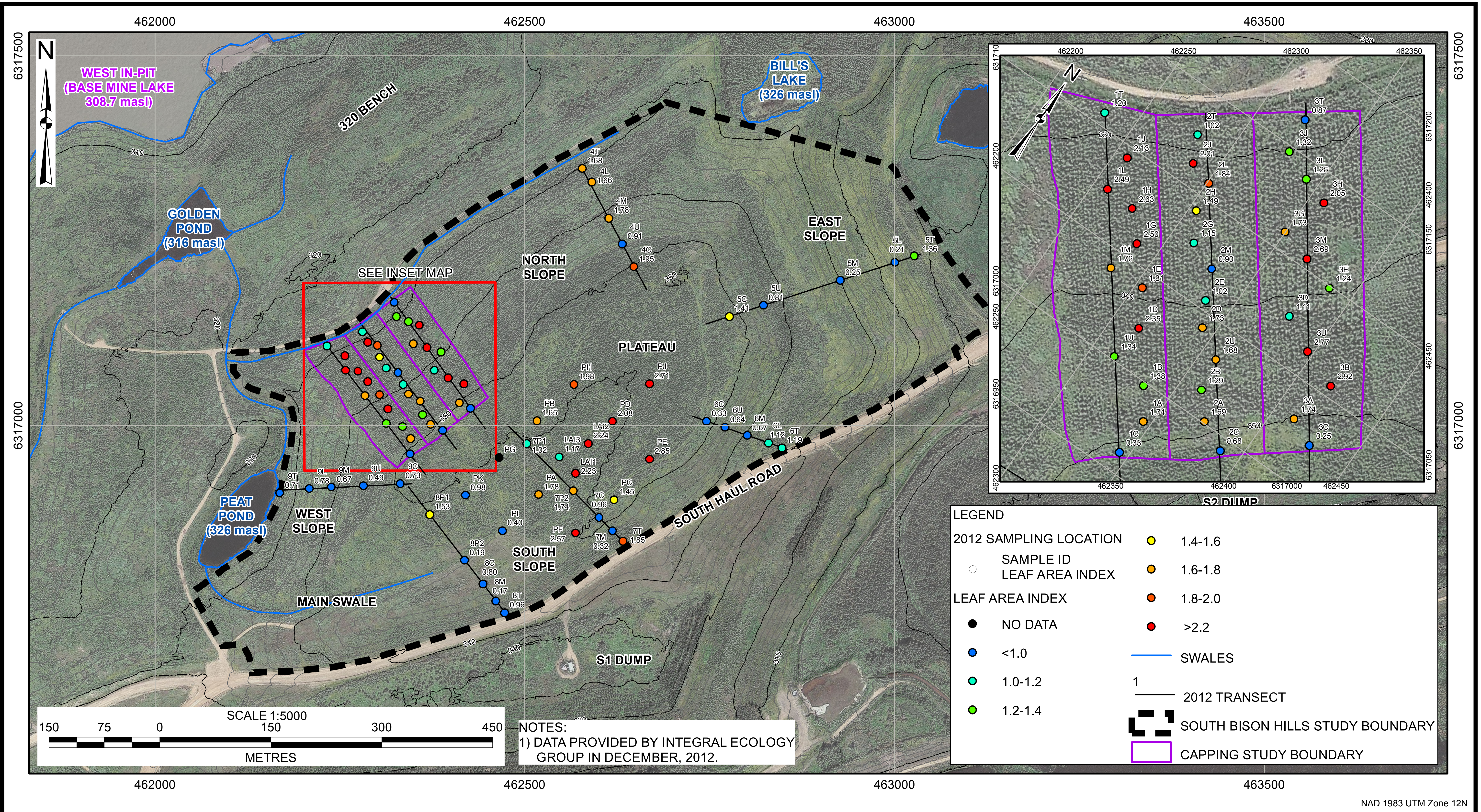
Figure 6. Leaf area index by plot location on the SBH study site



NOTES:
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SCALE: AS SHOWN
DATE: DEC 2012
DRAWN: RC
DESIGNED: JM
CHECKED: ES
APPROVED:

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILLS RESEARCH SYNTHESIS

TITLE:
LEAF AREA INDEX

PROJECT No.: 0534107
DWG No.: 24
REV.:

APPENDIX H – LAI DATA

Table 1. Leaf area index (LAI) and standard error of LAI for main plots across SBH.

Plot	LAI	SEL
1A	1.74	0.15
1B	1.38	0.14
1C	0.33	0.08
1D	2.35	0.16
1E	1.81	0.10
1G	2.50	0.09
1H	2.63	0.15
1J	2.13	0.13
1L	2.49	0.08
1M	1.76	0.15
1T	1.20	0.05
1U	1.34	0.10
2A	1.69	0.09
2B	1.29	0.19
2C	0.68	0.08
2D	1.73	0.18
2E	1.02	0.11
2G	1.15	0.09
2H	1.49	0.16
2J	2.01	0.22
2L	1.84	0.24
2M	0.90	0.05
2T	1.02	0.04
2U	1.68	0.12
3A	1.74	0.09
3B	2.92	0.19
3C	0.25	0.05
3D	1.11	0.09
3E	1.24	0.19
3G	1.73	0.11
3H	2.05	0.13
3J	1.32	0.08
3L	1.26	0.16
3M	2.69	0.14
3T	0.87	0.10
3U	2.77	0.16
4C	1.95	0.15
4L	1.66	0.15
4M	1.78	0.12
4T	1.68	0.11
4U	0.91	0.09
5C	1.41	0.14
5L	0.21	0.05
5M	0.25	0.05
5T	1.36	0.16
5U	0.81	0.12
6C	0.33	0.06
6L	1.12	0.16
6M	0.67	0.13
6T	1.19	0.15
6U	0.64	0.18
7C	0.96	0.11
7M	0.32	0.06
7P1	1.02	0.13
7P2	1.74	0.09
7T	1.85	0.19
8C	0.80	0.10
8M	0.17	0.06
8P1	1.53	0.19
8P2	0.19	0.05
8T1	0.96	0.19
9C	0.73	0.12
9L	0.78	0.29
9M	0.67	0.11
9T	0.71	0.14
9U	0.49	0.09
LAI1	2.23	0.14
LAI2	2.24	0.16
LAI3	1.17	0.10
PA	1.78	0.06
PB	1.65	0.21
PC	1.45	0.09
PD	2.08	0.19
PE	2.85	0.12
PF	2.57	0.15
PG		
PH	1.98	0.16
PI	0.40	0.00
PJ	2.71	0.12
PK	0.98	0.08

APPENDIX D
SOUTH BISON HILL 2012 RESEARCH SYNTHESIS ROOT DISTRIBUTIONS

SOUTH BISON HILL 2012 RESEARCH SYNTHESIS
ROOT DISTRIBUTIONS

PREPARED FOR:
Marty Yarmuch
Syncrude Canada Ltd.
9421 – 17 Ave
Edmonton, AB
T6N 1H4

PREPARED BY:

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1. Introduction

The objective of the South Bison Hills Research Synthesis is to *"determine the minimum soil cover depth(s) required that will deliver an appropriate amount of water for targeted boreal forest vegetation without inundating the soil cover with salt."* The specific objective of this project is to quantify the root biomass distributions at South Bison Hill and to determine if roots had penetrated the saline/sodic (Clearwater) overburden (Overburden). The root distribution data is also required for the modeling of long-term water dynamics at this site by another group at the University of Saskatchewan.

Previous work by Lazorko and Van Rees (2012) had shown that root distributions had penetrated the saline/sodic Overburden three years after planting; however, it was not known what species were growing into the Overburden. With Syncrude undertaking a review of cover thickness for reclamation covers constructed over saline/sodic shales, this project is following up on the root work done in 2003. The major questions being asked in this project are:

- **Do root distributions on these reclaimed sites follow those of natural boreal forest sites after 12 years?**
- **Are root systems impeded by the saline/sodic Overburden?**
- **Do root distributions indicate a minimum cover thickness?**

2. Material and Methods

Root samples were collected with a Riverside auger during September 2012 along nine transects at the South Bison Hills Research site. A detailed description of the sampling methodology, transect and sampling locations and field notes has been given by NorthWind Land Resources Inc. (2012). A total of 338 samples were shipped to the University of Saskatchewan and stored in a freezer at -4^{o}C. Soil samples were thawed and water added to individual bags and re-frozen for 48 hrs to aid in clay dispersal. Samples were thawed again and then washed inside a 1 mm mesh cloth in a bucket of water to remove the soil material (Oliveira et al., 2000). Samples were then placed in glass trays and individual roots picked manually from the sample in order to separate roots out from organic debris and peat material. Root samples were then oven-dried at

40°C for 48 hrs in a Fisher Scientific Isotemp 700 series oven and then weighed on a Mettler Toledo XS204 balance to four decimal places.

Oven-dry weights were converted to biomass per area by summing all root biomass for a core and dividing by the surface area (auger diameter 7 cm). Root biomass density was determined by calculating the volume of each sample using the auger diameter (7 cm) and depth increments of the samples (NorthWind Land Resources Inc., 2012).

3. Results and Discussion

Total root biomass for each slope position and transect is presented in Table 1. Root biomass per core for each of the transects and slope positions appeared to show no spatial trends across the South Bison Hills site (Figure 1).

Table 1. Total root biomass per core for each transect and slope position.

Transect	Slope Position						
	Crest	Upper	Middle	Plateau 1	Plateau 2	Lower	Toe
	$Mg{\cdot}ha^{-1}$						
1	9.45	7.98	3.50	-[†]	-	4.73	4.98
2	13.11	2.23	4.44	-	-	1.27	1.79
3	1.05	4.50	13.06	-	-	9.38	3.35
4	8.08	8.44	8.81	-	-	4.54	5.30
5	6.61	9.78	7.04	-	-	9.26	6.65
6	2.84	3.98	13.70	-	-	17.08	7.06
7	7.09	-	5.36	7.75	12.37	-	8.81
8	2.97	-	3.42	-	-	-	1.07
9	10.92	2.69	1.67	-	-	1.24	6.88
Mean	**6.90**	**5.65**	**6.78**	**7.75**	**12.37**	**6.79**	**5.10**

[†] not sampled.

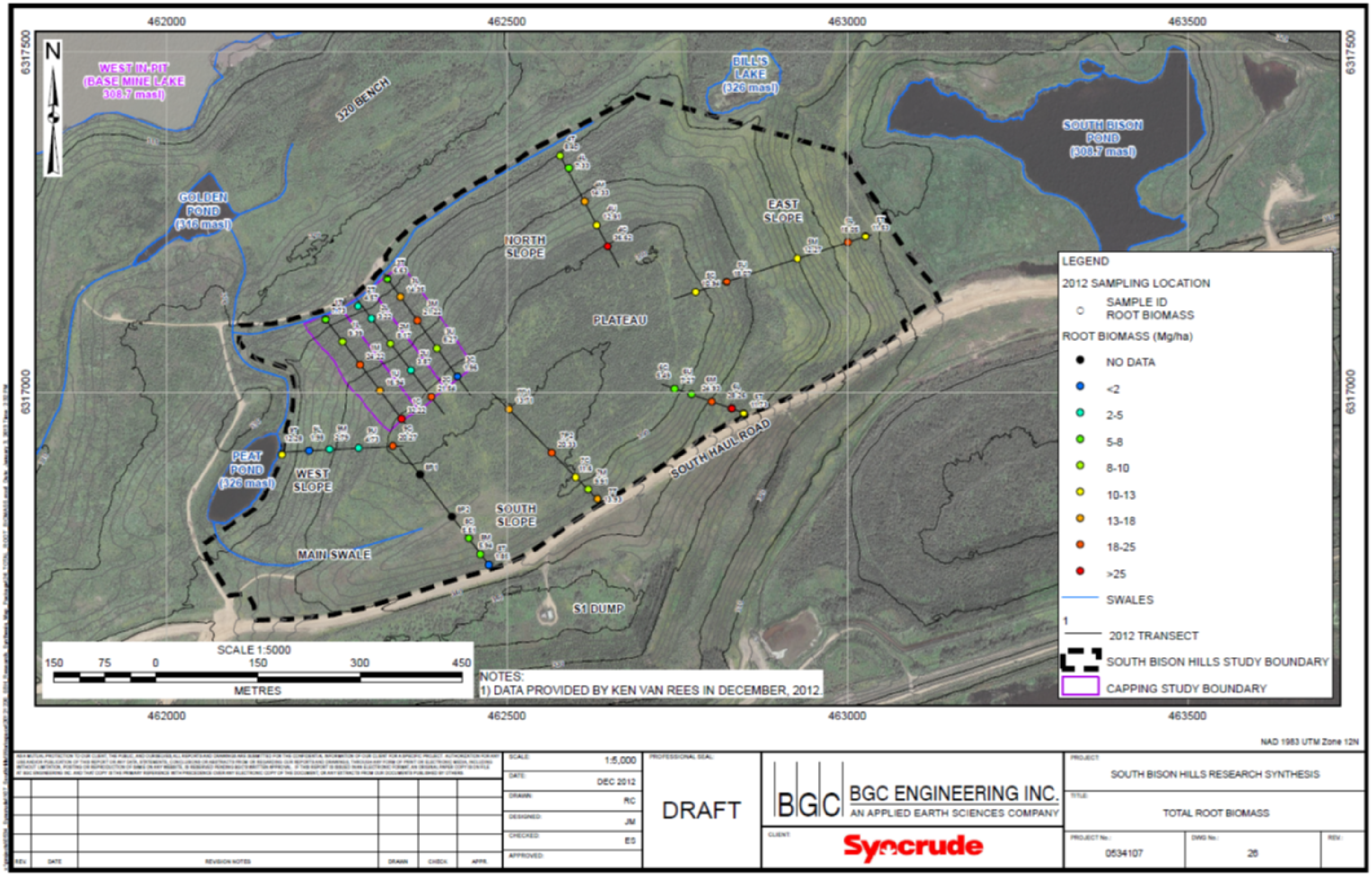


Figure 1. Location of root cores for each transect and slope position at South Bison Hills site. Total root biomass (Mg/ha) is presented for each slope position and transect by a color code based on several range bins.

Average root biomass by slope position was highest at the crest slope position (6.90 Mg/ha) and showed a slight decreasing trend towards the toe slope position which had the lowest values of root biomass (5.10 Mg/ha) (Figure 2). These trends are confounded by the fact that there were different prescriptions for the various transects as well as different vegetation planting dates and success of the plantation.

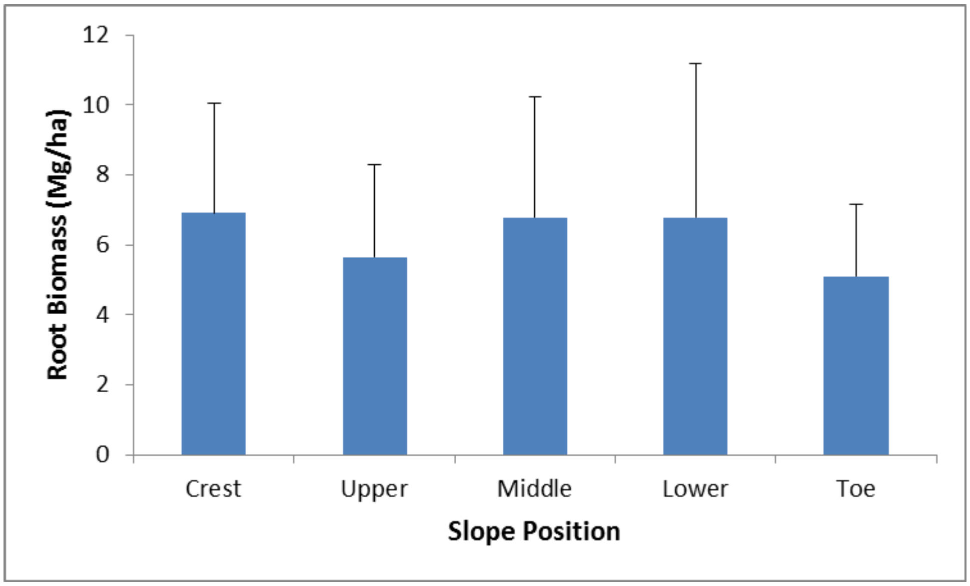


Figure 2. Average root biomass for each slope position (n=9 for Crest, Middle and Toe; n=7 for Upper and Lower). Error bars represent standard deviation.

There was no relationship between root biomass and the number of trees within a 2 m radius of the sampling hole when considering just planted white spruce (*Picea glauca*) and trembling aspen (*Populus tremuloides*) trees (Figure 3). When all species (planted and volunteer) were included in the analysis there was still no relationship between number of trees and total root biomass (Figure 4).

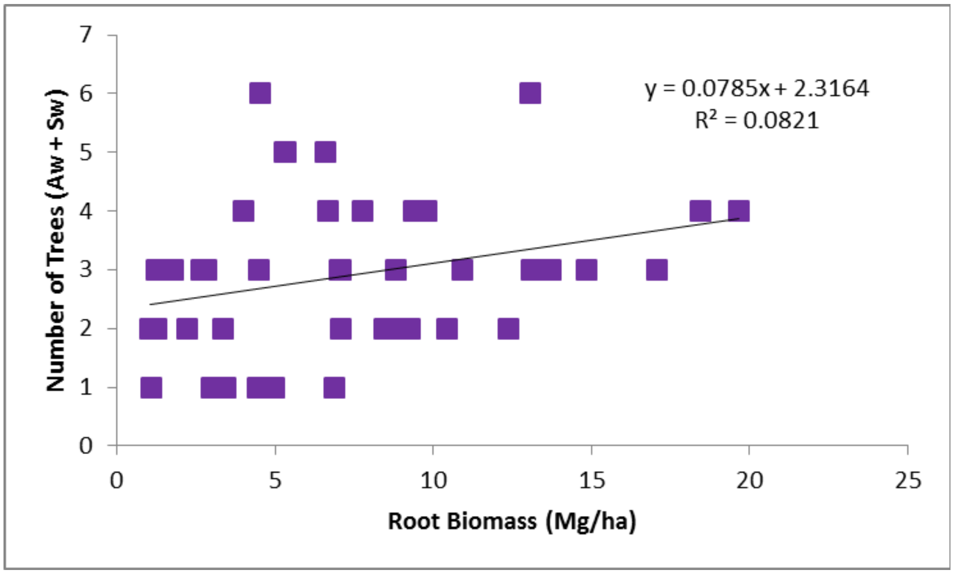


Figure 3. Comparison of total number of planted trees and root biomass within a 2 m radius of the sampling hole.

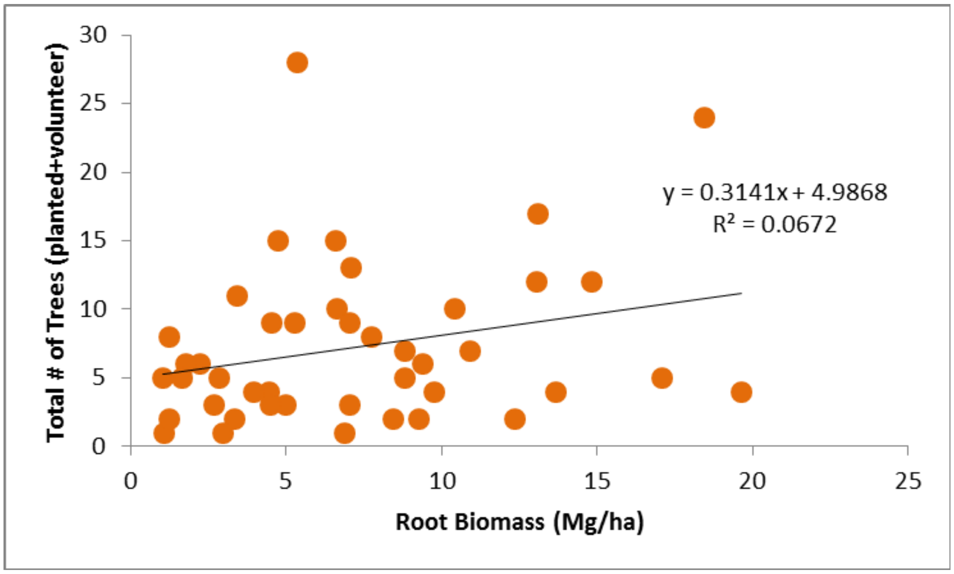


Figure 4. Comparison of total number of trees (planted and volunteer) and root biomass within a 2 m radius of the sampling hole.

Rooting density with cover depth when all the data was combined (transect and slope position) showed highest rooting densities at the surface and gradually decreased with depth (Figure 5). The highest rooting densities were located in the top 30 cm of the cover profile. Typically the top 30 cm of the profile was comprised of peat or a peat/mineral mix which is different than typical forest soils but did result in higher root densities. These rooting densities are similar to the pattern found by Strong and La Roi (1985) who examined boreal species from native forests (Figure 6) where root densities were highest in the surface and decreased with depth. Roots from tree species growing on clay loam soils appeared to decrease much quicker with depth especially with the Bt (clay) horizon at a 30 cm depth (comparable to what is happening at the South Bison Hill site which is dominated by a clay soil texture) than those trees growing on sandy textured soils.

Although rooting densities were very low at deeper depths, there were roots present in the saline/sodic Overburden. However, it is not known what plant species are associated with these roots in the Overburden material. Lazorko and Van Rees (2012) in their study on the SW30 Dump in 2003 examining the 100 cm cover, suggested that moderately salt tolerant species such as sweet clover and other understory species such as sow thistle, grasses, and volunteer tree species may have attributed roots in the Overburden as they were present in the understory. An inventory of the understory species present to determine the presence of salt tolerant or deep rooting species was not conducted during the time of this study (2012). Since this study did not associate roots with plant species, we were not able to confirm the rooting pattern of the planted aspen and spruce and if roots from these species are present in the Overburden.

When assessing rooting densities between cover and Overburden samples at the same depths within the upper 100 cm of the profile, root densities are generally lower in the Overburden material than the cover especially for those samples in the upper 50 cm of the profile (Figure 5). Root densities tend to decrease with depth in an exponential fashion and therefore root densities in Overburden material would be lower than the cover placed above the Overburden. However, when examining covers that are < 50 cm thick it would appear that rooting densities in the Overburden are very low compared to similar depths of cover suggesting that the Overburdens are not favorable for root growth. Salinity profiles and soil texture may also be influencing the rooting distribution at the site; however, their influence on rooting was not evaluated in this study.

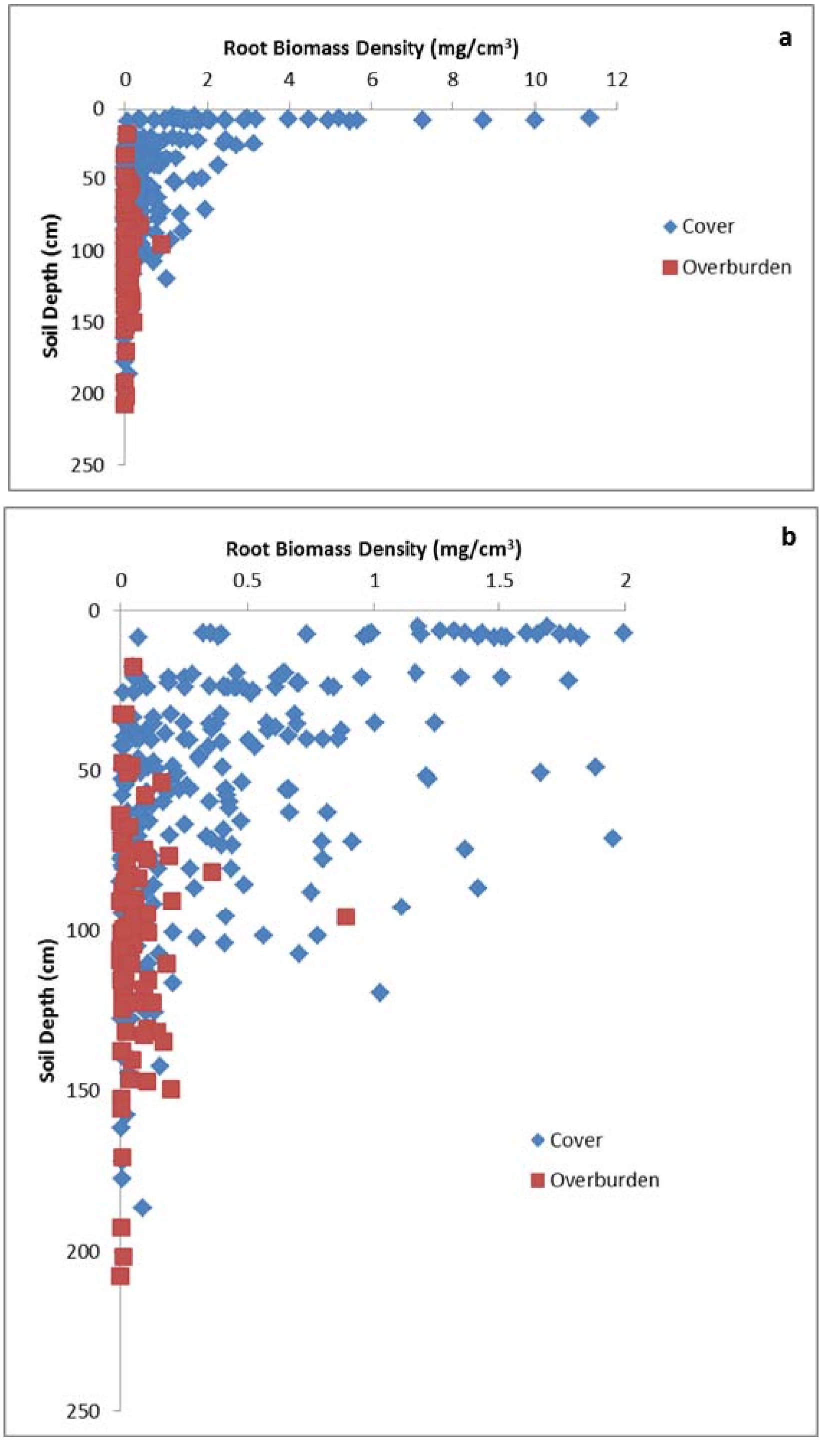


Figure 5. Root biomass density for samples in the cover and Overburden materials. All data is presented in (a) and the scale was changed (< 2 mg/cm^3) to see the spread of data for soil depths < 50 cm in (b).

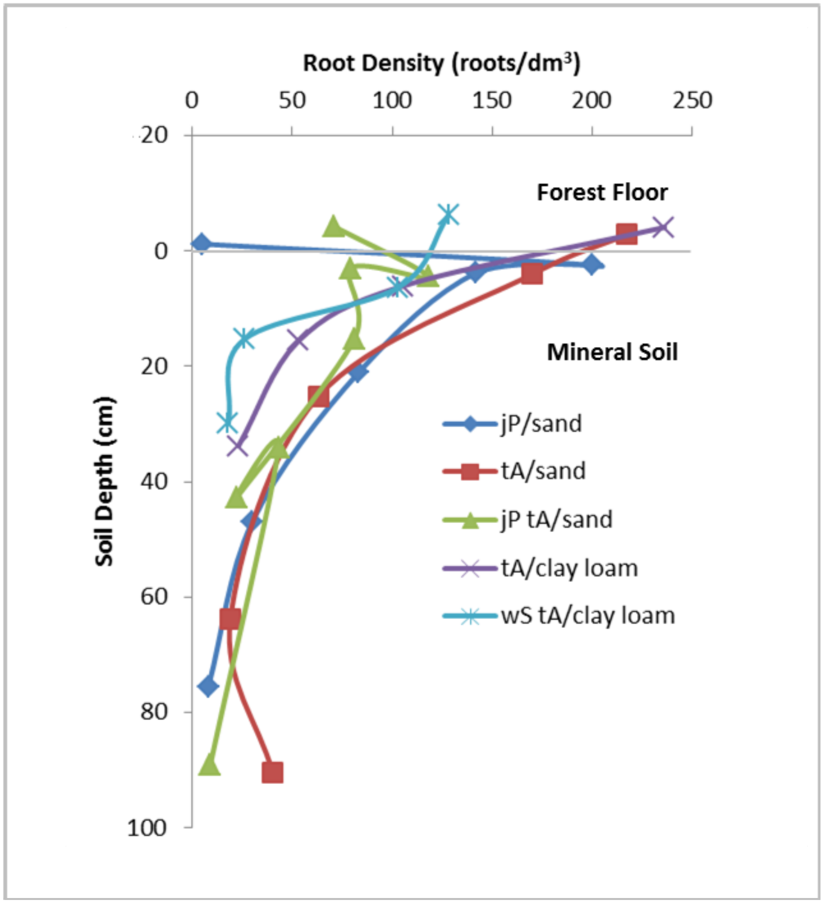
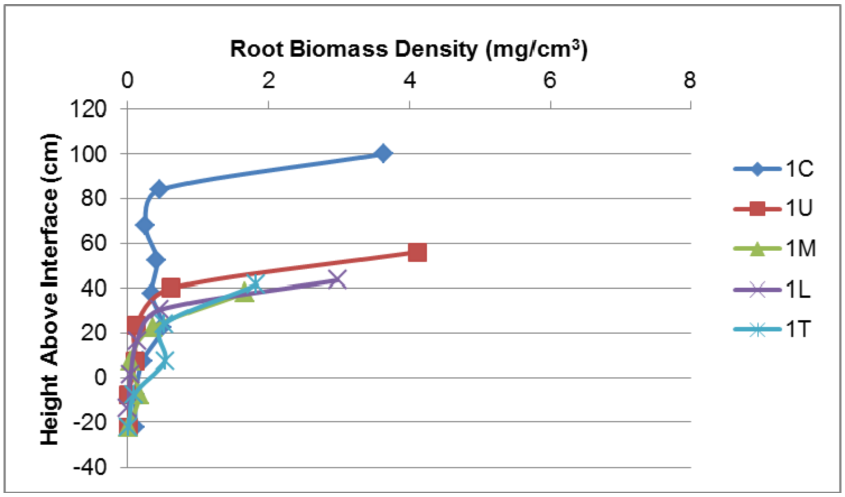


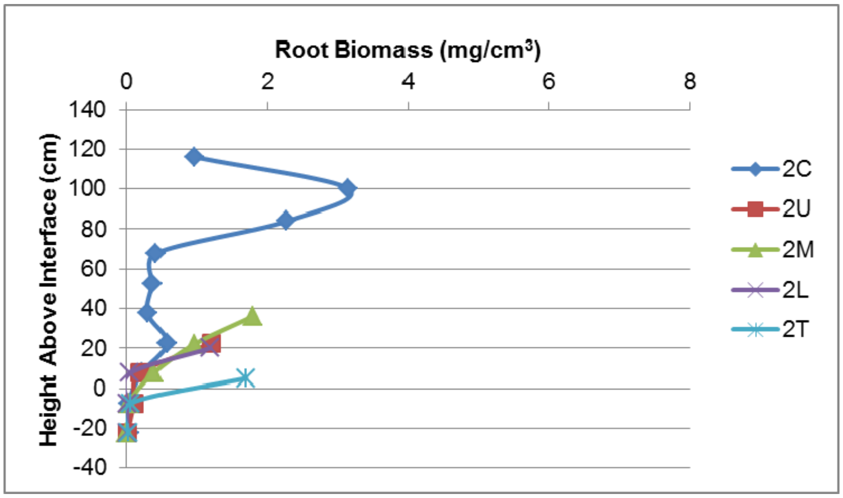
Figure 6. Root distributions of several boreal forest species (jP – jack pine, tA – trembling aspen, wS – white spruce) growing on different soil types. (source: Strong and La Roi, 1985).

Individual rooting densities for transects and slope positions are presented for transects 1-3 (Figure 7), transects 4-6 (Figure 8) and transects 7-9 (Figure 9). Rooting distributions generally decreased with depth in an exponential fashion with some anomalies where rooting density would increase at certain depths in the profile. Normally this was due to pockets of peat in the profile. Of the 82 Overburden samples only 6 samples had no root biomass and rooting densities were as high as 0.89 mg/cm^3. Although there was no relationship between root biomass and number of trees (Figures 3 and 4), transects 7, 8 and 9 had lower rooting densities and this was likely due to fewer trees in the sampling area.

The rooting densities for this study were comparable to rooting densities and exponential decline in biomass of several different aged boreal mixedwood stands in Saskatchewan growing on loam/clay loam soils (Figure 10).

A comparison of total root biomass with the depth to Overburden material showed that for shallow covers (i.e. < 50 cm thick) the total root biomass was < 5 Mg/ha, while covers > 50 thick ranged from 1 to 17 Mg/ha (Figure 11). The majority of the data peaks around a cover thickness of 100-120 cm.





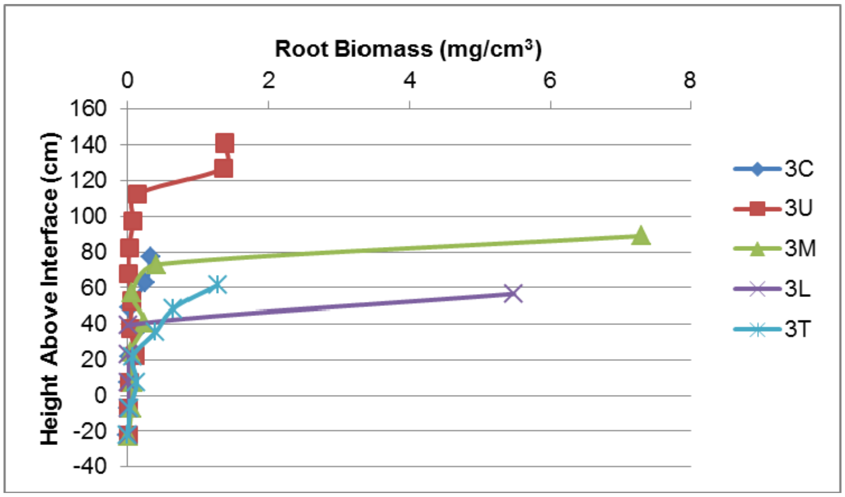
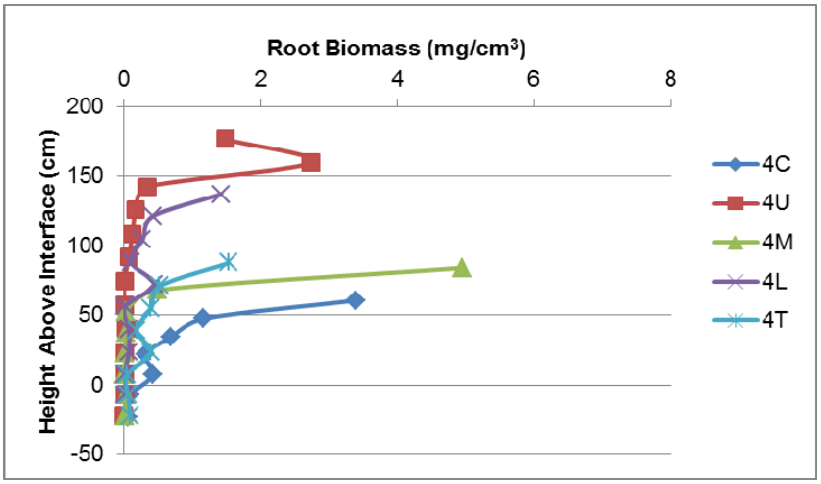
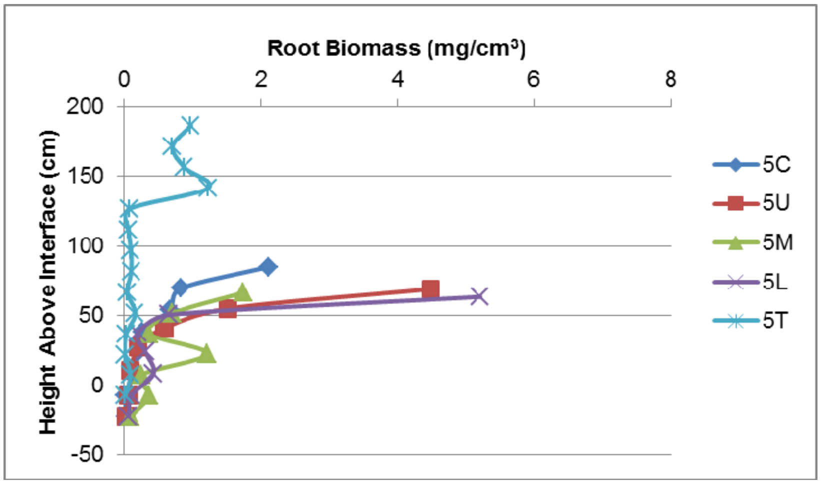


Figure 7. Root density profiles for transects 1 (top), 2 (middle) and 3 (bottom). (C, U, M, L, T represent crest, upper, middle, lower and toe slope positions, respectively).





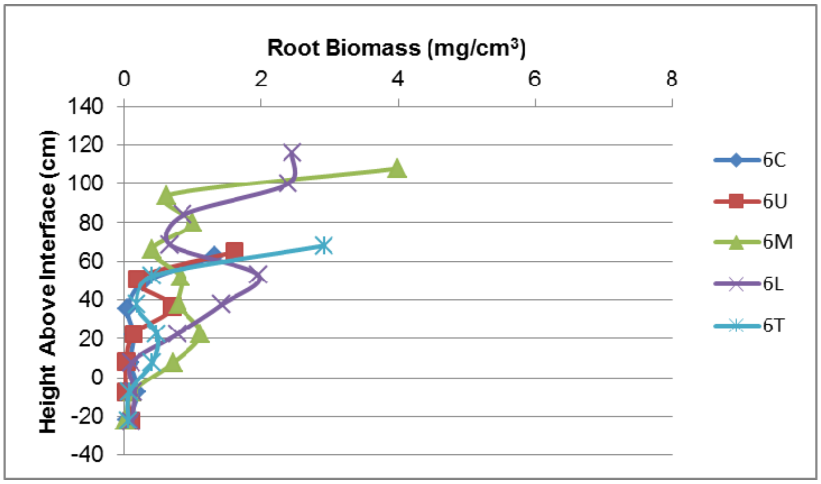
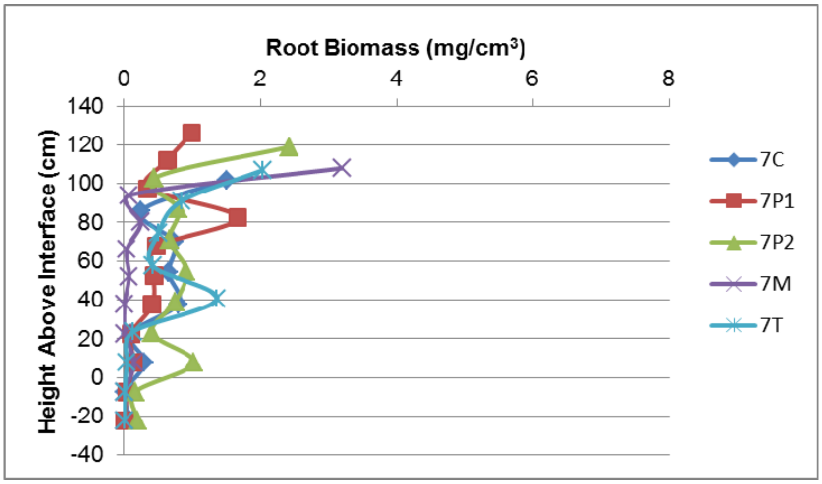
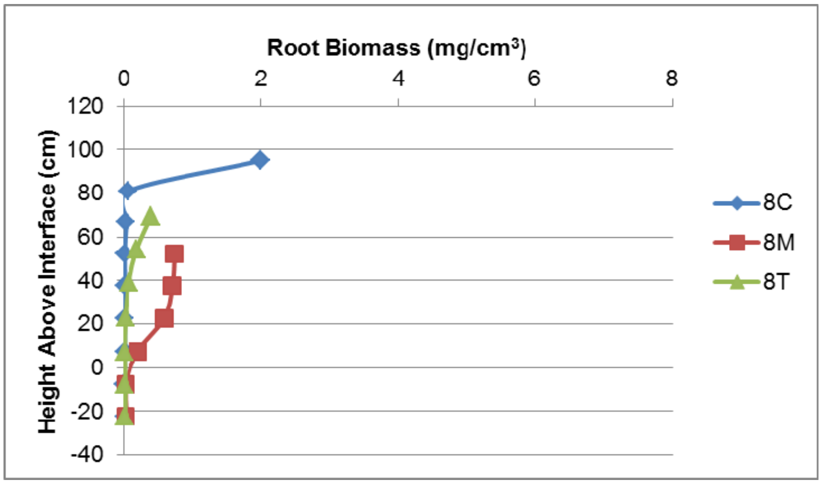


Figure 8. Root density profiles for transects 4 (top), 5 (middle) and 6 (bottom). (C, U, M, L, T represent crest, upper, middle, lower and toe slope positions, respectively).





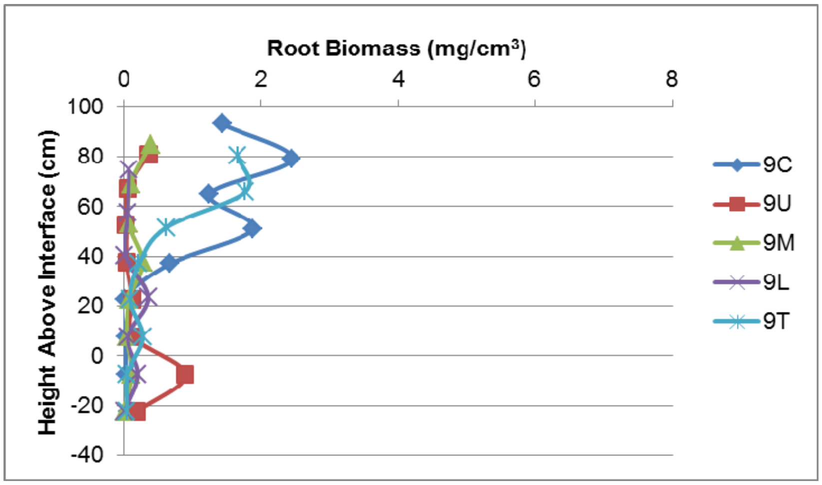


Figure 9. Root density profiles for transects 7 (top), 8 (middle) and 9 (bottom). (C, P, U, M, L, T represent crest, plateau, upper, middle, lower and toe slope positions, respectively).

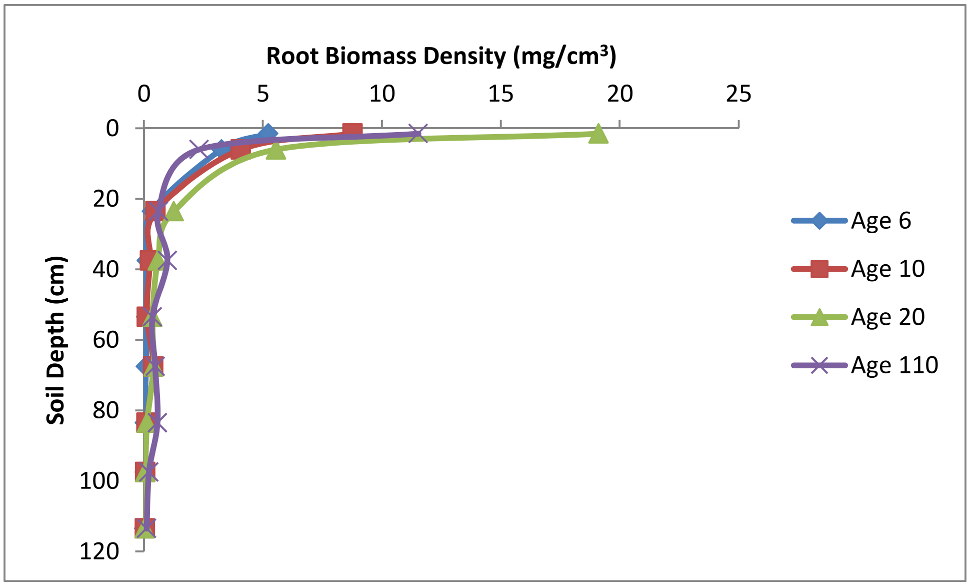


Figure 10. Root density distributions for mixedwood forests (aspen, spruce and understory) of various ages growing on Luvisolic soils in Saskatchewan (source: Van Rees, 1997).

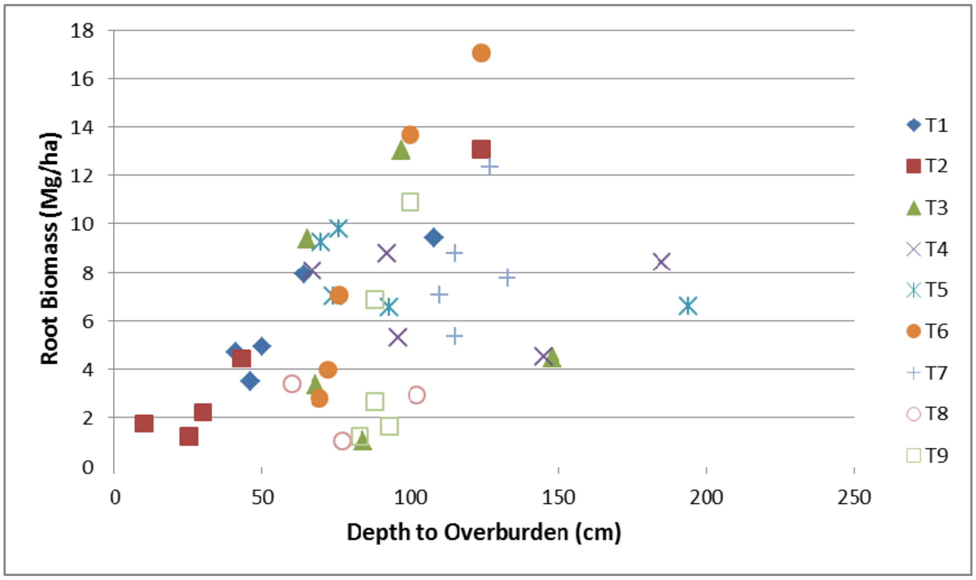


Figure 11. Distribution of total root biomass in relation to depth to Overburden for each transect and slope position.

4. Conclusions

The following conclusions were made from the root profile study.

1. Root distribution with cover depth appeared to follow the natural rooting patterns of other mixedwood boreal forests, with the majority of roots located in the surface and generally showing an exponential decrease with cover depth. Soil texture could also play a role in the rooting distributions where root densities are highest in the peat or peat/mineral mix at the surface and then decline rapidly as the roots enter the clayey mineral below which is similar for other mixedwood stands growing on Luvisolic soils.

2. Although roots are present in the Overburden at South Bison Hills, for thin capping depths (<100 cm) the density of rooting in the Overburden was lower than the reclamation cover at similar depths. However, the species of vegetation with roots in this material is unknown. In addition, it is not known how the salt profiles may be influencing the rooting distributions.

3. The root biomass data suggests that covers < 50 cm thick had lower root biomass values (predominantly < 5 Mg/ha), while covers > 50 cm had root biomass ranging from < 5 to 17 Mg/ha. The peak in root biomass generally occurred in the 100-125 cm thick cover suggesting that covers greater than 50 cm allow for greater root growth with maximum root densities around 100-120 cm thick.

4. Covers that are 100 cm thick over saline/sodic Overburden appear to have the highest root biomass, but these planted sites are still fairly young and may not represent more mature forests. Cover thicknesses between 50-100 cm may be satisfactory for root development, but the current forest is still young enough to warrant precautions.

5. Future Research

Based on the results of the root profile study, the following future research is recommended.

1. Investigate which plant species are developing their roots in the Overburden material, particularly to determine if the planted white spruce and trembling aspen root distributions are impacted by the soil chemical and physical limitations presented by the Overburden. Future monitoring may be required to determine whether the planted boreal tree species, as they mature and occupy the cover profile, are being impacted by the presence of a salt profile in the soil reclamation cover that originates from the Overburden.

2. A survey of plant understory species in the sampling areas would be useful to compare to the 2003 data (Lazorko, 2008) to help understand potential species that might show some degree of salt tolerance and ability to root in shallow capping depths and/or in the Overburden.

3. The relationship between the salt profiles, soil texture (bulk density) and root distributions was not examined in this report, but it should be analyzed to determine if the salt profiles are influencing root development.

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APPENDIX E
SOUTH BISON HILL RESEARCH SYNTHESIS 2012 SOUTH BISON HILL SALINITY STUDY

SYNCRUDE CANADA LTD.

Klohn Crippen Berger

Syncrude Canada Ltd.

South Bison Hill Research Synthesis

2012 South Bison Hill Salinity Study

March 2013
A03289A02.730

Klohn Crippen Berger

March 7, 2013

Syncrude Canada Ltd.
9421 - 17 Avenue
Edmonton, Alberta
Canada, T6N 1H4

Mr. Marty Yarmuch
Environmental Research - Project Lead

Dear Mr.Yarmuch:

South Bison Hill Research Synthesis
2012 South Bison Hill Salinity Study

Syncrude Canada Ltd. (SCL) has retained Klohn Crippen Berger Ltd. (KCB) to provide technical support in their efforts to compile and synthesize recent monitoring data from a reclaimed saline-sodic overburden disposal area. KCB was asked to assist with the plotting and analysis of salinity profiles collected from the study site in 2012 and to compare the new profiles with historic profiles from previous sampling programs.

The following report provides an assessment of the 2012 salinity profiles and an interpretation of spatial and temporal trends. We solicit your review and comments. If you have any questions regarding the contents of this report please contact Joel Hilderman at 306-974-1520.

Yours truly,
KLOHN CRIPPEN BERGER LTD.

Joel Hilderman, M.Sc., P.Eng.
Project Engineer

Syncrude Canada Ltd.

South Bison Hill Research Synthesis

2012 South Bison Hill Salinity Study

EXECUTIVE SUMMARY

In September 2012, Syncrude Canada Ltd. (SCL) conducted a soil sampling program at the South Bison Hill (SBH), a reclaimed saline-sodic overburden disposal area at the Mildred Lake Mine. The soil sampling program was intended to provide SCL with an opportunity to further evaluate the evolution of salt dynamics in the reclamation cover and upper saline-sodic overburden material.

The 2012 soil salinity data set covers more of the SBH study site than previous soil sampling programs at this site. Soil samples were collected from 9 transects around the SBH, with each starting at the crest or on the plateau and extending down the SBH slope. Soil samples were submitted to a laboratory for saturated paste extract testing to determine detailed salinity concentrations. The results from the soil salinity testing were used to create representative salinity profiles plotting concentration versus distance from the interface of the cover soil and Clearwater overburden.

The 2012 salinity profiles suggest that salts are moving upward into the cover to a height of approximately 60 cm above the interface, based on the median profile. When categorized by cover thickness, the data suggests that upward salt migration may be reaching greater heights in the thicker covers than the thinner covers. The median height of salt ingress appeared to range from 30 cm for the thinnest covers to 85 cm for the thickest covers. The profiles also suggest that the concentration of salt in the upper Clearwater overburden is slightly lower at sampling locations with thinner covers than those with thicker covers.

Despite this ingress of salt from the Clearwater overburden into the reclamation cover soil, for the median profile of all 2012 sampling locations, the soil cover is still within suitable (Good to Fair) soil reclamation guidelines for EC and only the bottom 10 to 15 cm of cover soil has been altered to Poor for SAR. When categorized by cover thickness, the 2012 profiles illustrate that the thickness of cover soil influences the soil quality classification. Evaluation of SAR values found the zone of Poor cover soil extends 5 cm above the interface in the thin covers (<75 cm), 10 cm in the medium thickness covers (75 to 100 cm) and 15 cm in the thickest covers (>100 cm).

The 2012 data did not indicate an observable trend in the salinity profiles when comparing north and south aspects of SBH. The 2012 profiles also showed no clear and consistent trends related to slope position.

The 2012 salinity profiles from Transects 1 to 3 on the north facing aspect of the SBH, were compared to historical profiles from 2002 and 2008. This comparison suggested that salt mass has steadily migrated upward from the Clearwater overburden into the cover soil, increasing the salt concentration in the cover soil. This suggests that the salt ingress into the cover has not yet been reversed by flushing of salt via net percolation and interflow. The salt concentration in the upper Clearwater overburden appears to have decreased between 2002 and 2008 but has changed very little between 2008 and 2012. This suggests that the source of the salt in the Clearwater overburden is now being depleted.

The concentration of salts in the Clearwater overburden beneath the thin covers is lower than that beneath the thicker covers. This may be the result of the more rapid oxidation of the shale beneath

the thinner covers combined with higher rates of flushing. As the source of salts in the upper Clearwater overburden depletes, the upward migration of salts by diffusion into the cover soil will decrease. Eventually the rate of salt outflow by net percolation and interflow will exceed the rate of salt ingress and a net flushing of salts from the cover will occur.

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1 INTRODUCTION

Surface mining of oil sands in the Athabasca Oil Sands Region of northern Alberta requires excavation and redistribution of overburden on a large scale. The post-mining landscape will consist of end-pit lakes, ponds, wetlands, reclaimed tailings sands storage areas, and reclaimed upland overburden disposal areas. Syncrude Canada Ltd. (SCL) contributes in the research and evaluation of reclamation techniques for these post-mining landforms in the oil sands region.

1.1 Study Site

The study site for this research synthesis is South Bison Hill (SBH). This site is located at SCL's Mildred Lake Mine approximately 40 km north of Fort McMurray, Alberta. The study site is shown in Figure 1.

The SBH is an upland overburden structure comprising mainly saline-sodic, Cretaceous clay shale with minor amounts of lean oil sand, glacial till, glaciolacustrine clay, and peat. The SBH was constructed over the course of two decades with the last lift of overburden placed in 1996 and final grading undertaken between 1996 and early 1999 (Kessler 2007). SBH rises approximately 30 m above original ground (Wall 2005) and covers an area of greater than 100 ha. The study site comprises 49 ha of the SBH.

Reclamation activities on the SBH occurred between 1996 and 2004 and included soil placement and revegetation. The materials used for soil capping at the SBH included:

- Direct placement – material containing a suitable balance of organic (peat) and mineral (Secondary), salvaged from the approximate surface 0.5 m of the pre-disturbance salvage area. This material was salvaged and placed without a further cover soil layer.
- Peat-mineral-mix – predominantly organic material generally containing little to no mineral material and placed as a cover soil layer over mineral subsoil (Secondary).
- Secondary – mineral soil material containing little to no organic materials. This material is suitable (Good to Fair soil quality) for use as subsoil (AAFRD, 1987) and is overlain by a cover soil layer.
- Non-sodic – mineral soil material that is similar to Secondary, except it does not meet all Good to Fair soil suitability requirements. Generally, these materials exceeded the % clay fraction and/or soil pH ratings.

The SBH Research Synthesis study site includes three instrumented test plots on the northwest-facing aspect of the SBH. Each test plot measures 1 ha in area (50 m wide x 200 m long). The three plots, designated D1, D2, and D3, were each constructed with a different cover prescription to study the effect of cover thickness on reclamation success. The cover configurations were as follows:

- D1: 20 cm of peat-mineral-mix over 30 cm of secondary;
- D2: 15 cm of peat-mineral-mix over 20 cm of secondary; and,
- D3: 20 cm of peat-mineral-mix over 80 cm of secondary.

The reclamation covers on the three test plots were constructed in early 1999 (winter), seeded with barley in June 1999 and planted with alternating rows of white spruce and aspen seedlings in the fall of 1999 (Boese 2003).

The remainder of the north slope was capped in 1999 with the same cover prescription as the D3 test plot (20 cm of peat-mineral mixture over 80 cm of secondary). This area of the SBH was also planted to white spruce and aspen in 2002.

The east slope was capped in 1996 with 50 cm of direct placement (peat-mineral-mix) over 50 cm of non-sodic material. The east slope was seeded to a pasture seed mix in 1996 and then to white spruce and aspen in 2002.

The south slope, west slope and plateau area of the SBH were capped in 2001 with a prescribed cover configuration of 20 cm of peat-mineral-mix over 30 cm of secondary, over 50 cm of non-sodic material. The south and west slopes were planted to white spruce and aspen in 2003. The plateau was planted with the same tree species in 2003. Soil placement and revegetation maps are included in Figure 2 and 3, respectively. Figure 4 shows a schematic of the various cover configurations.

1.2 Salinity Concerns

Generally, upland overburden disposal areas in the Athabasca Oil Sands Region when reclaimed are required to support a boreal forest ecosystem equivalent to that which existed before the disturbance (Qualizza et al. 2004). The two primary concerns for the successful revegetation of the reclaimed SBH study site are ensuring an adequate supply of water for the trees and understory vegetation and ensuring that the reclaimed vegetation is not detrimentally affected by salinity and sodicity in the cover soil or the underlying overburden material. The current research on the SBH study site is examining these concerns. This report is focused on the salinity and sodicity of the cover soil and the underlying saline-sodic overburden.

SBH is primarily composed of saline-sodic overburden. This Cretaceous clay shale from the Clearwater geologic formation was deposited in a marine environment and the porewater contains high concentrations of dissolved solids, especially sodium and sulphate. The sulphate is produced by oxidation of sulphide minerals, especially pyrite (Wall 2005). This reaction lowers the pH of the solution water which then is neutralized by the dissolution of carbonates, releasing calcium and magnesium cations into solution. The calcium and magnesium cations are preferentially adsorbed to clay particles releasing more Na^+ into the pore water (Nichol et al. 2006).

Salinity (dissolved salts) and sodicity (excess of sodium relative to other cations in solution) can have harmful effects on vegetation if levels exceed certain thresholds. High salinity in porewater creates osmotic pressure, making it more difficult for plant roots to extract water molecules from the soil pores (Sandoval and Gould, 1978). Electrical conductivity (EC) of pore water provides a measurement of total dissolved solids (TDS). Soils are considered saline if the EC of the saturated paste extract exceeds 4 dS/m (USDA Salinity Laboratory 1954).

Soils with a high ratio of sodium relative to divalent cations (Ca^{2+} and Mg^{2+}) will experience swelling and, potentially dispersion, of individual clay particles when exposed to fresh water (Simunek and Suarez 1997). These processes reduce the interconnected pore space required for root propagation and water transport. Soils are considered to be at risk of sodicity problems if the SAR value is greater than 12 (AAFRD 1987). Sodium toxicity can be an issue for some sensitive species of vegetation, but for most vegetation it is sodium’s contribution to total salinity, resulting in osmotic stress, and sodium’s potential to alter the soil structure that has the greatest detrimental effects (Saskatchewan Water Corporation 1987).

The Alberta Tier 1 Soil and Groundwater Remediation Guidlines publication (Alberta Environment 2010) presents a set of guidelines for maximum EC and SAR values in reclamation cover soils. These values are summarized in Table 1.1. SCL uses EC and SAR in the evaluation of the suitability of soil used for reclamation. Currently Good and Fair EC and SAR ratings are considered to be suitable for use as soil reclamation material (Syncrude Canada Ltd. 2011).

Table 1.1 Alberta Tier 1 Salt Remediation Guidelines (Alberta Environment 2010)

Rating Categories	Good	Fair	Poor	Unsuitable
Topsoil				
EC (dS/m)	<2	2 to 4	4 to 8	>8
SAR	<4	4 to 8	8 to 12	>12
Subsoil				
EC (dS/m)	<3	3 to 5	5 to 10	>10
SAR	<4	4 to 8	8 to 12	>12

The high concentration of salts in the Clearwater overburden creates a strong concentration gradient between the overburden material and the overlying cover immediately after capping (Kessler 2007). This concentration gradient drives salts upward into the cover soil through the process of diffusion. Under certain conditions, evapotranspiration can also draw saline water upward into the cover soil. One study indicated that salinization of the soil surface can occur if the water table is within 0.6 m of ground surface (Moran et al. 1990). This suggests that upward salt transport due to advection associated with evapotranspiration is a greater risk for covers thinner than 0.6 m.

Upward salt transport is counteracted by downward percolation of precipitation. This net percolation of water is greatest in flatter topographic locations such as the plateau where perched water tables can persist for longer periods of time (Hilderman 2011). Flushing of salts from the cover is also facilitated by lateral subsurface “interflow”. This is gravity driven flow of groundwater that becomes perched along the interface of the cover soil and the underlying Clearwater overburden (Kelln et al. 2007). As the interflow water moves downslope, it can carry with it salts that have migrated upward into the cover soil.

1.3 Previous Salinity Research

A number of research studies have been conducted at the SBH to answer questions related to site hydrology, soil-water dynamics, cover soil characteristics (e.g. water content and hydraulic conductivity), and chemistry. Some of the studies that pertain to soil chemistry are described below.

Wall (2004) investigated the geochemistry of the overburden material in the SBH and the evolution of the geochemistry due to geochemical reactions. Wall showed that oxidation of sulphide minerals (pyrite) in the Clearwater overburden resulted in a chain of geochemical reactions leading to increased porewater salinity, especially SO_4^{2-} and Na^+. Wall found that the oxidation zone extended 3 m into the soil profile and that SO_4^{2-} was being produced at 1.3 g/m²/day.

Kessler (2007) evaluated the salinity of the cover soils on the 3 instrumented test plots of the SBH. Kessler collected soil samples from the cover soil and upper Clearwater overburden to develop soil salinity profiles. These profiles were compared to soil quality guidelines to evaluate the soil suitability for reclamation. Kessler found that four years after cover soil placement, salt had migrated upward into the cover and that the dominant transport mechanism was diffusion. Kessler found that the extent of salt migration into the cover was similar for the three different cover thicknesses. When comparing the salinity profiles from different slope positions, Kessler found no trends or evidence of slope position effects on the salt profiles.

Nichol et al. (2006) developed a numerical model of the geochemical reactions and salt transport mechanisms in the cover soil and upper Clearwater overburden material based on the field observations from Wall and Kessler. He applied this model to evaluate the performance of the D1 test plot (35 cm thick cover), the D3 test plot (100 cm thick cover) and the plateau (100 cm thick cover). However, the key unknown in this study was the rate of net percolation at each location and therefore model results were presented for a number of net percolation values. For the D1 (35 cm thick) cover, Nichol et al. predicted that the entire cover soil would reach EC values of 2 dS/m or greater within 15 years if the net percolation rate was less than 8 mm/yr. For the D3 cover, the modeling predicted that the cover soil would remain non-saline (EC<2dS/m) in the upper 50 cm of cover but that the lower cover soil would become saline. The model results predicted higher salt ingress for the plateau than the D3 cover, if the net percolation rate is held constant.

Nichol et al. also found that the salinity levels in the cover soil would reach a maximum concentration at some point and then begin decreasing as interflow and net percolation flushed the salt away. Nichol et al. predicted that this maximum salt ingress could be reached after 5 years or may take over 100 years depending on the rates of net percolation and interflow.

Kelln et al. (2007, 2008, 2009) investigated the effects of topographic variation on soil moisture and transport mechanisms. In the first of these papers, Kelln et al. (2007) showed that snow melt infiltration was occurring through macropores while the ground was still frozen. As the temperature continues to rise, the ground thaws and the macropore water equilibrated with soil porewater. The downslope interflow water shows a seasonal evolution from fresh snowmelt to a chemical signature matching the porewater.

In the second paper, Kelln et al. (2008) mapped the spatial distribution of volumetric water content and salts on the D3 test plot. This study found that the lower slope locations were wetter than the upper slope locations. The wetter conditions result in an increased salt mass flux into the cover through molecular diffusion. However, this is balanced by enhanced flushing of salts through downward net percolation and lateral, downslope interflow. While the drier, upper slope locations have less upward mobilization of salts through diffusion, these locations also appear to have less salt flushing. Numerical modeling from this study also suggested that infiltration of snowmelt occurs through preferential flow paths rather than through the soil matrix.

In the third of their papers, Kelln et al. (2009) applied the knowledge gained from the first two papers to a numerical flow and transport model. The model used composite hydraulic functions and indicated that the macroporosity of the cover soil was approximate 3-4%. The model results suggested that most of the infiltration and interflow occurs through these macropores.

Hilderman (2011) collected soil samples in 2008 and 2009 from the same locations sampled by Kessler in 2002 and 2004. This comparison suggested that for the thinner covers (D1 and D2) the salt concentrations in the upper Clearwater overburden had decreased slightly, while the concentrations in the cover soil showed little change. For the thicker cover locations (D3), the concentration of salts did not change significantly in the upper Clearwater overburden but increased in the cover soil. For locations assessed on the plateau, the salt concentrations in both the cover and upper Clearwater overburden seemed to decrease slightly with time.

Hilderman also developed profiles of the stable isotopes of water (^{2}H and ^{18}O) in the soil profiles and used a 1D numerical model to estimate the net percolation at various topographic locations. This modeling suggested that the net percolation rate was 35 – 50 mm/yr for the plateau and generally 0 – 12 mm/yr for the slope (D3 cover plot). However, at one location on a mid-slope bench the estimated net percolation rate was 32 – 35 mm/yr, indicating the importance of undulations in the topography and underlying Clearwater overburden surface.

1.4 Research Objectives

The global objective of the research synthesis is to recommend an optimal reclamation cover thickness for saline-sodic overburden disposal areas in the post-mining landscape. This prescription will be based on scientific evidence and expert opinions developed from over a decade of research on the study site.

The specific objectives of the salinity study described in this report are to:

- Produce salinity profiles for the 2012 soil salinity data collected from the study site;
- Analyze the 2012 salinity profiles and provide interpretations of spatial trends, if any exist; and,
- Compare the 2012 salinity profiles to historic profiles (2002 and 2008) from nearby locations and provide interpretations of any apparent temporal trends in the data.

2 METHODOLOGY

The SBH Salinity Study described in this report is a component of the research collaboration that SCL has undertaken for this study site. The methodology described here refers only to the portions of research related to the salinity study.

2.1 Soil Sampling

Soil sampling for salinity analysis was performed by NorthWind Land Resources Inc. and O'Kane Consultants Inc. between September 10 and 13, 2012. A total of 400 samples were collected from 9 transects around the SBH as illustrated in Figure 1. Each transect was sampled at 5 discrete locations. Most transects (1-6, 9) were sampled at the crest (C), upper slope (U), middle slope (M), lower slope (L) and toe (T). Transects 7 and 8 were sampled twice on the plateau (P1 and P2), at the upper slope (U), middle slope (M) and lower slope (L). The transect and slope position are used in this report to define sampling locations. For example, the sampling location at the upper slope position (U) on Transect 6 is referred to as 6U.

Samples were collected using a 7 cm (outside diameter) riverside hand auger. Holes were drilled to a depth of at least 30 cm below the soil cover – Clearwater overburden interface. The interface was chosen as the reference point (0) for all sample intervals. From the interface, sample intervals typically ranged from 10 cm to 20 cm. With few exceptions, the sample intervals were as follows:

- Interface to +10 cm
- +10 cm to +20 cm
- 20 cm intervals thereafter
- Interface to -10 cm
- -10 to -20 cm
- -20 to -40 cm

Samples were placed in airtight bags and labeled with the hole location and depth. The bagged samples were then placed in coolers. At the end of the sampling program, the coolers were shipped to Exova Laboratory in Edmonton.

Field logs were recorded for each borehole and included details on:

- Sampling descriptions (interval depth, material types, other notes);
- Total depth of hole;
- Thickness of each different material type in the cover; and,
- Total thickness of the cover.

A detailed description of the sampling methodology can be found in the root and salinity sampling field program report (NorthWind Land Resources Inc. 2013).

2.2 Laboratory Testing

Soil samples were tested for the following parameters:

- Detailed Salinity of saturated pastes including pH, electrical conductivity (EC), sodium adsorption ratio (SAR), saturated water content (SAT%), concentrations of ions: Ca, Mg, Na, K, Cl, SO_4 (all samples);
- Gravimetric moisture content (all samples); and,
- Particle Size Distribution, hydrometer (some samples).

Detailed salinity parameters were measured using the saturated paste method of porewater extraction described in Rhoades (1982). This method develops saturated pastes by adding de-ionized water to the soil samples until the sample reaches a standardized consistency. The water from the paste can then be extracted and tested for pH, EC and the dissolved ions listed above. The saturated paste method underestimates total soluble salts as compared to higher dilution extract methods (Kessler 2007, Buckland and Hendry 1986). However, the saturated paste method is an industry standard for assessing soil salinity parameters and many soil quality guidelines and classification systems are based on this method (CEMA 2006, Alberta Environment 2010). This method was also used for previous soil salinity testing at the SBH study site (Kessler 2007, Hilderman 2011).

A detailed description of the laboratory testing methodology is included in the Root Sampling and Salinity Sampling Field Program Report (NorthWind Land Resources Inc. 2013).

3 RESULTS AND DISCUSSION

3.1 Detailed Salinity Results

3.1.1 Saturated Paste Extract Results

A summary table of the solute concentrations measured in the laboratory from the saturated paste extracts is included in Appendix I. The average values from the saturated paste extracts of the 2012 soil samples are summarized in Table 3.1.

Table 3.1 Average Salinity Values from the 2012 Saturated Paste Extracts

Sample Type	Moisture Content (%)	pH	EC (dS/m)	SAR	Soluble Cations and Anions					
					Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Cl^{-} (mg/L)	$S\text{-}SO_4^{2-}$ (mg/L)
Cover Soil Samples	25	7.3	2.4	4.5	258	80	332	9	40	305
Clearwater Overburden Samples	20	7.4	7.1	11.6	451	322	1334	54	56	1636

The average values for these materials are of less importance than the relationship between the parameters and the depth in the soil profile. This relationship is discussed further in Section 3.2.

The salinity results confirm that the primary ions contributing to soil salinity are Na^{+} and SO_4^{2-}. Though generally lower than these two ions, the concentration of Ca^{2+} and Mg^{2+} can also be significant. The other cation that was analyzed in the laboratory was potassium (K^{+}) but the concentration of K^{+} was mostly negligible in the soil samples.

The concentration of Cl^{-} can be of concern in soil due to its specific toxicity to certain types of vegetation. For the most part, the concentration of Cl^{-} was negligible with an average concentration of 45 mg/L (saturated paste extract) for all soil samples. However, there were 4 sampling locations that were observed to have higher than normal Cl^{-} concentrations. These locations are 5U, 7P1, 9L and 9T. The maximum concentrations at each of these four locations ranged from 192 to 403 mg/L. Sampling locations 9L and 9T are located at the bottom of Transect 9 near Peat Pond. The elevated chloride concentrations at this location may be originating from Peat Pond itself. Measured Cl^{-} concentrations in Peat Pond have been as high as 1440 mg/L on July 19, 2002, although subsequent readings have been much lower (unpublished data). The reason for the elevated Cl^{-} concentrations at 5U and 7P1 (155 and 166 mg/L, respectively) were not explored.

3.2 Statistical Salinity Profiles

The salinity results for all individual soil samples were categorized into classes based on their distance from the interface. The samples were grouped into 5 cm intervals and statistics were calculated for each of these groups for the saturated paste extract parameters EC, SAR, and Na^{+} (in mg solute / kg of soil). The analysis focused on EC and SAR as they are primary indices for evaluation of soil suitability for many soil classification guidelines including the Tier 1 Alberta Soil Quality Guidelines (Alberta Environment 2010). Sodium was also included in the plots as it is the cation present in the highest concentrations and is the ion of greatest concern to the overall health of the cover soil system.

These statistics included arithmetic mean, maximum, minimum, median, 25th percentile, and 75th percentile. These statistics were used to create a box and whisker plot of the data versus the distance of the sample group from the interface. A line was plotted through the median value of each plot interval to provide a representative profile for the group of sampling locations. The plot intervals with a small population size often diverged from the general trend of the data. Therefore, any plot interval with a population smaller than 5 samples was excluded from the plot.

The soil sampling program followed a regular sampling routine, as described in Section 2.1, with intervals being determined starting at the interface (based on a pilot hole). The uppermost sample at each hole typically varied from the regular 20 cm intervals. Since the uppermost sample intervals were not consistent with the regular sample intervals, they were more likely to have been dropped from the statistical analysis if they fell within a plot interval with an insufficient sample population ($n < 5$). Also, for deeper than normal capping depths, at sampling heights further from the interface (>1 m), the sample population size is decreased. Therefore, many of the samples that were excluded from the statistical analysis were from heights of greater than 1 m above the interface. To illustrate this point, for the statistical profiles of the complete 2012 dataset, 41 of 393 samples were excluded due to insufficient population size and 18 of these were from heights of 100 cm or greater. Removing these samples from the statistical analyses has no bearing on the interpretation of salt movement occurring at the interface.

3.2.1 2012 Statistical Salinity Profiles - All Data

Statistical plots were created for the entire 2012 data set for the three selected parameters (EC, SAR and Na^+) and are presented in Figures 5 to 7. These plots are relatively smooth with the exception of a few irregularities caused by sample groups with smaller populations. The EC and Na^+ plots suggest that the salinity levels in the upper cover soil are consistent and possibly at baseline concentrations from ground surface to a point approximately 60 cm above the interface. At 60 cm above the interface the concentration begins to increase in a pattern suggestive of salt diffusion. The salinity profiles then deflect again as they approach the interface and the concentration gradient increases. This deflection of the profile suggests that there are processes counteracting upward diffusion of salts and that these processes seem to have the greatest influence just above the interface.

The Na^+ and EC profiles are similar in shape in the cover soil but start to diverge in the Clearwater overburden. While the Na^+ profiles show a linear increase from just above the interface to the lowermost sampling depth, the EC profiles seem to round off at approximately 15 cm.

Similar to the EC and Na^+ profiles, the SAR profile begins to diverge from the apparent baseline value at 60 cm above the interface. However, at that point, the median SAR profile in the cover follows an approximately linear slope of increasing concentration to the Clearwater overburden interface and continues on a similar slope to the bottom of the sampling depth, 30 cm below the interface.

While the baseline and maximum concentrations of EC, SAR and Na^+ in the Clearwater overburden were not defined due to limited sampling depth, their approximate values can be interpreted from other studies. Kessler (2007) collected and analyzed soil samples from a Clearwater overburden spoil pile. The results were as follows:

- Average EC = 10.0 dS/m, Maximum EC = 16.7 dS/m; and
- Average SAR = 16.9, Maximum SAR = 35.0.

Based on these values, the measured EC and SAR in the Clearwater overburden from the 2012 sampling locations appear to be approaching baseline conditions or may increase marginally with increased depth.

Based on the Alberta Tier 1 Soil Quality Guidelines (Table 1.1), the median EC profile of the cover soil samples meets the Fair quality subsoil guideline from approximately 0 to 15 cm above the interface (Figure 5). Above 15 cm, the cover soil is Good quality for subsoil based on the EC measurements. For SAR guidelines, the median profiles suggests that the cover quality is Poor from 0 to 10 cm above the interface, Fair from 10 to 35 cm above the interface, and Good above 35 cm (Figure 6).

This study confirms the findings of previous research at the site (Kessler 2007, Kelln et al. 2008, Hilderman 2011) that upward salt movement is occurring into the soil reclamation cover. However, for the median profile, the entire soil cover is still within suitable soil reclamation guidelines for EC and has only altered the bottom 10 to 15 cm of cover soil to Poor for SAR.

3.2.2 2012 Statistical Salinity Profiles Grouped by Cover Thickness

All EC, SAR and Na^+ site data was further analyzed to determine if cover thickness influences upward salt movement. This data set was sub-divided by cover thickness into three categories: >100 cm, 75 – 100 cm, and <75 cm. The same parameters (EC, SAR and Na^+) were plotted for each of these three cover thickness categories using the statistical box and whisker format. The intent of these plots was to identify trends in the statistical profiles for the individual cover thickness classifications that were masked within the larger dataset. The plots are included in Figures 8 to 16.

The shapes of the plots are similar for EC, SAR and Na^+, displaying the same trend with varying cover thickness. However, a pattern of increased ingress of EC, SAR and Na^+ with increased cover thickness is also evident. This phenomenon is more pronounced for the EC parameter than SAR and Na^+. The shape of the EC profile for the thicker cover locations (>100 cm) shows that EC begins to increase above the assumed baseline concentration (about 1.4 dS/m) at approximately 85 cm above the interface and then seems to increase more rapidly below approximately 50 cm above the interface. For the medium thickness covers (75 – 100 cm) the shape of the EC profile suggests that the salt concentration starts to increase above baseline (about 1.1 to 1.2 dS/m) at approximately 70 cm above the interface. The EC profiles for the thinner covers suggest that the salt concentration remains near baseline (0.9 dS/m) until approximately 30 cm above the interface. One other difference is that the EC profiles seem to round off more sharply in the Clearwater overburden for the thinner covers. In addition, the median concentration at the lowest sampling depth in the Clearwater overburden (30 cm below the interface) is lower for the thinner covers than the thicker covers.

For the Na^+ plots, the median profile seems to diverge from baseline at approximately 75 cm above the interface for the thickest covers, 65 cm above the interface for the medium thickness covers and 30 cm above the interface for the thinnest covers. Similar to EC, the observed concentrations of Na^+

in the Clearwater overburden are lower in locations with thinner covers than those with thicker covers (based on the median profile).

The SAR profiles are similar but begin to diverge from baseline concentration at a greater height above the interface. The SAR profile appears to diverge from baseline at approximately 90 cm above the interface for the thickest covers, 75 cm above interface for the medium thickness covers and 40 cm above the interface for the thinnest covers. The SAR profiles of the thicker covers (75-100 cm and >100 cm) are more linear than the thinner cover median profile. For the thicker cover sampling locations, the SAR profile is approximately linear from the upper cover to the bottom of the sampling depth (30 cm below the interface). The SAR profile in the thinner covers has more of a “step” above the interface, rounding off at approximately 15 cm above the interface.

The SAR profile in the Clearwater overburden for the thinner covers is also slightly different than the overburden in the thicker cover profiles. The thinner cover SAR profile has more variance below the interface and does not increase with depth at the same rate as the thicker cover. The SAR values appear to be lower in the Clearwater overburden at the thinner cover locations (<75 cm).

Comparing the more limiting SAR values (relative to EC) to the Alberta Tier 1 Soil Quality Guidelines (Table 1.1) shows how cover thickness influences upward salt diffusion. The thicker cover soil range (>100 cm) is Poor from 0 to 15 cm, Fair from 15 to 50 cm and Good at heights of 50 cm or more above the interface. The medium thickness cover is Poor from 0 to 10 cm, Fair from 10 to 35 cm and Good above 35 cm. The thinnest cover is Poor from 0 to 5 cm, Fair from 5 to 22 cm and Good above 22 cm. These results suggest that enhanced upward salt diffusion is positively correlated with cover thickness.

3.2.3 2012 Statistical Salinity Profiles Grouped by Aspect

The 2012 dataset was also subdivided into two categories related to aspect of the transect. These two categories were north-facing and south-facing. The north-facing group included the data from Transects 3 and 4 only. Transects 1 and 2 were excluded to eliminate potential effects due to cover thickness. The south-facing group included data from Transects 6 – 8. The west-facing and east-facing aspects were excluded from this particular assessment as each of these directions has only a single transect to represent it. In addition, if any differences in the salinity profiles can be attributed to aspect, they should be most apparent when comparing the aspect of the dump that receives the most solar radiation (south) to the aspect that receives the least solar radiation (north). The same parameters (EC, SAR and Na^+) were plotted for each of the two aspect categories. However, to simplify the comparison, both profiles (north aspect and south aspect) were plotted together and only the median profile line was plotted without the box and whisker statistics.

The plots comparing salinity profiles by aspect are included in Figures 17 – 19. The median profile for the sampling locations from the north-facing aspects is similar to the profile representing the sampling locations from the south-facing aspect. The north-facing aspect appeared to have slightly lower salinity than the south-facing aspect and this difference was most noticeable in the EC plot (Figure 17). However, even this difference can be considered negligible given the range of scatter of the data (see box and whisker extents in Figures 5 – 7) and the relatively small sample size, especially for the north-facing aspect profile (10 sampling locations). This comparison appears to suggest that there is no significant difference in the salinity profiles between the north-facing and south-facing aspects of the SBH.

3.2.4 2012 Statistical Salinity Profiles Compared to Historic Profiles

The statistical median profile for the 2012 dataset was compared to the same statistical median profiles from 2002 and 2008. The salinity profile data from 2002 and 2008 is not presented in this report but is presented in Kessler (2007) and Hilderman (2011), respectively. The 2012 dataset was limited to those samples collected from Transects 1-3 which was the extent of the 2002 and 2008 sampling programs. Plots were created for EC, SAR, and Na^+. These plots are included in Figures 20 – 22.

It is noted that the 2012 median profile only extends to 50 cm above the interface. This is because the statistical analysis required a population size of at least 5 at each sample depth in order to record the statistics (including median value). The 2012 sampling program collected only 5 samples from each transect and, of the first three transects, only Transect 3 had a prescribed cover thickness greater than 50 cm. The 2002 and 2008 sampling programs collected 10 samples from each transect.

The statistical EC profiles from 2012, 2008 and 2002 suggest that the EC in the Clearwater overburden decreased from 2002 to 2008 but has been relatively stable from 2008 to 2012. The EC in the cover soil seems to have increased from 2002 to 2008 and from 2008 to 2012. This trend is repeated in the SAR and Na^+ profiles with the exception that the Na^+ profile in the Clearwater overburden had a less noticeable decrease from 2002 to 2008.

These observed trends in the historical and current profiles suggest that, since 2002, salt has been migrating upward from the Clearwater overburden into the cover soil. The trajectory of this trend is not certain but does suggest that the salinity profile in the cover has not stabilized. The profile in the upper Clearwater overburden does appear to have stabilized between 2008 and 2012. This suggests that the mass of salt produced through pyrite oxidation is balanced with the salt flux out of the Clearwater overburden (via upward diffusion and downward net percolation).

The continued shift towards increased salt concentrations in the cover soil suggests that a balance between input and output has not yet been attained in the cover. Based on the median profiles in Figures 20 - 22, slightly more salt is diffusing upward into the cover soil than is being flushed out by interflow or net percolation. However, the historical EC profiles also show that the mass of salt lost from the upper Clearwater overburden between 2002 and 2012 (represented by the area between these curves) is greater than the mass of salt that has been gained in the cover soil. This confirms that salt is being flushed from the system by interflow and net percolation.

Figures 20 – 22 show that the historical profiles have become smoother over time with less of a step shape at the interface. This occurs as the salt concentration increases in the cover soil and decreases in the upper Clearwater overburden. This smoothing of the profile reduces the concentration gradient across the interface resulting in a reduction in the upward migration of salts by diffusion.

Based on this expectation for decreasing rates of upward diffusion and the evidence of salt flushing occurring in the system, it follows that a salt flux balance will soon be achieved in the cover soil, after which reduction of salt concentrations will occur.

3.3 Individual Salinity Profiles

3.3.1 Salinity Profiles Grouped by Transect

In addition to the statistical plots described above in Section 3.2, individual salinity profiles were plotted for each of the 2012 sampling locations. The profiles for each sampling location were grouped by transect number. This allowed each transect to be examined for spatial trends (top to bottom of transect). Plots were created for EC, SAR and Na^+ and are included in Appendix II.

Kessler (2007) hypothesized that there could be an observable shift of salt mass from the top of the slope to the bottom as salts are flushed downslope by interflow. However, Kessler did not observe this in the 2002 salinity profiles and, similarly, the 2012 salinity profiles also do not provide any strong spatial trends from the top of slope to the bottom of slope. Kessler speculated that with additional time the trend may become more apparent. However, the analysis of the 2012 data suggests that this spatial trend has still not established itself.

A general observation from the individual transect plots is that the SAR profiles seem to be smoother (i.e., have less of a step) across the interface than the salinity profiles (i.e., EC, Na^+ and $S\text{-}SO_4^{2-}$). Also, approximately half of the SAR profiles have a slight bend or dip in the profile near the interface that was generally not observed in the salinity profiles.

4 TRANSPORT MECHANISMS DISCUSSION

The results described in Section 3.3 suggest that there is no clear pattern linking the topographic location to the shape of the salinity profile or range of salt concentrations. Kelln et al. (2009) showed that the upper slope is drier than the lower slope. One might expect that this drier soil condition would allow more oxidation of pyrite to occur in the upper Clearwater overburden. This would result in higher salt concentrations in the Clearwater overburden near the interface at upper slope locations. However this trend has not been observed in any of the salinity sampling programs to date.

In addition, it might be expected that the lower, wetter locations should have a higher molecular diffusion coefficient, allowing more of the salt to diffuse up into the cover. However, the salinity in the cover soil does not appear to be significantly different from the top of the slope to the bottom. This is likely due to the offsetting impact of upward diffusion and downward net percolation and/or interflow. For example, a perched water table is more likely to develop in lower slope positions. This will create elevated water contents which increase the rate of diffusion; however, this will also result in an increase in net percolation or interflow that flushes salts from the cover in this location. Lower slope locations would also experience more interflow as all of the interflow from upslope will flow past the lower slope locations.

Interflow monitoring at the site (Kelln et al. 2007, Hilderman 2011) shows that the interflow is flushing salts from the cover system. Kessler (2007) speculated that this interflow would likely shift salts from the cover soil at upper slope locations to the cover soil at lower slope locations. However, the lower slope cover soil does not appear to be accumulating salts at a faster rate than upper slope locations. Because the lower slope locations are typically drained by toe ditches, the interflow water does not pool at the base of the slope and evaporate, leaving behind salts. The interflow water continues to flow past the toe sampling location, either discharging to the surface water collection ditch or continuing downslope. Therefore, it is not surprising that interflow is not creating higher salinity concentrations in the lower slope locations, as it is being removed from the study area and not accumulating as it would at a ‘normal’ discharge location.

The 2012 salinity profiles also suggest that aspect has little effect on salt transport. The aspect of the slope controls the amount of exposure to solar radiation and, therefore, is likely to have an effect on the vegetation and near surface soil moisture. However, it is the deeper soil moisture, just above the interface, that has the greater influence on salt transport mechanisms. Kelln et al. (2008) showed that this deeper soil moisture primarily originates from snow melt and percolates down through the cover via macropores. Since the snow depth across SBH is relatively uniform (unpublished data) it is likely that the mechanisms associated with snow melt (net percolation and interflow) may be similar, regardless of aspect.

The 2012 salinity profiles suggest that cover thickness may have an impact on water flow and salt transport processes. Based on the median profile, the thinner covers (<0.75 m) have lower salt concentrations in both the near surface Clearwater overburden and the reclamation cover soil immediately above the interface. It is suspected that the Clearwater overburden beneath the thinner cover experienced higher rates of oxidation in early years after reclamation. The thinner cover is drier than the thicker cover (Huang et al. 2012) and presents a shorter flow path for oxygen ingress. The increased pyrite oxidation would have caused a spike in the salinity of the Clearwater overburden beneath the thinner cover. However, due to the thinner covers being drier than thicker covers, the diffusion coefficient is lower and less of the salt diffuses up into the cover. Also, because the thinner covers have a lower available water holding capacity (AWHC), less of the snowmelt infiltration is held in the cover and more of this water may flush downward as net percolation. The spike of salinity in the near surface Clearwater overburden is believed to have been flushed, likely by net percolation as it is not visible in the current salinity profiles. The increased oxidation in early years would have depleted more of the reservoir of pyrite in the Clearwater overburden resulting in decreased salt production in later years (i.e. present time).

The locations with thicker cover soil (>0.75 m) have a higher AWHC and a higher volumetric water content for longer durations each year, especially at greater depths (Huang et al. 2012). This increases the molecular diffusion coefficient for the soil and allows more salt to diffuse upward into the cover and to reach greater heights.

5 IMPLICATIONS FOR THE FUTURE OF SOUTH BISON HILL

The observations and conclusions in this report provide some indication of the general trajectory and future geochemical evolution of the reclamation cover at SBH. However, the expectations presented in this chapter are speculative in nature and should be confirmed through a subsequent round of soil sampling and salinity profiling (e.g., 5 years in the future).

The salinity profiles described in this report indicate that the salinity in the upper Clearwater overburden is reduced at locations with thinner covers (<75 cm) compared to locations with thicker covers. This suggests that the rate of salt production through pyrite oxidation has peaked at these thinner cover locations, and that the reservoir of pyrite in the upper Clearwater overburden is being depleted. This agrees with the observations of Hilderman (2011) that the salt concentrations decreased slightly in the upper Clearwater overburden at the D1 (35 cm) and D2 (50 cm) sampling locations. As the oxidation front moves further down into the Clearwater overburden, the rate of upward salt diffusion will decrease. The rate of net percolation and interflow will remain relatively constant which will eventually result in an overall flushing of salt from the cover soil. The current study did not sample the exact same locations that were sampled in 2002 and 2008 and therefore it is not known if this net flushing of salts from the thinner cover (D1 and D2) has already begun.

The majority of the SBH is capped with a prescribed reclamation cover thickness of 100 cm. Therefore, the measured salinity profiles in the thicker covers (>75 cm) are of greater relevance to the SBH as a whole. The higher salinity in the upper Clearwater overburden of the thicker covers suggests that at these locations the salt concentration in the upper Clearwater overburden:

1. Peaked later than at the thinner cover locations; or,
2. Has not yet peaked and is still increasing.

The work of Hilderman (2011) showed no obvious increase in the salinity of the upper Clearwater overburden in the D3 test plot between 2002 and 2008. In addition, the historical comparison of the D1, D2 and D3 salinity profiles (collectively) suggests that the salinity in the upper Clearwater overburden was relatively unchanged between 2008 and 2012. Therefore, it is presumed that, for most of SBH, the salt concentration in the upper Clearwater overburden is approximately at equilibrium. This means that the amount of salt produced by pyrite oxidation is balanced by the mass flux out by diffusion and net percolation. Since the reservoir of pyrite in the Clearwater overburden is finite, this balance cannot be maintained indefinitely and the salinity will eventually decrease. This appears to have already begun in Clearwater overburden beneath the thinner covers.

The results of this study also indicate that the cover soil in the thicker cover locations is not at equilibrium. Hilderman (2011) indicated that the concentration of salt in the cover soil increased between 2002 and 2008. The historical salinity profiles presented in this report also suggest that the salt concentration in the cover soil has increased between 2008 and 2012.

The increasing salt concentration in the cover soil is reducing the concentration gradient between the Clearwater overburden and the cover soil. This, combined with an eventual reduction in the salt concentration of the upper Clearwater overburden, will gradually reduce the rate of upward salt diffusion into the cover soil. The profiles presented in this study suggest that the concentration of salts in the Clearwater overburden beneath the thinner covers has peaked and is now decreasing. Therefore, it is anticipated that the same will occur soon in the thicker covers. When this occurs, the cover soil in the thicker cover locations will begin to flush out salts though it will lag behind the thinner covers.

6 SUMMARY AND CONCLUSIONS

The 2012 soil salinity data set covers a much broader area of the SBH study site than any previous soil sampling program at this site. Samples were collected from 9 transects extending down the SBH slope at varying aspects. The expanded scope of the data set, in comparison to other sampling programs (2002, 2008), was intended to identify spatial trends across the site and to evaluate the effect of slope aspect on the salt transport in the cover soil profile.

When considered together, the median salinity profile for all of the 2012 data suggests that salts are moving upward into the cover to an approximate height of 60 cm above the interface. The concentration of salts increases with depth through the cover. It appears that the maximum salt concentration in the Clearwater overburden occurs at a lower depth than the lowermost sampling depth from 2012 (30 cm below the interface). The median profile also has a slight step shape at the interface suggesting there is some impediment to upward diffusion or a counteracting flushing mechanism.

Although upward salt movement is evident at the site, it has not resulted in a significant degradation of the soil quality when compared to soil quality guidelines (Alberta Environment 2010). Upward salt movement has had a greater effect on the SAR soil quality classification than the EC soil quality classification. The EC of the cover soil samples is rated as Fair for subsoil from approximately 0 to 15 cm above the interface and is Good above 15 cm in the cover. For SAR the cover quality is Poor from 0 to 10 cm above the interface, Fair from 10 to 35 cm and Good above 35 cm. These ratings are based on the median profile for the 2012 sampling locations.

When categorized by cover thickness, the 2012 data suggests that upward salt migration may be reaching greater heights in the thicker covers. The median height of salt ingress appeared to be 30 cm for the thin covers (<75 cm), 50 cm for the medium thickness covers (75-100 cm) and 85 cm for the thick covers (>100 cm). The profiles also suggest that the concentration of salt in the upper Clearwater overburden is slightly lower at sampling locations with thinner covers than those with thicker covers, although the salinity profiles for locations with thinner covers have more variance in the Clearwater overburden.

The cover thickness also influences the subsoil quality rating. For the thinner covers (<75 cm), the SAR soil quality classification is Poor for the 5 cm of soil directly above the interface. This zone of Poor soil (based on the SAR quality guidelines) extends to 10 cm above the interface for medium thickness covers (75 – 100 cm) and 15 cm above the interface for thick covers (>100 cm). The EC soil quality rating of the soil cover is in the Good and Fair range for the median profiles of all three categories of cover thickness.

When the 2012 data were grouped by north-facing and south-facing aspects, no discernible differences were evident between the two sample location groups. This suggests aspect has a minimal effect on the transport of salts into and out of the cover soil.

The comparison of median historical profiles suggests that since 2002, salt mass has steadily migrated upward from the Clearwater overburden into the cover soil, increasing the salt concentration in the cover soil. The salinity concentration in the upper Clearwater overburden appears to have decreased between 2002 and 2008 but has since stabilized. This suggests that a balance may exist in the upper Clearwater overburden between salt production by oxidation and salt transport by upward diffusion and downward net percolation.

Based on the synthesis of the results of salinity studies conducted at SBH, the data and interpretations support the following conclusions:

- Salt transport from the Clearwater overburden upward into the overlying reclamation cover is evident. The compiled 2012 SBH sample data shows the salt ingress in the cover is approximately 60 cm for the median profile.
- The salt ingress in the cover has not resulted in a significant reduction in the EC and SAR soil quality of the reclamation material. For the median profile of the 2012 sampling locations, the EC of the cover still remains within Good-Fair quality, which is suitable for use as reclamation material (Fair rating 0 to 15 cm above interface, Good > 15 cm). The SAR of the cover is Poor from 0 to 10 cm above the interface and is Good-Fair upward in the soil cover (Fair rating 10 to 35 cm and Good > 35 cm).
- Thicker covers (75-100 cm and >100 cm) show greater salt ingress in the cover (50 to 85 cm for EC and SAR), while thinner covers (<75 cm) show reduced salt ingress (30 cm for EC and SAR).
- Slope and aspect do not appear to be affecting salt ingress within the landscape scope investigated in this study.
- Comparison of the 2012 data with previous sampling events suggests that salt migration in the cover may not have peaked to date. However, the same comparison of the near-surface Clearwater overburden has shown a decrease in EC and SAR from 2002 levels. This suggests that a balance, or net flushing, may have been reached between salt production and salt transport (upward diffusion, net percolation and interflow) from the Clearwater overburden. This was especially evident in the thinner cover locations.

7 RECOMMENDATIONS FOR FUTURE RESEARCH

The observation and conclusions reported in this study present some interesting evolutionary trends for the SBH reclamation cover. However, it is apparent that in most locations, the cover soil quality has not yet reached a state of equilibrium or trajectory towards improvement. Therefore, it is recommended that monitoring and sampling at later date(s) be continued at SBH. Continued research and monitoring will eventually confirm the predictions for the cover soil geochemical evolution, where it will reach a point of balance in the salt flux, followed by net flushing of salts.

This salinity report highlights the influence of cover thickness on salinity profiles. SCL could further investigate this relationship by evaluating the impact of cover thickness on specific parameters including pyrite oxidation, net percolation and interflow.

Additional research to determine the sulphur speciation in the Clearwater overburden could provide insight on the pyrite reservoir remaining, which is the primary constituent in salt generation via oxidation. Confirming the amount of pyrite remaining near the interface and determining the oxidation rate could provide the best indication of the time necessary for salt generation to cease and start flushing salts downward in the soil cover and Clearwater overburden.

SCL could also progress the research on net percolation at the SBH study site by expanding on the work of Hilderman (2011). Hilderman developed profiles using stable isotopes of water (^{2}H and ^{18}O) to estimate the rate of net percolation into the Clearwater overburden. However, this profiling was done only on the plateau and D3 cover plot and did not include thinner cover locations.

Researchers studying the SBH have expended considerable effort to observe and understand the process of interflow. This work included the installation and monitoring of an interflow measurement system at the base of each of the three instrumented cover plots (D1, D2, and D3). However, the previous research and the design of the monitoring system is based on the premise that interflow is horizontal flow downslope above the interface of cover soil and Clearwater overburden. If a component of downslope flow is actually occurring through the upper Clearwater overburden, this could have important consequences on the understanding of salt transport processes in the SBH system. It is understood that the secondary structure of the soil is responsible for majority of flow in the cover soil (Kelln et al. 2007 and 2009, Meiers et al. 2011) and that this secondary structure is developed through processes that include freeze-thaw and wet-dry cycles (Meiers et al. 2011). The effect of these cycles are more likely to create structure in the Clearwater overburden beneath thinner covers and therefore the potential for interflow occurring beneath the interface is greater in locations with thinner covers.

8 CLOSING

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Syncrude Canada Ltd. (Client) for the specific application to the South Bison Hill Salinity Study. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

We trust this meets your requirements at this time. Please contact Joel Hilderman at 306-974-1520 with any questions regarding this report.

Yours truly,
KLOHN CRIPPEN BERGER LTD.

PROFESSIONAL ENGINEER ALBERTA
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March 9 2013

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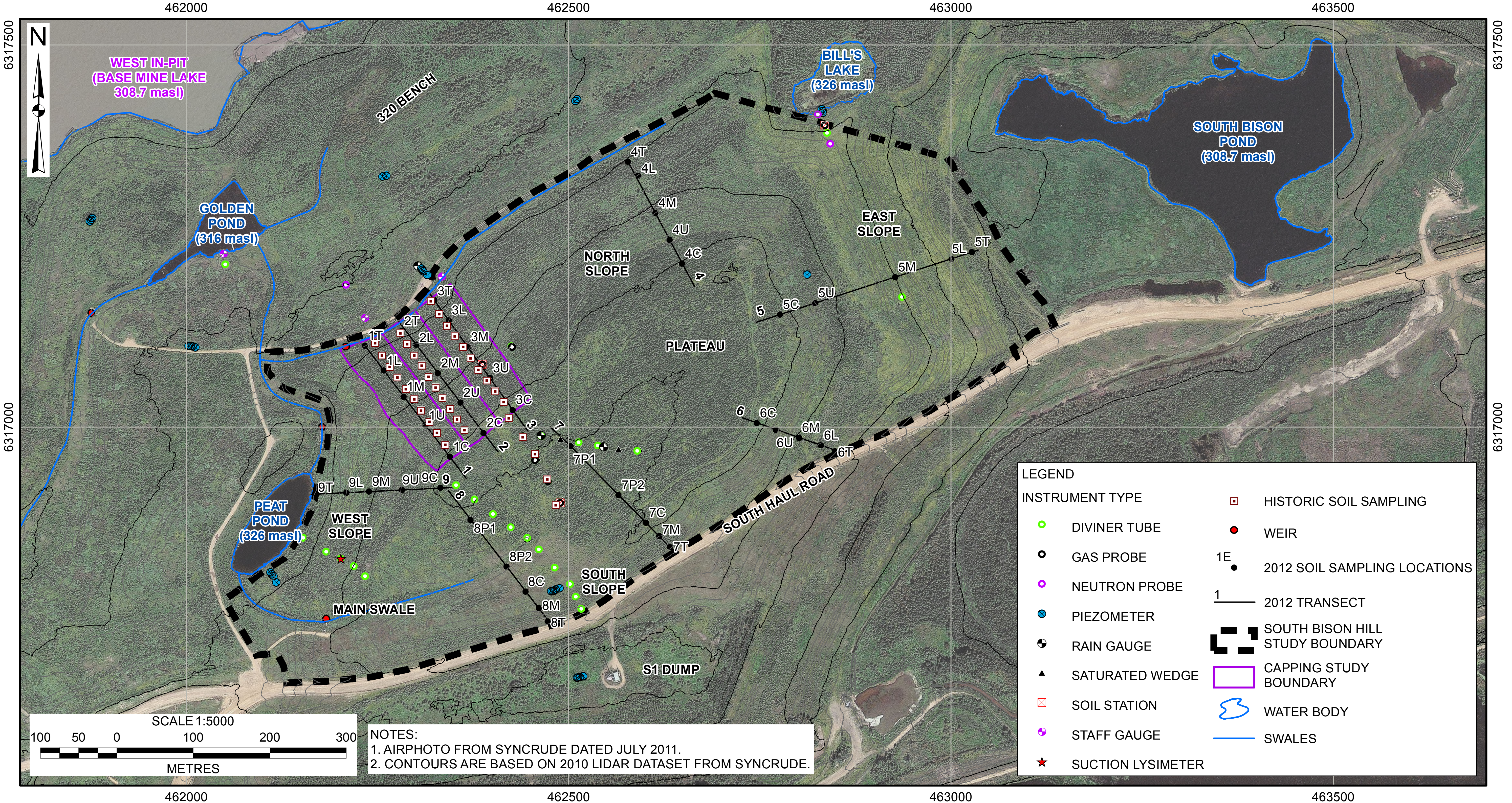
FIGURES



NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

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DESIGNED: ES, JM
CHECKED: ES
APPROVED: TGH

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE: SOUTH BISON HILL STUDY SALINITY SAMPLING OVERVIEW

PROJECT No.: 0534107
FIG No.: 01
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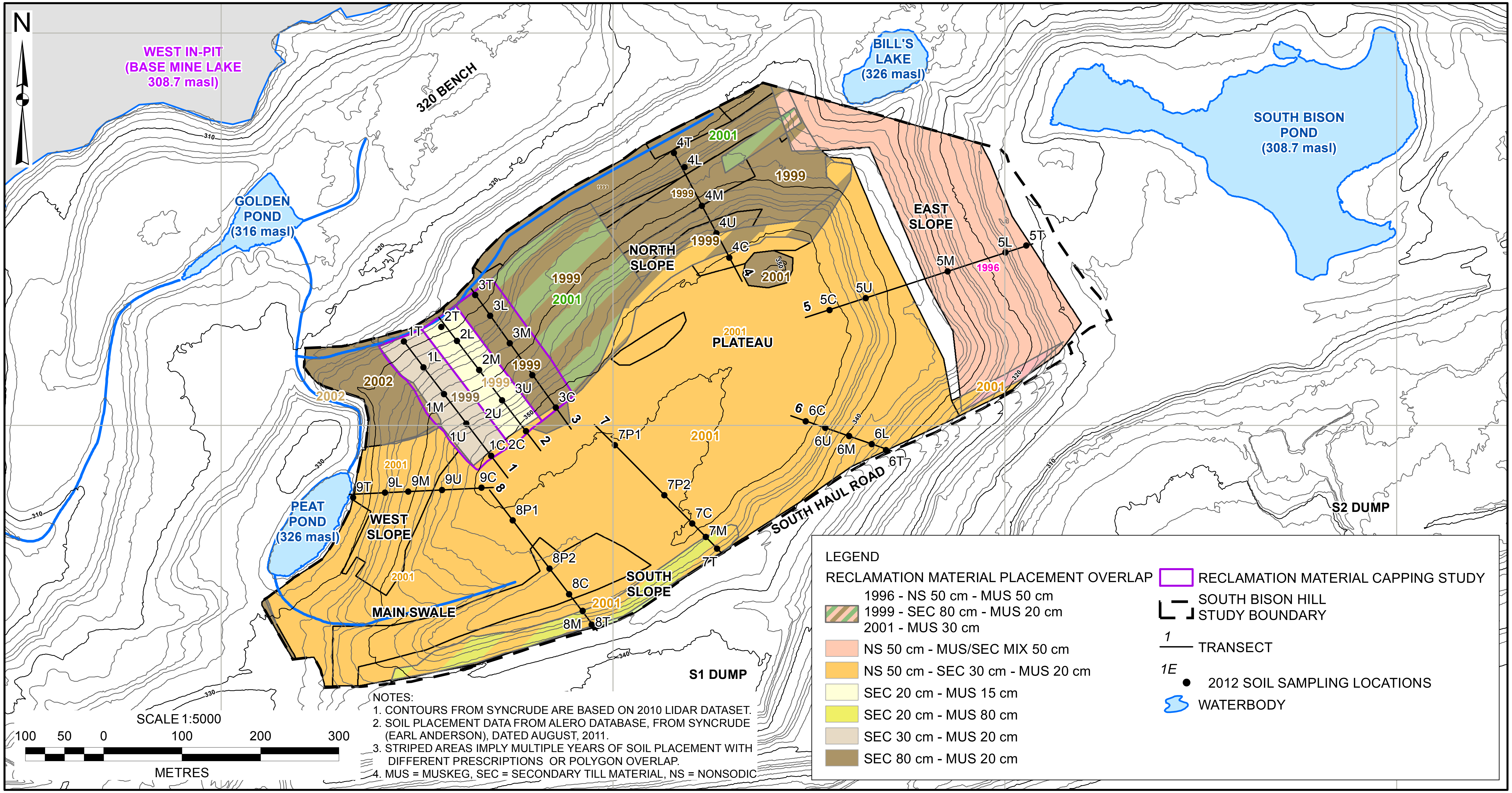

LEGEND

RECLAMATION MATERIAL PLACEMENT OVERLAP

▨ 1996 - NS 50 cm - MUS 50 cm
1999 - SEC 80 cm - MUS 20 cm
2001 - MUS 30 cm

🟥 NS 50 cm - MUS/SEC MIX 50 cm

🟧 NS 50 cm - SEC 30 cm - MUS 20 cm

🟨 SEC 20 cm - MUS 15 cm

🟨 SEC 20 cm - MUS 80 cm

⬜ SEC 30 cm - MUS 20 cm

🟫 SEC 80 cm - MUS 20 cm

🟪 RECLAMATION MATERIAL CAPPING STUDY

SOUTH BISON HILL STUDY BOUNDARY

1 TRANSECT

1E ● 2012 SOIL SAMPLING LOCATIONS

WATERBODY

NOTES:

1. CONTOURS FROM SYNCRUDE ARE BASED ON 2010 LIDAR DATASET.
2. SOIL PLACEMENT DATA FROM ALERO DATABASE, FROM SYNCRUDE (EARL ANDERSON), DATED AUGUST, 2011.
3. STRIPED AREAS IMPLY MULTIPLE YEARS OF SOIL PLACEMENT WITH DIFFERENT PRESCRIPTIONS OR POLYGON OVERLAP.
4. MUS = MUSKEG, SEC = SECONDARY TILL MATERIAL, NS = NONSODIC

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CHECKED: ES
APPROVED: TGH

PROFESSIONAL SEAL:

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AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE: AS BUILT SOIL PLACEMENT PLAN

PROJECT No.: 0534107
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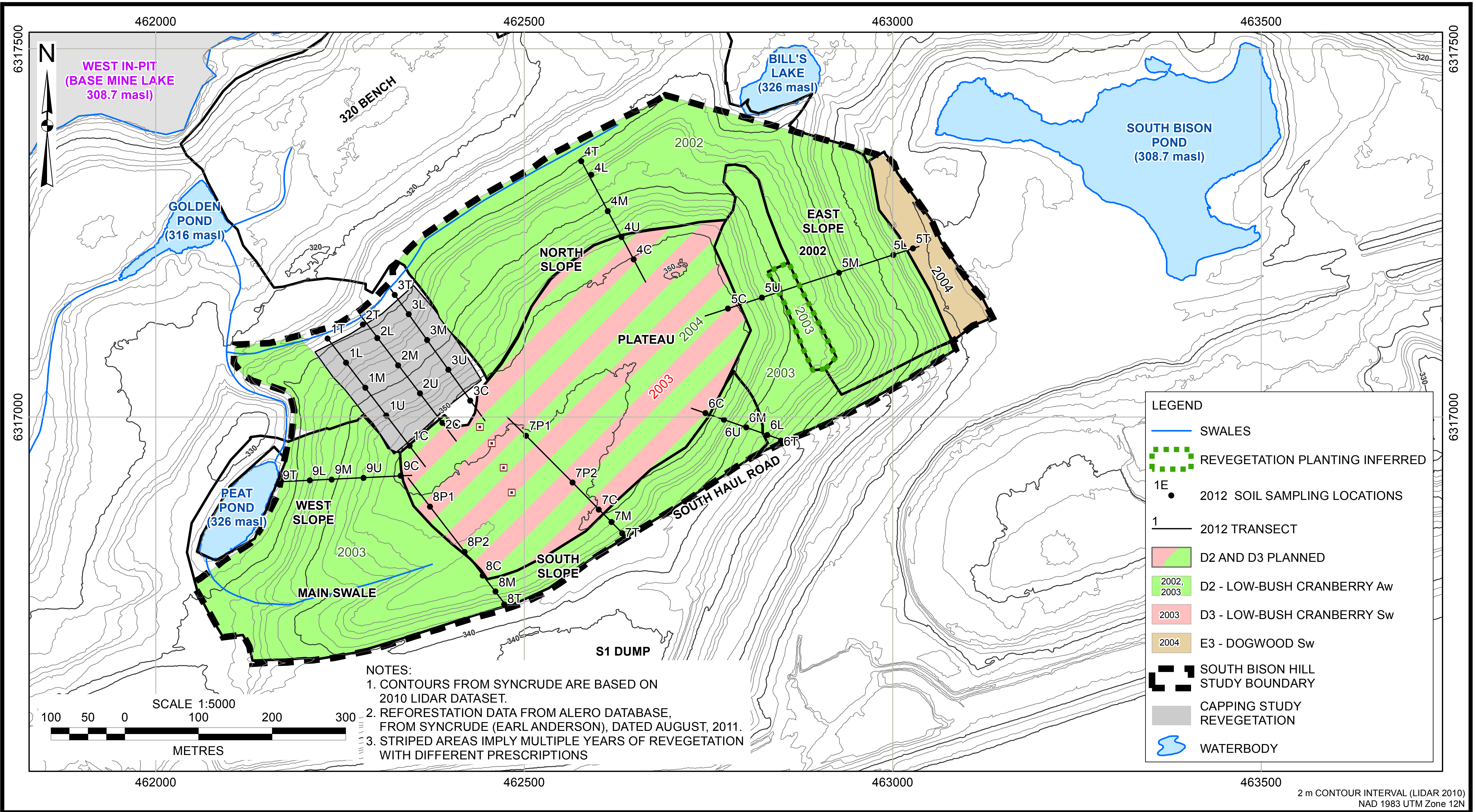

NOTES:

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3. STRIPED AREAS IMPLY MULTIPLE YEARS OF REVEGETATION WITH DIFFERENT PRESCRIPTIONS

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CHECKED: ES
APPROVED: TGH

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
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CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE: REVEGETATION PLAN

PROJECT No.: 0534107
FIG No.: 03
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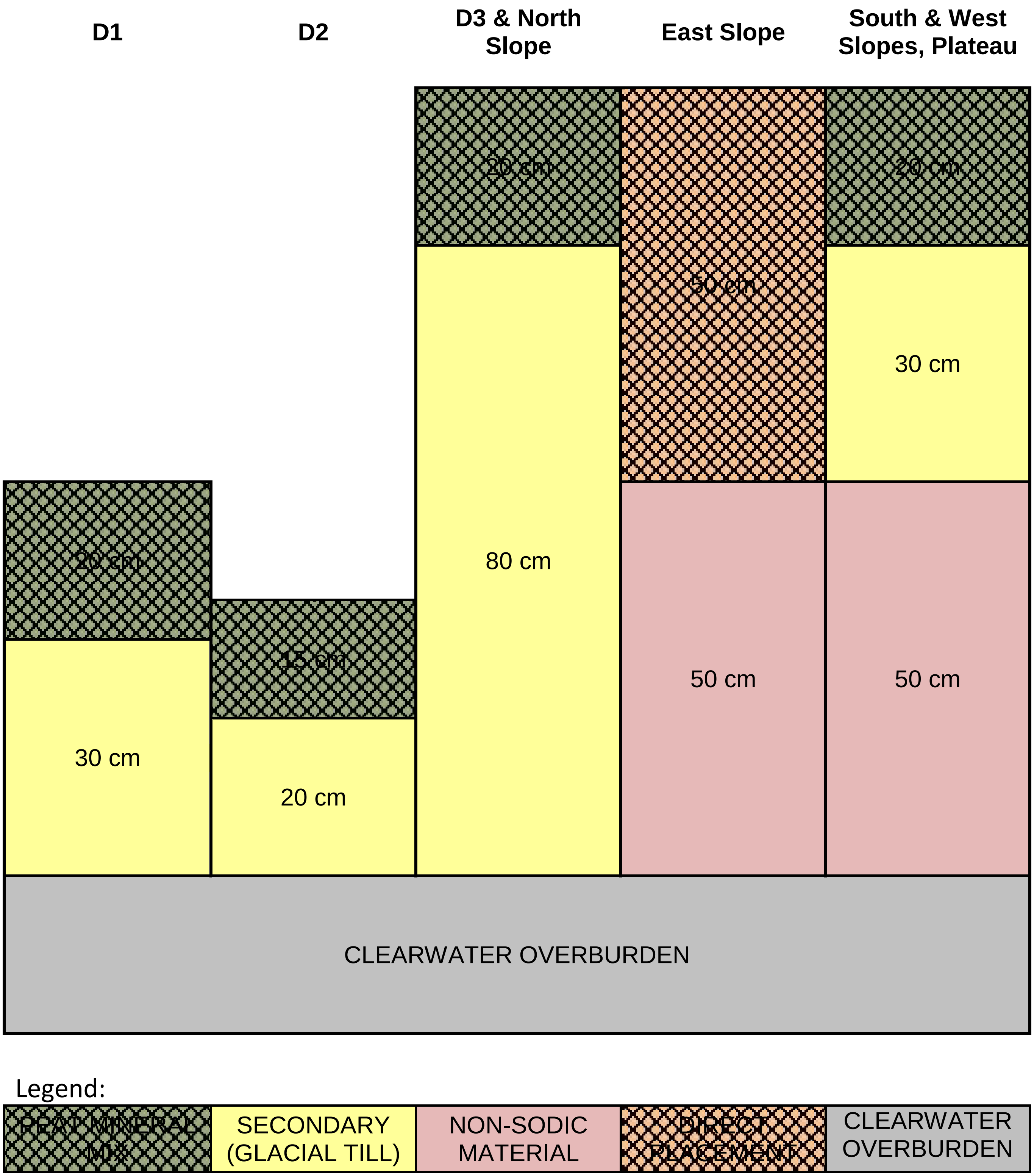


Figure 4 SBH Study Site Primary Cover Prescriptions

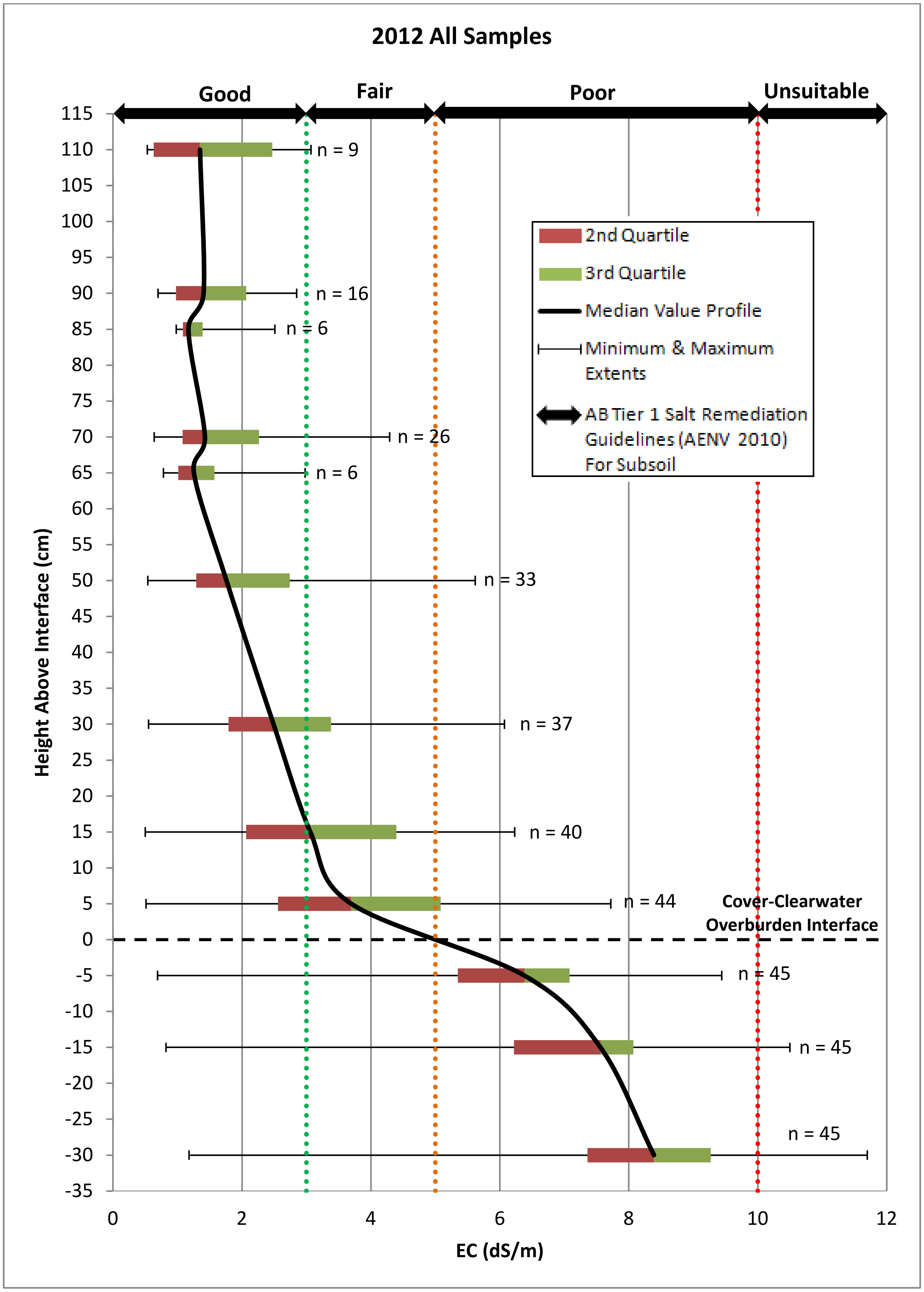


Figure 5 2012 Statistical EC Profile

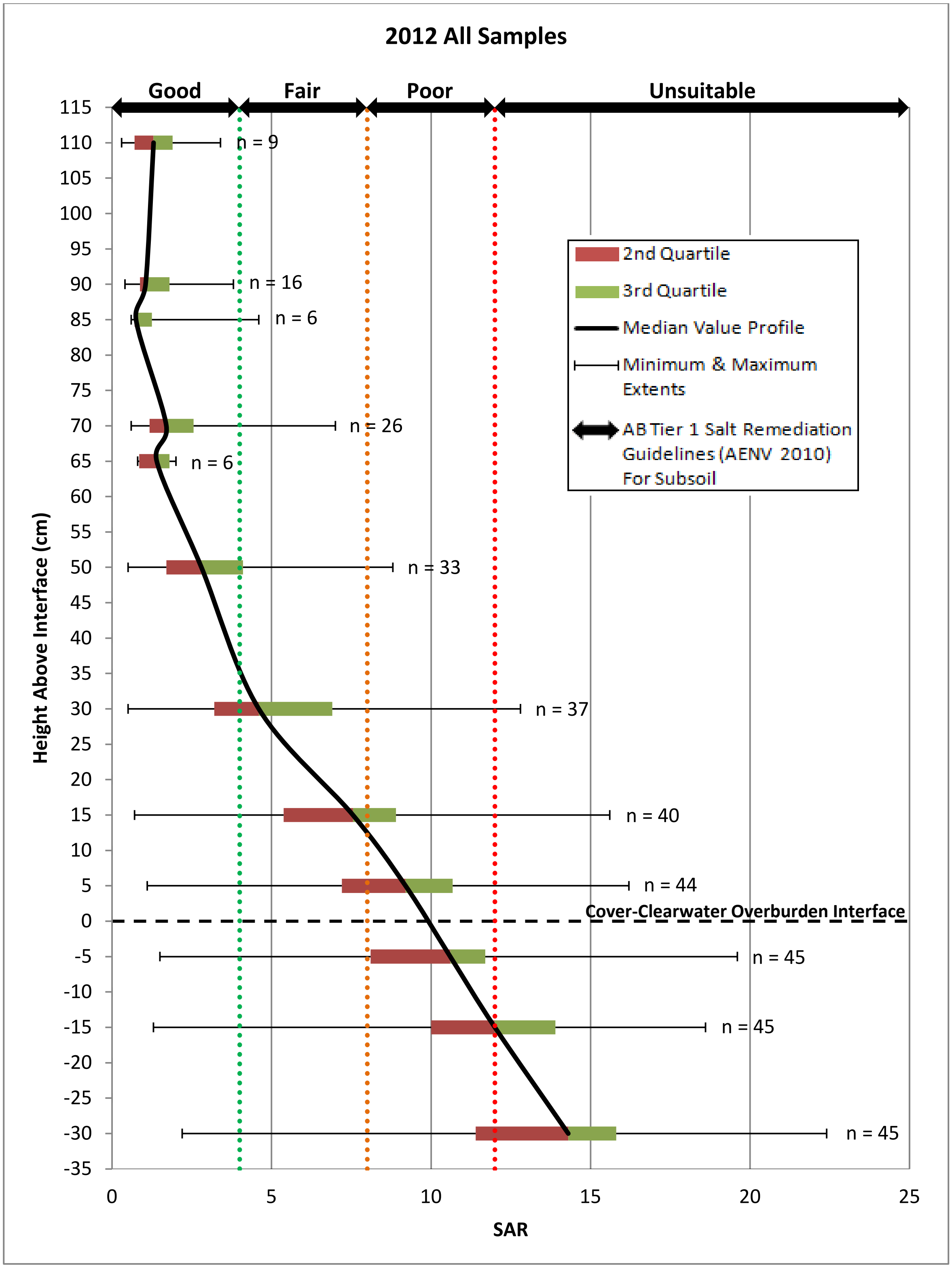


Figure 6 **2012 Statistical SAR Profile**

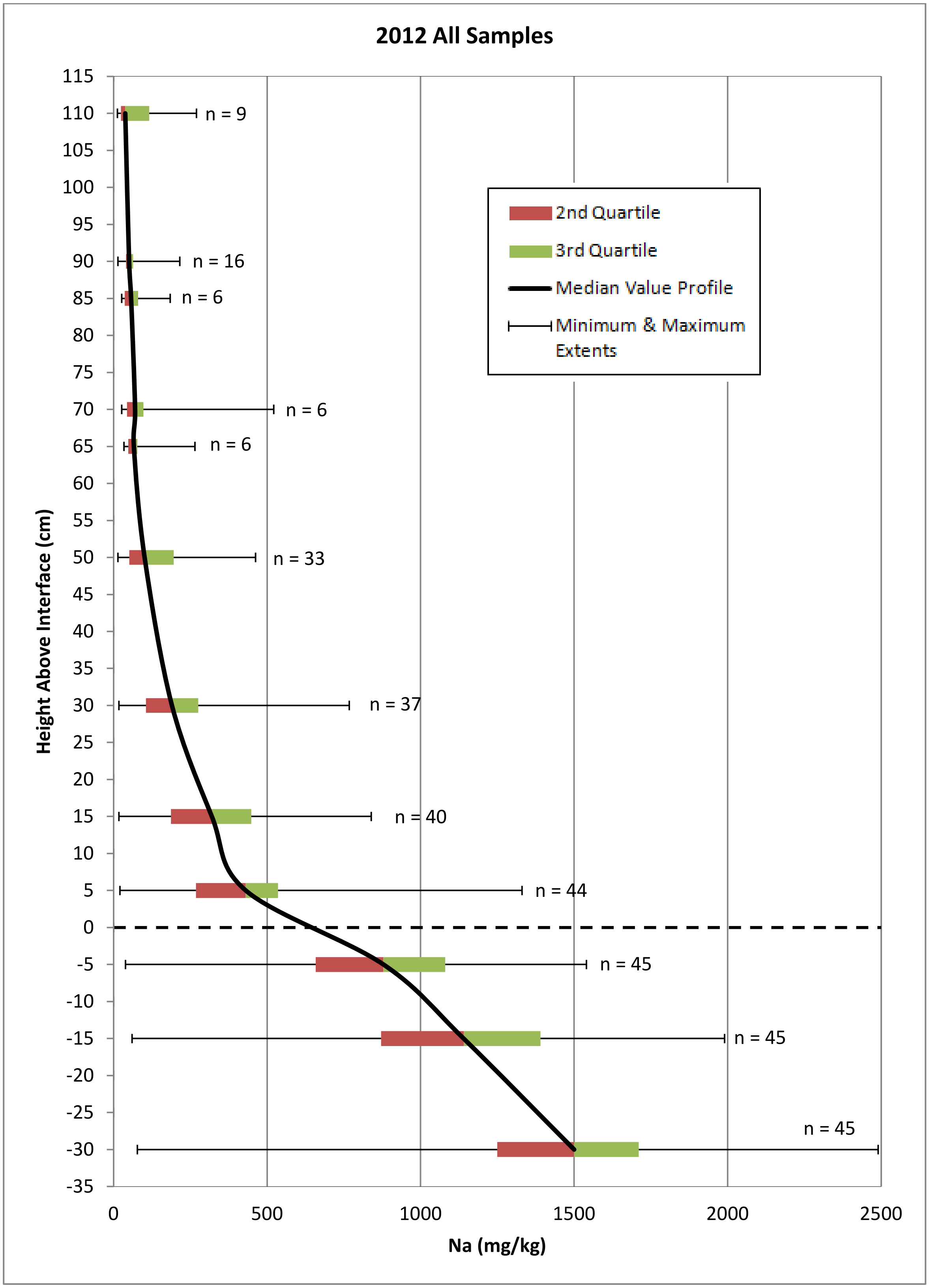


Figure 7 2012 Statistical Na^+ Profile

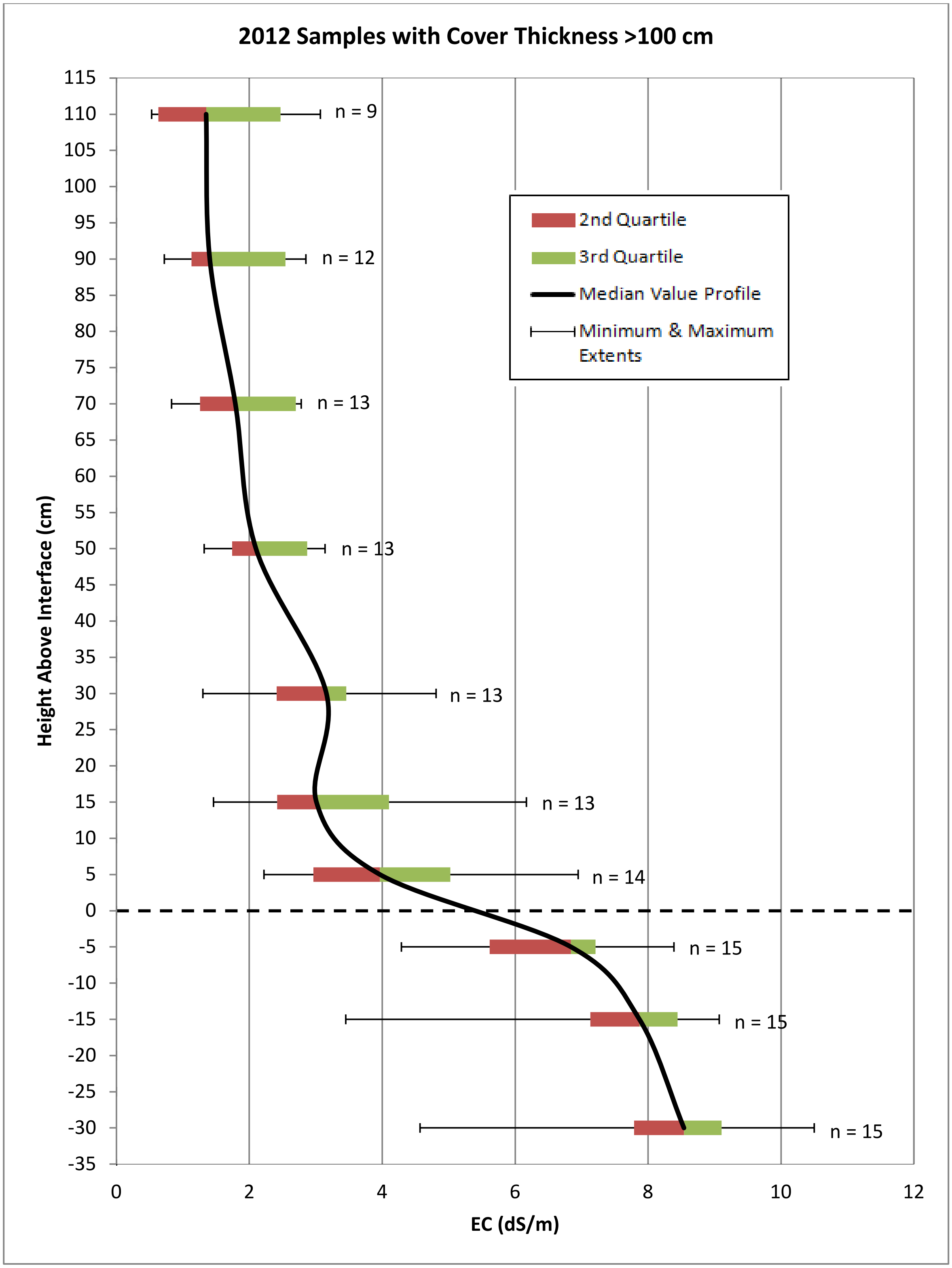


Figure 8 2012 Statistical EC Profile for Locations with Cover Thickness > 100 cm

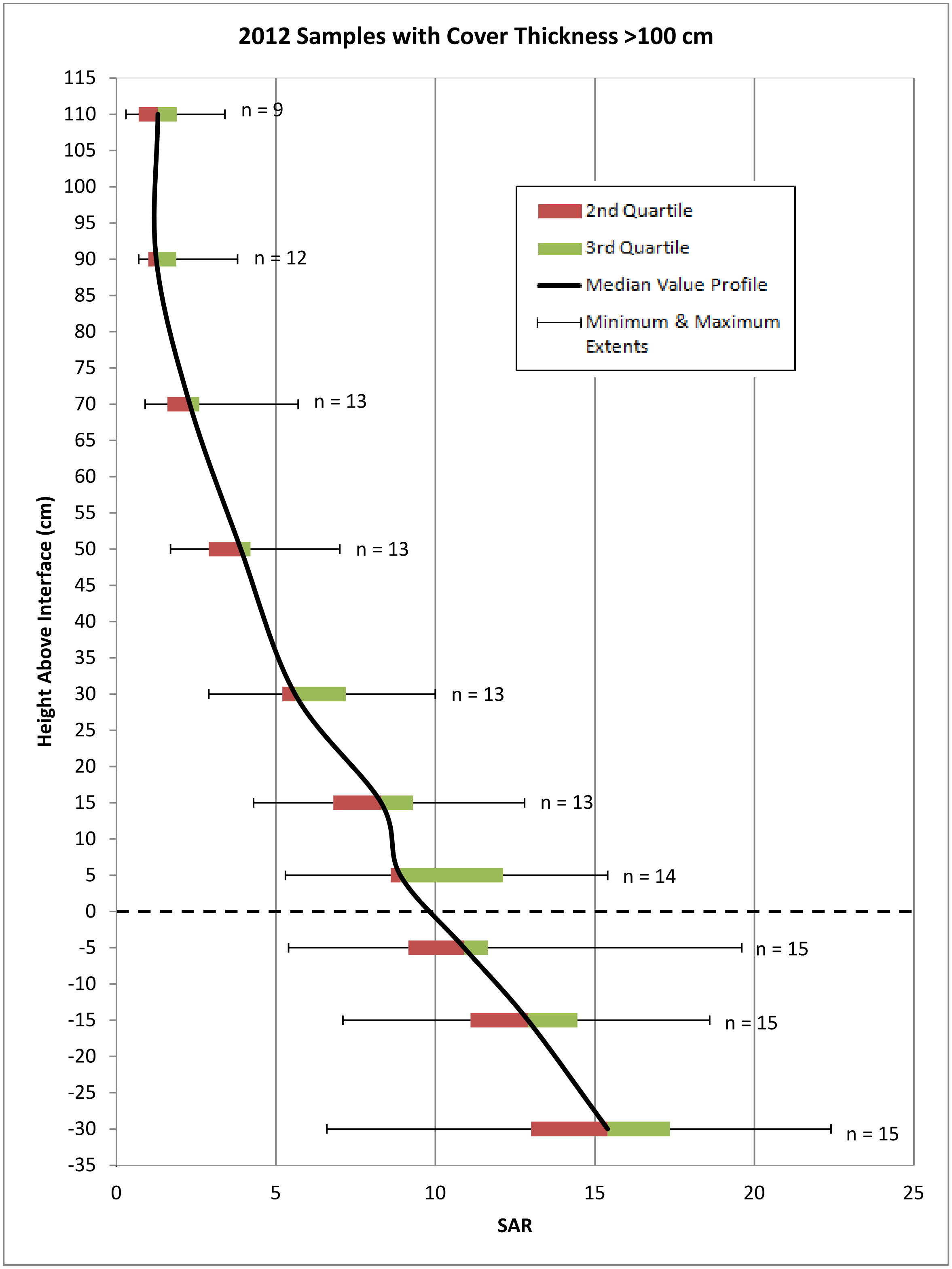


Figure 9 2012 Statistical SAR Profile for Locations with Cover Thickness > 100 cm

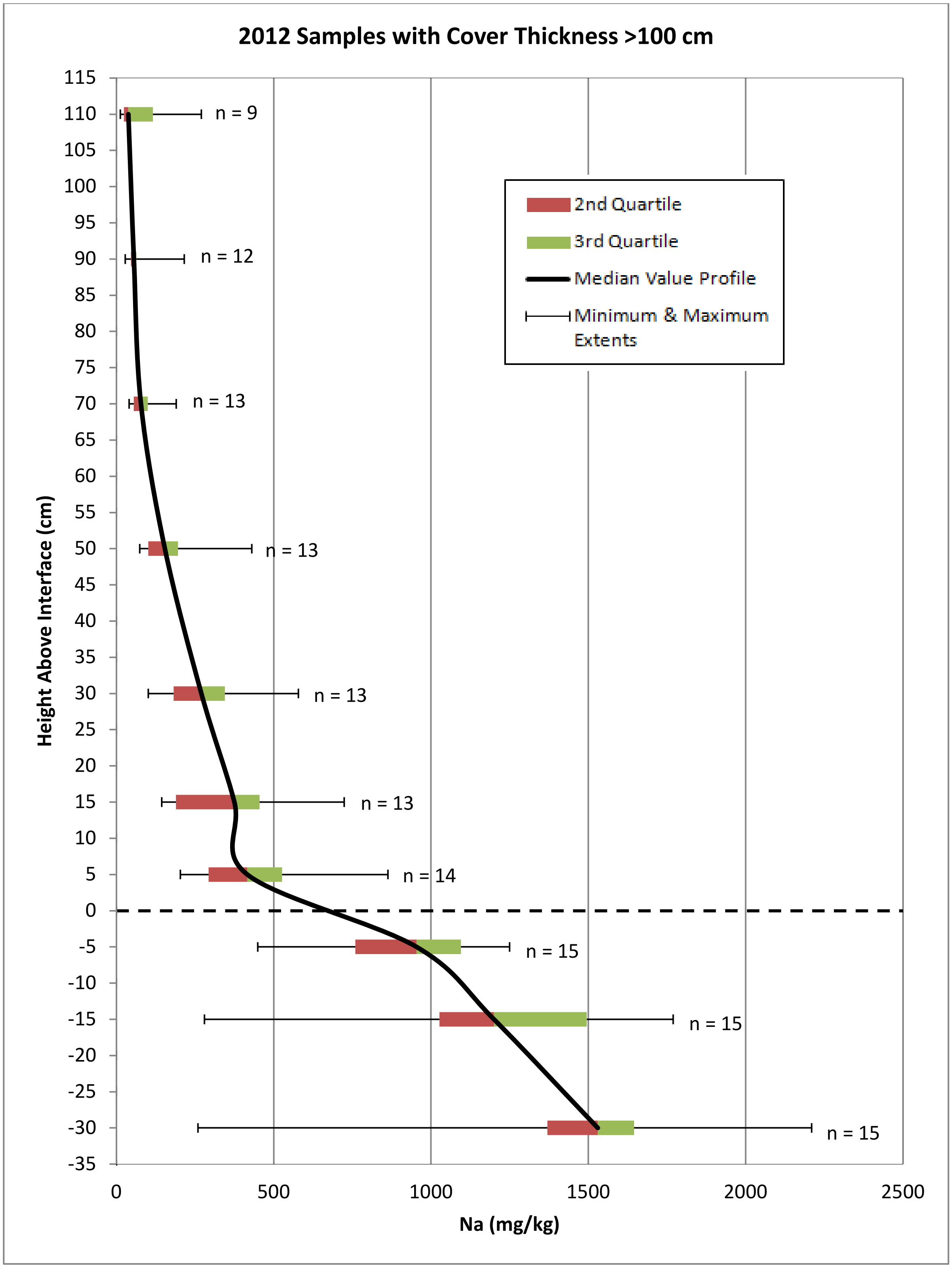


Figure 10 2012 Statistical Na^+ Profile for Locations with Cover Thickness > 100 cm

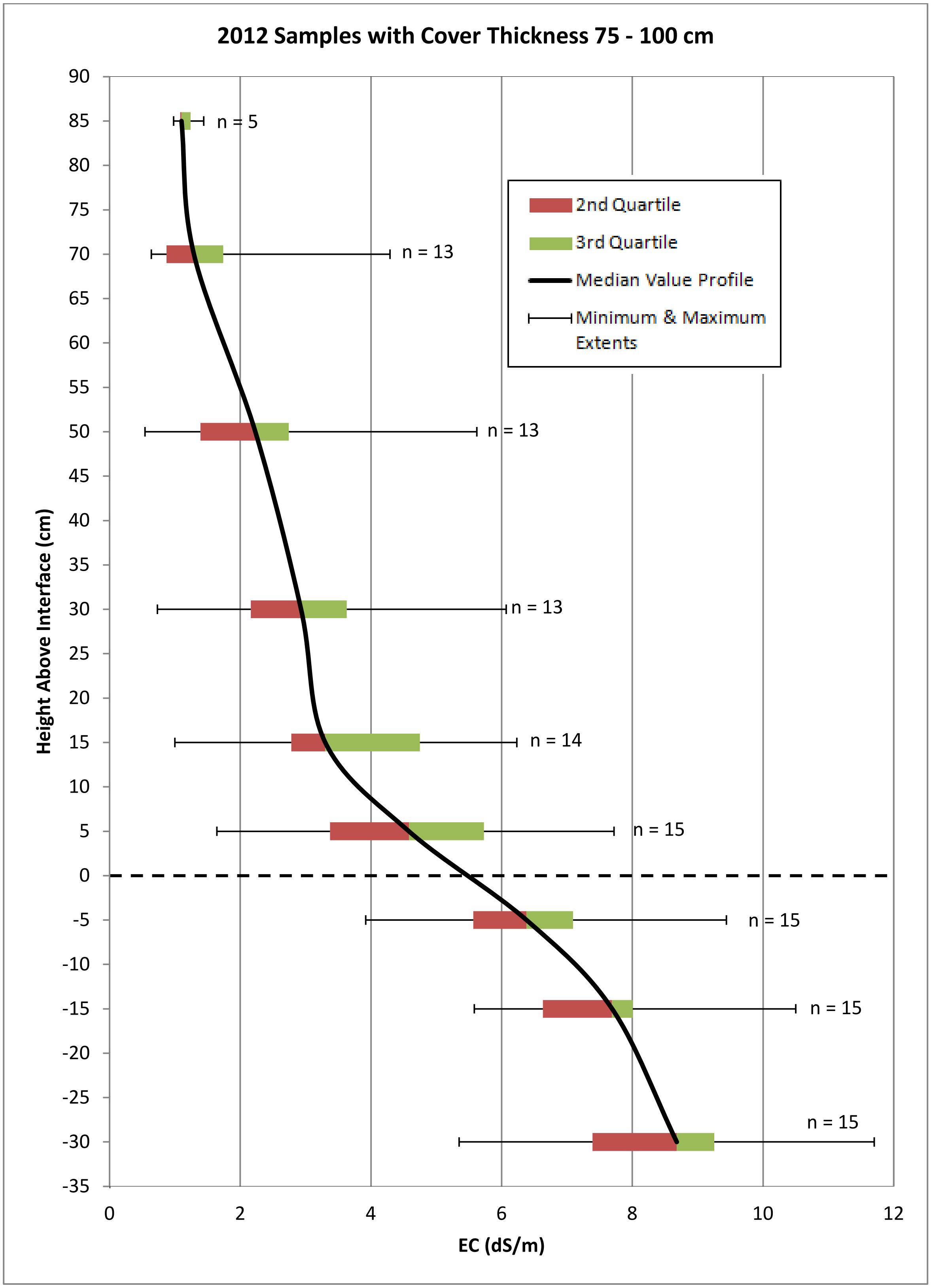


Figure 11 2012 Statistical EC Profile for Locations with Cover Thickness 75 – 100 cm

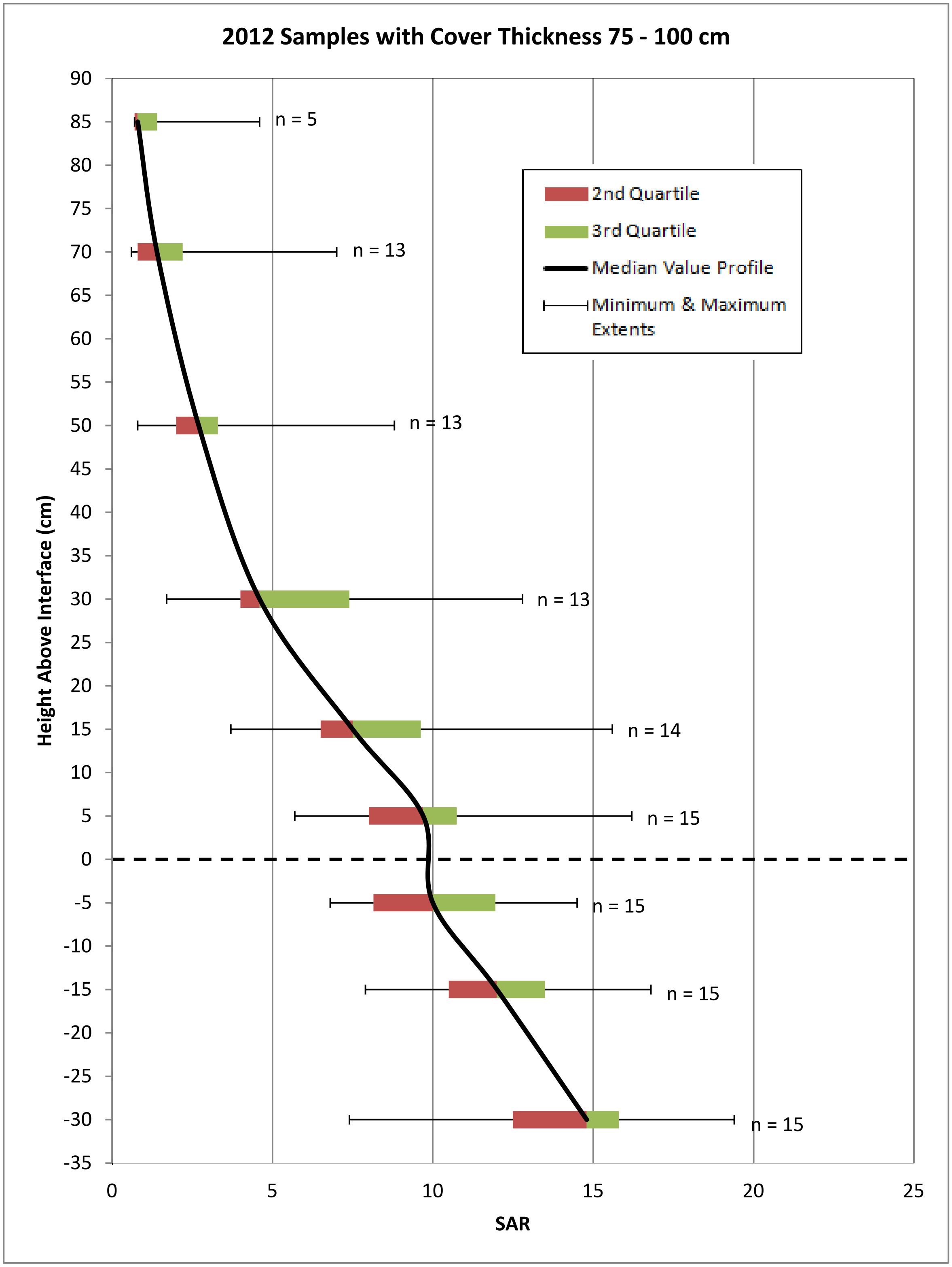


Figure 12 2012 Statistical SAR Profile for Locations with Cover Thickness 75 – 100 cm

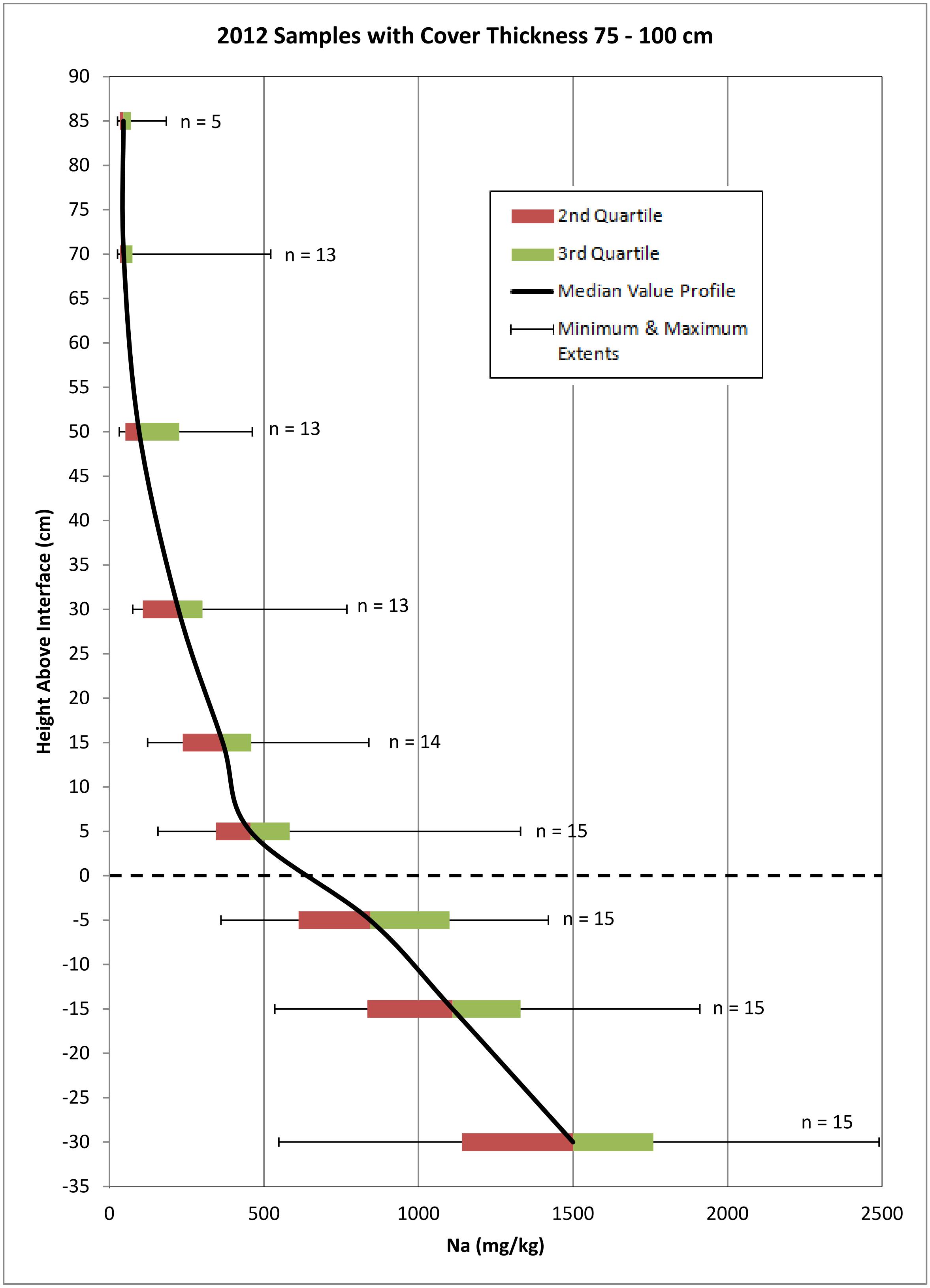


Figure 13 2012 Statistical Na^+ Profile for Locations with Cover Thickness 75 – 100 cm

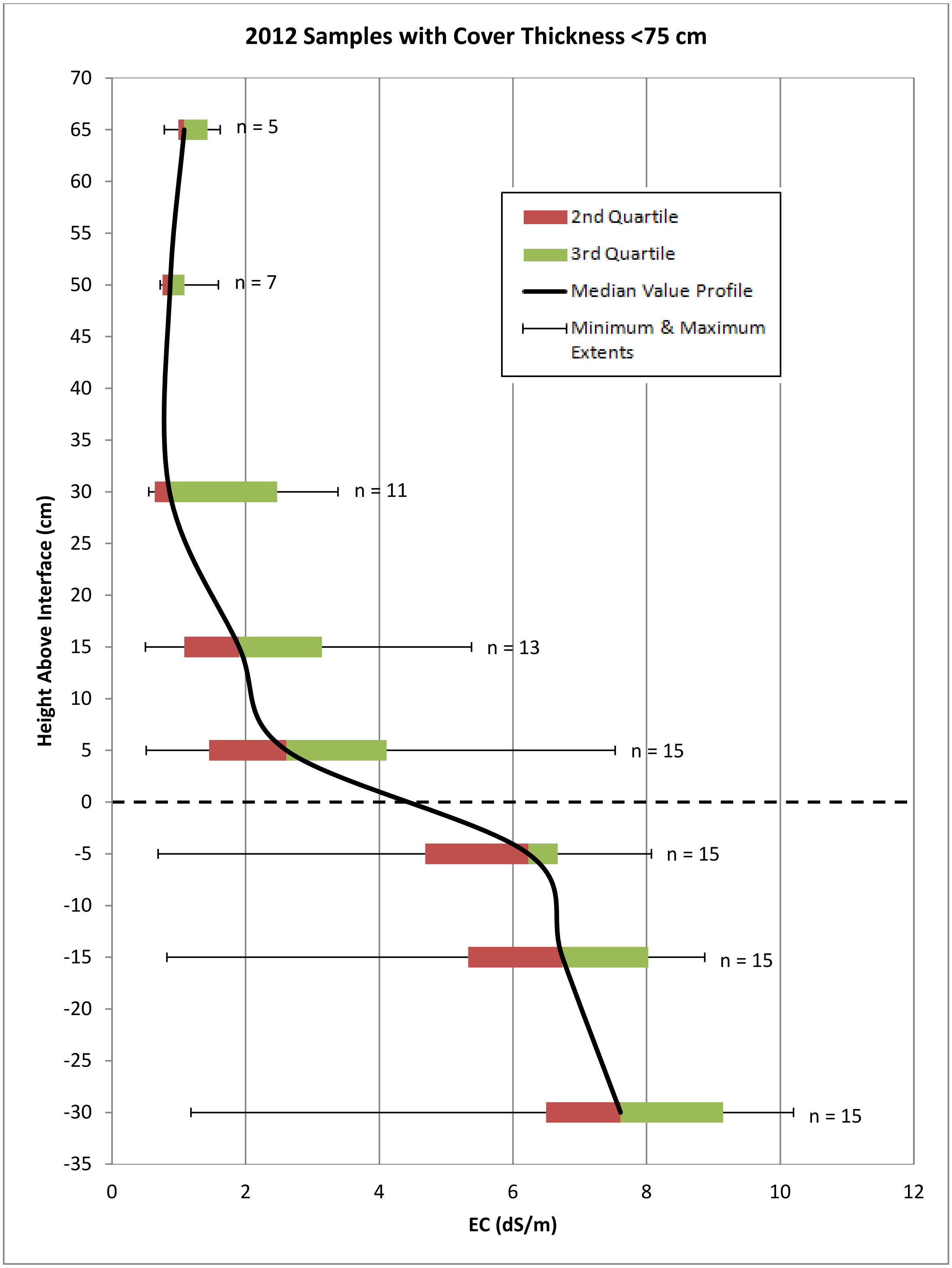


Figure 14 2012 Statistical EC Profile for Locations with Cover Thickness <75 cm

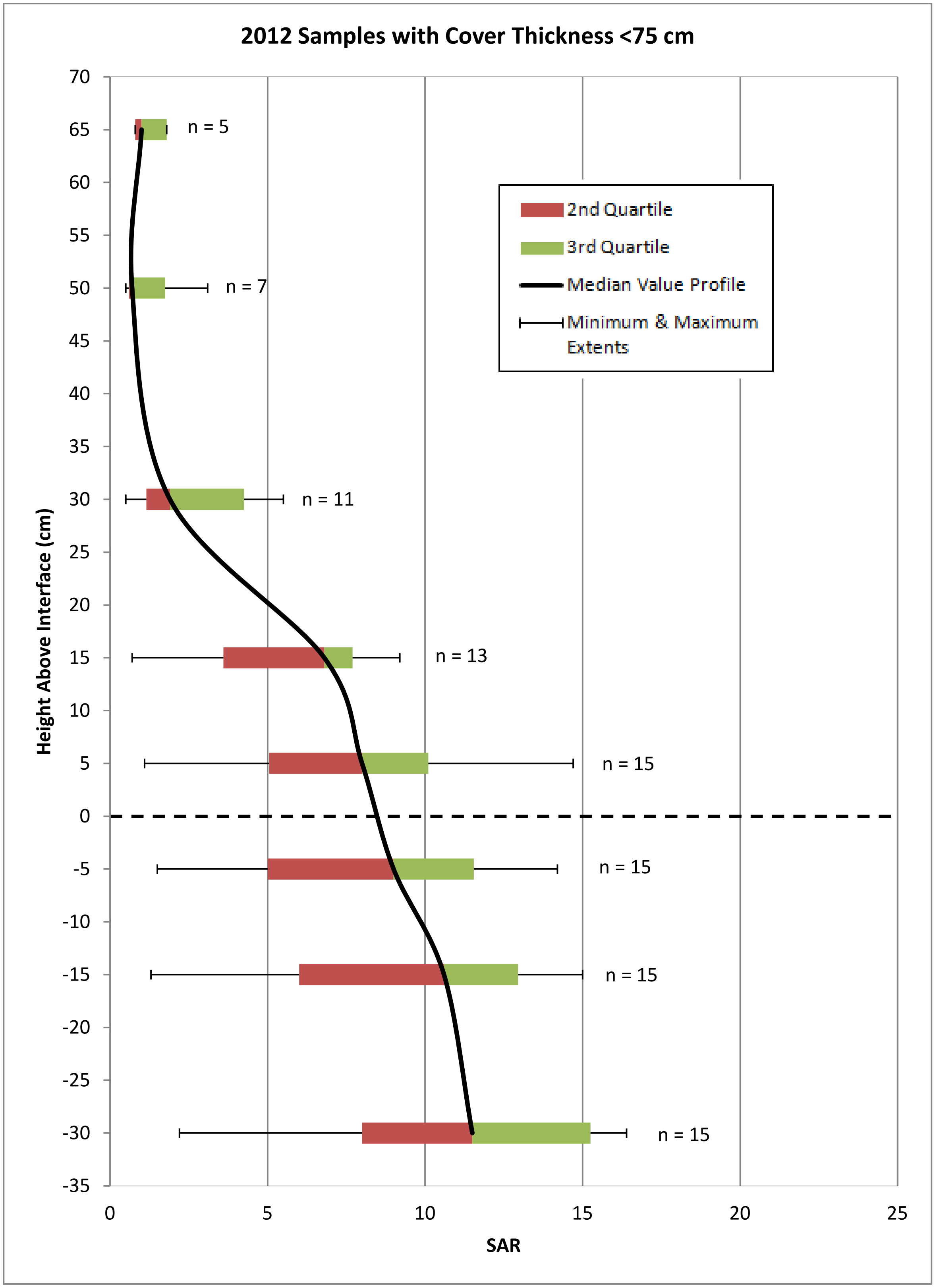


Figure 15 2012 Statistical SAR Profile for Locations with Cover Thickness <75 cm

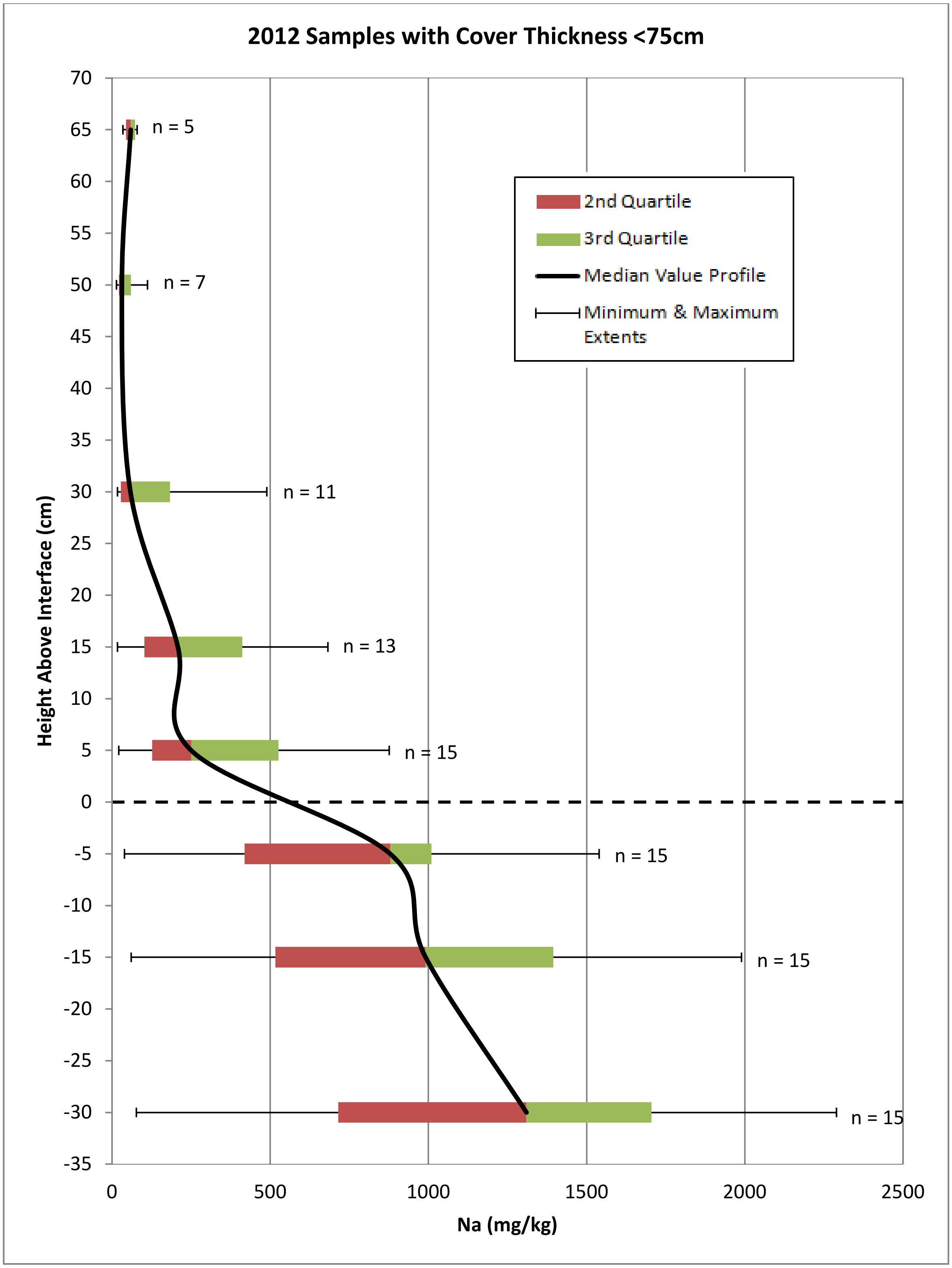


Figure 16 2012 Statistical Na$^+$ Profile for Locations with Cover Thickness <75 cm

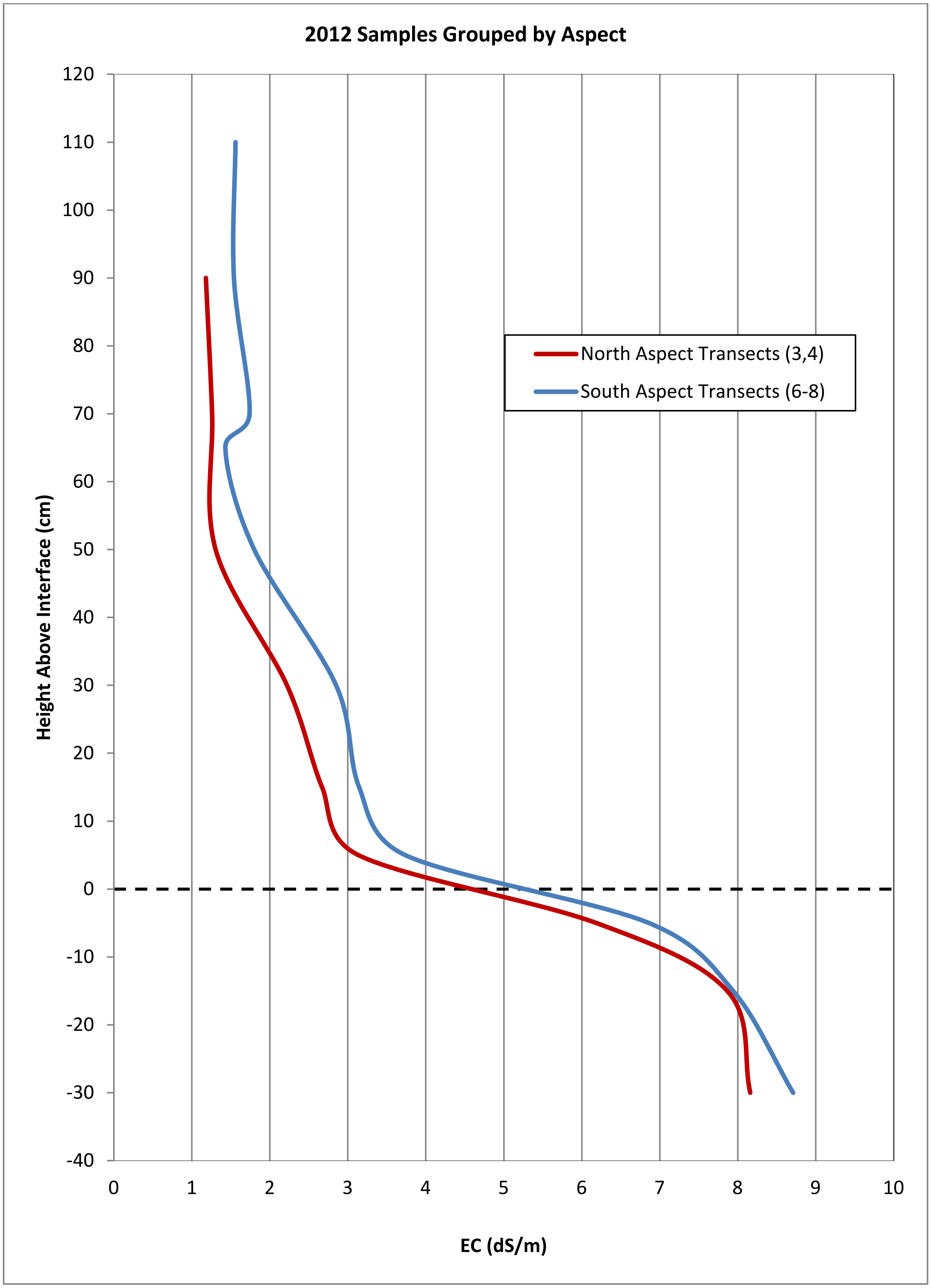


Figure 17 2012 Statistical Median EC Profile for North and South Facing Aspects

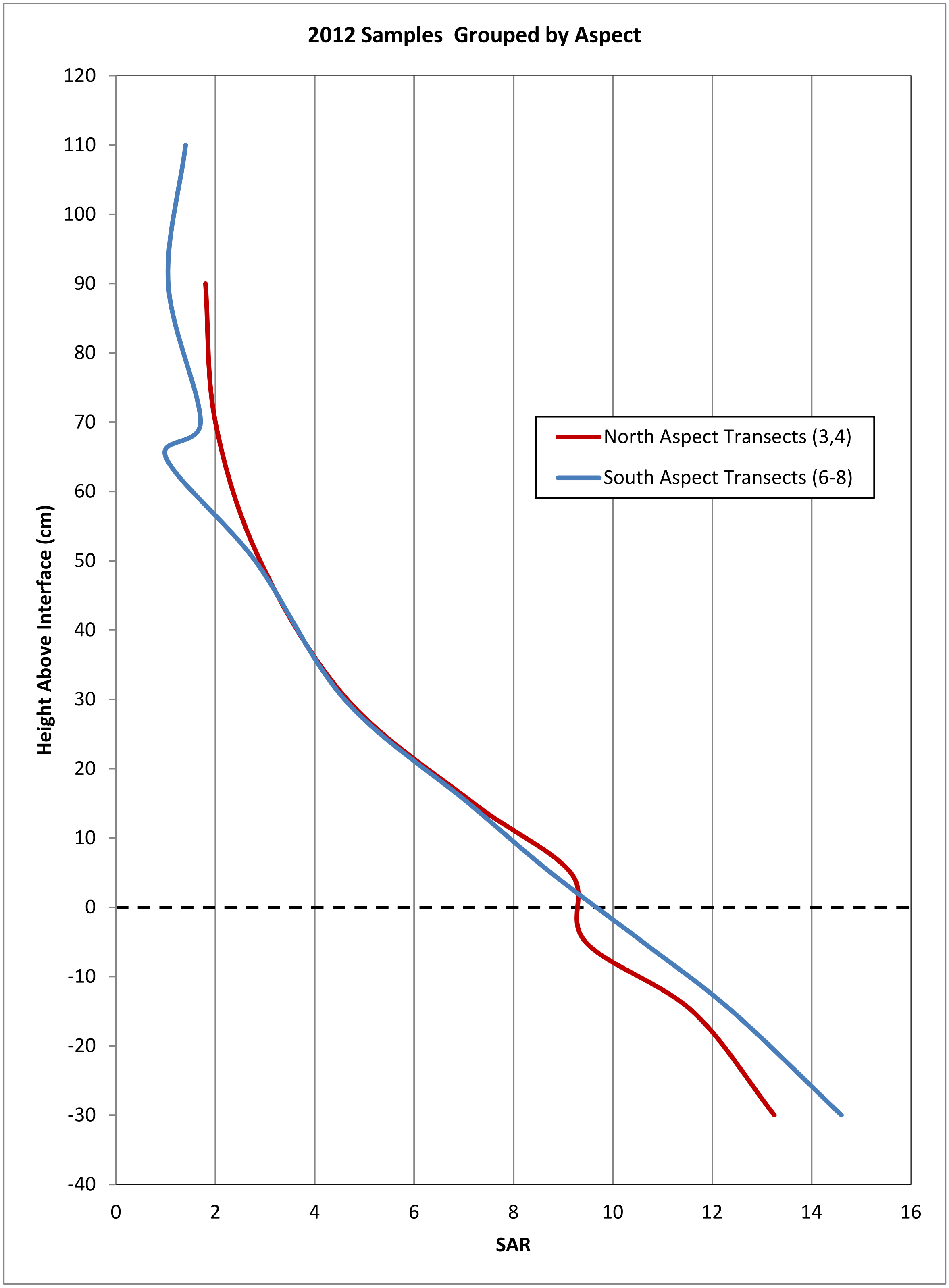


Figure 18 2012 Statistical Median SAR Profile for North and South Facing Aspects

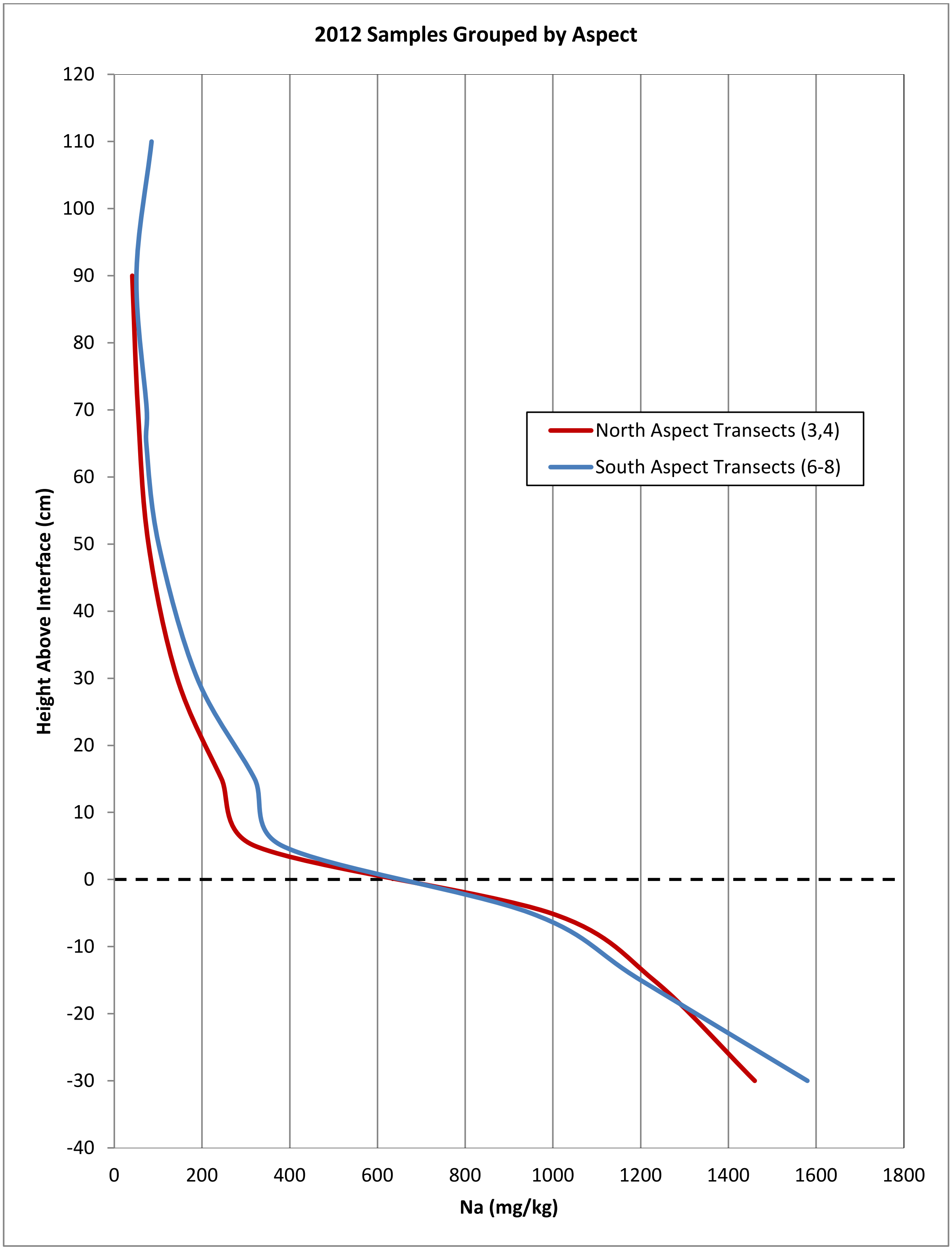


Figure 19 2012 Statistical Median Na^+ Profile for North and South Facing Aspects

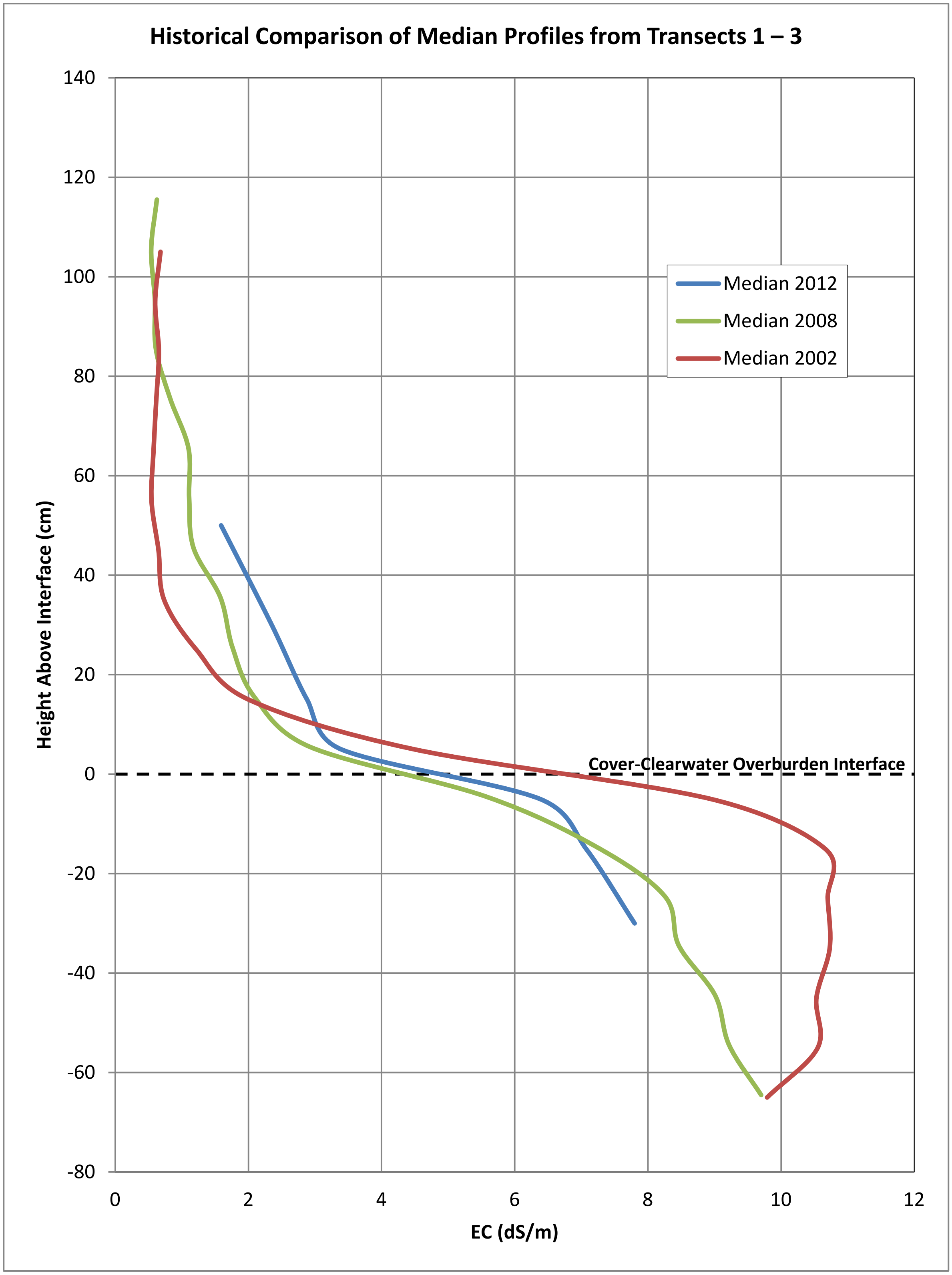


Figure 20 Statistical EC Profile for 2012 (T1-3), 2008 and 2002

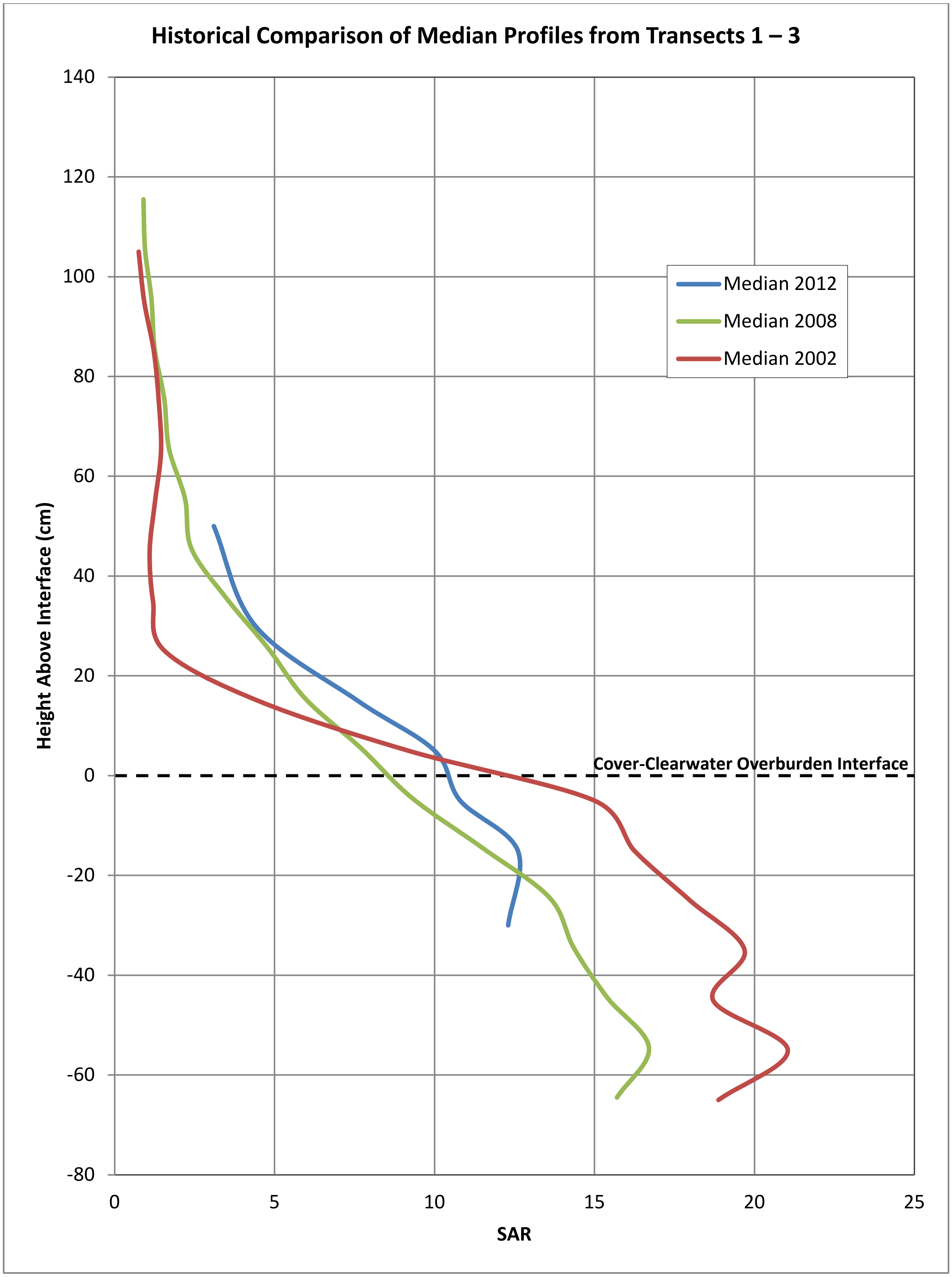


Figure 21 Statistical SAR Profile for 2012 (T1-3), 2008 and 2002

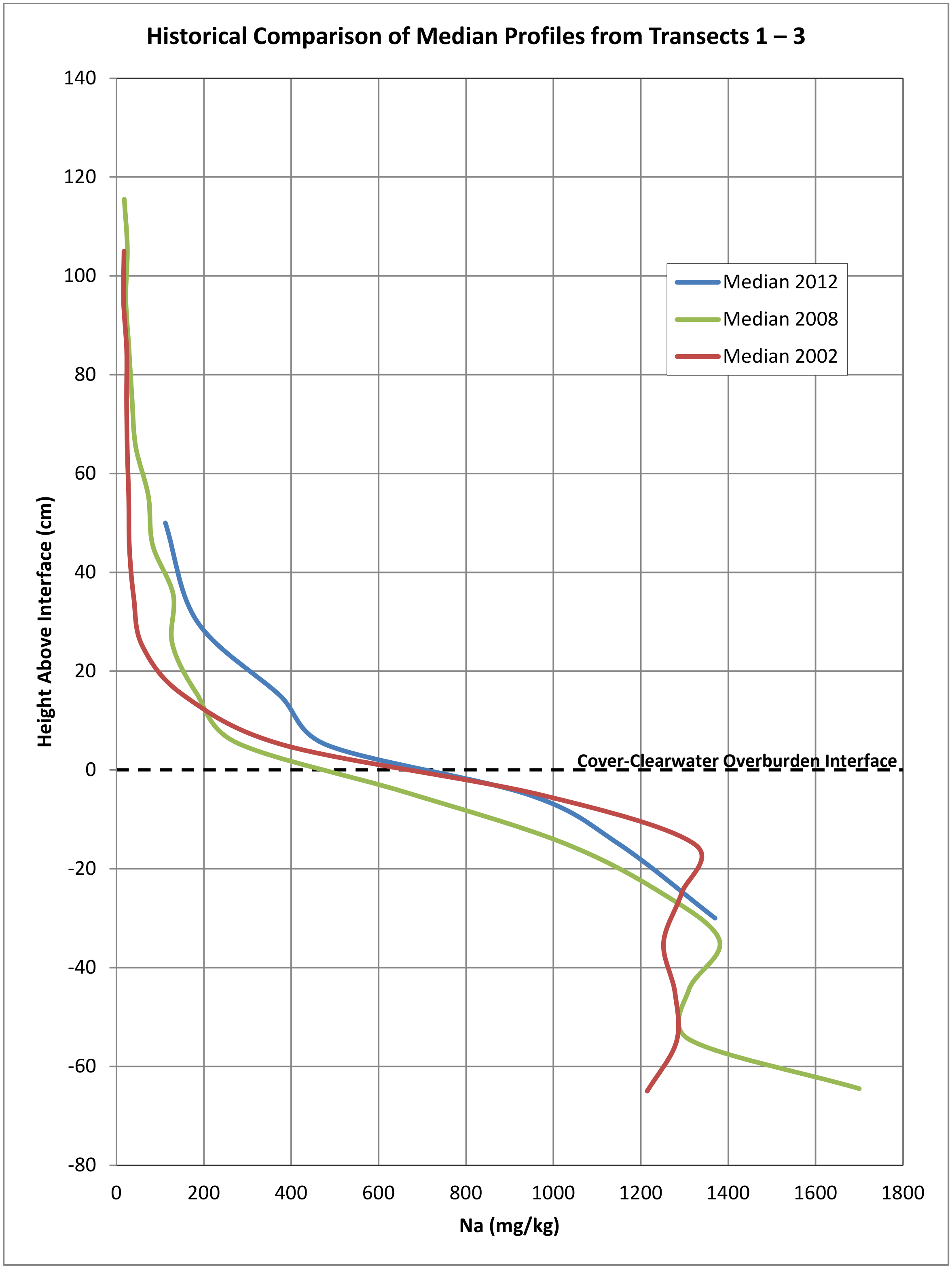


Figure 22 **Statistical Na^+ Profile for 2012 (T1-3), 2008 and 2002**

APPENDIX I

2012 Soil Salinity Laboratory Test Results

								Detailed Salinity (Saturated Paste)																						Estimated In-situ Porewater Concentrations (PHREEQ/C)						Ratio of Phreeq/c concetnrations to sat paste				Particle Size Analysis										
Transect	Position	Depth (cm)	Point Depth	Ht above Interface	Northing (m)	Easting (m)	MC	pH	EC	SAR	Sat%	Calcium	Calcium	Calcium	Magnesium	Magnesium	Magnesium	Sodium	Sodium	Sodium	Potassium	Potassium	Potassium	Chloride	Chloride	Chloride	Sulfate-S	Sulfate-S	Sulfate-S	Sodium	Sodium	Calcium	Calcium	Sulfate-S	Sulfate-S	Sodium	Calcium	Sulfate-S	Texture	Sand 50µm - 2mm	Silt 2µm - 50µm	Clay <2 µm	Prescribed Peat Thickness	Prescribed Till Thickness	Prescribed Non-Sodic Thickness	Prescribed Total Thickness	Year of Soil Placement	Measured Peat Thickness	Measured Till Thickness	Measured Total Thickness
			cm	cm			%	pH	dS/m		%	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	mol/L	mg/L	mol/L	mg/L	mol/L	mg/L	PhrC/Sat Paste	PhrC/Sat Paste	PhrC/Sat Paste		% weight	% weight	% weight	m	m	m	m		m	m	m
Transect 1	T1-C	0-8	4	104	6316961	462345	28%	7.3	0.75	0.8	77	4.39	68.1	88.4	2.44	22.9	29.7	1.46	26	33.8	0.22	6	7.8	0.67	18	23.4	3.1	38.4	49.9	2.79E-03	64.2	6.51E-03	260.7	4.24E-03	135.9	190%	295%	273%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	8-28	18	90	6316961	462345	40%	7	0.98	1	91	5.98	109	119.8	3.11	34.4	37.8	2.26	47	51.6	0.08	3	3.3	0.53	17	18.7	5.95	86.9	95.5	3.96E-03	90.9	7.29E-03	292.0	6.76E-03	216.7	176%	244%	227%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	28-48	38	70	6316961	462345	19%	7.7	0.83	2.6	60	3.09	37.2	62.0	1.6	11.6	19.3	3.97	55	91.7	0.06	1	1.7	0.39	8	13.3	5.31	51	85.0	8.45E-03	194.3	6.48E-03	259.5	8.49E-03	272.2	212%	419%	320%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	48-68	58	50	6316961	462345	79%	7	1.68	4.1	204	6.56	268	131.4	3.58	88.5	43.4	9.15	430	210.8	0.06	5	2.5	0.64	47	23.0	14.3	467	228.9	1.96E-02	449.9	9.88E-03	396.1	1.85E-02	594.3	213%	302%	260%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	68-88	78	30	6316961	462345	23%	6.8	3.22	5.5	101	17.6	355	351.5	9.07	111	109.9	20	463	458.4	<0.2	<10	9.9	0.73	26	25.7	40.8	658	651.5	4.20E-02	965.2	1.21E-02	484.6	2.94E-02	942.3	211%	138%	145%	Loam	50.4	28.2	21.4	0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	88-98	93	15	6316961	462345	20%	7.2	3.01	7.6	87	11.6	202	232.2	5.99	63.3	72.8	22.6	455	523.0	<0.2	<9	#VALUE!	0.82	25	28.7	35.4	495	569.0	4.86E-02	1118.0	1.14E-02	458.7	3.18E-02	1019.4	214%	198%	179%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C	98-108	103	5	6316961	462345	17%	7.3	3.99	8.2	80	14.3	227	283.8	8.74	84.4	105.5	27.9	512	640.0	0.43	13	16.3	0.51	14	17.5	45.7	584	730.0	5.81E-02	1335.8	1.10E-02	441.9	3.67E-02	1177.1	209%	156%	161%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C-OB	108-118	113	-5	6316961	462345	19%	7.2	5.67	7.9	85	25.2	431	507.1	19.9	206	242.4	37.4	735	864.7	0.92	30	35.3	0.44	13	15.3	75.9	1040	1223.5	7.43E-02	1708.9	1.03E-02	411.7	4.86E-02	1559.6	198%	81%	127%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C-OB	118-128	123	-15	6316961	462345	19%	7.4	7.19	10.4	88	24	421	478.4	29.5	313	355.7	54	1090	1238.6	1.4	49	55.7	0.48	15	17.0	102	1430	1625.0	1.23E-01	2838.1	8.67E-03	347.6	8.78E-02	2816.2	229%	73%	173%					0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-C-OB	128-148	138	-30	6316961	462345	19%	7.3	8.12	11.3	106	23	486	458.5	37.2	475	448.1	61.9	1500	1415.1	1.9	78	73.6	0.53	20	18.9	117	1980	1867.9	1.92E-01	4406.0	7.68E-03	307.7	1.55E-01	4962.5	311%	67%	266%	Clay Loam	24.4	36.2	39.4	0.20/0.20	0.30/0.30	0.00/0.50	0.50/1.00	1999/2001	0.3	0.78	1.08
Transect 1	T1-U	0-18	9	49	6317002	462313	57%	5.8	0.74	0.7	125	4.31	108	86.4	2.42	36.6	29.3	1.3	37	29.6	0.46	22	17.6	0.91	40	32.0	4.24	84.8	67.8	2.27E-03	52.1	5.04E-03	201.9	4.63E-03	148.4	176%	234%	219%					0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U	18-38	28	30	6317002	462313	15%	7.3	0.86	2.9	56	3.5	38.9	69.5	1.47	9.9	17.7	4.53	58	103.6	0.06	1	1.8	0.39	8	14.3	4.35	38.7	69.1	1.06E-02	244.1	8.83E-03	353.7	8.36E-03	268.1	236%	509%	388%	Clay Loam	44.4	22.8	32.8	0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U	38-48	43	15	6317002	462313	15%	7.6	1.9	8.4	58	4.15	48.5	83.6	1.78	12.6	21.7	14.4	194	334.5	0.03	<1	#VALUE!	0.38	8	13.8	16.6	156	269.0	3.59E-02	826.0	1.17E-02	468.4	2.70E-02	866.0	247%	560%	322%					0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U	48-58	53	5	6317002	462313	21%	7.5	3.86	13.9	75	6.92	104	138.7	4.16	37.9	50.5	32.8	569	758.7	<0.2	<8	#VALUE!	0.6	16	21.3	38.3	462	616.0	7.16E-02	1646.2	1.02E-02	408.0	4.22E-02	1354.2	217%	294%	220%					0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U-OB	58-68	63	-5	6317002	462313	22%	7.5	7.69	13.9	101	23.8	480	475.2	21.8	267	264.4	66.3	1540	1524.8	1.3	53	52.5	0.66	24	23.8	107	1730	1712.9	1.59E-01	3655.3	8.28E-03	332.0	9.94E-02	3188.1	240%	70%	186%					0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U-OB	68-78	73	-15	6317002	462313	23%	7.5	8.87	15	114	22.3	509	446.5	28.6	394	345.6	75.9	1990	1745.6	1.7	74	64.9	0.7	28	24.6	125	2290	2008.8	2.29E-01	5275.5	7.31E-03	293.0	1.64E-01	5259.5	302%	66%	262%					0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-U-OB	78-98	88	-30	6317002	462313	23%	7	10.2	15.4	111	22.7	505	455.0	44.5	599	539.6	89.5	2290	2063.1	2	85	76.6	0.95	38	34.2	153	2710	2441.4	2.96E-01	6805.6	6.88E-03	275.6	2.37E-01	7604.9	330%	61%	311%	Clay	20.4	33.2	46.4	0.2	0.3	0	0.5	1999	0.15	0.43	0.58
Transect 1	T1-M	0-6	3	43	6317040	462284	101%	5.7	0.66	1.4	218	2.94	128	58.7	1.63	43.1	19.8	2.06	103	47.2	0.46	39	17.9	0.51	40	18.3	3.99	139	63.8	3.74E-03	86.0	3.53E-03	141.7	4.31E-03	138.3	182%	241%	217%					0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M	6-26	16	30	6317040	462284	19%	5.8	2.25	4.5	64	9.9	126	196.9	5.46	42.2	65.9	12.6	185	289.1	0.16	4	6.3	0.54	12	18.8	24.8	254	396.9	2.43E-02	557.7	1.19E-02	478.8	2.51E-02	805.8	193%	243%	203%	Clay Loam	28.4	35.2	36.4	0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M	26-36	31	15	6317040	462284	27%	6.9	5.18	8.4	82	23.1	379	462.2	13.6	134	163.4	36.2	682	831.7	<0.2	<8	#VALUE!	0.96	28	34.1	66.1	868	1058.5	6.03E-02	1386.7	1.06E-02	424.5	3.89E-02	1248.1	167%	92%	118%					0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M	36-46	41	5	6317040	462284	22%	7.4	5.09	10	80	16.6	268	335.0	12.2	119	148.8	38	704	880.0	<0.2	<8	#VALUE!	0.66	19	23.8	62.1	800	1000.0	7.05E-02	1621.2	9.85E-03	394.9	4.62E-02	1480.9	184%	118%	148%					0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M-OB	46-56	51	-5	6317040	462284	22%	7.2	6.23	9	82	25.6	419	511.0	22.5	224	273.2	44.4	837	1020.7	1.2	38	46.3	0.75	22	26.8	88.4	1160	1414.6	8.25E-02	1896.5	9.44E-03	378.4	5.70E-02	1827.9	186%	74%	129%					0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M-OB	56-66	61	-15	6317040	462284	25%	7.2	6.74	9.8	86	24.2	418	486.0	27.8	291	338.4	49.8	991	1152.3	1.4	49	57.0	0.82	25	29.1	95.6	1320	1534.9	9.67E-02	2223.2	9.17E-03	367.4	6.86E-02	2198.6	193%	76%	143%					0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-M-OB	66-86	76	-30	6317040	462284	26%	7.3	7.8	11.5	93	23.6	441	474.2	32.9	371	398.9	61.2	1310	1408.6	1.6	58	62.4	1.12	37	39.8	112	1670	1795.7	1.34E-01	3069.8	8.40E-03	336.6	9.74E-02	3122.7	218%	71%	174%	Clay Loam	23.4	39.2	37.4	0.2	0.3	0	0.5	1999	0.35	0.11	0.46
Transect 1	T1-L	0-21	11	30.5	6317074	462258	54%	6	0.55	0.5	124	3.84	95.5	77.0	2.06	30.9	24.9	0.8	23	18.5	0.2	10	8.1	0.66	29	23.4	3	59.7	48.1	1.43E-03	32.9	4.67E-03	187.0	3.47E-03	111.4	178%	243%	231%	Clay	30	27.6	42.4	0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-L	21-31	26	15	6317074	462258	22%	7	0.79	0.7	73	6.28	91.8	125.8	2.32	20.6	28.2	1.41	24	32.9	0.12	3	4.1	0.37	10	13.7	3.32	38.9	53.3	2.80E-03	64.5	9.13E-03	365.8	5.40E-03	173.0	196%	291%	325%					0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-L	31-41	36	5	6317074	462258	13%	7.6	0.61	1.1	52	3.75	39.2	75.4	1.36	8.6	16.5	1.76	21	40.4	0.1	2	3.8	0.31	6	11.5	2.97	24.8	47.7	3.96E-03	91.1	8.56E-03	343.0	5.82E-03	186.6	226%	455%	391%					0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-L-OB	41-51	46	-5	6317074	462258	14%	7.6	0.8	1.5	65	4.38	57.1	87.8	1.67	13.2	20.3	2.62	39	60.0	0.31	8	12.3	0.3	7	10.8	5.82	60.7	93.4	6.83E-03	157.0	1.28E-02	514.5	1.37E-02	440.9	262%	586%	472%					0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-L-OB	51-61	56	-15	6317074	462258	15%	7.2	2.36	1.3	74	21.9	324	437.8	7.36	65.8	88.9	5.16	88	118.9	0.92	26	35.1	0.3	8	10.8	32	379	512.2	1.01E-02	232.2	1.49E-02	598.7	1.81E-02	581.3	195%	137%	113%					0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-L-OB	61-81	71	-30	6317074	462258	16%	7.2	2.96	2.2	75	27	406	541.3	12.5	114	152.0	9.82	170	226.7	1.2	35	46.7	0.3	8	10.7	46.6	561	748.0	1.82E-02	417.4	1.35E-02	542.0	2.24E-02	716.8	184%	100%	96%	Clay Loam	28.4	35.2	36.4	0.2	0.3	0	0.5	1999	0.24	0.17	0.41
Transect 1	T1-T	0-10	5	45	6317107	462233	104%	7.2	0.67	0.4	225	3.94	177	78.7	2.17	59	26.2	0.72	37	16.4	0.5	44	19.6	0.26	20	8.9	3.92	141	62.7	1.31E-03	30.1	4.48E-03	179.4	4.23E-03	135.7	183%	228%	217%					0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T	10-30	20	30	6317107	462233	25%	7.4	0.61	0.7	63	3.89	49.3	78.3	1.69	13	20.6	1.19	17	27.0	0.12	3	4.8	0.2	4	6.3	3.27	33.2	52.7	2.09E-03	48.0	5.21E-03	209.0	4.06E-03	130.2	178%	267%	247%	Clay Loam	44.4	27.6	28	0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T	30-40	35	15	6317107	462233	18%	7.7	0.5	1	54	2.98	32.4	60.0	1.09	7.2	13.3	1.39	17	31.5	0.14	3	5.6	0.22	4	7.4	2.42	21	38.9	2.69E-03	61.9	5.09E-03	203.9	3.62E-03	115.9	197%	340%	298%					0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T	40-50	45	5	6317107	462233	18%	7.8	0.51	1.6	51	2.21	22.5	44.1	0.97	6	11.8	2.08	24	47.1	0.22	4	7.8	0.24	4	7.8	2.27	18.4	36.1	3.98E-03	91.5	3.83E-03	153.4	3.17E-03	101.6	194%	348%	282%					0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T-OB	50-60	55	-5	6317107	462233	16%	7.8	0.69	3.1	52	2.17	22.5	43.3	1.09	6.8	13.1	3.96	47	90.4	0.28	6	11.5	0.21	4	7.7	4.21	34.9	67.1	8.75E-03	201.1	5.21E-03	208.7	6.94E-03	222.6	223%	482%	332%					0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T-OB	60-70	65	-15	6317107	462233	14%	7.7	0.82	4.6	49	1.63	16	32.7	1.12	6.6	13.5	5.38	60	122.4	0.3	6	12.2	0.19	3	6.1	6.38	49.8	101.6	1.29E-02	297.4	4.94E-03	198.1	1.13E-02	361.3	243%	607%	356%					0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 1	T1-T-OB	70-90	80	-30	6317107	462233	11%	7.6	1.18	5.7	42	2.11	17.6	41.9	1.83	9.2	21.9	7.97	77	183.3	0.37	6	14.3	0.24	4	9.5	10.5	70	166.7	2.01E-02	462.2	7.17E-03	287.5	1.99E-02	638.5	252%	686%	383%	Sandy Loam	57.4	28.2	14.4	0.2	0.3	0	0.5	1999	0.1	0.4	0.5
Transect 2	T2-C	0-4	2	112	6316993	462389	88%	5.4	0.53	0.3	200	3.17	127	63.5	1.48	35.7	17.9	0.51	24	12.0	0.74	57	28.5	1.14	81	40.5	2.82	90.4	45.2	9.45E-04	21.7	3.85E-03	154.4	3.19E-03	102.4	181%	243%	227%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	4-24	14	100	6316993	462389	30%	6.1	0.93	0.4	84	7.66	128	152.4	2.94	29.7	35.4	1.01	19	22.6	0.19	6	7.1	0.83	24	28.6	4.8	64.3	76.5	2.00E-03	45.9	1.12E-02	449.8	6.75E-03	216.5	203%	295%	283%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	24-44	34	80	6316993	462389	16%	7.4	0.61	1	60	3.73	44.6	74.3	1.44	10.4	17.3	1.59	22	36.7	0.08	2	3.3	0.45	10	16.7	2.8	26.8	44.7	3.49E-03	80.2	7.79E-03	312.1	5.13E-03	164.6	219%	420%	369%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	44-64	54	60	6316993	462389	13%	7.6	0.91	2.1	52	4.38	45.8	88.1	1.9	12	23.1	3.66	44	84.6	0.17	3	5.8	0.47	9	17.3	6.91	57.8	111.2	8.77E-03	201.6	1.16E-02	466.1	1.43E-02	458.4	238%	529%	412%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	64-84	74	40	6316993	462389	10%	7.7	1.04	3.4	44	3.84	34	77.3	1.72	9.2	20.9	5.66	58	131.8	0.18	3	6.8	0.82	13	29.5	8.04	57	129.5	1.43E-02	329.4	1.22E-02	489.8	1.74E-02	557.6	250%	634%	430%	ndy Clay Loa	58.4	21.2	20.4	0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	84-104	94	20	6316993	462389	12%	7.7	1.32	5.1	54	3.88	42	77.8	1.76	11.5	21.3	8.63	107	198.1	0.22	4	7.4	0.6	12	22.2	11	95.6	177.0	2.32E-02	533.6	1.31E-02	523.6	2.23E-02	716.1	269%	673%	405%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C	104-114	109	5	6316993	462389	13%	7.8	2.22	8.9	55	4.62	51	92.7	2.89	19.3	35.1	17.3	220	400.0	0.2	4	7.3	0.6	12	21.8	22.2	196	356.4	4.15E-02	954.7	1.08E-02	432.3	3.21E-02	1028.5	239%	466%	289%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C-OB	114-124	119	-5	6316993	462389	17%	7.4	5.56	9.4	71	22.5	321	452.1	17.3	149	209.9	42	690	971.8	1.1	31	43.7	0.61	16	22.5	77.4	884	1245.1	7.72E-02	1775.0	9.94E-03	398.3	4.96E-02	1590.3	183%	88%	128%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C-OB	124-134	129	-15	6316993	462389	21%	7.4	7.07	12.6	92	24	440	478.3	23.1	256	278.3	61	1290	1402.2	1.6	57	62.0	1	32	34.8	104	1520	1652.2	1.36E-01	3116.3	8.52E-03	341.3	8.75E-02	2805.7	222%	71%	170%					0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-C-OB	134-154	144	-30	6316993	462389	20%	7.5	7.88	15.4	92	22.5	414	450.0	22.6	252	273.9	73.4	1550	1684.8	1.6	59	64.1	1.3	42	45.7	114	1680	1826.1	1.83E-01	4208.6	8.03E-03	321.9	1.14E-01	3667.9	250%	72%	201%	Clay Loam	33.4	27.8	38.8	0.15/0.20	0.20/0.30	0.00/0.50	0.50/1.00	1999/2001	0.24	0.9	1.14
Transect 2	T2-U	0-10	5	25	6317032	462359	52%	6.4	0.83	2.3	117	3.37	78.9	67.4	1.86	26.4	22.6	3.71	100	85.5	0.46	21	17.9	0.56	23	19.7	5.94	111	94.9	6.70E-03	154.0	4.54E-03	182.0	6.73E-03	215.7	180%	270%	227%					0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-U	10-20	15	15	6317032	462359	95%	6.4	1.08	7.1	205	2.09	85.7	41.8	0.91	22.5	11.0	8.7	411	200.5	0.07	6	2.9	1.17	85	41.5	7.68	252	122.9	1.63E-02	375.7	3.14E-03	126.0	8.26E-03	264.8	187%	301%	215%					0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-U	20-30	25	5	6317032	462359	22%	7.5	2.61	13.6	78	4.24	66.6	85.4	2.49	23.6	30.3	25	451	578.2	<0.2	<8	#VALUE!	1.36	38	48.7	26.6	335	429.5	6.18E-02	1420.4	1.04E-02	418.2	3.79E-02	1215.1	246%	490%	283%					0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-U-OB	30-40	35	-5	6317032	462359	19%	7.4	6.43	10.8	91	24.3	440	483.5	20.9	230	252.7	51.2	1070	1175.8	1.2	41	45.1	0.92	30	33.0	93.2	1350	1483.5	1.10E-01	2522.7	8.84E-03	354.2	7.19E-02	2306.8	215%	73%	155%					0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-U-OB	40-50	45	-15	6317032	462359	19%	7.4	6.9	10.6	92	23.6	433	470.7	29	322	350.0	54.3	1150	1250.0	1.4	52	56.5	0.91	30	32.6	105	1540	1673.9	1.30E-01	2999.1	8.19E-03	328.4	9.78E-02	3136.2	240%	70%	187%					0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-U-OB	50-70	60	-30	6317032	462359	21%	7.2	7.61	10.7	104	22.7	471	452.9	34.8	436	419.2	57.5	1370	1317.3	1.6	67	64.4	0.79	29	27.9	114	1890	1817.3	1.61E-01	3698.2	7.66E-03	307.1	1.34E-01	4283.5	281%	68%	236%	Silty Clay	14.4	42.2	43.4	0.15	0.2	0	0.35	1999	0.19	0.11	0.3
Transect 2	T2-M	0-23	12	31.5	6317071	462329	44%	6.6	3.38	4.4	115	22.9	527	458.3	12.4	172	149.6	18.5	489	425.2	0.38	17	14.8	1.15	47	40.9	48.7	896	779.1	3.17E-02	729.5	1.16E-02	464.7	2.86E-02	916.3	172%	101%	118%	Clay	28.4	28.8	42.8	0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-M	23-33	28	15	6317071	462329	14%	7.4	5.38	9.2	59	24.8	292	494.9	14.4	102	172.9	40.7	550	932.2	<0.2	<6	#VALUE!	1.13	24	40.7	73.4	690	1169.5	6.78E-02	1558.1	1.08E-02	433.4	3.98E-02	1276.2	167%	88%	109%					0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-M	33-43	38	5	6317071	462329	17%	7.6	7.53	14.7	55	22.8	251	456.4	21.2	141	256.4	69	876	1592.7	0.36	8	14.5	1.85	36	65.5	106	932	1694.5	1.13E-01	2607.9	9.01E-03	361.1	6.79E-02	2178.0	164%	79%	129%					0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-M-OB	43-53	48	-5	6317071	462329	23%	7.6	8.07	14.2	90	24.8	444	493.3	29	314	348.9	73.4	1510	1677.8	1.2	43	47.8	1.19	38	42.2	118	1700	1888.9	1.67E-01	3828.6	8.26E-03	331.0	1.07E-01	3443.2	228%	67%	182%					0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-M-OB	53-63	58	-15	6317071	462329	23%	7.6	8.68	14.8	78	24.8	386	494.9	31	292	374.4	78.1	1400	1794.9	1.2	38	48.7	1.68	46	59.0	128	1600	2051.3	1.58E-01	3641.0	8.15E-03	326.7	1.05E-01	3372.6	203%	66%	164%					0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-M-OB	63-83	73	-30	6317071	462329	23%	7.5	8.95	16.3	90	22.9	415	461.1	29.7	324	360.0	83.8	1740	1933.3	1.6	56	62.2	1.68	54	60.0	132	1920	2133.3	2.04E-01	4696.2	7.65E-03	306.7	1.37E-01	4401.5	243%	67%	206%	Clay Loam	26	35.6	38.4	0.15	0.2	0	0.35	1999	0.19	0.24	0.43
Transect 2	T2-L	0-5	3	22.5	6317108	462301	75%	6.3	0.91	2.5	153	4.11	126	82.4	2.24	41.5	27.1	4.43	156	102.0	0.39	24	15.7	0.87	47	30.7	5.69	140	91.5	7.65E-03	175.9	4.80E-03	192.5	5.83E-03	187.0	173%	234%	204%					0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-L	5-15	10	15	6317108	462301	36%	6.9	2.88	7.7	84	11.3	190	226.2	6.58	66.7	79.4	23.2	446	531.0	<0.2	<8	#VALUE!	1.51	45	53.6	30.1	403	479.8	4.08E-02	937.8	1.20E-02	480.5	2.87E-02	921.3	177%	212%	192%					0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-L	15-25	20	5	6317108	462301	19%	7.4	5.66	10	68	27	367	539.7	15.4	126	185.3	46.1	720	1058.8	0.62	16	23.5	2.68	64	94.1	78.6	854	1255.9	7.70E-02	1769.7	1.07E-02	428.6	4.27E-02	1368.3	167%	79%	109%					0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-L-OB	25-35	30	-5	6317108	462301	20%	7.4	6.67	12.6	70	24.6	347	495.7	18.2	155	221.4	58.4	945	1350.0	0.86	24	34.3	3.05	76	108.6	91.9	1030	1471.4	1.03E-01	2369.1	9.75E-03	390.6	5.73E-02	1835.7	175%	79%	125%					0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-L-OB	35-45	40	-15	6317108	462301	21%	7.5	6.71	12.8	72	24.1	349	484.7	17.4	152	211.1	58.6	974	1352.8	1	29	40.3	2	51	70.8	94.9	1100	1527.8	1.01E-01	2333.4	9.13E-03	366.1	6.13E-02	1967.0	172%	76%	129%					0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-L-OB	45-65	55	-30	6317108	462301	22%	7.5	7.56	15.1	80	23.9	380	475.0	19.3	186	232.5	70.2	1280	1600.0	1.3	40	50.0	2.84	80	100.0	107	1360	1700.0	1.37E-01	3147.2	8.69E-03	348.1	7.97E-02	2554.8	197%	73%	150%	Clay Loam	36.4	30.8	32.8	0.15	0.2	0	0.35	1999	0.12	0.13	0.25
Transect 2	T2-T	0-10	5	5	6317126	462281	37%	7.6	1.47	6.6	91	3.2	58.4	64.2	2.07	22.9	25.2	10.7	224	246.2	0.2	7	7.7	1.11	36	39.6	10.8	157	172.5	2.12E-02	486.8	5.67E-03	227.3	1.33E-02	425.2	198%	354%	246%					0.15	0.2	0	0.35	1999	0.1	0	0.1
Transect 2	T2-T-OB	10-20	15	-5	6317126	462281	23%	7.5	6.38	11.6	76	24.9	381	501.3	18	167	219.7	53.6	943	1240.8	0.9	27	35.5	2.59	70	92.1	89.7	1100	1447.4	9.25E-02	2125.6	9.55E-03	382.8	5.54E-02	1776.2	171%	76%	123%					0.15	0.2	0	0.35	1999	0.1	0	0.1
Transect 2	T2-T-OB	20-30	25	-15	6317126	462281	23%	7.5	8.07	14	83	24.3	404	486.7	29.1	293	353.0	72.6	1390	1674.7	1.6	51	61.4	3.33	98	118.1	115	1530	1843.4	1.53E-01	3513.5	8.58E-03	343.8	9.54E-02	3059.2	210%	71%	166%					0.15	0.2	0	0.35	1999	0.1	0	0.1
Transect 2	T2-T-OB	30-50	40	-30	6317126	462281	24%	7.5	8.39	14.2	98	23.2	455	464.3	31.7	375	382.7	74.5	1670	1704.1	1.8	70	71.4	2.02	70	71.4	123	1920	1959.2	1.88E-01	4329.3	7.89E-03	316.2	1.30E-01	4158.7	254%	68%	212%	Clay	33.4	24.2	42.4	0.15	0.2	0	0.35	1999	0.1	0	0.1
Transect 3	T3-C	0-4	2	82	6317023	462427	32%	6.3	0.78	1	100	4.14	83	83.0	2.07	25.2	25.2	1.84	42	42.0	0.27	10	10.0	1.45	52	52.0	4.84	77.8	77.8	3.97E-03	91.4	7.42E-03	297.3	7.67E-03	246.0	218%	358%	316%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C	4-24	14	70	6317023	462427	15%	7.5	1.29	2	63	7.87	98.9	157.0	3.44	26.2	41.6	4.67	67	106.3	0.15	4	6.3	1.12	25	39.7	12.2	122	193.7	1.06E-02	243.6	1.48E-02	594.2	1.83E-02	587.1	229%	378%	303%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C	24-44	34	50	6317023	462427	15%	7.5	2.6	4.1	63	16.6	210	333.3	7.84	59.9	95.1	14.4	209	331.7	<0.2	<6	#VALUE!	1.75	39	61.9	32.2	325	515.9	2.76E-02	634.0	1.39E-02	558.5	2.25E-02	723.0	191%	168%	140%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C	44-64	54	30	6317023	462427	10%	7.8	3.25	7.4	58	13.3	155	267.2	8.27	58.6	101.0	24.3	327	563.8	<0.2	<6	#VALUE!	2.4	50	86.2	40.7	381	656.9	4.97E-02	1143.6	1.22E-02	487.6	3.07E-02	982.9	203%	182%	150%	Loam	46	28.6	25.4	0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C	64-74	69	15	6317023	462427	11%	7.9	3.19	10.4	61	9	110	180.3	6.1	45.1	73.9	28.7	403	660.7	<0.2	<6	#VALUE!	2.64	57	93.4	37.8	369	604.9	6.58E-02	1512.9	1.16E-02	464.4	3.58E-02	1147.2	229%	258%	190%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C	74-84	79	5	6317023	462427	12%	7.8	4.58	10.9	60	14	167	278.3	10.3	74.6	124.3	38.1	526	876.7	0.37	9	15.0	2.45	52	86.7	55.6	533	888.3	7.70E-02	1769.7	1.10E-02	439.3	4.19E-02	1343.5	202%	158%	151%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C-OB	84-94	89	-5	6317023	462427	11%	7.6	5	8.2	50	19	190	380.0	19.9	121	242.0	36.1	415	830.0	0.92	18	36.0	2.05	36	72.0	68.9	551	1102.0	6.54E-02	1502.8	1.10E-02	439.9	4.30E-02	1380.4	181%	116%	125%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C-OB	94-104	99	-15	6317023	462427	12%	7.5	6.22	8.8	51	23.2	238	466.7	29.2	182	356.9	45.3	535	1049.0	1.2	23	45.1	2.21	40	78.4	90.1	741	1452.9	7.96E-02	1829.5	1.02E-02	409.1	5.43E-02	1740.8	174%	88%	120%					0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-C-OB	104-124	114	-30	6317023	462427	16%	7.3	6.6	10.2	69	24.2	333	482.6	26	217	314.5	51.3	812	1176.8	1.3	36	52.2	2.3	56	81.2	96.9	1070	1550.7	9.99E-02	2297.0	9.18E-03	367.9	6.71E-02	2150.6	195%	76%	139%	ndy Clay Loa	53.4	21.8	24.8	0.20/0.20	0.80/0.30	0.00/0.50	0.50/1.00	1999/2001	0	0.84	0.84
Transect 3	T3-U	0-8	4	144	6317064	462397	38%	5.9	0.61	0.8	160	3.29	105	65.6	1.84	35.5	22.2	1.28	47	29.4	0.39	24	15.0	0.64	36	22.5	4.07	104	65.0	3.51E-03	80.7	7.96E-03	318.9	8.61E-03	276.2	275%	486%	425%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	8-28	18	130	6317064	462397	15%	7.3	0.68	0.8	68	4.26	57.9	85.1	2.01	16.6	24.4	1.38	22	32.4	0.15	4	5.9	0.58	14	20.6	3.14	34.2	50.3	3.37E-03	77.4	1.01E-02	405.2	7.19E-03	230.4	239%	476%	458%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	28-48	38	110	6317064	462397	11%	7.6	0.63	1.2	54	3.42	36.7	68.0	1.41	9.1	16.9	1.91	24	44.4	0.12	2	3.7	1.08	20	37.0	2.85	24.4	45.2	4.92E-03	113.1	1.02E-02	409.7	7.02E-03	225.0	254%	603%	498%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	48-68	58	90	6317064	462397	14%	7.6	1.18	1.8	63	7.26	92.1	146.2	2.67	20.5	32.5	4	58	92.1	0.17	4	6.3	0.78	17	27.0	10.8	110	174.6	9.45E-03	217.2	1.50E-02	599.5	1.76E-02	563.3	236%	410%	323%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	68-88	78	70	6317064	462397	15%	7.6	1.63	2.6	68	10	136	200.0	3.62	29.6	43.5	6.76	105	154.4	0.18	5	7.4	1.02	24	35.3	17.4	189	277.9	1.47E-02	337.4	1.40E-02	559.3	1.92E-02	616.3	219%	280%	222%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	88-108	98	50	6317064	462397	17%	7.6	2.1	3.9	64	11.7	150	234.4	4.07	31.6	49.4	11	162	253.1	0.22	5	7.8	1.03	24	37.5	24.2	249	389.1	2.11E-02	484.9	1.24E-02	498.7	2.21E-02	708.1	192%	213%	182%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	108-128	118	30	6317064	462397	17%	7.6	2.41	7.4	70	7.92	110	157.1	3.04	25.6	36.6	17.2	276	394.3	0.19	5	7.1	0.85	21	30.0	25.3	281	401.4	3.66E-02	841.3	1.13E-02	452.2	2.79E-02	893.9	213%	288%	223%	Clay	30.4	24.2	45.4	0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	128-138	133	15	6317064	462397	18%	7.8	2.55	11.3	73	5.18	75.8	103.8	2.56	22.7	31.1	22.3	375	513.7	<0.2	<7	#VALUE!	0.67	17	23.3	27.6	323	442.5	5.27E-02	1210.7	1.02E-02	407.3	3.62E-02	1160.0	236%	392%	262%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U	138-148	143	5	6317064	462397	18%	7.9	3.17	13.1	70	6.3	88.4	126.3	4.2	35.7	51.0	30	485	692.9	0.31	8	11.4	0.64	16	22.9	36.1	405	578.6	6.78E-02	1557.8	1.01E-02	405.4	4.20E-02	1347.1	225%	321%	233%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U-OB	148-158	153	-5	6317064	462397	22%	7.5	6.8	10.9	94	24.4	460	489.4	24	273	290.4	53.6	1160	1234.0	1.5	54	57.4	0.46	16	17.0	99.6	1500	1595.7	1.17E-01	2689.6	8.53E-03	341.9	8.13E-02	2606.6	218%	70%	163%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U-OB	158-168	163	-15	6317064	462397	25%	7.4	8.05	12.9	100	23.6	474	474.0	34.2	415	415.0	69.4	1600	1600.0	1.8	73	73.0	0.5	18	18.0	118	1890	1890.0	1.73E-01	3973.8	8.05E-03	322.6	1.23E-01	3953.4	248%	68%	209%					0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-U-OB	168-188	178	-30	6317064	462397	21%	7.3	7.7	12.3	97	23.2	452	466.0	29.5	347	357.7	63.3	1420	1463.9	1.9	71	73.2	0.52	18	18.6	114	1780	1835.1	1.61E-01	3711.3	7.89E-03	316.4	1.18E-01	3791.8	254%	68%	207%	Clay Loam	20.4	40.8	38.8	0.2	0.8	0	1	1999	0.25	1.23	1.48
Transect 3	T3-M	0-17	9	88.5	6317105	462368	29%	6.4	0.7	1.1	94	3.76	70.9	75.4	1.9	21.8	23.2	1.81	39	41.5	0.11	4	4.3	0.66	22	23.4	4.98	75.2	80.0	3.87E-03	89.0	6.83E-03	273.6	7.98E-03	255.7	215%	363%	320%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M	17-37	27	70	6317105	462368	16%	7.2	0.71	0.8	78	4.67	73.4	94.1	2.1	19.9	25.5	1.54	28	35.9	0.1	3	3.8	0.47	13	16.7	1.89	23.8	30.5	3.65E-03	84.0	9.04E-03	362.1	4.54E-03	145.4	234%	385%	477%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M	37-57	47	50	6317105	462368	14%	6.9	0.54	1.7	64	2.01	25.9	40.5	1.16	9	14.1	2.15	32	50.0	0.04	<1	#VALUE!	0.68	15	23.4	3.24	33.4	52.2	5.43E-03	124.9	5.99E-03	240.2	7.27E-03	233.2	250%	594%	447%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M	57-77	67	30	6317105	462368	15%	7.1	0.73	4	69	1.72	23.9	34.6	0.98	8.2	11.9	4.71	75	108.7	0.03	<1	#VALUE!	0.34	8	11.6	5.84	64.9	94.1	1.31E-02	301.1	6.64E-03	266.3	1.31E-02	420.7	277%	769%	447%	Heavy Clay	24	15.6	60.4	0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M	77-87	82	15	6317105	462368	17%	7.4	1	6.4	71	1.82	25.8	36.3	0.95	8.2	11.5	7.55	123	173.2	0.05	1	1.4	0.49	12	16.9	8.29	94.2	132.7	2.10E-02	482.2	7.14E-03	286.2	1.69E-02	540.6	278%	788%	407%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M	87-97	92	5	6317105	462368	13%	7.6	1.64	5.7	61	5.06	61.7	101.1	2.66	19.6	32.1	11.2	157	257.4	0.12	3	4.9	0.81	18	29.5	15.5	151	247.5	2.81E-02	644.9	1.25E-02	500.8	2.46E-02	788.0	251%	495%	318%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M-OB	97-107	102	-5	6317105	462368	18%	7.5	6.8	11.7	86	24.8	428	497.7	21.4	224	260.5	56.3	1120	1302.3	1.4	48	55.8	1.61	49	57.0	95	1310	1523.3	1.21E-01	2786.3	9.19E-03	368.3	7.22E-02	2313.8	214%	74%	152%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M-OB	107-117	112	-15	6317105	462368	25%	7.5	8.93	16	99	23.3	462	466.7	30	360	363.6	82.5	1880	1899.0	1.8	72	72.7	2	70	70.7	129	2050	2070.7	2.07E-01	4762.1	7.76E-03	311.0	1.37E-01	4394.2	251%	67%	212%					0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-M-OB	117-137	127	-30	6317105	462368	22%	7.4	9.92	19.4	111	23	510	459.5	28	375	337.8	97.7	2490	2243.2	1.8	80	72.1	2.28	90	81.1	144	2560	2306.3	3.18E-01	7306.2	7.00E-03	280.7	2.09E-01	6688.7	326%	61%	290%	Clay	20	32.6	47.4	0.2	0.8	0	1	1999	0.31	0.66	0.97
Transect 3	T3-L	0-5	3	62.5	6317140	462343	51%	6.8	1.1	1.5	149	6.58	196	131.5	3.1	56	37.6	3.34	114	76.5	0.52	30	20.1	1.39	74	49.7	6.73	160	107.4	7.29E-03	167.5	9.99E-03	400.2	9.85E-03	315.7	219%	304%	294%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L	5-25	15	50	6317140	462343	23%	7.4	1.59	2.8	68	9.64	132	194.1	3.45	28.6	42.1	7.1	112	164.7	0.18	5	7.4	1.44	35	51.5	14.7	161	236.8	1.42E-02	327.1	1.46E-02	583.8	1.85E-02	593.3	199%	301%	251%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L	25-45	35	30	6317140	462343	17%	7.6	2.35	4.1	63	13	164	260.3	5.5	42	66.7	12.5	182	288.9	0.26	6	9.5	2.08	47	74.6	26.5	268	425.4	2.38E-02	547.1	1.32E-02	527.6	2.22E-02	710.3	189%	203%	167%	Clay Loam	42	20	38	0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L	45-55	50	15	6317140	462343	15%	7.7	3.14	7.5	56	13.7	153	273.2	7.24	49.1	87.7	24.4	314	560.7	<0.2	<6	#VALUE!	2.96	59	105.4	38.2	343	612.5	4.54E-02	1044.5	1.24E-02	497.7	2.83E-02	908.8	186%	182%	148%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L	55-65	60	5	6317140	462343	13%	7.7	4.36	10.2	59	14.6	171	289.8	10.2	72.8	123.4	35.7	483	818.6	0.31	7	11.9	4.36	91	154.2	50.9	478	810.2	7.13E-02	1638.8	1.19E-02	476.5	3.65E-02	1170.4	200%	164%	144%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L-OB	65-75	70	-5	6317140	462343	14%	7.7	6.67	11.5	58	23.1	267	460.3	22.6	158	272.4	55	728	1255.2	1.1	24	41.4	3.9	80	137.9	88.9	820	1413.8	1.00E-01	2308.7	1.02E-02	410.5	5.58E-02	1790.4	184%	89%	127%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L-OB	75-85	80	-15	6317140	462343	16%	7.7	7.86	13.1	59	22.9	270	457.6	30.4	217	367.8	67.6	917	1554.2	1.5	34	57.6	4.04	84	142.4	112	1060	1796.6	1.26E-01	2900.8	9.01E-03	361.1	7.97E-02	2556.5	187%	79%	142%					0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-L-OB	85-105	95	-30	6317140	462343	19%	7.7	9.73	16.4	64	22.7	292	456.3	37.3	290	453.1	90.1	1330	2078.1	1.7	43	67.2	5.7	130	203.1	143	1470	2296.9	1.84E-01	4230.3	7.85E-03	314.5	1.25E-01	4012.5	204%	69%	175%	Clay Loam	44	27.6	28.4	0.2	0.8	0	1	1999	0.12	0.53	0.65
Transect 3	T3-T	0-8	4	64	6317166	462324	23%	7	0.78	1.8	85	3.56	60.7	71.4	1.76	18.1	21.3	3.01	59	69.4	0.34	11	12.9	0.7	21	24.7	4.58	62.4	73.4	7.05E-03	162.1	8.04E-03	322.2	8.30E-03	266.2	234%	451%	363%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T	8-28	18	50	6317166	462324	15%	7.6	1.29	3.1	56	5.94	65.9	117.7	2.53	17	30.4	6.46	82	146.4	0.17	4	7.1	1.08	21	37.5	10.6	94	167.9	1.52E-02	348.5	1.44E-02	575.8	1.93E-02	618.2	238%	489%	368%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T	28-48	38	30	6317166	462324	11%	7.6	3.32	5.5	49	21.6	212	432.7	9.21	54.6	111.4	21.4	241	491.8	0.3	6	12.2	2.81	49	100.0	46.9	368	751.0	3.57E-02	820.4	1.30E-02	519.6	2.48E-02	795.3	167%	120%	106%	Clay Loam	43.4	26.2	30.4	0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T	48-58	53	15	6317166	462324	11%	7.8	3.4	6.8	49	17.9	177	361.2	8.77	52.5	107.1	24.7	281	573.5	0.31	6	12.2	2.94	52	106.1	45.9	363	740.8	4.26E-02	979.2	1.23E-02	492.1	2.78E-02	891.5	171%	136%	120%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T	58-68	63	5	6317166	462324	13%	7.8	3.39	9.7	52	10.5	109	209.6	7	44	84.6	28.6	342	657.7	0.3	6	11.5	3.52	65	125.0	39.7	330	634.6	5.61E-02	1290.0	1.14E-02	455.4	3.40E-02	1089.3	196%	217%	172%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T-OB	68-78	73	-5	6317166	462324	18%	7.4	5.89	8.4	99	25	493	498.0	24.2	288	290.9	41.8	949	958.6	1.2	46	46.5	2.18	76	76.8	83.8	1320	1333.3	9.99E-02	2297.0	9.68E-03	388.0	6.45E-02	2069.0	240%	78%	155%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T-OB	78-88	83	-15	6317166	462324	23%	7.4	6.72	10	98	24.4	481	490.8	30.1	358	365.3	52	1180	1204.1	1.6	60	61.2	2.17	76	77.6	97.4	1530	1561.2	1.21E-01	2786.1	8.94E-03	358.4	8.39E-02	2690.3	231%	73%	172%					0.2	0.8	0	1	1999	0.22	0.46	0.68
Transect 3	T3-T-OB	88-108	98	-30	6317166	462324	25%	7.5	7.17	11.4	94	24.2	457	486.2	29.7	340	361.7	59	1280	1361.7	1.6	58	61.7	2.41	81	86.2	103	1560	1659.6	1.27E-01	2921.2	8.82E-03	353.6	8.51E-02	2728.5	215%	73%	164%	Clay	26.4	25.2	48.4	0.2	0.8	0	1	1999	0.22	0.46	0.68

								Detailed Salinity (Saturated Paste)																						Estimated In-situ Porewater Concentrations (PHREEQ/C)						Ratio of Phreeq/c concetnrations to sat paste				Particle Size Analysis										
Transect	Position	Depth (cm)	Point Depth	Ht above Interface	Northing (m)	Easting (m)	MC	pH	EC	SAR	Sat%	Calcium	Calcium	Calcium	Magnesium	Magnesium	Magnesium	Sodium	Sodium	Sodium	Potassium	Potassium	Potassium	Chloride	Chloride	Chloride	Sulfate-S	Sulfate-S	Sulfate-S	Sodium	Sodium	Calcium	Calcium	Sulfate-S	Sulfate-S	Sodium	Calcium	Sulfate-S	Texture	Sand	Silt	Clay	Prescribed Peat Thickness	Prescribed Till Thickness	Prescribed Non-Sodic Thickness	Prescribed Total Thickness	Year of Soil Placement	Measured Peat Thickness	Measured Till Thickness	Measured Total Thickness
																																								0µm - 2mm	2µm - 50µm	<2 µm								
			cm	cm			%	pH	dS/m		%	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	mol/L	mg/L	mol/L	mg/L	mol/L	mg/L	PhrC/Sat Paste	PhrC/Sat Paste	PhrC/Sat Paste		% weight	% weight	% weight	m	m	m	m		m	m	m
Transect 4	T4-C	0-7	4	63.5	6317214	462648	69%	5.9	1.08	0.8	168	8.32	278	165.5	3.52	71.3	42.4	2.05	79	47.0	0.41	27	16.1	0.61	36	21.4	9.91	266	158.3	4.03E-03	92.8	1.07E-02	428.3	1.20E-02	385.1	197%	259%	243%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C	7-27	17	50	6317214	462648	40%	7	0.88	0.6	101	6.68	135	133.7	2.57	31.4	31.1	1.34	31	30.7	0.11	4	4.0	0.45	16	15.8	6.29	102	101.0	2.53E-03	58.3	8.96E-03	359.3	8.01E-03	256.9	190%	269%	254%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C	27-47	37	30	6317214	462648	23%	7.1	2.59	1.4	71	29.3	418	588.7	10.4	89.4	125.9	6.44	105	147.9	<0.2	<7	#VALUE!	0.55	14	19.7	40.1	456	642.3	1.05E-02	240.5	1.48E-02	592.6	1.84E-02	588.6	163%	101%	92%	Clay Loam	38	27.6	34.4	0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C	47-57	52	15	6317214	462648	19%	7.1	2.79	4	59	19.4	228	386.4	9.81	69.7	118.1	15.4	208	352.5	<0.2	<6	#VALUE!	0.81	17	28.8	38.7	363	615.3	2.55E-02	586.2	1.30E-02	522.5	2.37E-02	761.0	166%	135%	124%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C	57-67	62	5	6317214	462648	15%	7.4	2.75	5.6	59	13	154	261.0	8.14	58.4	99.0	18.3	250	423.7	<0.2	<6	#VALUE!	0.91	19	32.2	35.4	335	567.8	3.40E-02	782.3	1.18E-02	471.3	2.84E-02	911.3	185%	181%	160%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C-OB	67-77	72	-5	6317214	462648	18%	7.3	6.02	8.4	89	24.6	440	494.4	26.8	291	327.0	42.7	879	987.6	1.3	47	52.8	1.22	38	42.7	89.2	1280	1438.2	9.44E-02	2170.9	9.36E-03	375.1	6.71E-02	2151.5	220%	76%	150%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C-OB	77-87	82	-15	6317214	462648	23%	7.4	7.98	11.9	95	22.9	434	456.8	38.9	446	469.5	66.3	1440	1515.8	1.8	65	68.4	1.62	54	56.8	122	1840	1936.8	1.70E-01	3907.9	7.92E-03	317.3	1.32E-01	4241.5	258%	69%	219%					0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-C-OB	87-107	97	-30	6317214	462648	24%	7.4	9.83	15.8	99	22.7	449	453.5	41.5	498	503.0	89.6	2040	2060.6	2	78	78.8	2.17	76	76.8	149	2360	2383.8	2.56E-01	5877.2	7.18E-03	287.9	1.94E-01	6206.1	285%	63%	260%	Clay	20.4	30.8	48.8	0.2	0.3	0.5	1	2001	0.2	0.47	0.67
Transect 4	T4-U	0-5	3	182.5	6317245	462632	30%	7.2	0.72	0.8	84	4.05	68	81.0	2.47	25.1	29.9	1.45	28	33.3	0.07	2	2.4	0.4	12	14.3	4.28	57.6	68.6	2.84E-03	65.2	6.24E-03	250.1	6.06E-03	194.4	196%	309%	283%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	5-25	15	170	6317245	462632	20%	7.7	0.53	1.3	61	2.5	30.5	50.0	1.31	9.7	15.9	1.74	24	39.3	0.05	1	1.6	0.26	6	9.8	2.36	23.1	37.9	3.49E-03	80.3	4.53E-03	181.7	3.64E-03	116.8	204%	363%	308%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	25-45	35	150	6317245	462632	27%	7.3	1.57	1.9	72	10	145	201.4	5.8	50.8	70.6	5.35	89	123.6	0.11	3	4.2	0.27	7	9.7	17.2	199	276.4	1.01E-02	232.4	1.34E-02	538.8	2.05E-02	656.4	188%	268%	237%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	45-65	55	130	6317245	462632	47%	6.9	2.95	2.7	103	25.9	534	518.4	13.5	169	164.1	12.2	288	279.6	<0.2	<10	#VALUE!	0.26	10	9.7	47.1	777	754.4	1.88E-02	431.2	1.22E-02	490.7	2.42E-02	777.3	154%	95%	103%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	65-85	75	110	6317245	462632	18%	7.1	2.52	2.4	53	21.8	232	437.7	9.72	62.6	118.1	9.5	116	218.9	<0.2	<5	#VALUE!	0.21	4	7.5	37.4	319	601.9	1.46E-02	336.3	1.31E-02	526.7	2.10E-02	674.9	154%	120%	112%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	85-105	95	90	6317245	462632	15%	7.1	1.91	2.1	48	13.2	126	262.5	6.66	38.6	80.4	6.66	74	154.2	0.12	2	4.2	0.32	6	12.5	23.8	183	381.3	1.16E-02	266.2	1.31E-02	524.4	2.07E-02	663.1	173%	200%	174%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	105-125	115	70	6317245	462632	13%	7.2	1.26	2.3	46	6.12	56	121.7	3.79	21	45.7	5.13	54	117.4	0.09	2	4.3	0.54	9	19.6	12.6	92.8	201.7	1.10E-02	252.2	1.29E-02	515.5	2.14E-02	685.0	215%	423%	340%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	125-145	135	50	6317245	462632	15%	7.2	1.58	4.2	48	5.42	52.3	109.0	3.72	21.7	45.2	9.07	101	210.4	0.12	2	4.2	0.91	16	33.3	15	115	239.6	1.95E-02	448.1	1.18E-02	472.3	2.37E-02	760.8	213%	433%	318%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	145-165	155	30	6317245	462632	18%	7.5	2.09	7.2	50	5.51	55.3	110.6	3.74	22.7	45.4	15.5	179	358.0	0.19	4	8.0	1.05	19	38.0	20.7	166	332.0	3.25E-02	746.2	1.13E-02	454.4	2.87E-02	919.3	208%	411%	277%	Loam	37.4	37.2	25.4	0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	165-175	170	15	6317245	462632	11%	7.3	1.99	9.3	43	3.69	31.7	73.7	2.41	12.6	29.3	16.3	162	376.7	0.13	2	4.7	0.73	11	25.6	17.8	122	283.7	4.13E-02	949.9	1.16E-02	463.5	3.00E-02	962.7	252%	629%	339%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U	175-185	180	5	6317245	462632	12%	7.2	3.1	12.8	41	6.12	50.6	123.4	3.98	19.9	48.5	28.8	274	668.3	<0.2	<4	#VALUE!	1.05	15	36.6	32	212	517.1	6.03E-02	1387.3	1.10E-02	440.8	3.61E-02	1158.4	208%	357%	224%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U-OB	185-195	190	-5	6317245	462632	25%	7.2	5.19	11.8	107	14.7	316	295.3	10.8	141	131.8	42	1040	972.0	1.1	45	42.1	0.65	25	23.4	63.6	1090	1018.7	9.39E-02	2159.2	9.34E-03	374.4	5.76E-02	1847.8	222%	127%	181%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U-OB	195-205	200	-15	6317245	462632	23%	7.3	5.04	15.7	112	8.56	192	171.4	7.19	97.5	87.1	44.2	1140	1017.9	0.9	39	34.8	0.9	36	32.1	58.6	1050	937.5	1.16E-01	2673.2	8.45E-03	338.6	7.29E-02	2337.9	263%	198%	249%					0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-U-OB	205-225	215	-30	6317245	462632	21%	7.3	6.19	19.8	112	9.72	219	195.5	8.41	114	101.8	59.7	1540	1375.0	1.3	56	50.0	1.67	66	58.9	73.9	1330	1187.5	1.74E-01	3992.9	8.21E-03	329.0	9.79E-02	3138.8	290%	168%	264%	Clay Loam	22.4	39.2	38.4	0.2	0.8	0	1	1999	0.04	1.81	1.85
Transect 4	T4-M	0-12	6	86	6317280	462614	46%	6.8	1.1	0.7	112	7.76	174	155.4	3.7	50	44.6	1.75	45	40.2	0.33	14	12.5	0.88	35	31.3	6.1	109	97.3	3.25E-03	74.6	9.25E-03	370.7	7.50E-03	240.5	186%	239%	247%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M	12-32	22	70	6317280	462614	26%	7.1	1.15	0.8	75	8.56	128	170.7	3.87	35	46.7	2.03	35	46.7	0.09	3	4.0	1.67	44	58.7	5.97	71.3	95.1	3.87E-03	89.0	1.12E-02	449.8	8.59E-03	275.5	191%	264%	290%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M	32-52	42	50	6317280	462614	12%	7.5	1.2	1.2	54	8.35	90.8	168.1	3.42	22.5	41.7	2.91	36	66.7	0.07	1	1.9	0.51	10	18.5	11.2	97	179.6	6.50E-03	149.3	1.56E-02	623.7	1.71E-02	547.5	224%	371%	305%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M	52-72	62	30	6317280	462614	11%	7.6	1.79	3.8	50	8.62	86.8	173.6	3.23	19.7	39.4	9.29	108	216.0	0.08	2	4.0	0.39	7	14.0	18	145	290.0	1.94E-02	446.6	1.34E-02	535.2	2.08E-02	666.7	207%	308%	230%	Clay Loam	41	26.4	32.6	0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M	72-82	77	15	6317280	462614	12%	7.5	4.71	6.9	53	24.3	258	486.8	11.6	74.9	141.3	29.3	358	675.5	<0.2	<5	#VALUE!	0.41	8	15.1	60.1	511	964.2	4.75E-02	1092.3	1.17E-02	470.9	3.09E-02	990.5	162%	97%	103%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M	82-92	87	5	6317280	462614	12%	7.6	5.69	8.6	56	22.9	254	453.6	16.9	113	201.8	38.4	490	875.0	0.34	7	12.5	0.4	8	14.3	74.3	660	1178.6	6.43E-02	1478.1	1.02E-02	408.8	4.33E-02	1388.1	169%	90%	118%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M-OB	92-102	97	-5	6317280	462614	18%	7.6	7.1	10	90	23.3	420	466.7	30.8	336	373.3	52.2	1080	1200.0	1.2	43	47.8	0.36	12	13.3	98	1410	1566.7	1.26E-01	2897.9	8.73E-03	349.9	9.07E-02	2906.8	241%	75%	186%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M-OB	102-112	107	-15	6317280	462614	20%	7.5	7.95	11	92	22.6	418	454.3	36.9	413	448.9	59.9	1280	1391.3	1.5	54	58.7	0.4	13	14.1	112	1660	1804.3	1.54E-01	3530.2	8.14E-03	326.3	1.20E-01	3834.6	254%	72%	213%					0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-M-OB	112-132	122	-30	6317280	462614	18%	7.5	8.62	11.8	98	21.9	430	438.8	41.5	493	503.1	66.3	1500	1530.6	1.4	56	57.1	0.52	18	18.4	127	1990	2030.6	2.10E-01	4816.6	7.33E-03	293.7	1.81E-01	5803.1	315%	67%	286%	lty Clay Loa	12	48.4	39.6	0.2	0.8	0	1	1999	0.19	0.73	0.92
Transect 4	T4-L	0-5	3	142.5	6317329	462591	68%	6.8	1.12	0.5	131	7.42	194	148.1	3.47	55	42.0	1.14	34	26.0	0.62	32	24.4	0.48	22	16.8	4.42	92.6	70.7	1.82E-03	41.8	6.78E-03	271.7	4.24E-03	136.0	161%	183%	192%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	5-25	15	130	6317329	462591	34%	7.1	1.03	0.6	78	8.02	125	160.3	3.23	30.6	39.2	1.42	26	33.3	0.21	6	7.7	0.72	20	25.6	2.34	29.2	37.4	2.28E-03	52.3	7.09E-03	284.2	2.70E-03	86.7	157%	177%	232%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	25-45	35	110	6317329	462591	16%	7.5	0.6	1.4	50	3.09	31	62.0	1.13	6.9	13.8	1.97	23	46.0	0.05	1	2.0	0.37	6	12.0	2.03	16.3	32.6	3.96E-03	91.1	5.74E-03	230.1	3.20E-03	102.5	198%	371%	315%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	45-65	55	90	6317329	462591	10%	7.6	0.88	1.8	53	3.97	42	79.2	2.12	13.6	25.7	3.24	40	75.5	0.06	1	1.9	0.23	4	7.5	5.86	49.7	93.8	8.64E-03	198.7	1.30E-02	522.7	1.50E-02	480.4	263%	660%	512%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	65-85	75	70	6317329	462591	11%	7.6	1.46	2.3	57	7.48	85.5	150.0	4.1	28.4	49.8	5.55	73	128.1	0.04	<1	#VALUE!	0.18	4	7.0	14.3	131	229.8	1.29E-02	297.3	1.40E-02	561.3	2.03E-02	651.3	232%	374%	283%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	85-105	95	50	6317329	462591	12%	7.6	1.32	3	52	5.72	59.6	114.6	2.96	18.6	35.8	6.2	74	142.3	0.06	1	1.9	0.23	4	7.7	11.6	96.5	185.6	1.48E-02	339.8	1.38E-02	551.8	2.05E-02	657.7	239%	481%	354%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	105-125	115	30	6317329	462591	15%	7.7	1.3	5.2	53	3.32	35.4	66.8	1.73	11.2	21.1	8.26	101	190.6	0.04	<1	#VALUE!	0.25	5	9.4	9.69	82.7	156.0	1.94E-02	445.5	8.97E-03	359.4	1.67E-02	535.8	234%	538%	343%	Sandy Clay	46	18.4	35.6	0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	125-135	130	15	6317329	462591	17%	7.8	1.46	8.3	66	2.26	29.8	45.2	1.3	10.4	15.8	11.1	169	256.1	<0.03	<1	#VALUE!	0.28	6	9.1	10.6	112	169.7	3.04E-02	698.1	8.53E-03	341.7	2.04E-02	653.7	273%	757%	385%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L	135-145	140	5	6317329	462591	17%	7.7	2.26	8.6	72	4.69	67.2	93.3	3.26	28.2	39.2	17.1	282	391.7	0.08	2	2.8	0.29	7	9.7	20.6	236	327.8	4.31E-02	991.4	1.14E-02	458.1	3.13E-02	1003.4	253%	491%	306%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L-OB	145-155	150	-5	6317329	462591	25%	7.3	6.35	8.9	106	23.3	495	467.0	22.7	292	275.5	42.7	1040	981.1	1.3	54	50.9	0.28	11	10.4	85	1440	1358.5	9.43E-02	2167.0	9.12E-03	365.6	6.69E-02	2144.9	221%	78%	158%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L-OB	155-165	160	-15	6317329	462591	26%	6.4	7.87	11.3	100	22.3	447	447.0	35	424	424.0	60.4	1390	1390.0	1.7	65	65.0	0.45	16	16.0	111	1780	1780.0	1.43E-01	3289.4	8.40E-03	336.8	1.07E-01	3428.4	237%	75%	193%					0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-L-OB	165-185	175	-30	6317329	462591	25%	7.4	8.71	14.2	97	22	427	440.2	36.4	427	440.2	76.7	1710	1762.9	1.8	67	69.1	0.66	23	23.7	130	2010	2072.2	1.96E-01	4498.9	7.66E-03	307.0	1.45E-01	4657.8	255%	70%	225%	Clay	22	32	46	0.2	0.8	0	1	1999	0.23	1.22	1.45
Transect 4	T4-T	0-16	8	88	6317347	462578	27%	7.2	1.63	0.8	71	11.9	168	236.6	5.81	49.7	70.0	2.5	41	57.7	0.44	12	16.9	1	25	35.2	9.86	112	157.7	4.45E-03	102.4	1.31E-02	526.9	1.30E-02	416.2	177%	223%	264%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T	16-36	26	70	6317347	462578	25%	7.4	0.64	1.1	75	3.16	47.6	63.5	1.52	13.8	18.4	1.69	29	38.7	0.06	2	2.7	0.45	12	16.0	2.2	26.5	35.3	3.42E-03	78.5	5.42E-03	217.1	3.33E-03	106.8	203%	342%	302%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T	36-56	46	50	6317347	462578	24%	7.3	0.56	2.4	83	1.61	26.7	32.2	0.9	9.1	11.0	2.69	51	61.4	0.03	<1	#VALUE!	0.46	13	15.7	3.33	44.3	53.4	6.14E-03	141.1	3.85E-03	154.3	5.72E-03	183.5	230%	480%	344%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T	56-76	66	30	6317347	462578	17%	7.5	1.35	3.2	72	5.56	80.1	111.3	2.78	24.2	33.6	6.54	108	150.0	0.05	1	1.4	0.33	8	11.1	12.1	140	194.4	1.61E-02	369.1	1.31E-02	525.0	2.13E-02	682.4	246%	472%	351%	Clay	25	18.4	56.6	0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T	76-86	81	15	6317347	462578	14%	7.6	2.09	5.4	60	9	107	178.3	4.45	32.1	53.5	14	193	321.7	<0.2	<6	#VALUE!	0.36	8	13.3	23.9	228	380.0	2.94E-02	676.6	1.24E-02	495.7	2.51E-02	806.3	210%	278%	212%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T	86-96	91	5	6317347	462578	14%	7.5	2.68	7.4	63	9.86	125	198.4	5.63	43.2	68.6	20.6	300	476.2	<0.2	<6	#VALUE!	0.37	8	12.7	31.2	317	503.2	4.28E-02	984.5	1.18E-02	472.9	2.99E-02	957.6	207%	238%	190%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T-OB	96-106	101	-5	6317347	462578	14%	7.5	5.05	7.3	62	25	309	498.4	17.6	132	212.9	33.8	481	775.8	0.61	15	24.2	0.37	8	12.9	71.8	710	1145.2	5.81E-02	1336.7	1.08E-02	433.1	3.93E-02	1261.5	172%	87%	110%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T-OB	106-116	111	-15	6317347	462578	15%	7.5	5.58	8.4	67	23	307	458.2	20	162	241.8	38.7	596	889.6	0.63	16	23.9	0.33	8	11.9	77.9	834	1244.8	7.05E-02	1621.1	9.91E-03	397.2	4.90E-02	1571.8	182%	87%	126%					0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 4	T4-T-OB	116-136	126	-30	6317347	462578	16%	7.4	5.35	7.4	67	24.4	326	486.6	21.8	176	262.7	35.6	548	817.9	0.94	24	35.8	0.42	10	14.9	76.7	820	1223.9	6.41E-02	1474.2	1.04E-02	417.5	4.53E-02	1453.6	180%	86%	119%	Clay	31	27	42	0.2	0.8	0	1	1999	0.19	0.77	0.96
Transect 5	T5-C	0-13	7	86.5	6317147	462777	34%	7.5	0.98	0.8	87	7.06	123	141.4	2.17	23	26.4	1.65	33	37.9	0.17	6	6.9	0.56	17	19.5	4.95	69.1	79.4	3.00E-03	68.9	8.61E-03	345.3	6.34E-03	203.3	182%	244%	256%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C	13-33	23	70	6317147	462777	25%	7.4	1.07	1.4	65	7.06	92.4	142.2	2.55	20.2	31.1	3.08	46	70.8	0.07	2	3.1	0.77	18	27.7	8.34	87.4	134.5	5.67E-03	130.4	1.01E-02	403.9	1.07E-02	344.0	184%	284%	256%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C	33-53	43	50	6317147	462777	18%	7.6	1.57	2	58	10.6	123	212.1	4.62	32.3	55.7	5.4	72	124.1	0.08	2	3.4	0.8	16	27.6	13.5	125	215.5	1.06E-02	244.1	1.51E-02	606.6	1.82E-02	582.5	197%	286%	270%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C	53-73	63	30	6317147	462777	18%	7.7	3.29	4.1	54	26.5	288	533.3	11.9	77.8	144.1	17.9	223	413.0	<0.2	<5	#VALUE!	1.43	28	51.9	51.3	445	824.1	2.65E-02	609.1	1.25E-02	501.2	2.43E-02	779.6	148%	94%	95%	Loam	45	29.4	25.6	0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C	73-83	78	15	6317147	462777	16%	7.6	3.11	8.5	64	11.3	144	225.0	6.73	51.9	81.1	25.6	375	585.9	<0.2	<6	#VALUE!	1.68	38	59.4	39.7	404	631.3	4.95E-02	1138.8	1.07E-02	430.7	3.42E-02	1098.1	194%	191%	174%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C	83-93	88	5	6317147	462777	15%	7.8	3.24	9.7	59	8.94	105	178.0	6.02	42.9	72.7	26.5	359	608.5	<0.2	<6	#VALUE!	1.93	40	67.8	39.1	368	623.7	5.24E-02	1204.5	9.99E-03	400.4	3.81E-02	1220.5	198%	225%	196%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C-OB	93-103	98	-5	6317147	462777	16%	7.5	6.38	10.6	71	22.3	315	443.7	21.3	182	256.3	49.6	808	1138.0	1.1	30	42.3	1.54	38	53.5	89.8	1020	1436.6	9.44E-02	2171.4	9.09E-03	364.3	6.33E-02	2030.0	191%	82%	141%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C-OB	103-113	108	-15	6317147	462777	20%	7.6	8.03	13.4	76	21.6	330	434.2	30.4	282	371.1	68.1	1200	1578.9	1.4	43	56.6	2.12	58	76.3	120	1470	1934.2	1.45E-01	3323.8	7.79E-03	312.3	1.08E-01	3476.6	211%	72%	180%					0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-C-OB	113-133	123	-30	6317147	462777	24%	7.5	9.35	16	96	20.9	400	416.7	35	405	421.9	84.7	1860	1937.5	1.7	64	66.7	2.41	82	85.4	138	2110	2197.9	2.27E-01	5207.4	7.27E-03	291.4	1.67E-01	5355.9	269%	70%	244%	Clay	23	32.4	44.6	0.2	0.3	0.5	1	2001	0.22	0.71	0.93
Transect 5	T5-U	0-16	8	68	6317162	462823	39%	6.6	1.75	2.6	89	9.35	167	187.6	5.36	58	65.2	7.16	147	165.2	0.16	6	6.7	0.53	17	19.1	1.75	25	28.1	1.12E-02	257.9	6.76E-03	270.8	1.98E-03	63.4	156%	144%	226%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U	16-36	26	50	6317162	462823	19%	7.2	4.84	6.5	57	24.2	278	487.7	15.4	107	187.7	29	382	670.2	<0.2	<6	#VALUE!	1.08	22	38.6	65	596	1045.6	4.27E-02	981.0	1.05E-02	422.2	3.44E-02	1104.4	146%	87%	106%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U	36-56	46	30	6317162	462823	20%	7.7	6.07	12.8	62	17.9	221	356.5	17.8	133	214.5	54.1	768	1238.7	0.31	7	11.3	3.63	80	129.0	82.9	820	1322.6	9.29E-02	2135.8	9.33E-03	374.0	5.79E-02	1857.8	172%	105%	140%	Clay Loam	38	26	36	0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U	56-66	61	15	6317162	462823	20%	7.9	6.03	15.6	63	13	163	258.7	14.6	111	176.2	58	839	1331.7	<0.2	<6	#VALUE!	4.21	94	149.2	76.7	771	1223.8	1.08E-01	2473.4	9.25E-03	370.8	6.31E-02	2022.7	186%	143%	165%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U	66-76	71	5	6317162	462823	20%	7.8	6.92	14.3	61	21.1	259	424.6	20.7	154	252.5	65.5	926	1518.0	0.34	8	13.1	4.38	95	155.7	94	924	1514.8	1.11E-01	2559.6	9.60E-03	384.9	6.20E-02	1986.6	169%	91%	131%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U-OB	76-86	81	-5	6317162	462823	26%	7.5	8.38	14.5	79	24.8	393	497.5	33.1	318	402.5	78.1	1420	1797.5	1.3	40	50.6	5.34	150	189.9	124	1570	1987.3	1.52E-01	3494.5	8.54E-03	342.4	9.63E-02	3086.4	194%	69%	155%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U-OB	86-96	91	-15	6317162	462823	24%	7.4	8.62	13.6	85	24.2	410	482.4	33.4	341	401.2	72.8	1420	1670.6	1.8	58	68.2	4.83	145	170.6	119	1610	1894.1	1.57E-01	3598.5	8.49E-03	340.4	1.02E-01	3271.9	215%	71%	173%					0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-U-OB	96-116	106	-30	6317162	462823	26%	7.4	8.88	16.2	86	25	432	502.3	28	293	340.7	83.3	1660	1930.2	1.7	58	67.4	6.52	200	232.6	122	1690	1965.1	1.74E-01	3995.1	8.53E-03	342.0	1.01E-01	3225.9	207%	68%	164%	lty Clay Loa	19	41.4	39.6	0.2	0.3	0.5	1	2001	0.33	0.43	0.76
Transect 5	T5-M	0-14	7	67	6317196	462927	20%	7.4	1.62	1.8	62	11.3	141	227.4	3.99	30.1	48.5	5.06	73	117.7	0.25	6	9.7	0.7	15	24.2	14.5	144	232.3	9.78E-03	224.8	1.51E-02	605.6	1.75E-02	561.0	191%	266%	242%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M	14-34	24	50	6317196	462927	17%	7.7	0.72	0.6	56	4.91	54.6	97.5	1.66	11.2	20.0	1.06	14	25.0	0.1	2	3.6	0.67	13	23.2	2.79	24.8	44.3	2.15E-03	49.4	8.58E-03	343.7	4.58E-03	146.8	198%	353%	331%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M	34-54	44	30	6317196	462927	19%	7.7	0.67	1.6	57	3.07	35.1	61.6	1.69	11.7	20.5	2.54	33	57.9	0.06	1	1.8	0.46	9	15.8	2.51	22.9	40.2	5.09E-03	116.9	5.53E-03	221.5	3.79E-03	121.6	202%	360%	303%	Clay	34	23.4	42.6	0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M	54-64	59	15	6317196	462927	15%	7.8	1.02	3.6	56	3.25	36.3	64.8	2.15	14.6	26.1	6	77	137.5	0.06	1	1.8	0.23	4	7.1	6.82	61	108.9	1.45E-02	333.5	8.95E-03	358.8	1.30E-02	417.5	243%	554%	383%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M	64-74	69	5	6317196	462927	13%	7.8	1.43	5	56	4	44.6	79.6	3.03	20.4	36.4	9.3	119	212.5	0.1	2	3.6	0.2	4	7.1	12.6	113	201.8	2.42E-02	557.1	1.26E-02	503.2	2.54E-02	814.4	262%	632%	404%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M-OB	74-84	79	-5	6317196	462927	15%	7.4	4.32	4.3	68	26.6	365	536.8	19.2	159	233.8	20.7	326	479.4	1.1	29	42.6	0.23	6	8.8	61.8	677	995.6	3.71E-02	851.9	1.19E-02	475.0	3.19E-02	1023.4	178%	88%	103%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M-OB	84-94	89	-15	6317196	462927	16%	7.4	4.91	5.1	72	26.2	379	526.4	24.3	212	294.4	25.5	423	587.5	1.4	39	54.2	0.22	6	8.3	70.6	816	1133.3	4.76E-02	1094.8	1.11E-02	444.2	3.96E-02	1271.1	186%	84%	112%					0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-M-OB	94-114	104	-30	6317196	462927	17%	6.5	5.65	5	68	26.6	364	535.3	39.4	326	479.4	29	457	672.1	1.2	33	48.5	0.3	7	10.3	87.7	960	1411.8	5.56E-02	1277.7	1.06E-02	423.0	5.32E-02	1705.5	190%	79%	121%	Clay Loam	28	34.4	37.6	0.5	0	0.5	1	1996	0.74	0	0.74
Transect 5	T5-L	0-8	4	64	6317220	463001	23%	7.6	1.43	1	68	10.8	146	214.7	3.8	31.2	45.9	2.8	44	64.7	0.8	21	30.9	0.8	19	27.9	5.52	60	88.2	4.96E-03	114.0	1.10E-02	439.2	8.14E-03	260.9	176%	205%	296%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L	8-28	18	50	6317220	463001	32%	7.5	0.87	0.5	83	6.68	110	132.5	2.12	21.3	25.7	1.14	22	26.5	0.24	8	9.6	0.46	14	16.9	3.06	40.6	48.9	2.01E-03	46.3	7.45E-03	298.7	3.97E-03	127.4	175%	225%	260%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L	28-48	38	30	6317220	463001	19%	7.6	0.55	0.9	57	2.95	33.9	59.5	1.2	8.4	14.7	1.37	18	31.6	0.13	3	5.3	0.31	6	10.5	1.79	16.5	28.9	2.67E-03	61.4	4.99E-03	200.1	2.68E-03	85.8	194%	336%	296%	Clay	38.6	19.8	41.6	0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L	48-58	53	15	6317220	463001	17%	7.8	1.47	4.2	52	5.58	57.6	110.8	2.65	16.5	31.7	8.63	102	196.2	0.15	3	5.8	0.31	6	11.5	13.2	109	209.6	1.86E-02	427.3	1.20E-02	481.3	2.07E-02	664.1	218%	435%	317%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L	58-68	63	5	6317220	463001	18%	7.7	2.31	8	57	6.95	79.3	139.1	3.98	27.4	48.1	18.7	246	431.6	<0.2	<6	#VALUE!	0.35	7	12.3	25.8	236	414.0	3.78E-02	869.7	1.11E-02	446.2	2.99E-02	960.1	202%	321%	232%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L-OB	68-78	73	-5	6317220	463001	27%	7.5	6.86	11.5	84	24.6	413	491.7	24.1	244	290.5	57	1100	1309.5	1.3	42	50.0	0.53	16	19.0	99.9	1340	1595.2	1.03E-01	2371.3	9.01E-03	361.1	6.84E-02	2193.4	181%	73%	137%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L-OB	78-88	83	-15	6317220	463001	28%	6.2	8.45	12.7	90	24.8	447	496.7	41	447	496.7	72.9	1510	1677.8	1.4	50	55.6	0.75	24	26.7	130	1880	2088.9	1.57E-01	3608.9	8.25E-03	330.6	1.15E-01	3696.5	215%	67%	177%					0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-L-OB	88-108	98	-30	6317220	463001	27%	7.2	9.34	14.6	95	23.6	449	472.6	40.6	468	492.6	82.9	1810	1905.3	1.8	66	69.5	0.64	22	23.2	142	2170	2284.2	2.00E-01	4595.4	7.59E-03	304.4	1.50E-01	4807.0	241%	64%	210%	Clay	23	25.4	51.6	0.5	0	0.5	1	1996	0.68	0	0.68
Transect 5	T5-T	0-14	7	187	6317229	463027	46%	6.9	1.25	1	96	8.67	166	172.9	3.83	44.5	46.4	2.46	54	56.3	0.38	14	14.6	0.74	25	26.0	5.04	77.4	80.6	3.94E-03	90.6	7.83E-03	313.7	5.26E-03	168.8	161%	181%	209%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	14-34	24	170	6317229	463027	18%	7.3	2.7	1.8	52	29.9	313	601.9	11.5	72.6	139.6	8.35	100	192.3	<0.2	<5	#VALUE!	0.74	14	26.9	46	385	740.4	1.19E-02	274.2	1.36E-02	543.2	1.97E-02	632.0	143%	90%	85%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	34-54	44	150	6317229	463027	17%	7.4	3.1	2.8	56	30.7	345	616.1	13.2	89.8	160.4	13.3	172	307.1	<0.2	<6	#VALUE!	1.26	25	44.6	51.8	466	832.1	2.00E-02	460.9	1.36E-02	546.3	2.16E-02	693.0	150%	89%	83%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	54-74	64	130	6317229	463027	12%	7.4	3	2.9	54	29.2	314	581.5	11.4	74.1	137.2	13.1	162	300.0	0.39	8	14.8	0.62	12	22.2	49.6	427	790.7	2.15E-02	494.2	1.41E-02	563.5	2.12E-02	679.0	165%	97%	86%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	74-94	84	110	6317229	463027	13%	7.4	3.07	3.4	59	28.9	340	576.3	10.3	73.2	124.1	15	202	342.4	0.45	10	16.9	0.5	10	16.9	49.5	465	788.1	2.48E-02	569.3	1.36E-02	545.7	2.20E-02	705.9	166%	95%	90%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	94-114	104	90	6317229	463027	17%	7.4	2.85	3.8	62	23.2	288	464.5	7.76	58.3	94.0	15.1	216	348.4	0.27	6	9.7	0.72	16	25.8	41.8	415	669.4	2.50E-02	575.7	1.31E-02	525.0	2.23E-02	713.5	165%	113%	107%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	114-134	124	70	6317229	463027	18%	7.4	2.25	4.4	62	13.7	168	271.0	4.82	35.9	57.9	13.4	190	306.5	<0.2	<6	#VALUE!	0.96	21	33.9	26.9	265	427.4	2.47E-02	568.5	1.34E-02	535.5	2.17E-02	695.4	186%	198%	163%	Clay Loam	38	24.4	37.6	0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	134-154	144	50	6317229	463027	19%	7.5	2.24	5.1	59	12.1	142	240.7	4.4	31.2	52.9	14.6	196	332.2	<0.2	<6	#VALUE!	1.17	24	40.7	26.3	247	418.6	2.62E-02	603.5	1.27E-02	507.9	2.29E-02	734.1	182%	211%	175%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	154-174	164	30	6317229	463027	23%	7.7	2.49	7.2	66	8.94	119	180.3	3.39	27.3	41.4	17.8	272	412.1	<0.2	<7	#VALUE!	1.2	28	42.4	26.3	280	424.2	3.38E-02	776.1	1.14E-02	458.4	2.68E-02	857.8	188%	254%	202%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	174-184	179	15	6317229	463027	20%	7.7	3	8	59	12.1	143	242.4	4.92	35.3	59.8	23.5	320	542.4	<0.2	<6	#VALUE!	1.31	28	47.5	36.1	342	579.7	4.06E-02	933.3	1.11E-02	446.6	2.94E-02	941.7	172%	184%	162%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T	184-194	189	5	6317229	463027	22%	7.7	2.92	8.9	61	9.92	122	200.0	4.5	33.5	54.9	23.9	338	554.1	<0.2	<6	#VALUE!	1.18	26	42.6	33.7	332	544.3	4.31E-02	991.5	1.10E-02	439.5	3.08E-02	986.4	179%	220%	181%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T-OB	194-204	199	-5	6317229	463027	24%	7.7	4.29	8	66	18.7	248	375.8	9.47	76	115.2	29.9	455	689.4	0.8	21	31.8	1.04	24	36.4	53.6	568	860.6	4.73E-02	1087.6	1.07E-02	429.9	3.37E-02	1081.5	158%	114%	126%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T-OB	204-214	209	-15	6317229	463027	14%	7.8	3.45	7.1	46	19.3	179	389.1	8.24	46.3	100.7	26.2	280	608.7	0.48	9	19.6	0.97	16	34.8	49.8	370	804.3	3.95E-02	909.1	1.13E-02	451.7	2.93E-02	939.6	149%	116%	117%					0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 5	T5-T-OB	214-234	224	-30	6317229	463027	13%	7.7	4.57	6.6	40	26.1	207	517.5	10.6	50.6	126.5	28.5	259	647.5	0.52	8	20.0	0.92	13	32.5	60.9	385	962.5	3.85E-02	885.7	1.14E-02	458.4	2.86E-02	917.2	137%	89%	95%	Sandy Loam	66	18	16	0.5	0	0.5	1	1996	0.1	1.84	1.94
Transect 6	T6-C	0-9	5	74.5	6317005	462746	48%	6	0.8	0.7	113	4.8	108	95.6	2.6	35.4	31.3	1.39	36	31.9	0.28	12	10.6	0.68	27	23.9	5.09	91.8	81.2	2.52E-03	58.0	6.05E-03	242.4	6.00E-03	192.3	182%	254%	237%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C	9-29	19	60	6317005	462746	21%	7	0.84	1.1	56	5.03	56.6	101.1	2.61	17.8	31.8	2.25	29	51.8	0.04	<1	#VALUE!	0.47	9	16.1	4.27	38.4	68.6	4.14E-03	95.1	7.41E-03	297.1	5.70E-03	182.8	184%	294%	267%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C	29-49	39	40	6317005	462746	18%	7.5	1.29	3	56	5.96	66.3	118.4	2.8	18.8	33.6	6.22	79	141.1	0.05	1	1.8	0.74	14	25.0	11	97.7	174.5	1.31E-02	300.1	1.17E-02	470.4	1.71E-02	549.6	213%	397%	315%	Clay	33	23	44	0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C	49-59	54	25	6317005	462746	23%	7.4	2.68	6.4	72	12.2	174	241.7	6.28	54.3	75.4	19.4	319	443.1	<0.2	<7	#VALUE!	1.32	34	47.2	32.2	369	512.5	3.61E-02	829.8	1.20E-02	479.9	2.74E-02	878.6	187%	199%	171%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C	59-69	64	15	6317005	462746	21%	7.5	4.29	7.7	68	18.7	257	377.9	10.6	87.9	129.3	29.6	466	685.3	<0.2	<7	#VALUE!	1.67	40	58.8	52.2	573	842.6	5.05E-02	1160.4	1.13E-02	452.8	3.32E-02	1063.0	169%	120%	126%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C	69-79	74	5	6317005	462746	16%	7.7	5.14	8.7	55	20.8	229	416.4	13.5	89.9	163.5	36	456	829.1	0.29	6	10.9	1.81	35	63.6	65.7	579	1052.7	5.67E-02	1303.0	1.03E-02	414.4	3.87E-02	1240.6	157%	100%	118%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C-OB	79-89	84	-5	6317005	462746	27%	7.6	7.69	12.2	91	23.5	429	471.4	30.4	336	369.2	63.5	1330	1461.5	1.6	59	64.8	2.11	68	74.7	113	1650	1813.2	1.32E-01	3030.5	8.32E-03	333.3	9.38E-02	3008.7	207%	71%	166%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C-OB	89-99	94	-15	6317005	462746	27%	7.6	7.94	12.4	89	23.7	424	476.4	32.8	354	397.8	66.2	1360	1528.1	1.7	60	67.4	2.07	65	73.0	120	1710	1921.3	1.37E-01	3160.2	8.06E-03	322.8	1.02E-01	3272.2	207%	68%	170%					0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-C-OB	99-119	109	-30	6317005	462746	24%	7.6	9.16	14.3	102	23.3	472	462.7	39.7	487	477.5	80.3	1870	1833.3	2	81	79.4	1.95	70	68.6	144	2340	2294.1	2.23E-01	5121.9	7.08E-03	283.8	1.80E-01	5771.8	279%	61%	252%	Clay	18	33.6	48.4	0.2	0.3	0.5	1	2001	0.13	0.66	0.79
Transect 6	T6-U	0-12	6	66	6316997	462771	30%	6.2	0.99	0.8	83	6.22	103	124.1	3.29	33	39.8	1.8	34	41.0	0.37	12	14.5	0.72	21	25.3	6.77	89.8	108.2	3.54E-03	81.5	9.43E-03	377.9	9.44E-03	302.8	199%	305%	280%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U	12-32	22	50	6316997	462771	24%	7.2	0.77	0.7	68	4.98	67.3	99.0	2.48	20.3	29.9	1.4	22	32.4	0.07	2	2.9	0.42	10	14.7	2.96	32.1	47.2	2.62E-03	60.3	7.05E-03	282.7	4.15E-03	133.0	187%	286%	282%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U	32-52	42	30	6316997	462771	16%	7.5	0.83	1.9	41	3.85	31.9	77.8	2.15	10.8	26.3	3.35	32	78.0	0.06	1	2.4	0.31	4	9.8	5.11	33.9	82.7	5.91E-03	135.8	5.71E-03	229.0	6.40E-03	205.1	174%	294%	248%	Clay Loam	31	39	30	0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U	52-62	57	15	6316997	462771	17%	7.4	1.62	3	58	8.03	93.3	160.9	4.69	33	56.9	7.66	102	175.9	0.1	2	3.4	0.26	5	8.6	16.3	151	260.3	1.58E-02	362.8	1.33E-02	533.5	2.17E-02	695.0	206%	332%	267%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U	62-72	67	5	6316997	462771	17%	7.7	1.69	5.1	55	5.07	55.4	100.7	3.64	24.1	43.8	10.7	135	245.5	0.17	4	7.3	0.28	5	9.1	16.2	142	258.2	2.41E-02	555.2	1.18E-02	474.7	2.62E-02	840.8	226%	471%	326%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U-OB	72-82	77	-5	6316997	462771	25%	7.4	5.05	5.7	78	26.1	407	521.8	24.6	232	297.4	28.5	512	656.4	1.3	40	51.3	0.36	10	12.8	75.4	942	1207.7	4.80E-02	1103.2	1.03E-02	413.9	4.21E-02	1350.6	168%	79%	112%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-U-OB	82-92	87	-15	6316997	462771	25%	7.3	5.75	6.5	76	25.1	385	506.6	31.7	294	386.8	34.6	609	801.3	1.5	44	57.9	0.4	11	14.5	89.4	1090	1434.2	5.90E-02	1356.3	9.36E-03	375.1	5.51E-02	1766.3	169%	74%	123%					0.2	0.3	0.5	1	2001	0.27	0.45	0.72

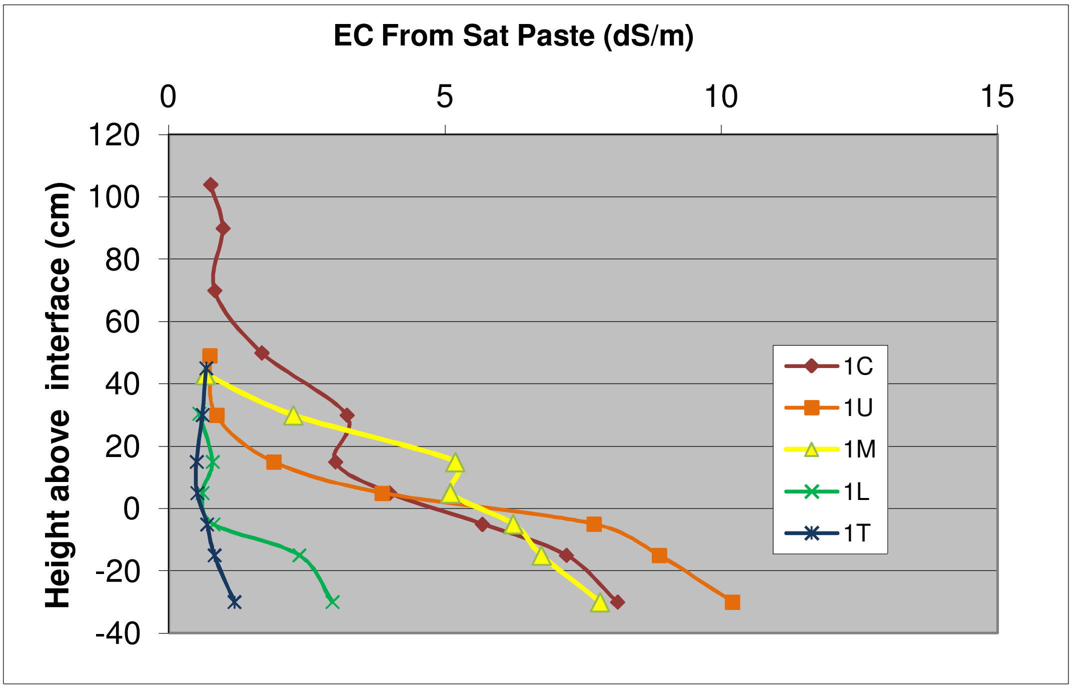
								Detailed Salinity (Saturated Paste)																						Estimated In-situ Porewater Concentrations (PHREEQ/C)						Ratio of Phreeq/c concetnrations to sat paste				Particle Size Analysis										
Transect	Position	Depth (cm)	Point Depth	Ht above Interface	Northing (m)	Easting (m)	MC	pH	EC	SAR	Sat%	Calcium	Calcium	Calcium	Magnesium	Magnesium	Magnesium	Sodium	Sodium	Sodium	Potassium	Potassium	Potassium	Chloride	Chloride	Chloride	Sulfate-S	Sulfate-S	Sulfate-S	Sodium	Sodium	Calcium	Calcium	Sulfate-S	Sulfate-S	Sodium	Calcium	Sulfate-S	Texture	Sand 50µm - 2mm	Silt 2µm - 50µm	Clay <2 µm	Prescribed Peat Thickness	Prescribed Till Thickness	Prescribed Non-Sodic Thickness	Prescribed Total Thickness	Year of Soil Placement	Measured Peat Thickness	Measured Till Thickness	Measured Total Thickness
			cm	cm			%	pH	dS/m		%	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	mol/L	mg/L	mol/L	mg/L	mol/L	mg/L	PhrC/Sat Paste	PhrC/Sat Paste	PhrC/Sat Paste		% weight	% weight	% weight	m	m	m	m		m	m	m
Transect 6	T6-U-OB	92-112	102	-30	6316997	462771	23%	7.4	6.59	8.3	78	24.9	387	496.2	36.6	343	439.7	45.8	818	1048.7	1.2	37	47.4	0.49	14	17.9	104	1290	1653.8	8.60E-02	1977.6	8.83E-03	354.1	7.37E-02	2361.9	189%	71%	143%	Clay	23	37	40	0.2	0.3	0.5	1	2001	0.27	0.45	0.72
Transect 6	T6-M	0-20	10	110	6316986	462801	92%	5.6	1.35	1.9	264	6.7	354	134.1	4.66	149	56.4	4.44	270	102.3	0.6	62	23.5	0.55	51	19.3	12.8	541	204.9	1.06E-02	242.8	1.08E-02	433.5	1.85E-02	593.0	237%	323%	289%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	20-40	30	90	6316986	462801	19%	7.3	1.2	3.6	54	4.95	53.4	98.9	2.22	14.5	26.9	6.73	84	155.6	0.08	2	3.7	0.42	8	14.8	8.44	72.8	134.8	1.37E-02	315.7	9.48E-03	379.9	1.23E-02	395.6	203%	384%	293%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	40-60	50	70	6316986	462801	20%	7.6	1.11	5.7	60	2.46	29.3	48.8	1.27	9.2	15.3	7.82	107	178.3	0.04	<1	#VALUE!	0.4	8	13.3	7.36	70.1	116.8	1.72E-02	395.2	5.85E-03	234.6	1.10E-02	352.8	222%	480%	302%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	60-80	70	50	6316986	462801	22%	7.6	1.91	7	69	5.02	68.9	99.9	2.6	21.6	31.3	13.6	214	310.1	0.06	2	2.9	0.74	18	26.1	16.7	184	266.7	3.14E-02	720.9	1.20E-02	479.1	2.60E-02	834.9	232%	480%	313%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	80-100	90	30	6316986	462801	12%	7.6	2.85	10	37	7.5	55.6	150.3	4.51	20.2	54.6	24.5	209	564.9	<0.2	<4	#VALUE!	0.58	8	21.6	32.2	191	516.2	4.63E-02	1063.4	1.08E-02	433.3	3.30E-02	1059.5	188%	288%	205%	Loam	39	34.6	26.4	0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	100-110	105	15	6316986	462801	17%	7.6	3.18	11.9	59	7.2	85.3	144.6	5.15	36.8	62.4	29.6	402	681.4	<0.2	<6	#VALUE!	0.6	13	22.0	36	341	578.0	6.17E-02	1418.7	1.06E-02	425.4	3.86E-02	1238.3	208%	294%	214%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M	110-120	115	5	6316986	462801	23%	7.7	4.34	14	71	7.82	111	156.3	6.96	59.6	83.9	38.1	621	874.6	<0.2	<7	#VALUE!	0.87	22	31.0	48	544	766.2	7.66E-02	1761.4	9.55E-03	382.7	4.92E-02	1576.1	201%	245%	206%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M-OB	120-130	125	-5	6316986	462801	26%	7.6	7.37	13.1	79	23.8	377	477.2	24.5	235	297.5	64.5	1180	1493.7	0.56	17	21.5	0.95	27	34.2	110	1400	1772.2	1.15E-01	2636.3	8.38E-03	335.8	7.86E-02	2521.5	176%	70%	142%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M-OB	130-140	135	-15	6316986	462801	28%	7.6	8.43	14.7	93	24.4	451	484.9	29	326	350.5	75.9	1620	1741.9	1.5	53	57.0	0.94	31	33.3	127	1880	2021.5	1.60E-01	3679.4	7.85E-03	314.6	1.11E-01	3561.5	211%	65%	176%					0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-M-OB	140-160	150	-30	6316986	462801	32%	7.6	8.54	15.7	105	23.7	497	473.3	27.4	348	331.4	79.3	1910	1819.0	1.7	68	64.8	1.02	38	36.2	129	2170	2066.7	1.76E-01	4040.1	7.66E-03	306.8	1.21E-01	3879.6	222%	65%	188%	Clay	18	32	50	0.2	0.3	0.5	1	2001	0.24	0.96	1.2
Transect 6	T6-L	0-4	2	122	6316976	462830	40%	7.6	1.27	0.6	88	9.28	164	186.4	3.6	38.4	43.6	1.55	31	35.2	0.99	34	38.6	0.8	25	28.4	4.46	62.9	71.5	2.46E-03	56.5	7.71E-03	309.0	4.91E-03	157.5	160%	166%	220%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	4-24	14	110	6316976	462830	17%	7.6	0.69	0.6	51	4.28	43.4	85.1	1.81	11.1	21.8	1.05	12	23.5	0.1	2	3.9	0.93	17	33.3	2.92	23.7	46.5	2.00E-03	46.1	6.89E-03	276.0	4.36E-03	139.9	196%	324%	301%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	24-44	34	90	6316976	462830	22%	7.5	0.72	1	66	4.13	54.8	83.0	1.85	14.9	22.6	1.82	28	42.4	0.05	1	1.5	0.46	11	16.7	3.77	40	60.6	3.66E-03	84.2	7.11E-03	285.0	5.80E-03	185.9	198%	343%	307%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	44-64	54	70	6316976	462830	18%	7.6	0.92	1.7	54	4.93	53.3	98.7	2.29	15	27.8	3.21	40	74.1	0.06	1	1.9	0.51	10	18.5	6.71	58.1	107.6	6.31E-03	145.0	8.54E-03	342.3	9.92E-03	318.0	196%	347%	296%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	64-84	74	50	6316976	462830	22%	7.6	1.74	4.2	56	7.58	85.7	153.0	3.84	26.3	47.0	10.1	131	233.9	0.04	<1	#VALUE!	0.7	14	25.0	17.1	155	276.8	1.93E-02	444.8	1.24E-02	496.8	2.21E-02	708.4	190%	325%	256%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	84-104	94	30	6316976	462830	23%	7.4	4.81	7.5	77	24.9	383	497.4	12.8	119	154.5	32.6	578	750.6	<0.2	<8	#VALUE!	1.08	30	39.0	64.2	792	1028.6	5.41E-02	1244.5	1.09E-02	437.2	3.54E-02	1136.6	166%	88%	110%	Clay	25	23	52	0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	104-114	109	15	6316976	462830	18%	7.4	6.17	12.8	59	23	270	457.6	12.2	86.4	146.4	53.6	724	1227.1	<0.2	<6	#VALUE!	1.02	21	35.6	82.9	779	1320.3	8.28E-02	1904.4	9.69E-03	388.2	4.85E-02	1554.8	155%	85%	118%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L	114-124	119	5	6316976	462830	18%	7.6	6.95	15.4	58	23.2	269	463.8	12	84.2	145.2	64.8	863	1487.9	0.31	7	12.1	1.29	26	44.8	95.5	885	1525.9	1.01E-01	2314.4	9.02E-03	361.4	5.85E-02	1875.4	156%	78%	123%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L-OB	124-134	129	-5	6316976	462830	24%	7.6	8.39	19.6	67	21.1	281	419.4	13.4	108	161.2	81.3	1250	1865.7	0.79	20	29.9	1.55	37	55.2	112	1200	1791.0	1.33E-01	3061.8	8.33E-03	333.7	7.80E-02	2501.9	164%	80%	140%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L-OB	134-144	139	-15	6316976	462830	27%	7.6	8.66	18.6	93	22.2	412	443.0	17.4	195	209.7	82.7	1770	1903.2	1.3	46	49.5	1.03	34	36.6	123	1820	1957.0	1.72E-01	3959.8	7.61E-03	304.8	1.10E-01	3524.5	208%	69%	180%					0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-L-OB	144-164	154	-30	6316976	462830	28%	7.6	9.27	19.6	100	23.1	463	463.0	19.3	235	235.0	90.3	2080	2080.0	1.5	58	58.0	1.15	41	41.0	132	2120	2120.0	2.05E-01	4712.9	7.45E-03	298.8	1.29E-01	4120.6	227%	65%	194%	Clay	20	37	43	0.2	0.3	0.5	1	2001	0.07	1.17	1.24
Transect 6	T6-T	0-16	8	68	6316969	462848	114%	6.6	1.74	2.4	227	10.2	465	204.8	4.92	135	59.5	6.48	339	149.3	0.68	60	26.4	1.17	94	41.4	13	474	208.8	1.14E-02	261.6	1.03E-02	411.2	1.29E-02	413.9	175%	201%	198%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T	16-36	26	50	6316969	462848	22%	7.2	3.32	3.3	64	28.8	371	579.7	12.9	100	156.3	15.3	226	353.1	0.33	8	12.5	1.03	23	35.9	54	556	868.8	2.26E-02	519.6	1.19E-02	476.9	2.47E-02	793.1	147%	82%	91%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T	36-56	46	30	6316969	462848	17%	7.4	3.63	4.6	54	26.7	286	529.6	13.7	88.6	164.1	20.6	253	468.5	0.29	6	11.1	0.79	15	27.8	58.7	502	929.6	2.97E-02	682.1	1.11E-02	444.2	2.85E-02	913.9	146%	84%	98%	ndy Clay Loa	52	25	23	0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T	56-66	61	15	6316969	462848	16%	7.6	3.18	5.3	50	16.8	167	334.0	9.07	54.5	109.0	19	217	434.0	0.16	3	6.0	0.76	13	26.0	40.4	321	642.0	3.04E-02	698.0	1.19E-02	475.7	2.67E-02	856.3	161%	142%	133%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T	66-76	71	5	6316969	462848	21%	7.4	6.19	9.5	79	24.1	380	481.0	23.5	224	283.5	46.2	838	1060.8	1.3	39	49.4	0.41	11	13.9	89.6	1130	1430.4	8.73E-02	2008.0	9.35E-03	374.5	6.07E-02	1945.0	189%	78%	136%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T-OB	76-86	81	-5	6316969	462848	16%	7.5	3.92	7.8	58	14.6	169	291.4	9.32	65.2	112.4	27.1	361	622.4	<0.2	<6	#VALUE!	0.77	16	27.6	47.1	436	751.7	4.71E-02	1081.8	1.07E-02	429.2	3.45E-02	1106.7	174%	147%	147%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T-OB	86-96	91	-15	6316969	462848	24%	7.5	7.69	12.6	87	23.4	406	466.7	29.7	312	358.6	64.9	1300	1494.3	1.6	55	63.2	0.37	12	13.8	116	1620	1862.1	1.36E-01	3137.5	8.09E-03	324.2	9.94E-02	3186.9	210%	69%	171%					0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 6	T6-T-OB	96-116	106	-30	6316969	462848	24%	7.6	8.68	14.8	90	23	416	462.2	32.8	359	398.9	78.2	1630	1811.1	1.8	65	72.2	0.38	12	13.3	133	1930	2144.4	1.82E-01	4194.3	7.55E-03	302.7	1.34E-01	4299.3	232%	65%	200%	Silty Clay	15	40	45	0.2	0.3	0.5	1	2001	0.15	0.61	0.76
Transect 7	T7-P2	0-7	4	123.5	6316911	462566	47%	5.2	1.18	1	98	8.13	159	162.2	3.8	44.9	45.8	2.36	53	54.1	0.47	18	18.4	0.96	33	33.7	10.3	160	163.3	3.98E-03	91.5	9.07E-03	363.6	1.08E-02	346.1	169%	224%	212%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	7-27	17	110	6316911	462566	19%	7	2.47	0.7	56	29.5	333	594.6	7.73	52.8	94.3	2.9	38	67.9	<0.2	<6	#VALUE!	0.53	11	19.6	36.6	331	591.1	4.40E-03	101.2	1.52E-02	608.7	1.62E-02	518.1	149%	102%	88%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	27-47	37	90	6316911	462566	16%	7.3	2.56	1.1	53	31.2	329	620.8	9.66	61.6	116.2	4.98	60	113.2	<0.2	<5	#VALUE!	0.29	5	9.4	41.4	349	658.5	7.59E-03	174.5	1.53E-02	612.9	1.71E-02	547.5	154%	99%	83%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	47-67	57	70	6316911	462566	15%	7.2	2.76	1.7	58	30.2	350	603.4	10.4	73	125.9	7.51	100	172.4	<0.2	<6	#VALUE!	0.26	5	8.6	43	398	686.2	1.23E-02	281.7	1.49E-02	599.1	1.84E-02	591.3	163%	99%	86%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	67-87	77	50	6316911	462566	14%	7.2	3.03	2.3	58	28.4	333	574.1	13.8	98	169.0	10.8	145	250.0	<0.2	<6	#VALUE!	0.44	9	15.5	48.2	452	779.3	1.77E-02	407.4	1.39E-02	557.8	2.16E-02	691.2	163%	97%	89%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	87-107	97	30	6316911	462566	15%	7.2	3.16	2.9	64	26.5	338	528.1	13.5	104	162.5	12.8	189	295.3	<0.2	<6	#VALUE!	0.62	14	21.9	47.1	482	753.1	2.21E-02	507.2	1.36E-02	546.5	2.29E-02	734.1	172%	103%	97%	Clay	28.6	21.4	50	0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	107-117	112	15	6316911	462566	25%	6.9	3.85	5.2	130	26.3	682	524.6	13.2	206	158.5	23	684	526.2	0.29	15	11.5	0.99	46	35.4	53.4	1110	853.8	5.43E-02	1247.9	1.20E-02	482.7	3.37E-02	1079.2	237%	92%	126%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2	117-127	122	5	6316911	462566	14%	7.3	5.03	7.4	57	24.4	278	487.7	13.7	94.4	165.6	32.3	424	743.9	<0.2	<6	#VALUE!	0.98	20	35.1	64.9	593	1040.4	5.24E-02	1204.1	1.13E-02	451.2	3.41E-02	1094.5	162%	93%	105%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2-OB	127-137	132	-5	6316911	462566	18%	7.4	7	10.9	79	23.3	369	467.1	25.3	243	307.6	53.9	984	1245.6	1.3	41	51.9	0.69	19	24.1	98.1	1240	1569.6	1.12E-01	2568.9	8.91E-03	357.1	7.54E-02	2417.1	206%	76%	154%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2-OB	137-147	142	-15	6316911	462566	19%	7.4	7.91	12.9	81	22.6	366	451.9	27.4	268	330.9	64.6	1200	1481.5	1.6	52	64.2	0.83	24	29.6	112	1450	1790.1	1.44E-01	3301.0	8.15E-03	326.6	1.00E-01	3214.3	223%	72%	180%					0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P2-OB	147-167	157	-30	6316911	462566	21%	7.3	8.94	16	82	23	378	461.0	27.8	276	336.6	80.9	1530	1865.9	1.8	57	69.5	0.96	28	34.1	131	1720	2097.6	1.84E-01	4224.9	7.57E-03	303.4	1.27E-01	4078.5	226%	66%	194%	Clay	25	32.6	42.4	0.2	0.3	0.5	1	2001	0.26	1.01	1.27
Transect 7	T7-P1	0-13	7	126.5	6316975	462503	61%	4.7	1.5	1	145	9.42	274	189.0	5.69	100	69.0	2.8	94	64.8	0.36	20	13.8	1.11	57	39.3	14.9	348	240.0	5.36E-03	123.3	1.18E-02	474.0	1.76E-02	564.8	190%	251%	235%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	13-33	23	110	6316975	462503	34%	4.8	1.56	1.3	100	10.7	214	214.0	5.64	68.4	68.4	3.68	85	85.0	0.17	7	7.0	1.25	44	44.0	16.9	272	272.0	7.38E-03	169.8	1.35E-02	541.3	1.96E-02	627.8	200%	253%	231%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	33-53	43	90	6316975	462503	19%	7.2	1.45	1.4	54	10.7	116	214.8	4.07	26.5	49.1	3.92	48	88.9	0.13	3	5.6	0.78	15	27.8	14	121	224.1	7.40E-03	170.2	1.51E-02	603.7	1.73E-02	553.9	191%	281%	247%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	53-73	63	70	6316975	462503	18%	7.4	1.79	2.7	48	10.2	97.6	203.3	4.98	28.8	60.0	7.46	82	170.8	0.08	2	4.2	1.62	27	56.3	18.4	141	293.8	1.34E-02	308.7	1.34E-02	535.3	2.03E-02	651.9	181%	263%	222%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	73-93	83	50	6316975	462503	21%	7.4	2.75	4.3	61	16	194	318.0	8.5	62.6	102.6	15.2	212	347.5	<0.2	<6	#VALUE!	2.74	59	96.7	32.6	318	521.3	2.63E-02	605.4	1.34E-02	535.9	2.33E-02	745.6	174%	169%	143%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	93-113	103	30	6316975	462503	21%	7.5	3.38	6.9	62	16.8	207	333.9	8.16	60.9	98.2	24.3	345	556.5	<0.2	<6	#VALUE!	3.91	85	137.1	41.8	412	664.5	4.06E-02	933.1	1.21E-02	484.2	2.77E-02	887.2	168%	145%	134%	Clay Loam	39	24	37	0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	113-123	118	15	6316975	462503	24%	7.4	5.52	9.3	62	24.8	307	495.2	12.8	95.8	154.5	40.4	576	929.0	<0.2	<6	#VALUE!	4.68	103	166.1	68.5	679	1095.2	5.94E-02	1365.8	1.10E-02	440.8	3.54E-02	1136.0	147%	89%	104%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1	123-133	128	5	6316975	462503	26%	7.5	5.75	9.7	57	24.5	278	487.7	12.8	88	154.4	42.1	549	963.2	0.26	6	10.5	4.34	87	152.6	70.9	644	1129.8	5.75E-02	1321.2	1.06E-02	424.8	3.63E-02	1164.5	137%	87%	103%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1-OB	133-143	138	-5	6316975	462503	20%	7.4	7.3	11.1	62	24	299	482.3	28.8	218	351.6	57	818	1319.4	1.3	31	50.0	4.35	96	154.8	101	1010	1629.0	9.74E-02	2239.7	9.47E-03	379.4	6.35E-02	2035.9	170%	79%	125%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1-OB	143-153	148	-15	6316975	462503	14%	7.5	8.51	13.9	55	21.2	234	425.5	30.4	202	367.3	70.5	893	1623.6	1.4	29	52.7	4.08	80	145.5	120	1060	1927.3	1.33E-01	3050.8	8.11E-03	325.1	9.42E-02	3019.8	188%	76%	157%					0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-P1-OB	153-173	163	-30	6316975	462503	15%	7.7	9.73	22.4	60	18.5	221	368.3	17.4	126	210.0	94.8	1300	2166.7	2.2	50	83.3	5.41	115	191.7	131	1250	2083.3	2.01E-01	4628.8	7.51E-03	301.2	1.25E-01	3999.0	214%	82%	192%	ndy Clay Loa	52	24	24	0.2	0.3	0.5	1	2001	0.12	1.21	1.33
Transect 7	T7-C	0-10	5	105	6316875	462601	57%	6.4	1.76	2.2	146	8.9	260	178.1	5.36	94.7	64.9	5.9	198	135.6	0.74	42	28.8	0.72	37	25.3	17.4	407	278.8	1.21E-02	277.6	1.27E-02	507.7	2.19E-02	703.1	205%	285%	252%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	10-30	20	90	6316875	462601	37%	6.7	1.36	1	82	9.81	162	197.6	4.29	42.8	52.2	2.79	53	64.6	0.2	6	7.3	0.48	14	17.1	8.87	117	142.7	4.75E-03	109.1	1.08E-02	432.6	9.89E-03	317.2	169%	219%	222%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	30-50	40	70	6316875	462601	18%	7.2	2.52	0.9	53	29	307	579.2	10.1	64.8	122.3	4.1	50	94.3	<0.2	<5	#VALUE!	0.77	14	26.4	38.9	330	622.6	6.11E-03	140.4	1.50E-02	599.3	1.73E-02	554.0	149%	103%	89%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	50-70	60	50	6316875	462601	17%	7.3	2.87	1.7	55	27.5	305	554.5	12.6	85	154.5	7.8	100	181.8	<0.2	<6	#VALUE!	0.41	8	14.5	44	391	710.9	1.19E-02	273.3	1.37E-02	549.4	2.03E-02	649.9	150%	99%	91%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	70-90	80	30	6316875	462601	14%	7.4	3.46	3.3	53	27.9	296	558.5	12.8	82.5	155.7	14.9	182	343.4	<0.2	<5	#VALUE!	0.78	15	28.3	51	433	817.0	2.31E-02	530.1	1.32E-02	528.4	2.29E-02	735.9	154%	95%	90%	ndy Clay Loa	55	22	23	0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	90-100	95	15	6316875	462601	11%	7.6	2.42	6.4	50	9.06	89.9	179.8	4.4	26.4	52.8	16.6	189	378.0	0.18	3	6.0	1.03	18	36.0	25.3	201	402.0	3.50E-02	804.7	1.29E-02	518.0	2.51E-02	806.0	213%	288%	200%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C	100-110	105	5	6316875	462601	16%	7.5	5.01	10.1	60	18.6	222	370.0	10.5	76.2	127.0	38.6	531	885.0	0.31	7	11.7	1.72	36	60.0	60	574	956.7	6.68E-02	1535.8	1.09E-02	438.5	3.83E-02	1226.9	174%	119%	128%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C-OB	110-120	115	-5	6316875	462601	18%	7.4	6.84	11.5	74	23.2	342	462.2	21.9	196	264.9	54.8	932	1259.5	1.3	36	48.6	1.16	30	40.5	94.7	1120	1513.5	1.06E-01	2430.6	9.18E-03	368.0	6.69E-02	2145.8	193%	80%	142%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C-OB	120-130	125	-15	6316875	462601	21%	7.4	8.46	14.2	77	23.3	359	466.2	29.9	279	362.3	73.3	1300	1688.3	1.7	52	67.5	1.36	37	48.1	122	1500	1948.1	1.53E-01	3520.4	8.16E-03	326.9	1.04E-01	3334.8	209%	70%	171%					0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-C-OB	130-150	140	-30	6316875	462601	20%	7.5	9.5	15.5	81	22.6	367	453.1	37.4	366	451.9	84.8	1580	1950.6	1.9	59	72.8	1.3	37	45.7	138	1800	2222.2	2.09E-01	4800.2	7.66E-03	306.9	1.49E-01	4783.1	246%	68%	215%	Clay	19	37	44	0.2	0.3	0.5	1	2001	0.16	0.94	1.1
Transect 7	T7-M	0-15	8	107.5	6316857	462619	23%	7.6	1.38	0.8	65	9.98	130	200.0	4.12	32.4	49.8	2.24	33	50.8	0.36	9	13.8	0.78	18	27.7	10.7	111	170.8	4.28E-03	98.3	1.42E-02	568.0	1.50E-02	481.3	194%	284%	282%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	15-35	25	90	6316857	462619	19%	7.4	2.54	0.7	56	29.2	324	578.6	11.5	77.6	138.6	3.4	43	76.8	<0.2	<6	#VALUE!	0.31	6	10.7	39.6	352	628.6	5.18E-03	119.1	1.51E-02	604.0	1.75E-02	562.3	155%	104%	89%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	35-55	45	70	6316857	462619	15%	7.5	2.77	1.4	50	28.2	282	564.0	13.4	81.3	162.6	6.47	74	148.0	<0.2	<5	#VALUE!	0.2	4	8.0	45.5	365	730.0	9.58E-03	220.2	1.33E-02	531.3	2.04E-02	654.9	149%	94%	90%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	55-75	65	50	6316857	462619	16%	7.7	1.8	2.6	54	9.99	108	200.0	6.6	43.2	80.0	7.53	94	174.1	0.1	2	3.7	0.16	3	5.6	21	182	337.0	1.44E-02	331.8	1.28E-02	512.4	2.27E-02	728.1	191%	256%	216%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	75-95	85	30	6316857	462619	15%	7.8	1.88	3.3	54	9	97.7	180.9	6.33	41.6	77.0	9.09	114	211.1	0.17	4	7.4	0.17	3	5.6	21.7	188	348.1	1.80E-02	413.3	1.23E-02	491.9	2.44E-02	783.3	196%	272%	225%	Clay Loam	42	27.6	30.4	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	95-105	100	15	6316857	462619	17%	7.7	2.12	4.3	52	8.8	92.1	177.1	6.46	40.9	78.7	11.9	144	276.9	0.14	3	5.8	0.22	4	7.7	24.1	202	388.5	2.23E-02	513.7	1.17E-02	470.4	2.63E-02	844.4	186%	266%	217%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M	105-115	110	5	6316857	462619	16%	7.7	2.41	5.3	58	9.02	106	182.8	7.24	51.2	88.3	15.1	203	350.0	<0.2	<6	#VALUE!	0.18	4	6.9	28	262	451.7	2.99E-02	687.2	1.15E-02	460.2	2.93E-02	938.7	196%	252%	208%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M-OB	115-125	120	-5	6316857	462619	18%	7.2	4.73	5.4	76	24.6	375	493.4	19.8	183	240.8	25.6	449	590.8	1	31	40.8	0.24	6	7.9	67	818	1076.3	4.64E-02	1065.8	1.06E-02	425.6	3.87E-02	1241.3	180%	86%	115%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M-OB	125-135	130	-15	6316857	462619	21%	7.2	5.95	7.8	88	23.6	414	470.5	26.6	282	320.5	39.3	791	898.9	1.5	51	58.0	0.17	5	5.7	85.5	1200	1363.6	8.11E-02	1865.0	9.42E-03	377.6	6.20E-02	1988.5	207%	80%	146%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-M-OB	135-155	145	-30	6316857	462619	25%	7.3	7.89	12.8	96	22.8	440	458.3	33.9	395	411.5	68.2	1510	1572.9	1.8	68	70.8	0.23	8	8.3	112	1730	1802.1	1.62E-01	3723.2	8.30E-03	332.5	1.13E-01	3615.6	237%	73%	201%	Clay	16.8	31.6	51.6	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.1	1.05	1.15
Transect 7	T7-T	0-15	8	102.5	6316843	462633	79%	6.9	1.26	1	140	8.01	224	160.0	2.7	45.5	32.5	2.41	77	55.0	0.96	52	37.1	1.11	55	39.3	6.07	135	96.4	3.70E-03	85.0	7.08E-03	283.6	5.39E-03	172.8	155%	177%	179%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	15-35	25	85	6316843	462633	69%	5.5	2.51	0.6	128	29.8	764	596.9	13.1	203	158.6	2.8	83	64.8	0.35	18	14.1	0.84	38	29.7	39.5	811	633.6	4.16E-03	95.6	1.46E-02	585.2	1.84E-02	589.9	147%	98%	93%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	35-55	45	65	6316843	462633	43%	5.3	2.98	2	124	28.4	705	568.5	16.6	250	201.6	9.27	265	213.7	<0.2	<10	#VALUE!	0.58	25	20.2	46.6	928	748.4	1.74E-02	400.9	1.42E-02	568.7	2.31E-02	739.7	188%	100%	99%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	55-75	65	45	6316843	462633	18%	6.7	3.66	4.6	69	27.8	385	558.0	14.9	125	181.2	21.1	336	487.0	<0.2	<7	#VALUE!	1.02	25	36.2	54	599	868.1	3.63E-02	834.5	1.33E-02	531.6	2.65E-02	849.6	171%	95%	98%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	75-95	85	25	6316843	462633	16%	7.2	3.51	7.7	64	15	192	300.0	9.63	74.6	116.6	27.1	400	625.0	<0.2	<6	#VALUE!	1.06	24	37.5	44.5	456	712.5	5.13E-02	1178.8	1.17E-02	467.5	3.30E-02	1057.3	189%	156%	148%	Clay	30.4	28	41.6	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	95-105	100	10	6316843	462633	17%	7.1	3.63	10.3	77	10.4	161	209.1	8.54	79.6	103.4	31.8	563	731.2	<0.2	<8	#VALUE!	0.98	27	35.1	45.3	558	724.7	6.95E-02	1598.4	1.05E-02	419.5	4.30E-02	1377.6	219%	201%	190%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T	105-110	108	2.5	6316843	462633	21%	7.4	6.19	10.2	80	23.2	372	465.0	21.2	206	257.5	48	884	1105.0	0.45	14	17.5	1.28	36	45.0	85.4	1090	1362.5	9.16E-02	2105.9	9.61E-03	385.3	5.81E-02	1861.7	191%	83%	137%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T-OB	110-120	115	-5	6316843	462633	24%	7.3	7.45	11.9	83	23.7	395	475.9	27.3	275	331.3	59.9	1150	1385.5	1.1	36	43.4	1.47	43	51.8	107	1430	1722.9	1.16E-01	2673.9	8.52E-03	341.4	8.13E-02	2606.2	193%	72%	151%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T-OB	120-130	125	-15	6316843	462633	25%	7.4	9.07	15	91	24	440	483.5	35.4	391	429.7	81.7	1720	1890.1	1.7	61	67.0	1.94	63	69.2	128	1880	2065.9	1.91E-01	4381.8	8.03E-03	321.9	1.28E-01	4089.1	232%	67%	198%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 7	T7-T-OB	130-150	140	-30	6316843	462633	26%	7.4	10.5	18.7	93	22.3	413	444.1	39	438	471.0	103	2210	2376.3	1.9	70	75.3	2.4	79	84.9	156	2320	2494.6	2.65E-01	6093.0	7.28E-03	291.9	1.83E-01	5882.7	256%	66%	236%	Clay	26.8	28.2	45	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.74	0.36	1.1
Transect 8	T8-P1	0-15	8	107.5	6316879	462372	62%	5.6	2.19	1.3	120	18.6	447	372.5	7.25	105	87.5	4.83	133	110.8	0.36	17	14.2	0.89	38	31.7	26.2	503	419.2	7.63E-03	175.4	1.38E-02	552.9	1.86E-02	595.9	158%	148%	142%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	15-35	25	90	6316879	462372	20%	7.1	2.63	0.9	60	31.4	376	626.7	11.5	83.5	139.2	4.2	58	96.7	<0.2	<6	#VALUE!	0.42	9	15.0	44.6	428	713.3	6.24E-03	143.3	1.37E-02	549.6	1.85E-02	593.4	148%	88%	83%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	35-55	45	70	6316879	462372	18%	7.3	2.78	1.5	55	29.2	322	585.5	13	86.7	157.6	6.82	87	158.2	<0.2	<6	#VALUE!	0.49	10	18.2	47.2	417	758.2	9.80E-03	225.3	1.26E-02	506.2	2.09E-02	668.7	142%	86%	88%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	55-75	65	50	6316879	462372	17%	7.3	3.1	2.9	51	27.4	278	545.1	13.4	82.3	161.4	13.2	154	302.0	<0.2	<5	#VALUE!	0.8	14	27.5	49	399	782.4	1.95E-02	448.0	1.32E-02	529.7	2.24E-02	718.2	148%	97%	92%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	75-95	85	30	6316879	462372	16%	7.1	3.66	5.3	65	24.6	319	490.8	14.1	111	170.8	23.4	349	536.9	<0.2	<6	#VALUE!	1.12	26	40.0	57.5	597	918.5	3.93E-02	902.6	1.16E-02	466.4	3.03E-02	970.3	168%	95%	106%	Clay	32.4	21.2	46.4	0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	95-105	100	15	6316879	462372	16%	7.3	4.1	6.8	59	24.8	292	494.9	13.6	97.1	164.6	29.9	404	684.7	<0.2	<6	#VALUE!	1.14	24	40.7	64.1	604	1023.7	4.73E-02	1087.4	1.09E-02	436.7	3.38E-02	1083.3	159%	88%	106%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1	105-115	110	5	6316879	462372	15%	7.4	3.94	8.8	55	15.1	167	303.6	11.3	75.7	137.6	32	408	741.8	<0.2	<6	#VALUE!	0.8	16	29.1	54.5	482	876.4	5.51E-02	1266.1	1.03E-02	412.5	3.92E-02	1256.0	171%	136%	143%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1-OB	115-125	120	-5	6316879	462372	23%	7	7.12	9.8	78	23.7	372	476.9	34.7	330	423.1	52.8	954	1223.1	1.3	39	50.0	0.79	22	28.2	108	1350	1730.8	1.02E-01	2338.7	8.58E-03	343.7	8.16E-02	2615.3	191%	72%	151%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1-OB	125-135	130	-15	6316879	462372	23%	7.1	7.56	10.9	85	22.1	375	441.2	34.6	354	416.5	57.9	1130	1329.4	1.5	49	57.6	0.6	18	21.2	113	1530	1800.0	1.25E-01	2883.0	8.09E-03	324.1	1.01E-01	3248.2	217%	73%	180%					0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P1-OB	135-155	145	-30	6316879	462372	23%	7.4	8.64	13.2	77	22.7	348	451.9	40.6	377	489.6	74.6	1320	1714.3	1.9	58	75.3	0.58	16	20.8	136	1670	2168.8	1.61E-01	3691.8	7.72E-03	309.5	1.27E-01	4080.8	215%	68%	188%	Clay	37.4	22.6	40	0.2	0.3	0.5	1	2001	0.25	0.9	1.15
Transect 8	T8-P2	0-12	6	106	6316817	462419	32%	7.5	1.22	0.8	66	8.61	114	172.7	2.62	21	31.8	1.83	28	42.4	0.5	13	19.7	0.6	14	21.2	7.88	83.4	126.4	2.93E-03	67.5	9.32E-03	373.4	8.06E-03	258.4	159%	216%	204%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	24-Dec	18	94	6316817	462419	20%	7.4	2.39	0.8	56	25.2	281	501.8	6.73	45.4	81.1	3.11	40	71.4	0.37	8	14.3	0.57	11	19.6	31.6	282	503.6	4.78E-03	109.9	1.50E-02	599.9	1.63E-02	524.3	154%	120%	104%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	32-52	42	70	6316817	462419	17%	7.4	2.7	1.6	49	28.6	279	569.4	8.98	53	108.2	6.98	78	159.2	0.37	7	14.3	0.58	10	20.4	41.7	326	665.3	9.86E-03	226.7	1.36E-02	544.7	1.87E-02	598.2	142%	96%	90%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	52-72	62	50	6316817	462419	22%	7.5	3.14	3.4	54	28.1	305	564.8	9.55	62.6	115.9	14.9	185	342.6	0.29	6	11.1	0.9	17	31.5	49.1	425	787.0	2.02E-02	464.2	1.23E-02	491.1	2.24E-02	719.5	135%	87%	91%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	72-92	82	30	6316817	462419	20%	7.5	3.75	5.6	49	26.9	262	534.7	10.5	61.9	126.3	24.1	270	551.0	<0.2	<5	#VALUE!	1.05	18	36.7	58.1	453	924.5	3.18E-02	730.6	1.12E-02	447.9	2.74E-02	879.7	133%	84%	95%	Loam	30.4	43.6	26	0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	92-102	97	15	6316817	462419	17%	7.7	5.01	8.8	39	21.7	169	433.3	11.2	53	135.9	35.7	320	820.5	<0.2	<4	#VALUE!	1.2	17	43.6	64.5	403	1033.3	4.60E-02	1058.0	1.03E-02	414.7	3.42E-02	1097.2	129%	96%	106%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2	102-112	107	5	6316817	462419	70%	7.7	5.08	8.6	40	22.2	179	447.5	11.3	55.4	138.5	35.1	326	815.0	<0.2	<4	#VALUE!	1.18	17	42.5	66.2	428	1070.0	2.34E-02	539.0	5.29E-03	212.0	1.88E-02	602.8	66%	47%	56%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2-OB	112-122	117	-5	6316817	462419	-16%	7.4	6.86	11	63	24.4	307	487.3	23.9	182	288.9	54.1	783	1242.9	1.2	29	46.0	1.08	24	38.1	101	1020	1619.0	9.44E-02	2170.8	8.69E-03	348.2	6.72E-02	2154.8	175%	71%	133%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2-OB	122-132	127	-15	6316817	462419	21%	7.1	7.45	11.7	68	24.4	329	483.8	31.4	257	377.9	62	963	1416.2	1.5	40	58.8	0.99	24	35.3	113	1220	1794.1	1.12E-01	2565.2	8.69E-03	348.4	7.92E-02	2539.6	181%	72%	142%					0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-P2-OB	132-152	142	-30	6316817	462419	22%	7.2	7.42	13.4	77	22.7	351	455.8	20.3	189	245.5	62.3	1110	1441.6	1.6	50	64.9	0.85	23	29.9	105	1300	1688.3	1.14E-01	2615.1	8.27E-03	331.5	7.78E-02	2495.8	181%	73%	148%	Clay Loam	23.4	40.6	36	0.2	0.3	0.5	1	2001	0.21	0.91	1.12
Transect 8	T8-C	0-2	1	91	6316785	462444	27%	7.4	0.96	0.4	69	6.74	93.2	135.1	1.84	15.4	22.3	0.88	14	20.3	0.69	19	27.5	0.54	13	18.8	4.16	46	66.7	1.58E-03	36.4	8.62E-03	345.4	5.40E-03	173.2	179%	256%	260%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C	2-22	12	80	6316785	462444	24%	7.2	2.34	0.3	68	27	369	542.6	8.08	66.9	98.4	1.29	20	29.4	0.32	8	11.8	0.41	10	14.7	32.6	357	525.0	2.08E-03	47.9	1.56E-02	624.3	1.60E-02	511.8	163%	115%	97%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C	22-42	32	60	6316785	462444	17%	6.5	2.36	0.7	59	21.7	257	435.6	12.5	89.4	151.5	2.76	38	64.4	0.05	1	1.7	0.5	10	16.9	34.7	329	557.6	4.56E-03	104.9	1.34E-02	538.1	2.00E-02	641.8	163%	124%	115%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C	42-62	52	40	6316785	462444	16%	7.2	2.97	2.1	55	27.3	303	550.9	13.8	92.3	167.8	9.7	124	225.5	<0.2	<6	#VALUE!	1.32	26	47.3	46.8	415	754.5	1.52E-02	349.5	1.35E-02	539.3	2.15E-02	688.8	155%	98%	91%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C	62-82	72	20	6316785	462444	17%	7.4	3.8	6.5	56	21.3	241	430.4	11.3	77.1	137.7	26.3	342	610.7	<0.2	<6	#VALUE!	1.77	35	62.5	55.6	502	896.4	4.06E-02	933.4	1.08E-02	431.5	3.18E-02	1020.0	153%	100%	114%	Clay Loam	40.8	22.8	36.4	0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C	82-92	87	5	6316785	462444	17%	7.4	5.77	9.9	53	23.3	246	464.2	15.4	98.1	185.1	43.5	528	996.2	0.27	6	11.3	2.18	41	77.4	77.1	651	1228.3	6.54E-02	1503.2	1.00E-02	401.0	4.27E-02	1369.7	151%	86%	112%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C-OB	92-102	97	-5	6316785	462444	23%	7.5	9.44	14.5	70	23.7	334	477.1	35.2	301	430.0	78.9	1280	1828.6	1.4	39	55.7	2.78	69	98.6	135	1530	2185.7	1.50E-01	3455.1	7.88E-03	316.0	1.09E-01	3480.3	189%	66%	159%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C-OB	102-112	107	-15	6316785	462444	23%	7.6	10.5	16.8	85	22.8	387	455.3	44.4	456	536.5	97.7	1910	2247.1	1.9	64	75.3	2.58	78	91.8	161	2190	2576.5	2.47E-01	5688.7	7.15E-03	286.6	1.87E-01	6007.1	253%	63%	233%					0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-C-OB	112-132	122	-30	6316785	462444	19%	7.6	11.7	18.4	75	23	343	457.3	52.3	472	629.3	113	1940	2586.7	2.2	64	85.3	3.11	82	109.3	182	2170	2893.3	3.04E-01	6994.4	6.90E-03	276.6	2.33E-01	7482.1	270%	60%	259%	Clay	31.4	27.6	41	0.2	0.3	0.5	1	2001	0.18	0.74	0.92
Transect 8	T8-M	0-20	10	42	6316762	462461	74%	7	0.99	0.4	140	6.42	180	128.6	2.48	42	30.0	0.89	29	20.7	0.8	44	31.4	0.82	41	29.3	2.6	58.2	41.6	1.40E-03	32.2	5.65E-03	226.2	2.47E-03	79.2	156%	176%	191%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52
Transect 8	T8-M	20-40	30	22	6316762	462461	28%	7.3	1.36	1	70	10.8	150	214.3	3.38	28.5	40.7	2.55	41	58.6	0.14	4	5.7	0.74	18	25.7	11.8	131	187.1	4.65E-03	107.0	1.43E-02	572.0	1.47E-02	471.9	183%	267%	252%	Clay Loam	35.4	26.2	38.4	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52
Transect 8	T8-M	40-52	46	6	6316762	462461	23%	7.5	1.34	1.8	67	7.92	106	158.2	3.67	29.6	44.2	4.37	67	100.0	0.19	5	7.5	0.55	13	19.4	12	128	191.0	8.94E-03	205.5	1.36E-02	544.6	1.79E-02	573.8	205%	344%	300%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52
Transect 8	T8-M-OB	52-62	57	-5	6316762	462461	17%	7.2	2.94	2.2	51	28	288	564.7	17.2	107	209.8	10.6	125	245.1	0.8	16	31.4	0.48	9	17.6	52.5	432	847.1	1.55E-02	356.9	1.27E-02	510.1	2.36E-02	757.4	146%	90%	89%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52

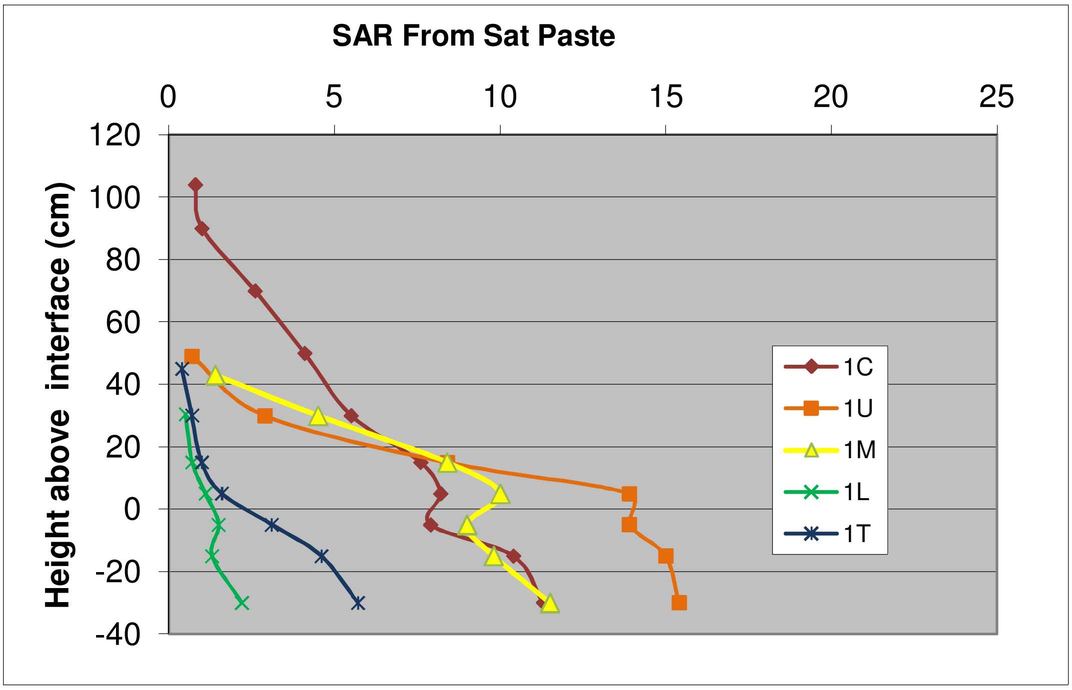
								Detailed Salinity (Saturated Paste)																						Estimated In-situ Porewater Concentrations (PHREEQ/C)						Ratio of Phreeq/c concetnrations to sat paste				Particle Size Analysis										
Transect	Position	Depth (cm)	Point Depth	Ht above Interface	Northing (m)	Easting (m)	MC	pH	EC	SAR	Sat%	Calcium	Calcium	Calcium	Magnesium	Magnesium	Magnesium	Sodium	Sodium	Sodium	Potassium	Potassium	Potassium	Chloride	Chloride	Chloride	Sulfate-S	Sulfate-S	Sulfate-S	Sodium	Sodium	Calcium	Calcium	Sulfate-S	Sulfate-S	Sodium	Calcium	Sulfate-S	Texture	Sand	Silt	Clay	Prescribed Peat Thickness	Prescribed Till Thickness	Prescribed Non-Sodic Thickness	Prescribed Total Thickness	Year of Soil Placement	Measured Peat Thickness	Measured Till Thickness	Measured Total Thickness
																																								0µm - 2mm	2µm - 50µm	<2 µm								
			cm	cm			%	pH	dS/m		%	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	meq/L	mg/kg	mg/L	mol/L	mg/L	mol/L	mg/L	mol/L	mg/L	PhrC/Sat Paste	PhrC/Sat Paste	PhrC/Sat Paste		% weight	% weight	% weight	m	m	m	m		m	m	m
Transect 8	**T8-M-OB**	**62-72**	**67**	**-15**	6316762	462461	14%	7.5	4.89	5.5	50	23.4	234	468.0	24.6	149	298.0	27.2	313	626.0	1	20	40.0	0.48	8	16.0	73.1	585	1170.0	4.21E-02	967.5	1.02E-02	409.8	4.03E-02	1291.9	155%	88%	110%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52
Transect 8	**T8-M-OB**	**72-92**	**82**	**-30**	6316762	462461	17%	7.4	6.4	7.7	62	22.6	282	454.8	38.4	289	466.1	42.7	612	987.1	1.6	40	64.5	0.6	13	21.0	100	999	1611.3	8.00E-02	1839.0	9.10E-03	364.8	7.12E-02	2283.6	186%	80%	142%	ndy Clay Loa	54	25	21	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.29	0.23	0.52
Transect 8	**T8-T**	**0-17**	**9**	**68.5**	6316746	462473	32%	7.5	0.87	0.8	80	4.41	70.9	88.6	1.95	19	23.8	1.39	26	32.5	1.04	32	40.0	0.7	20	25.0	3.47	44.7	55.9	2.58E-03	59.3	6.25E-03	250.5	4.38E-03	140.6	182%	283%	252%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T**	**17-37**	**27**	**50**	6316746	462473	33%	6.8	2.74	2.8	87	24.1	419	481.6	9.33	98.2	112.9	11.4	229	263.2	<0.2	<9	#VALUE!	2.96	91	104.6	37.6	524	602.3	1.90E-02	436.4	1.42E-02	568.4	2.03E-02	649.4	166%	118%	108%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T**	**37-57**	**47**	**30**	6316746	462473	16%	7.3	3.65	5.2	58	26.9	311	536.2	11.2	78	134.5	22.6	301	519.0	<0.2	<6	#VALUE!	2.09	43	74.1	55.5	513	884.5	3.51E-02	807.5	1.22E-02	489.7	2.63E-02	842.9	156%	91%	95%	Clay Loam	37	28.6	34.4	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T**	**57-67**	**62**	**15**	6316746	462473	17%	7.4	4.76	7.3	60	23.2	280	466.7	14	102	170.0	31.4	436	726.7	<0.2	<6	#VALUE!	1.98	42	70.0	64.1	617	1028.3	5.01E-02	1151.4	1.07E-02	428.0	3.55E-02	1137.1	158%	92%	111%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T**	**67-77**	**72**	**5**	6316746	462473	17%	7.7	3.53	10.6	64	8.69	112	175.0	7.97	62	96.9	30.6	453	707.8	<0.2	<6	#VALUE!	1.58	36	56.3	43	442	690.6	6.31E-02	1451.1	1.00E-02	402.6	4.31E-02	1380.5	205%	230%	200%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T-OB**	**77-87**	**82**	**-5**	6316746	462473	19%	7.4	7.08	9.7	79	23.4	369	467.1	34.6	330	417.7	52.3	949	1201.3	1.5	47	59.5	1.2	34	43.0	110	1380	1746.8	1.11E-01	2561.1	8.12E-03	325.6	9.36E-02	3002.1	213%	70%	172%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T-OB**	**87-97**	**92**	**-15**	6316746	462473	19%	7.4	7.98	10.8	76	23.3	357	469.7	45.2	418	550.0	63.1	1110	1460.5	1.9	56	73.7	1.1	30	39.5	130	1590	2092.1	1.44E-01	3317.3	7.79E-03	312.1	1.27E-01	4075.1	227%	66%	195%					0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 8	**T8-T-OB**	**97-117**	**107**	**-30**	6316746	462473	22%	7.4	9.68	13.2	85	22.5	383	450.6	57.4	592	696.5	83.4	1640	1929.4	2.2	74	87.1	1.02	31	36.5	160	2190	2576.5	2.24E-01	5159.6	7.14E-03	286.0	2.03E-01	6523.0	267%	63%	253%	Clay	19	35	46	0.20/0.20	0.30/0.00	0.50/0.00	1.00/0.20	2001/2003	0.27	0.5	0.77
Transect 9	**T9-C**	**0-20**	**10**	**90**	6316921	462332	42%	6.1	1.47	0.7	169	11.8	399	236.1	4.18	85.6	50.7	1.95	76	45.0	0.4	26	15.4	0.88	52	30.8	11.4	309	182.8	5.28E-03	121.3	1.89E-02	756.9	1.53E-02	490.4	270%	321%	268%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C**	**20-40**	**30**	**70**	6316921	462332	15%	7.2	1.37	1.4	61	9.48	116	190.2	3.46	25.7	42.1	3.53	50	82.0	0.11	3	4.9	0.63	14	23.0	12.3	121	198.4	7.68E-03	176.6	1.58E-02	632.1	1.68E-02	539.4	215%	332%	272%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C**	**40-60**	**50**	**50**	6316921	462332	11%	7.2	2.23	3.2	50	13.8	139	278.0	5.95	36.3	72.6	10.1	117	234.0	0.16	3	6.0	0.5	9	18.0	26.4	213	426.0	1.89E-02	434.5	1.36E-02	546.3	2.10E-02	672.7	186%	197%	158%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C**	**60-80**	**70**	**30**	6316921	462332	10%	7.6	2.47	7.4	46	8.7	80.4	174.8	4.13	23.1	50.2	18.8	200	434.8	<0.2	<5	#VALUE!	0.51	8	17.4	28.8	213	463.0	3.75E-02	862.8	1.14E-02	457.8	2.85E-02	915.2	198%	262%	198%	ndy Clay Loa	51	26.6	22.4	0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C**	**80-90**	**85**	**15**	6316921	462332	10%	7.5	3.41	8.4	48	14.8	141	293.8	7.15	41.2	85.8	28	306	637.5	<0.2	<5	#VALUE!	0.68	11	22.9	46.6	355	739.6	4.91E-02	1128.0	1.10E-02	441.0	3.27E-02	1049.3	177%	150%	142%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C**	**90-100**	**95**	**5**	6316921	462332	11%	7.6	3.51	11.2	45	10.4	93.2	207.1	5.91	32	71.1	32.1	330	733.3	<0.2	<4	#VALUE!	0.96	15	33.3	43.3	310	688.9	5.98E-02	1374.9	1.08E-02	432.7	3.64E-02	1168.2	187%	209%	170%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C-OB**	**100-110**	**105**	**-5**	6316921	462332	16%	7.4	6.42	11.2	62	23.3	289	466.1	19.3	145	233.9	51.8	738	1190.3	0.93	22	35.5	1	22	35.5	90.6	898	1448.4	8.94E-02	2054.5	9.29E-03	372.2	5.77E-02	1850.0	173%	80%	128%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C-OB**	**110-120**	**115**	**-15**	6316921	462332	16%	7.3	7.35	12	69	23.4	322	466.7	26.9	224	324.6	60	950	1376.8	1.4	38	55.1	0.98	24	34.8	106	1160	1681.2	1.20E-01	2767.2	8.73E-03	350.0	8.07E-02	2587.0	201%	75%	154%					0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-C-OB**	**120-140**	**130**	**-30**	6316921	462332	17%	7.5	9.07	15.6	71	22.3	316	445.1	32.7	280	394.4	81.8	1330	1873.2	1.8	50	70.4	1.1	28	39.4	136	1540	2169.0	1.86E-01	4277.2	7.52E-03	301.4	1.35E-01	4327.7	228%	68%	200%	Clay Loam	38.6	28.4	33	0.2	0.3	0.5	1	2001	0.28	0.72	1
Transect 9	**T9-U**	**0-8**	**4**	**84**	6316918	462282	20%	7.3	1.08	0.7	68	8.37	113	166.2	2.75	22.6	33.2	1.7	26	38.2	0.17	4	5.9	0.36	9	13.2	8.52	92.3	135.7	3.61E-03	83.0	1.47E-02	589.4	1.44E-02	460.7	217%	355%	339%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U**	**8-28**	**18**	**70**	6316918	462282	20%	7.4	2.27	0.6	59	28	331	561.0	7.15	51.1	86.6	2.53	34	57.6	0.23	5	8.5	0.3	6	10.2	36.8	348	589.8	3.70E-03	85.0	1.33E-02	533.4	1.73E-02	553.4	148%	95%	94%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U**	**28-48**	**38**	**50**	6316918	462282	19%	7.4	2.43	0.8	59	28	331	561.0	8.91	63.8	108.1	3.49	47	79.7	0.24	6	10.2	0.25	5	8.5	39	369	625.4	5.23E-03	120.3	1.33E-02	534.8	1.81E-02	580.9	151%	95%	93%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U**	**48-68**	**58**	**30**	6316918	462282	17%	7.4	2.32	1.7	57	20.5	235	412.3	8.59	59.5	104.4	6.6	87	152.6	0.16	4	7.0	0.32	6	10.5	32.3	296	519.3	1.10E-02	252.5	1.39E-02	555.2	1.94E-02	623.3	165%	135%	120%	Clay Loam	37	27	36	0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U**	**68-78**	**73**	**15**	6316918	462282	15%	7.5	2.53	3.7	56	18.8	212	378.6	9.75	66.3	118.4	14	181	323.2	<0.2	<6	#VALUE!	0.39	8	14.3	38.1	342	610.7	2.38E-02	547.5	1.29E-02	518.8	2.37E-02	759.9	169%	137%	124%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U**	**78-88**	**83**	**5**	6316918	462282	17%	7.6	2.99	6.4	61	13.2	162	265.6	9.44	70	114.8	21.6	305	500.0	<0.2	<6	#VALUE!	0.46	10	16.4	41.6	408	668.9	3.86E-02	887.5	1.07E-02	427.1	3.31E-02	1062.9	178%	161%	159%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U-OB**	**88-98**	**93**	**-5**	6316918	462282	17%	7.4	5.35	6.8	72	24.8	356	494.4	25.7	224	311.1	34.1	565	784.7	1.2	34	47.2	0.41	10	13.9	82.6	951	1320.8	6.18E-02	1419.8	9.56E-03	383.1	5.15E-02	1652.1	181%	77%	125%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U-OB**	**98-108**	**103**	**-15**	6316918	462282	18%	7.4	6.08	7.9	80	24.4	391	488.8	35.8	346	432.5	43.3	797	996.3	1.7	52	65.0	0.43	12	15.0	98.1	1260	1575.0	9.27E-02	2130.5	9.06E-03	362.9	7.68E-02	2463.8	214%	74%	156%					0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-U-OB**	**108-128**	**118**	**-30**	6316918	462282	15%	7.5	7.36	10	78	22.9	359	460.3	42.8	404	517.9	57.3	1030	1320.5	1.8	56	71.8	0.5	14	17.9	118	1470	1884.6	1.50E-01	3440.9	8.05E-03	322.4	1.29E-01	4138.0	261%	70%	220%	Clay Loam	36	30	34	0.2	0.3	0.5	1	2001	0.06	0.82	0.88
Transect 9	**T9-M**	**0-13**	**7**	**86.5**	6316916	462239	30%	7.1	1.24	1.4	88	7.6	134	152.3	3.57	38	43.2	3.41	69	78.4	0.23	8	9.1	0.88	28	31.8	6.77	95.4	108.4	6.75E-03	155.1	1.04E-02	417.7	9.98E-03	320.0	198%	274%	295%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M**	**13-33**	**23**	**70**	6316916	462239	20%	7.5	1.39	2.2	59	8.06	95.4	161.7	3.6	25.8	43.7	5.41	74	125.4	0.11	2	3.4	0.45	9	15.3	13.2	125	211.9	1.09E-02	250.3	1.38E-02	554.4	1.92E-02	616.2	200%	343%	291%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M**	**33-53**	**43**	**50**	6316916	462239	13%	7.7	1.76	2.7	55	11	121	220.0	4.74	31.6	57.5	7.61	96	174.5	0.15	3	5.5	0.38	8	14.5	20.2	178	323.6	1.53E-02	351.0	1.37E-02	550.7	2.02E-02	646.3	201%	250%	200%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M**	**53-73**	**63**	**30**	6316916	462239	16%	7.5	2.16	4.6	64	10.2	130	203.1	5.32	41.4	64.7	12.8	190	296.9	0.14	3	4.7	0.51	12	18.8	25.3	260	406.3	2.58E-02	593.0	1.21E-02	485.8	2.50E-02	801.4	200%	239%	197%	Clay	33	26	41	0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M**	**73-83**	**78**	**15**	6316916	462239	16%	7.6	2.67	6.8	64	11.1	141	220.3	6.66	51.3	80.2	20.2	296	462.5	<0.2	<6	#VALUE!	0.78	18	28.1	33.8	345	539.1	3.96E-02	911.4	1.15E-02	460.4	3.00E-02	963.3	197%	209%	179%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M**	**83-93**	**88**	**5**	6316916	462239	16%	7.4	3.98	6.4	65	25.9	336	516.9	16	126	193.8	29.4	437	672.3	0.46	12	18.5	0.88	20	30.8	65.9	683	1050.8	4.97E-02	1143.6	1.13E-02	454.3	3.43E-02	1101.3	170%	88%	105%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M-OB**	**93-103**	**98**	**-5**	6316916	462239	16%	7.4	5.78	8.1	70	24.6	346	494.3	25.3	216	308.6	40.6	658	940.0	1.3	36	51.4	0.84	21	30.0	86	968	1382.9	7.66E-02	1761.1	9.84E-03	394.3	5.46E-02	1749.6	187%	80%	127%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M-OB**	**103-113**	**108**	**-15**	6316916	462239	18%	7.5	7.13	10.9	66	23.5	310	469.7	31.8	254	384.8	57.4	871	1319.7	1.6	41	62.1	1.26	30	45.5	106	1120	1697.0	1.09E-01	2495.3	8.99E-03	360.5	7.64E-02	2450.4	189%	77%	144%					0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-M-OB**	**113-133**	**123**	**-30**	6316916	462239	23%	7.5	7.72	13.5	77	23.8	367	476.6	30.7	287	372.7	70.5	1250	1623.4	1.8	53	68.8	1.28	35	45.5	118	1450	1883.1	1.41E-01	3240.2	8.45E-03	338.6	9.47E-02	3035.2	200%	71%	161%	Clay Loam	41	23	36	0.2	0.3	0.5	1	2001	0.13	0.8	0.93
Transect 9	**T9-L**	**0-3**	**2**	**81.5**	6316914	462209	94%	5.8	0.99	0.6	355	4	284	80.0	2.73	117	33.0	1.01	82	23.1	1.62	225	63.4	1.24	156	43.9	3.26	185	52.1	3.03E-03	69.7	8.57E-03	343.5	6.16E-03	197.4	302%	429%	379%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L**	**3-23**	**13**	**70**	6316914	462209	41%	6	0.76	0.6	151	4.78	144	95.4	2.36	43.1	28.5	1.24	43	28.5	0.27	16	10.6	1.06	57	37.7	3.18	76.8	50.9	3.13E-03	72.0	9.49E-03	380.5	5.85E-03	187.7	253%	399%	369%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L**	**23-43**	**33**	**50**	6316914	462209	15%	7.3	1.39	2.4	45	7.99	71.8	159.6	3.47	18.9	42.0	5.73	59	131.1	0.07	1	2.2	0.92	15	33.3	12.8	92.2	204.9	1.14E-02	261.8	1.42E-02	567.7	1.89E-02	605.3	200%	356%	295%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L**	**43-63**	**53**	**30**	6316914	462209	16%	7.2	2.93	5.1	58	18.2	211	363.8	9.87	69.3	119.5	19	254	437.9	<0.2	<6	#VALUE!	2.91	60	103.4	40	372	641.4	3.35E-02	769.1	1.33E-02	531.2	2.49E-02	799.6	176%	146%	125%	Clay	33	27	40	0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L**	**63-73**	**68**	**15**	6316914	462209	19%	7.3	6.23	11.2	68	23.7	321	472.1	19.1	156	229.4	51.7	806	1185.3	<0.2	<7	#VALUE!	5.83	140	205.9	83.4	904	1329.4	9.19E-02	2113.7	1.04E-02	417.0	4.97E-02	1593.2	178%	88%	120%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L**	**73-83**	**78**	**5**	6316914	462209	25%	7.5	7.72	16.2	78	22.6	355	455.1	18.8	179	229.5	73.5	1330	1705.1	0.38	12	15.4	7.87	219	280.8	102	1280	1641.0	1.37E-01	3140.8	9.18E-03	367.9	7.16E-02	2295.1	184%	81%	140%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L-OB**	**83-93**	**88**	**-5**	6316914	462209	19%	7.4	6.33	13	67	22.6	302	450.7	12.9	104	155.2	55	843	1258.2	0.84	22	32.8	4.64	110	164.2	81.4	868	1295.5	9.52E-02	2189.7	1.01E-02	406.5	4.93E-02	1581.6	174%	90%	122%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L-OB**	**93-103**	**98**	**-15**	6316914	462209	19%	7.3	7.04	15.3	53	23.1	246	464.2	12.7	82.4	155.5	64.7	795	1500.0	1	21	39.6	4.96	94	177.4	91.1	778	1467.9	9.59E-02	2204.6	9.73E-03	390.1	5.13E-02	1644.7	147%	84%	112%					0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-L-OB**	**103-123**	**113**	**-30**	6316914	462209	19%	7.3	7.08	15.2	58	23.3	270	465.5	11	77.1	132.9	62.7	836	1441.4	0.94	21	36.2	3.61	74	127.6	87.5	811	1398.3	9.77E-02	2246.3	9.95E-03	398.6	5.01E-02	1607.9	156%	86%	115%	Loam	50	31	19	0.2	0.3	0.5	1	2001	0.19	0.64	0.83
Transect 9	**T9-T**	**0-8**	**4**	**84**	6316908	462169	31%	6.8	1.44	4.6	94	4.49	84	89.4	2.41	27.3	29.0	8.54	184	195.7	0.22	8	8.5	2.58	86	91.5	8.01	120	127.7	1.90E-02	436.0	9.14E-03	366.3	1.20E-02	385.1	223%	410%	302%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T**	**8-28**	**18**	**70**	6316908	462169	27%	6.9	4.29	7	80	21.5	344	430.0	11	106	132.5	28.4	522	652.5	<0.2	<8	#VALUE!	3.89	110	137.5	52.3	670	837.5	4.82E-02	1107.9	1.19E-02	475.3	3.05E-02	979.1	170%	111%	117%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T**	**28-48**	**38**	**50**	6316908	462169	18%	7.5	5.62	8.8	51	26.1	264	517.6	14	86.1	168.8	39.7	462	905.9	0.28	5	9.8	10.4	188	368.6	66.9	542	1062.7	5.91E-02	1358.8	1.22E-02	487.2	3.13E-02	1002.8	150%	94%	94%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T**	**48-68**	**58**	**30**	6316908	462169	23%	7.5	5.05	10.1	58	17.7	204	351.7	10.6	74.2	127.9	38	505	870.7	<0.2	<6	#VALUE!	11.4	234	403.4	51.9	479	825.9	6.12E-02	1407.5	1.20E-02	481.4	3.21E-02	1030.5	162%	137%	125%	ndy Clay Loa	45	21	34	0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T**	**68-78**	**73**	**15**	6316908	462169	27%	7.5	5.07	10	72	17.8	256	355.6	11.1	97.1	134.9	38	631	876.4	<0.2	<7	#VALUE!	10.8	276	383.3	52.6	608	844.4	6.50E-02	1493.3	1.19E-02	476.7	3.37E-02	1080.6	170%	134%	128%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T**	**78-88**	**83**	**5**	6316908	462169	26%	7.5	4.75	9.9	78	16.1	250	320.5	10	94.5	121.2	35.7	638	817.9	0.34	10	12.8	8.94	246	315.4	50.2	625	801.3	6.49E-02	1491.2	1.15E-02	462.0	3.49E-02	1118.6	182%	144%	140%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T-OB**	**88-98**	**93**	**-5**	6316908	462169	28%	7.4	5.81	9	92	24.9	460	500.0	17	190	206.5	41.2	875	951.1	1.1	38	41.3	8.13	266	289.1	72.6	1070	1163.0	7.60E-02	1746.8	1.08E-02	434.1	4.25E-02	1364.0	184%	87%	117%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T-OB**	**98-108**	**103**	**-15**	6316908	462169	23%	7.4	6.04	10.2	83	24.9	414	498.8	16.6	167	201.2	46.4	886	1067.5	1	32	38.6	7.29	214	257.8	78.1	1040	1253.0	8.62E-02	1981.6	1.05E-02	420.9	4.64E-02	1486.3	186%	84%	119%					0.2	0.3	0.5	1	2001	0.13	0.75	0.88
Transect 9	**T9-T-OB**	**108-128**	**118**	**-30**	6316908	462169	25%	7.2	7.42	15.1	89	23.6	419	470.8	16.2	174	195.5	67.6	1380	1550.6	1	37	41.6	5.94	187	210.1	97.8	1390	1561.8	1.34E-01	3074.9	9.10E-03	364.7	7.09E-02	2272.5	198%	77%	146%	Clay	27	27	46	0.2	0.3	0.5	1	2001	0.13	0.75	0.88

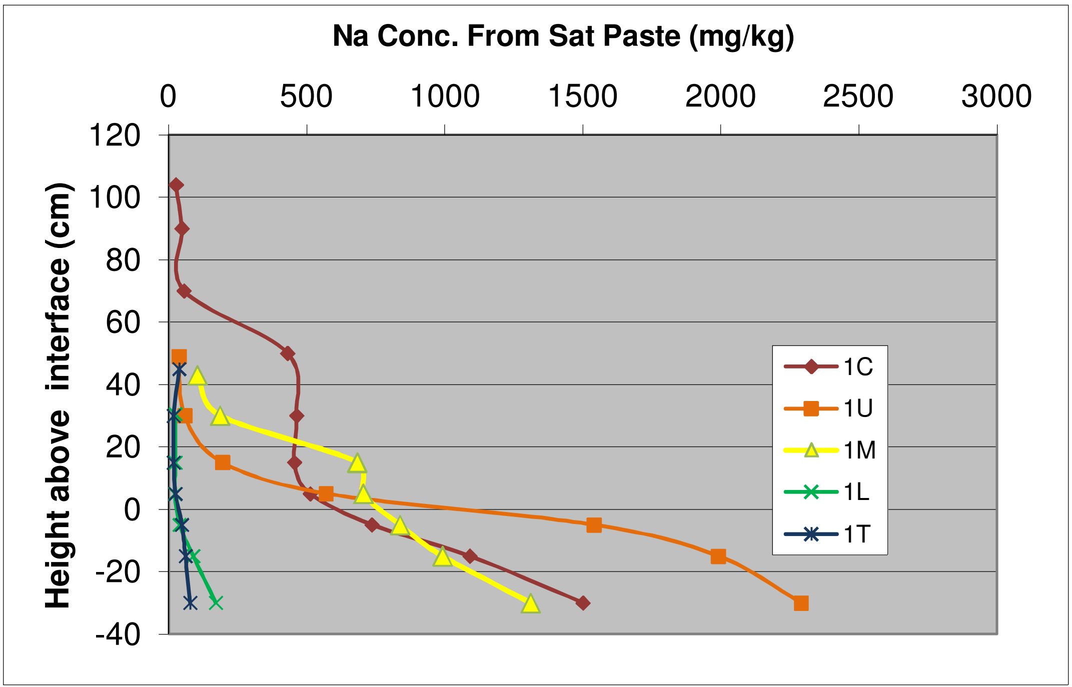
APPENDIX II

2012 Individual Soil Salinity Profiles Grouped by Transect

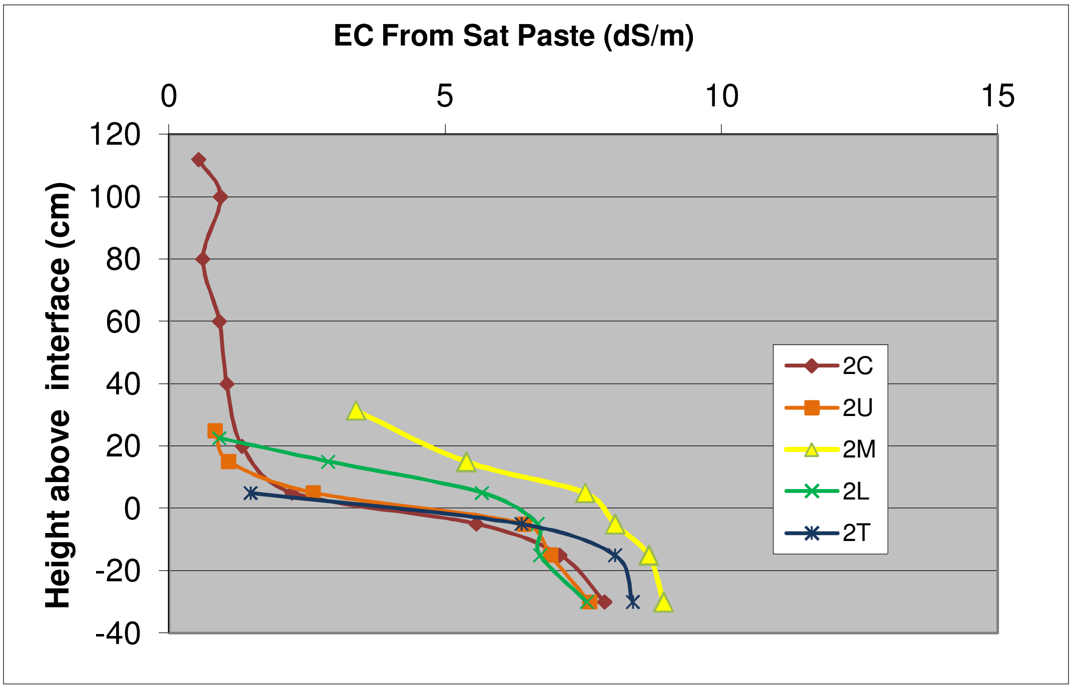
Transect 1

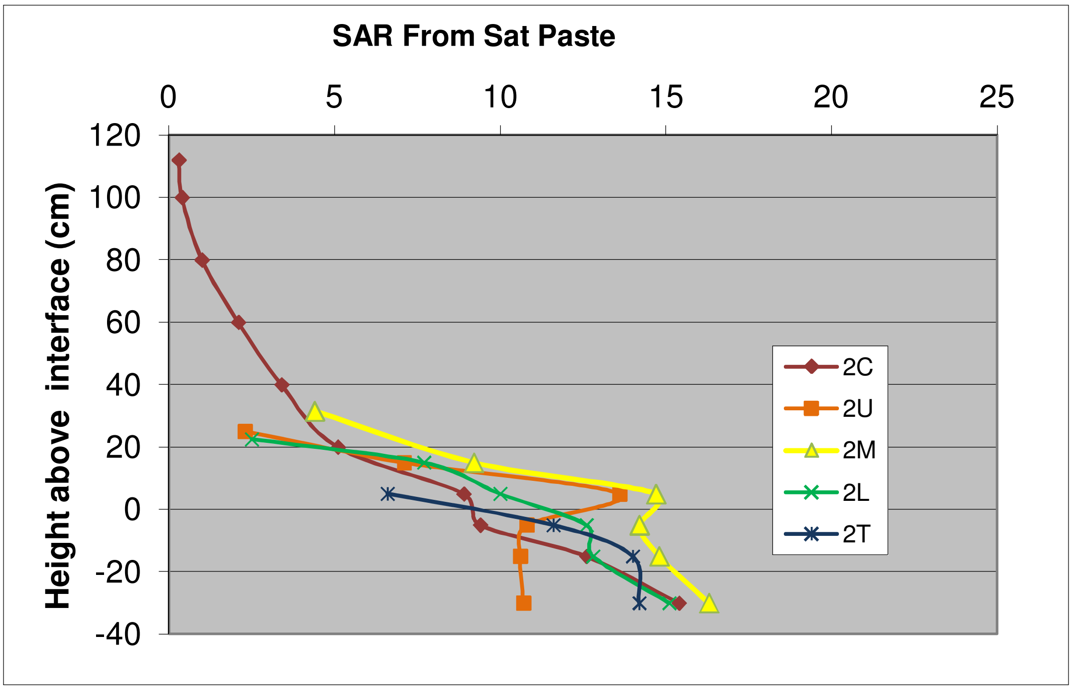

EC From Sat Paste (dS/m)
0
5
10
15
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
1C
1U
1M
1L
1T

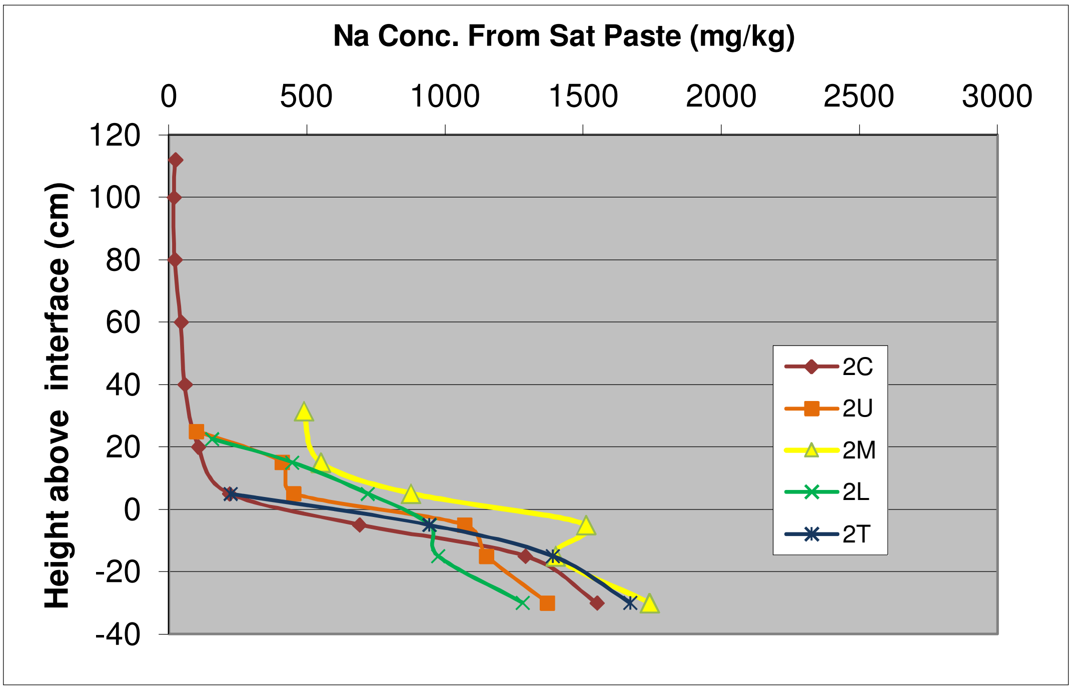

SAR From Sat Paste
0
5
10
15
20
25
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
1C
1U
1M
1L
1T


Na Conc. From Sat Paste (mg/kg)
0
500
1000
1500
2000
2500
3000
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
1C
1U
1M
1L
1T

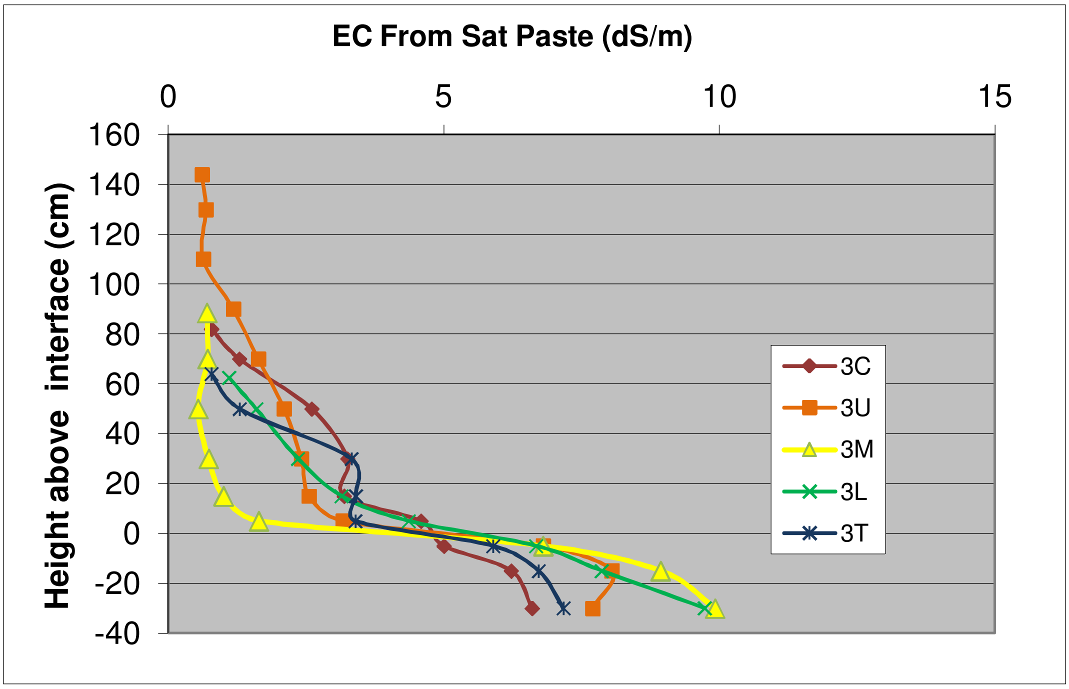
Transect 2

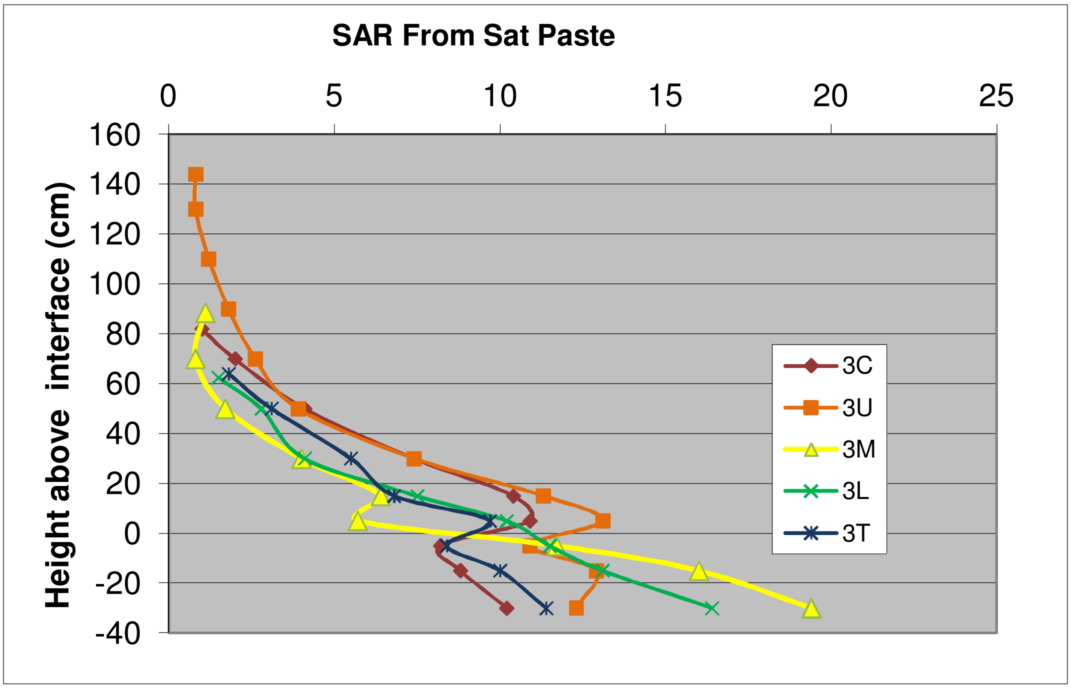

EC From Sat Paste (dS/m)
0
5
10
15
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
2C
2U
2M
2L
2T

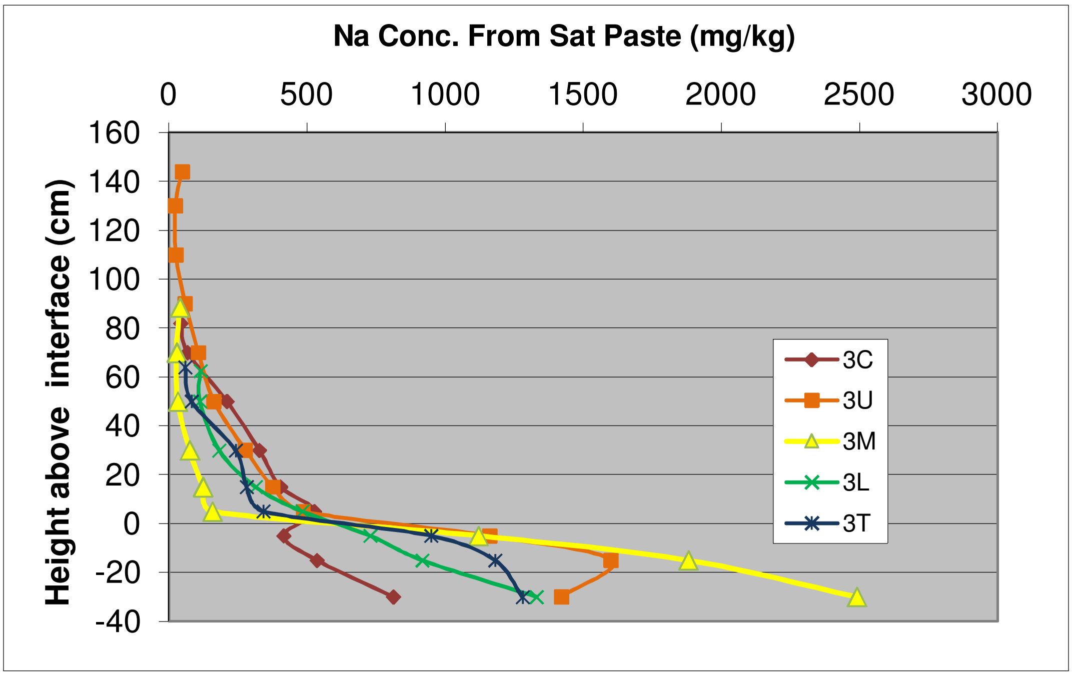

SAR From Sat Paste
0
5
10
15
20
25
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
2C
2U
2M
2L
2T


Na Conc. From Sat Paste (mg/kg)
0
500
1000
1500
2000
2500
3000
120
100
80
60
40
20
0
-20
-40
Height above interface (cm)
2C
2U
2M
2L
2T

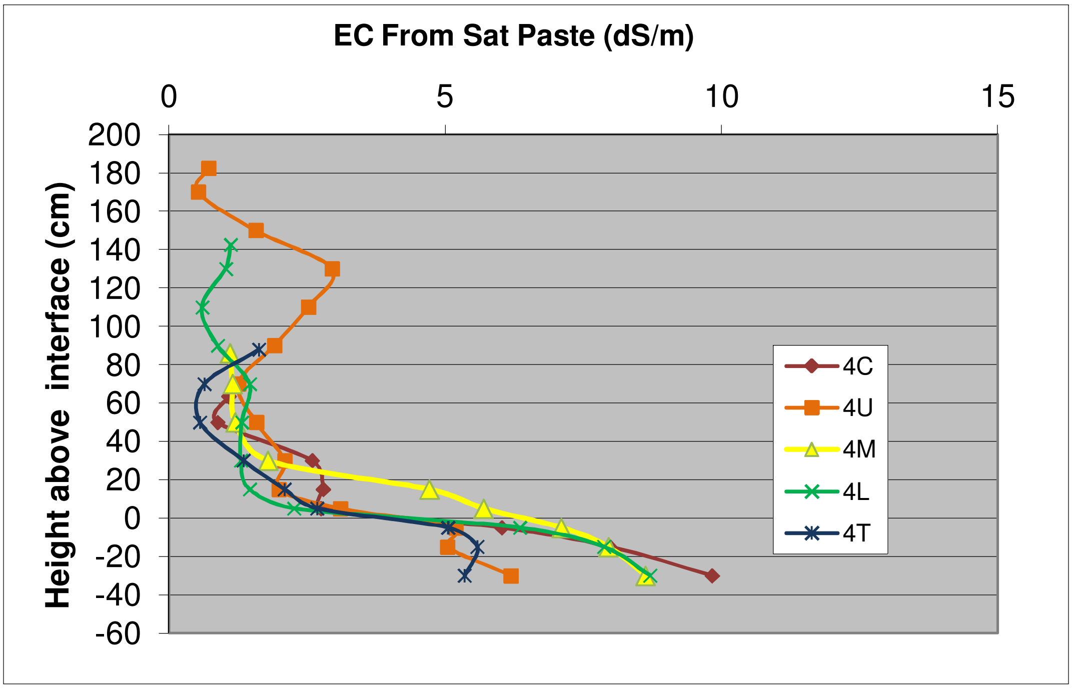
Transect 3


EC From Sat Paste (dS/m)
0
5
10
15
Height above interface (cm)
160
140
120
100
80
60
40
20
0
-20
-40
3C
3U
3M
3L
3T


SAR From Sat Paste
0
5
10
15
20
25
Height above interface (cm)
160
140
120
100
80
60
40
20
0
-20
-40
3C
3U
3M
3L
3T


Na Conc. From Sat Paste (mg/kg)
0
500
1000
1500
2000
2500
3000
Height above interface (cm)
160
140
120
100
80
60
40
20
0
-20
-40
3C
3U
3M
3L
3T

Transect 4


EC From Sat Paste (dS/m)
0
5
10
15
200
180
160
140
120
100
80
60
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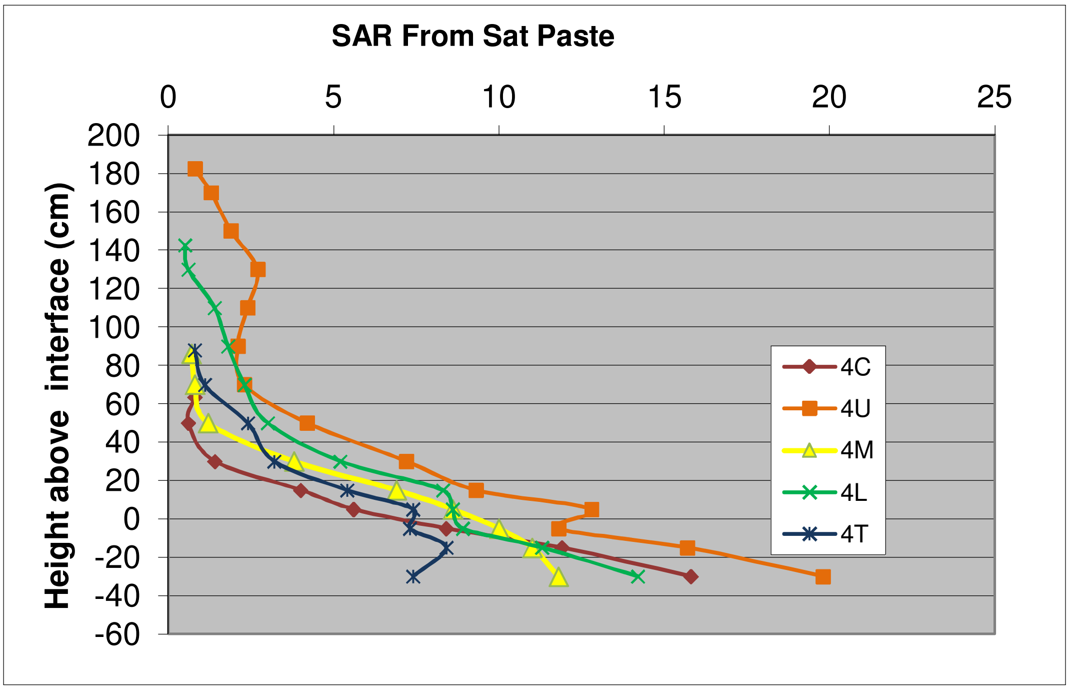
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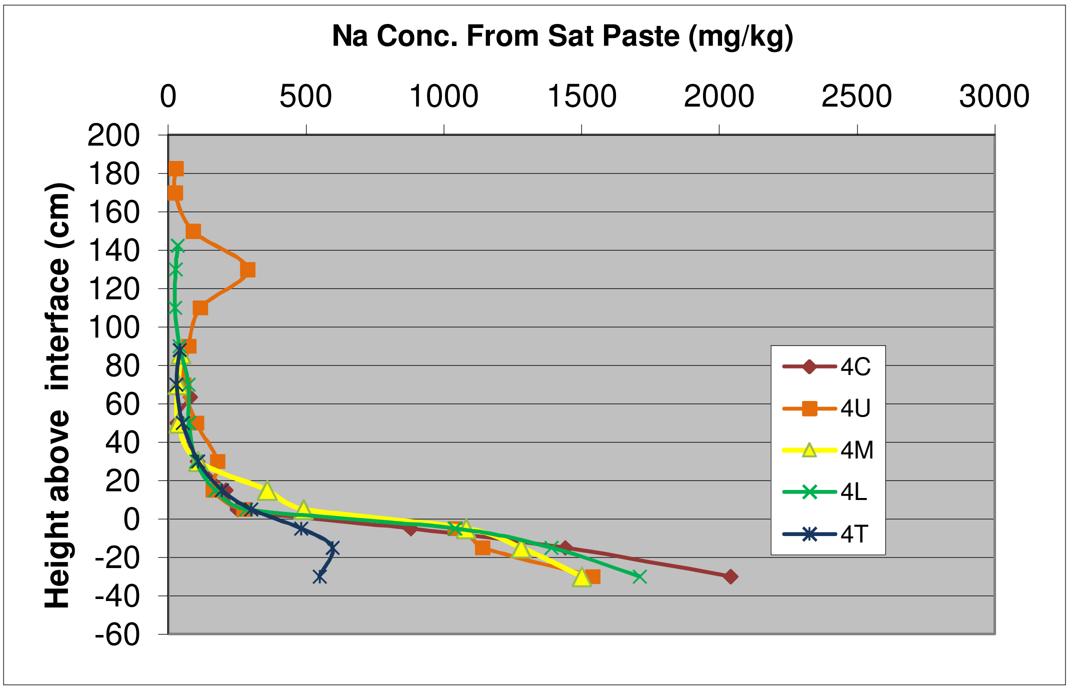
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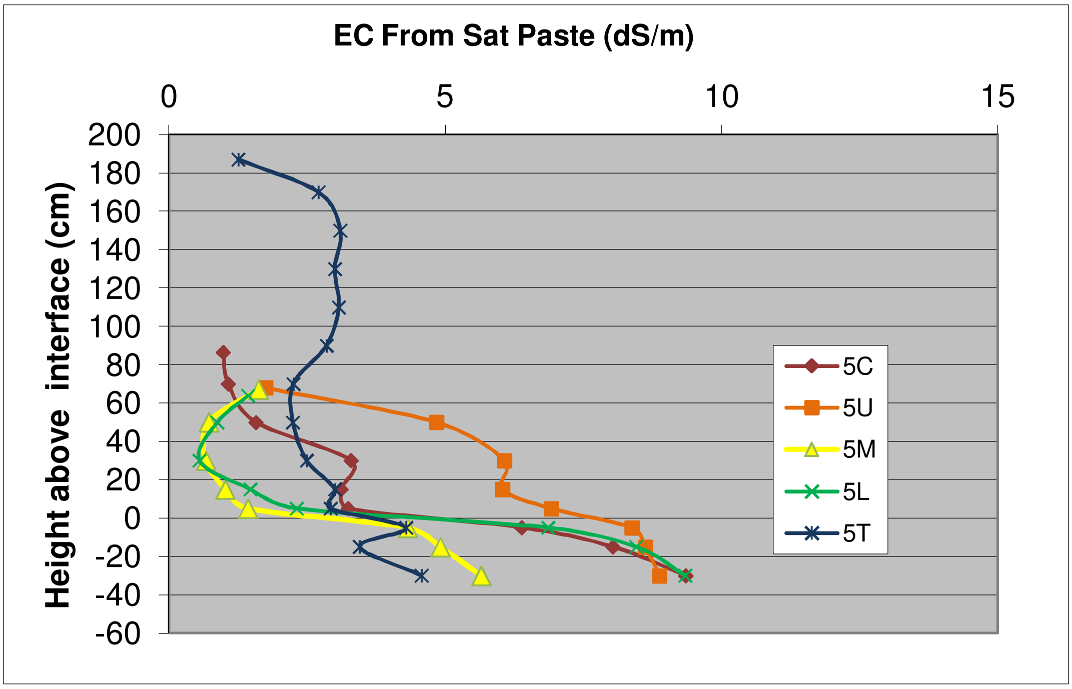
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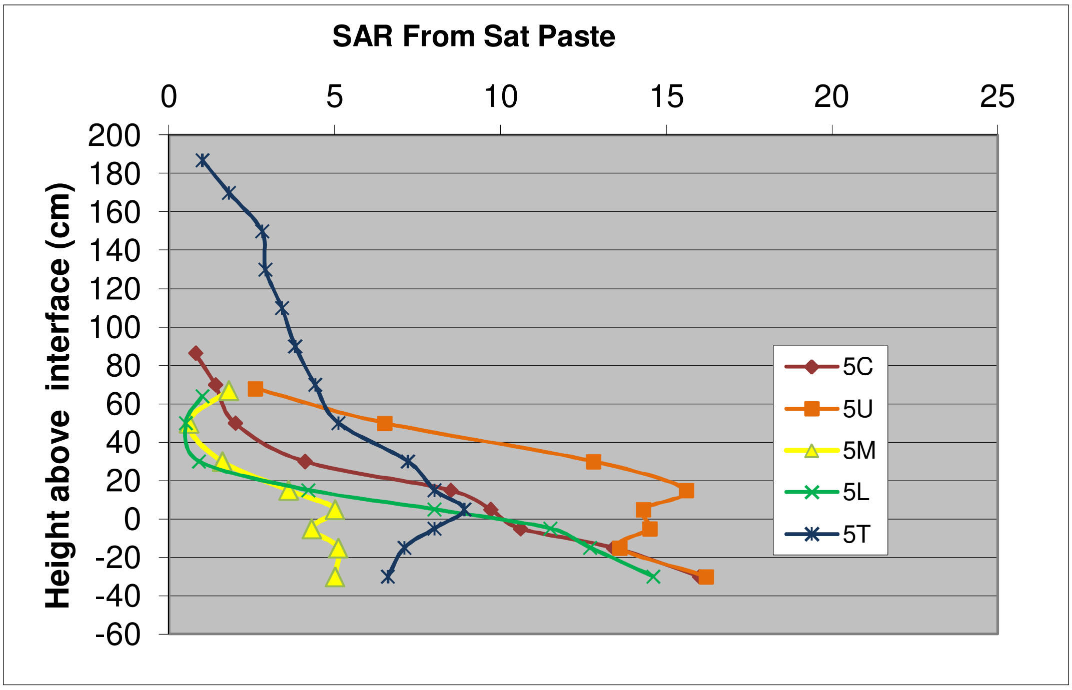
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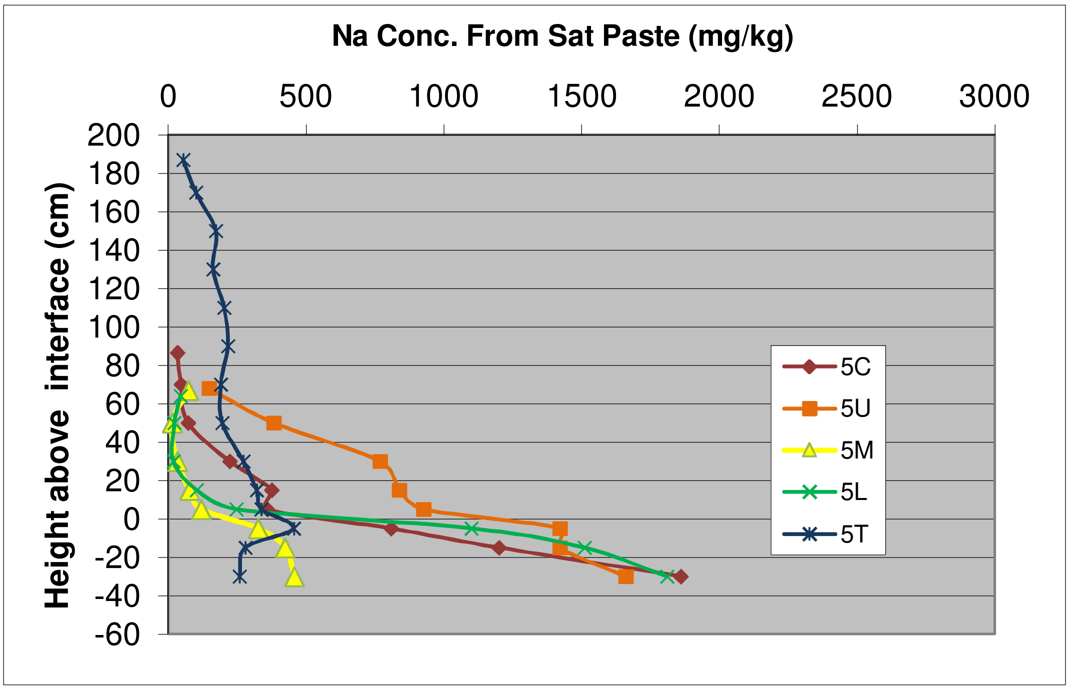
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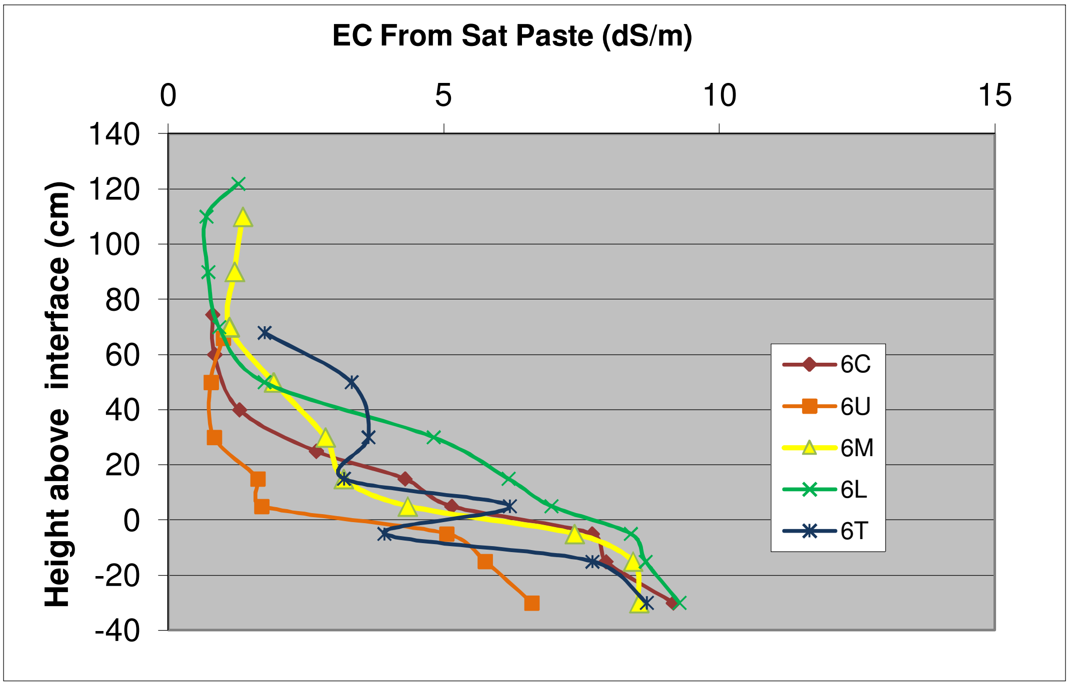
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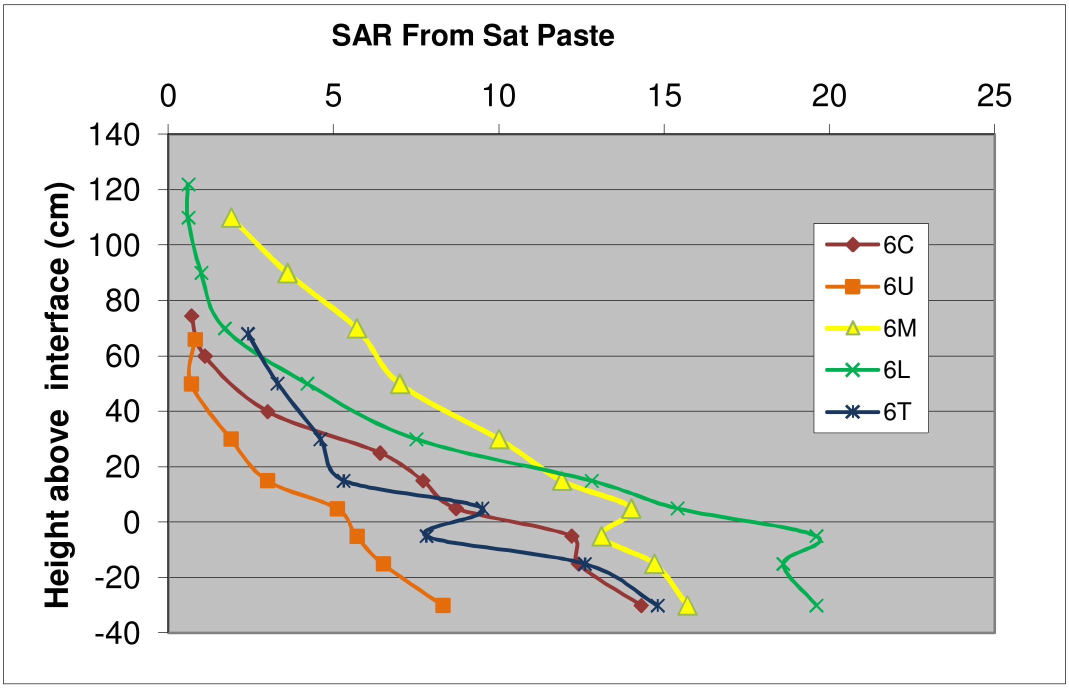
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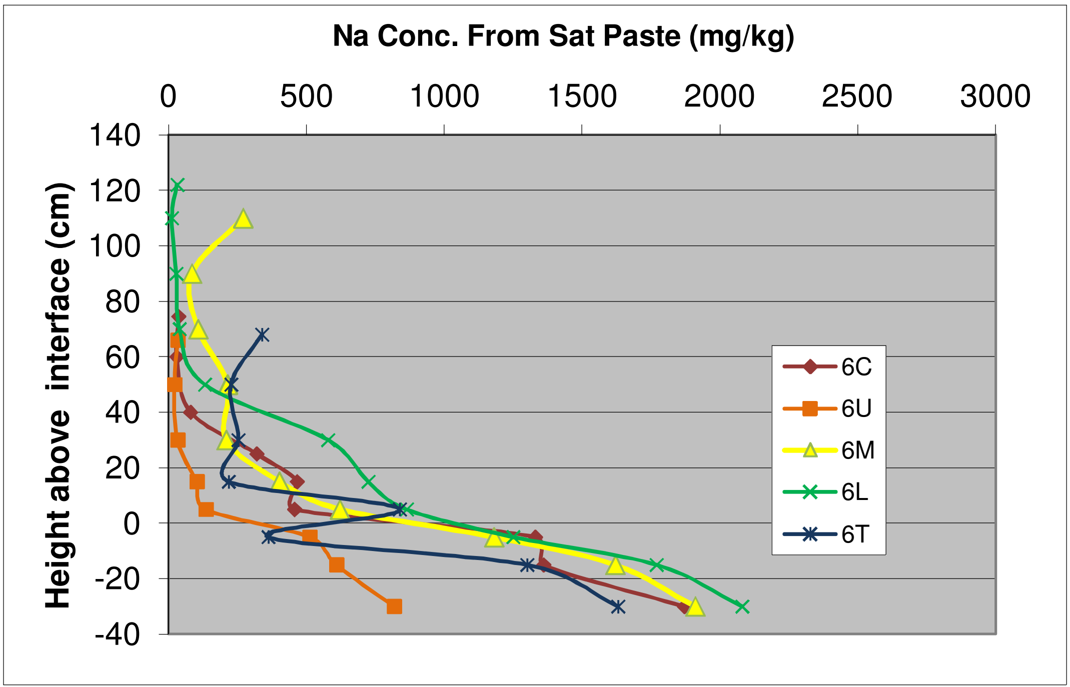
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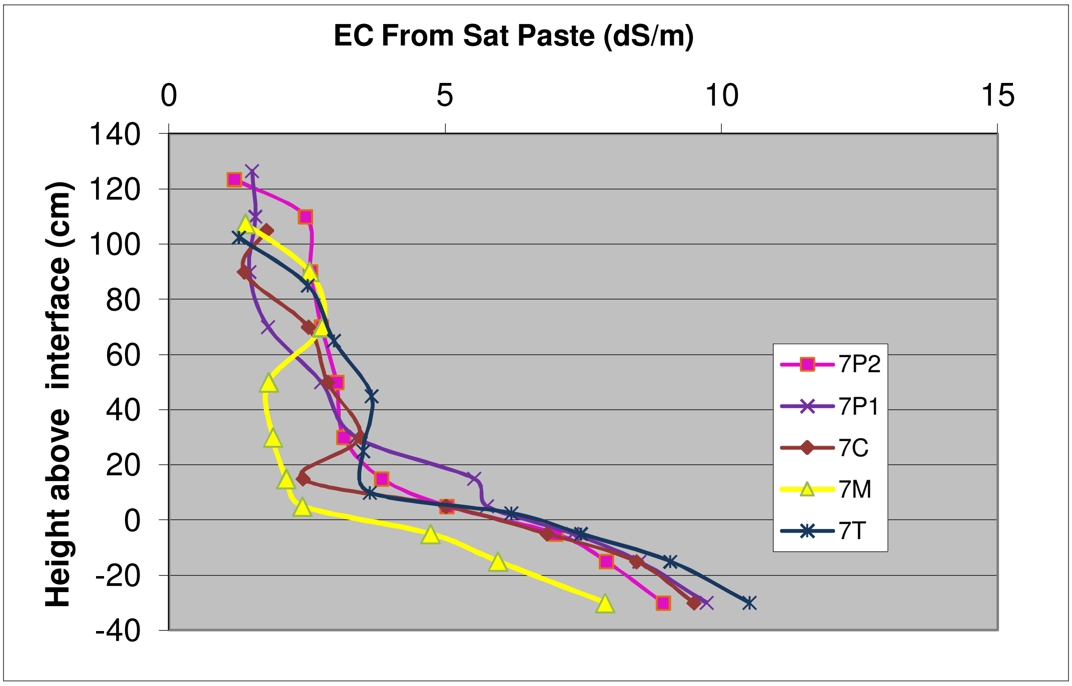
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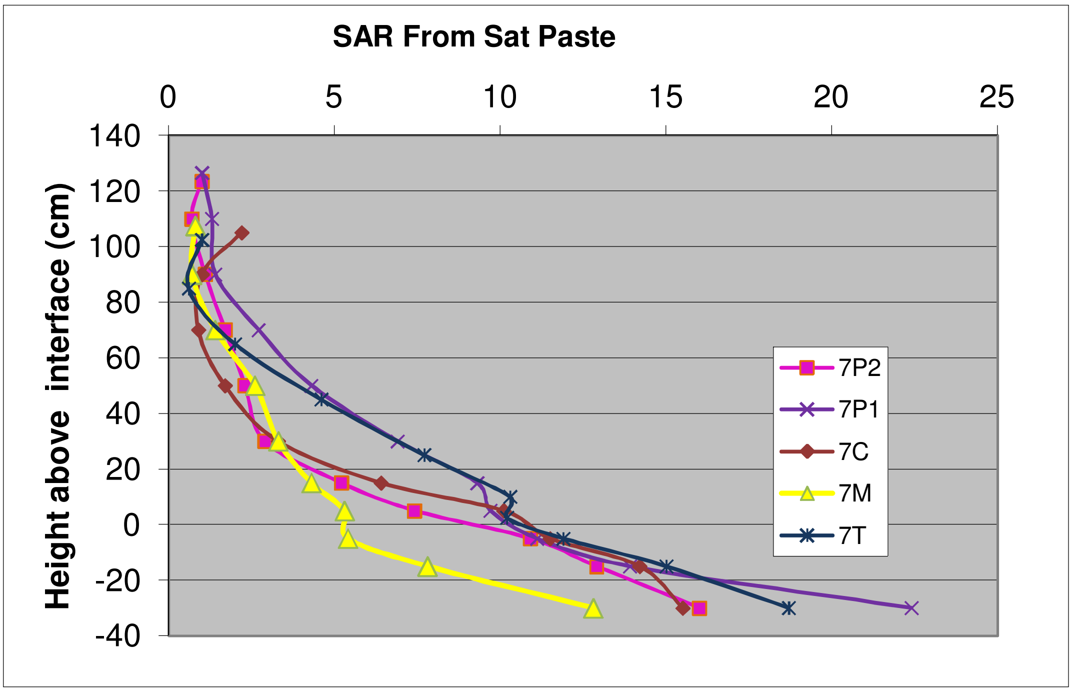
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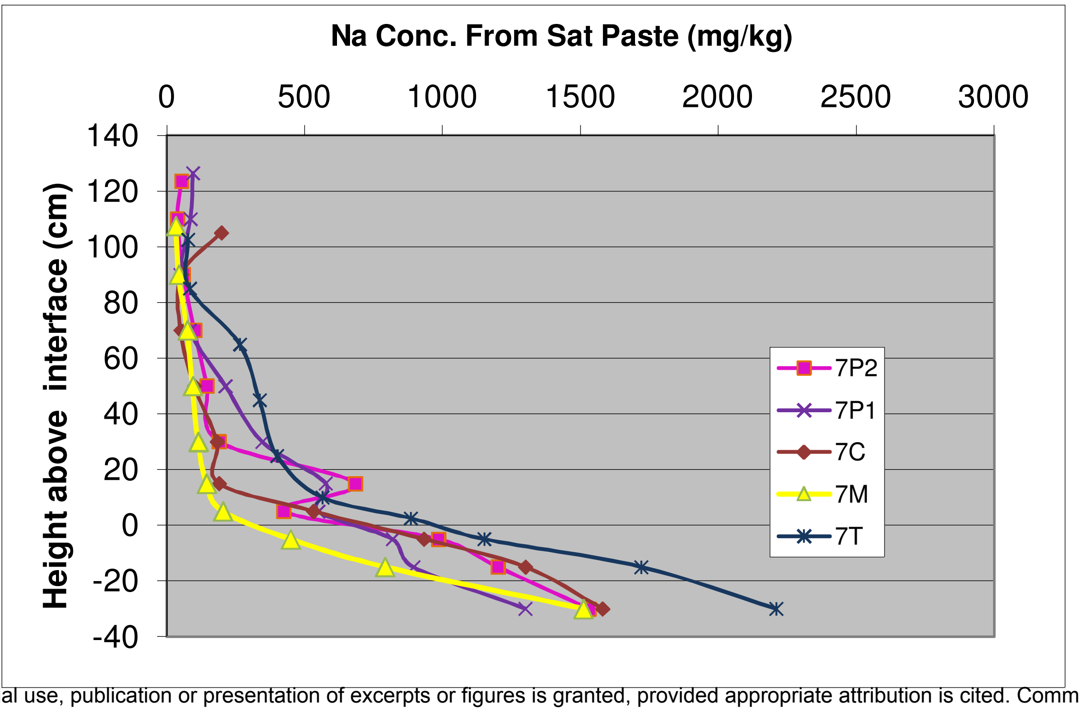
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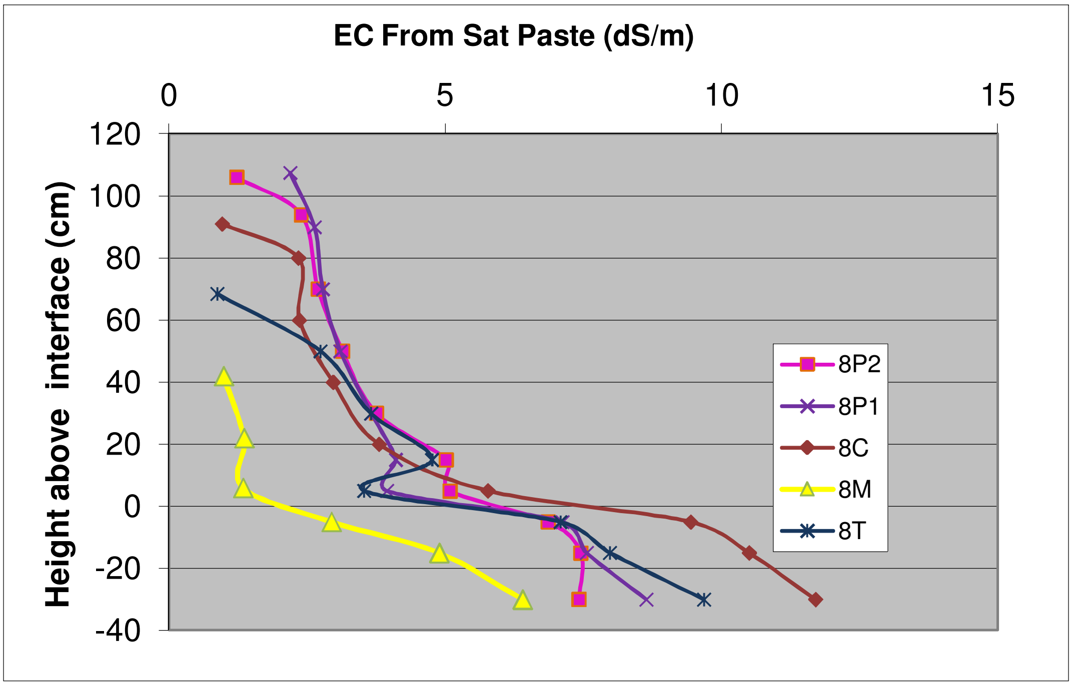
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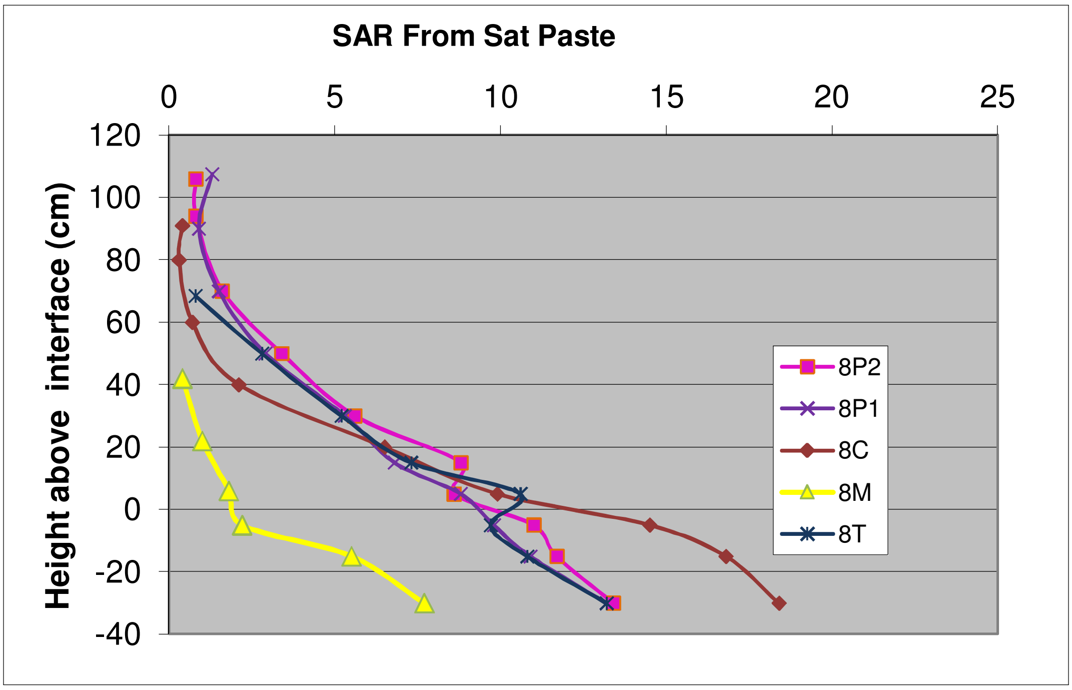
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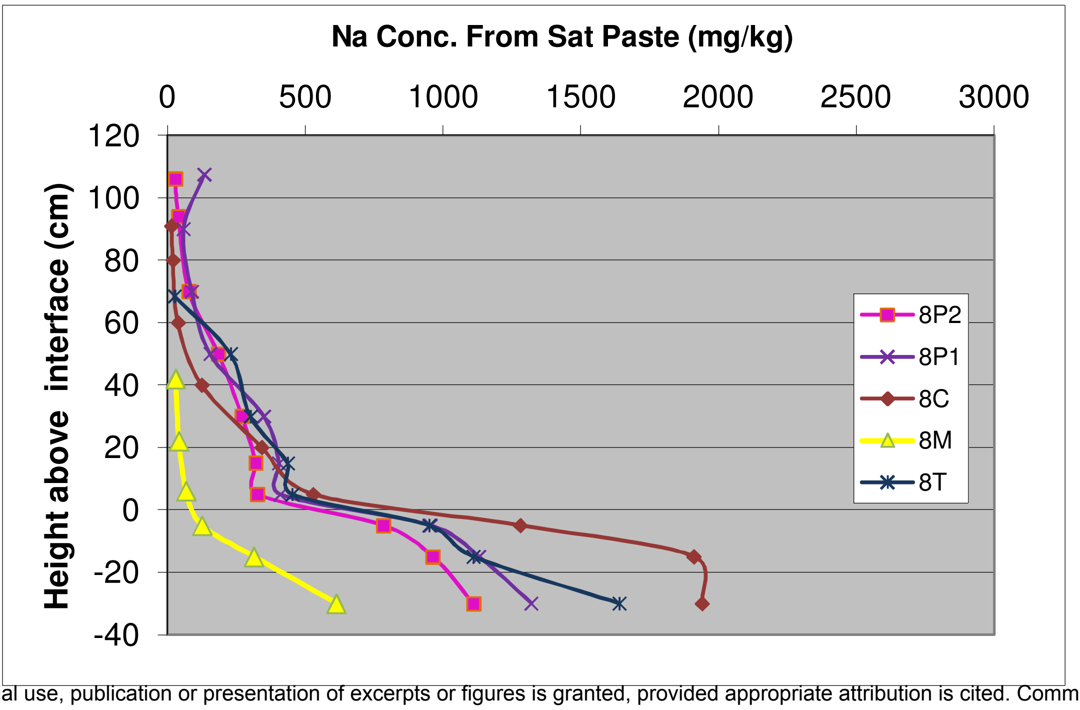
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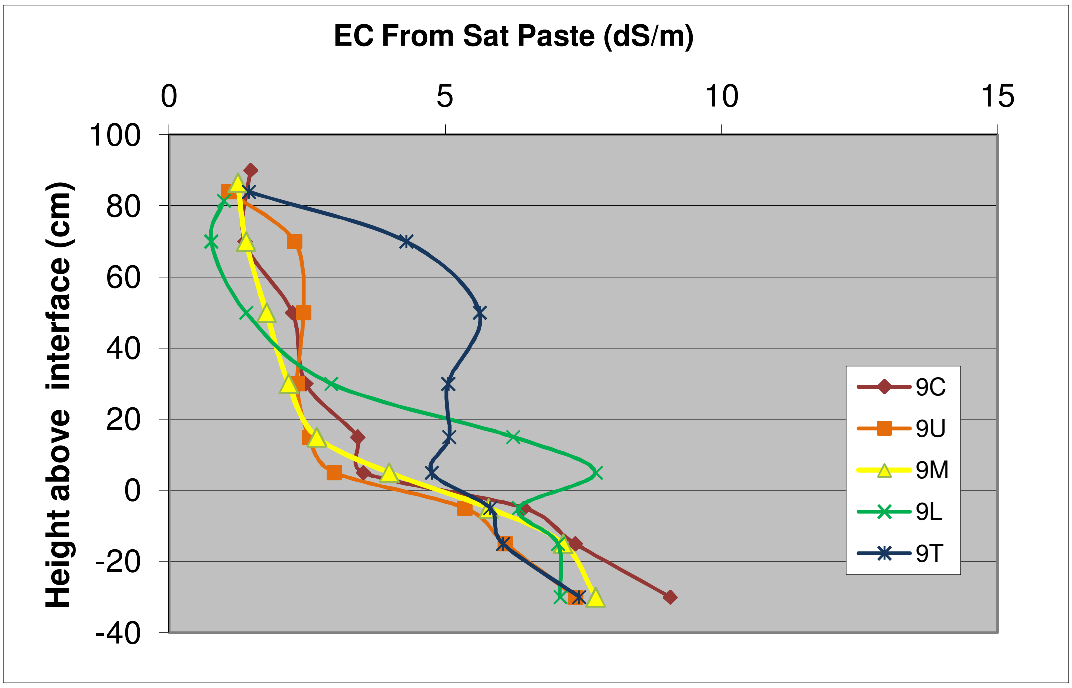
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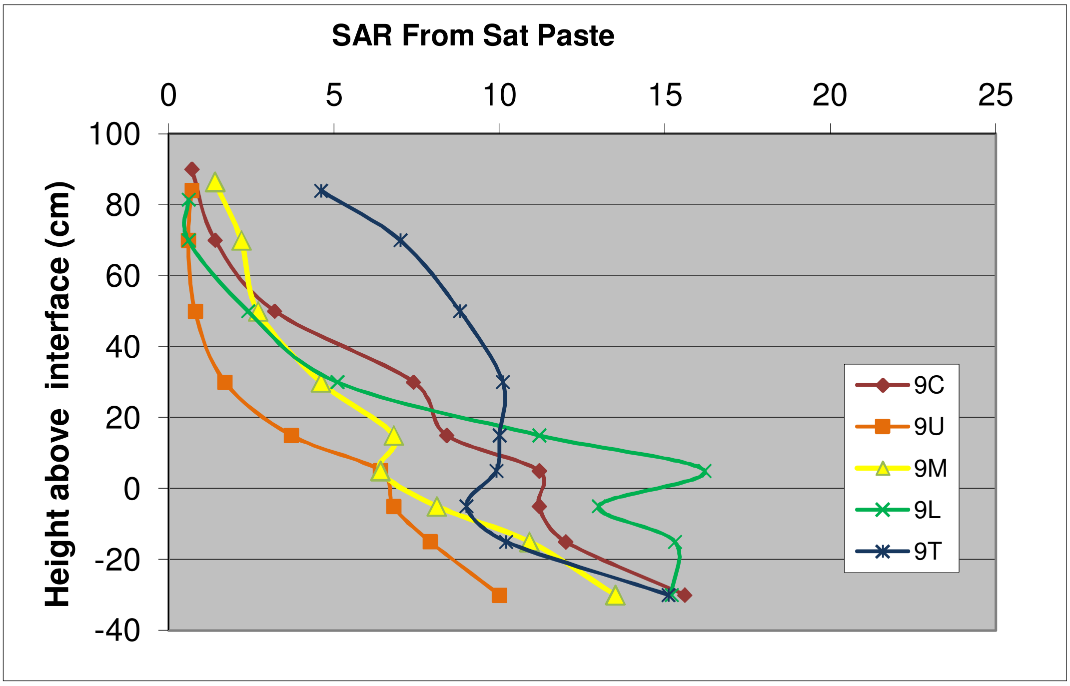
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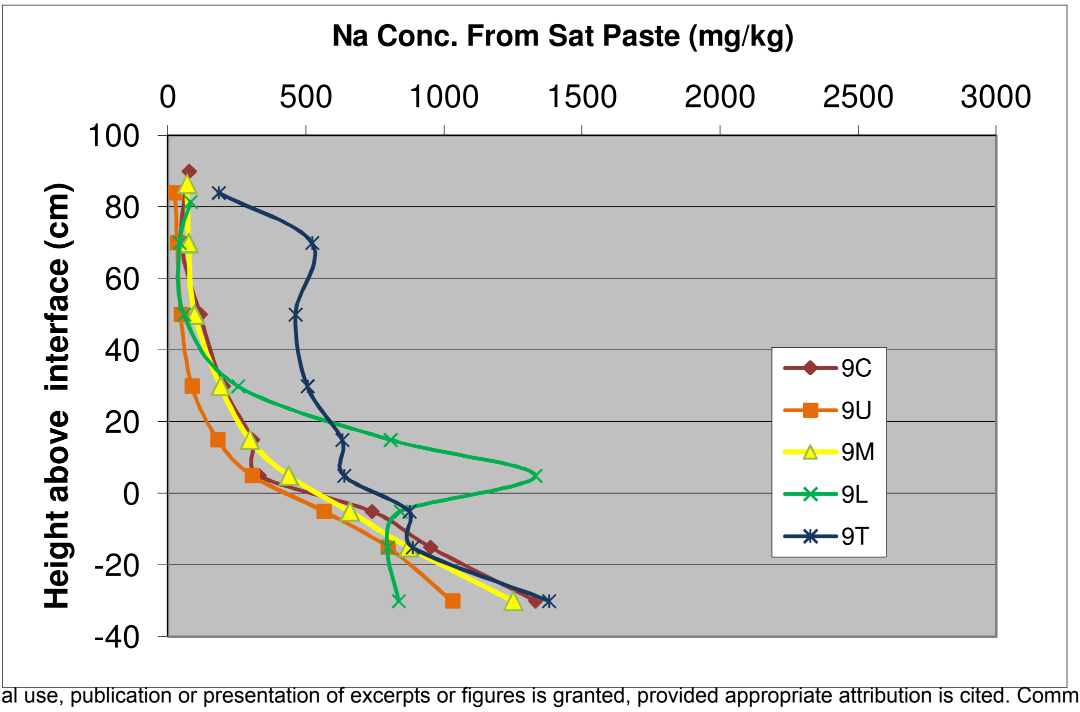
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APPENDIX F
NUMERICAL MODELING OF THE LONG-TERM WATER DYNAMICS AND THE IMPACT OF SOIL COVER DEPTH ON TRANSPIRATION FROM RECLAMATION SOIL COVER OVER SHALE OVERBURDEN

SYNCRUDE CANADA LTD.

Numerical Modelling of the Long-Term Water Dynamics and the Impact of Soil Cover Depth on Transpiration from Reclamation Soil Covers over Shale Overburden

Report Prepared For:

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and

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Date: December 20, 2012

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1. Introduction

Syncrude Canada Ltd (SCL) is undertaking a comprehensive evaluation of the efficacy of the prescribed cover thickness for reclamation covers constructed over cretaceous overburden, much of which is saline/sodic shale. In support of this project, the University of Saskatchewan has been asked to undertake a modeling study to evaluate the sensitivity of water storage and water dynamics to reclamation cover thickness. This work was to include an assessment of the monitored performance of a number of long-term, instrumented cover sites on South Bison Hill (SBH) also known as 30 Dump, and a sensitivity study to evaluate the variation in long-term (60 year) transpiration releases from covers of varied thickness placed over shale overburden.

The objectives of the study described in this technical report are as follows:

i. Compile and interpret existing field monitoring and site data on the hydrologic performance of reclamation covers on South Bison Hill.
ii. Develop a calibrated numerical model to simulate the available monitoring data obtained on 4 different cover thicknesses at South Bison Hill (D1, D2, D3 prototype covers plus plateau station).
iii. Simulate the long-term performance of a series of hypothetical covers of varying thickness (35, 50, 75, 100, 125, 150 cm) using the 60 years of climate data available from the Fort McMurray airport weather station.

2. Background and Objectives

South Bison Hills (SBH), also known as 30 Dump, was constructed by Syncrude Canada Ltd. between 1980 and 1996 with approximately 100×10^6 m^3 of shale overburden. It is 2 km^2 in area with a plateau elevation rising about 60 m above the surrounding landscape. After construction, the waste dump was contoured into a number of discrete watersheds and was capped with a soil cover. All soil cover capping materials were selectively salvaged and stockpiled prior to placement. The reclamation covers over most of the area of SBH were nominally 100 cm thick and comprised of an upper peat/glacial soil mixture overlaying fine grained glacial soil (also known as secondary).

Three soil test covers of varying thickness were constructed in 1998/99 on a north facing 5H:1V slope as part of a research program into reclamation cover performance. The three covers have nominal thicknesses of 35, 50, and 100 cm. Following the placement of the soil covers in early 1999, the reclaimed area was seeded with barley cultivar (Hordeum spp.) to prevent topsoil erosion. Later in the year, trembling aspen (Populus tremuloides Michx) and white spruce (Picea glauca (Moench) Voss) were planted (Kessler, 2007). A 4th instrumentation site was established at a site on the plateau of SBH, which was reclaimed in 2000. The thickness of the cover at the instrumentation site was 120 cm.

The three prototype covers had instrumentation stations to monitor soil water, soil temperature, and matric suction throughout the cover profile and the upper portion of the underlying overburden (Boese, 2003). An initial hydrologic interpretation and modelling of the three prototype covers was undertaken by Shurniak (2003). It was expected that the properties of the covers would change with time as a result of physical or biologic processes, such as freeze-thaw or wet-dry cycling, settlement of the waste material below the cover, and vegetation rooting. All of these processes produce changes in structure, such as the formation of macropores and fractures, which alter the hydraulic conductivity over time (Albrecht and Benson 2001; Meiers et al. 2011). Meiers et al. (2011) undertook repeated measurements of the hydraulic conductivity of the cover soils and the underlying shale overburden at SBH, over a five year period using a Guelph permeameter. The testing included repeated testing of an upper soil layer comprised of a mixture of peat and glacial clay soil, an underlying soil cover layer of only glacial clay, and the underlying shale overburden. The test results clearly demonstrated the evolution of the field saturated hydraulic conductivity of these layers within the first three to four years (1999-2003).

3. Materials and Methods

3.1 Soil Covers

The calibrated modeling undertaken in this study was based primarily on the field monitoring data from 2006 to 2011 based on the assumption that the hydraulic properties of the covers had stabilized. The modeling also focused on the 35 cm (D2), 100 cm (D3), and 120 cm (Plateau) covers. The 50 cm (D1) cover was not included in the calibration since a re-installation in 2007 appears to have caused an abrupt change in the monitoring trends (O'Kane 2012).

The D2 cover was constructed with a 15 cm layer of peat-mineral soil overlying approximately 22 cm of secondary. The D3 cover was constructed with a 20 cm layer of a peat-mineral soil overlying approximately 80 cm of secondary, while the Plateau cover has a 20 cm layer of a peat-mineral soil mixture overlying approximately 100 cm of secondary (Figure 1). For all covers, the overburden material is shale.

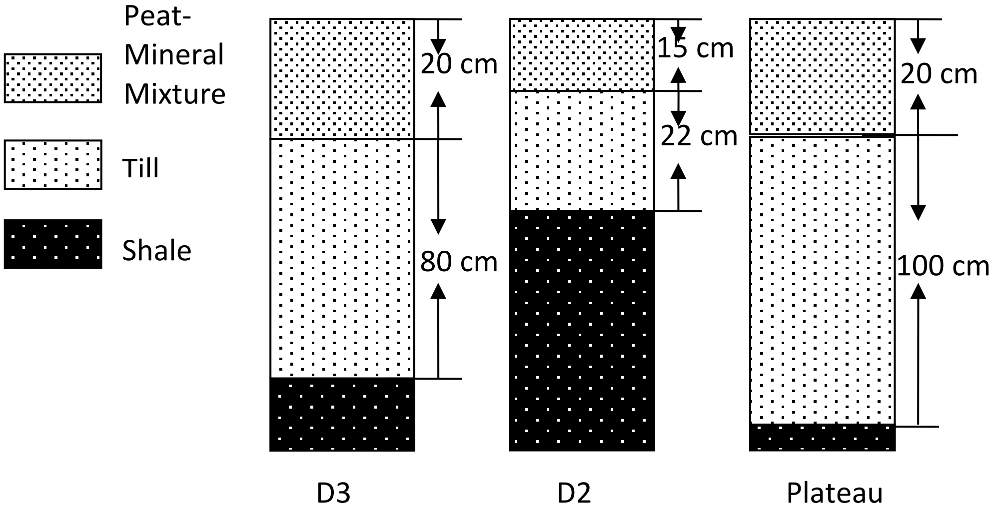


Fig. 1. Schematic diagram of Soil covers.

The peat-mineral and glacial soils are classified as fine-grained with over 60 to 70% fines and 25 to 40% clay based on the Unified Soil Classification System (USCS) (Boese, 2003). The underlying shale is slightly finer with 80 to 90% fines (material passing 0.045 mm) and 35 to 55% clay soil particles (less than 0.002 mm).

Water retention curves (WRC) for the cover soils and shale were measured using low pressure (100 kPa) acrylic Tempe cells (Soilmoisture Equipment Corp, Santa Barbara, California) and glass desiccators. The desiccators were employed to determine the WRC at high suctions (approximately 5,000 to 300,000 kPa). Figure 2 shows the measured WRC for peat, till and shale. It is important to note that the samples were not undisturbed but were recompacted at similar water contents and density as those observed in the field.

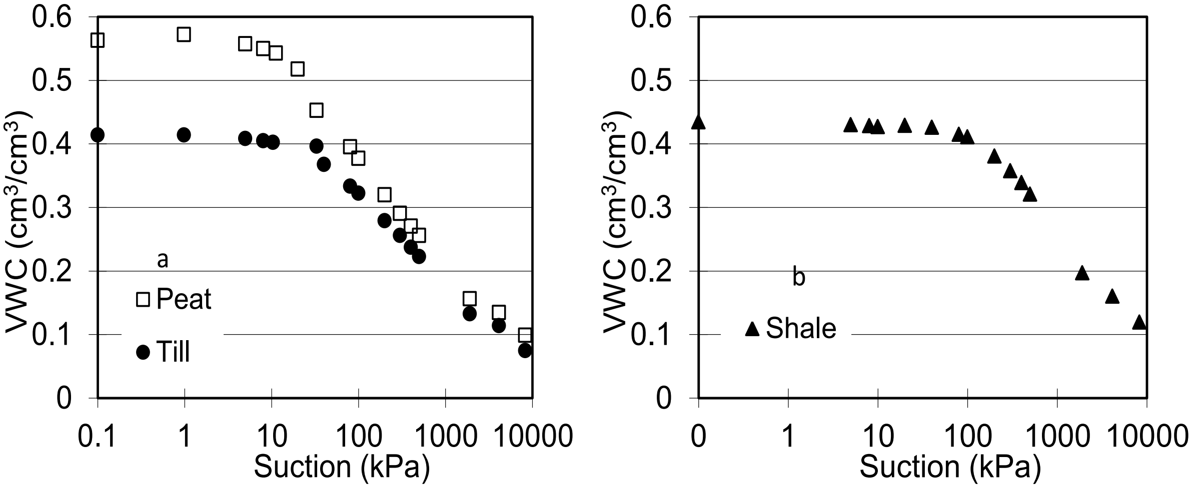


Fig. 2. The measured soil water characteristic curves for (a) Peat-mineral and glacial clay soils (Shurniak, 2003) and (b) Shale (Fenske, 2011).

The field saturated hydraulic conductivity (K_s) of each soil had been measured using a Guelph permeameter as reported by Meiers et al. (2011). The final measured Ks of these soils following an initial weathering period were 5.0e-5 m/s, 1.0e-6 m/s and 3.0e-8 m/s for peat-mineral, secondary, and shale, respectively (Meiers et al. 2011).

3.2 Field Measurements

Various field measurements of soil, vegetation, and climate have been made over the years. The soil properties of soil moisture, soil temperature, and matric suction, were continuously monitored at different depths for each cover. The detailed monitored positions in the profiles of D2, D3, and Plateau can be found in Table 1. Vegetation data includes LAI, tree height, and tree diameter at breast height (DBH). A meteorological station was installed at each site to measure precipitation, air temperature, relative humidity, wind speed, and solar radiation. These measured data were used to calculate potential evapotranspiration by the Penman-Monteith (Allen, 1998) method.

Table 1 Monitored depths for soil moisture, temperature and matric suction

Material	D2 (cm)	D3 (cm)	Plateau (cm)
Peat-mineral mixture	5	5	5
Peat-mineral mixture	10	20	15
Till	20	30	25
Till	25	55	40
Till	32	90	115
Shale	42	115	125
Shale	80	125	
Shale		145	
Shale		170	

3.2.1 LAI

Measurements of LAI on the plateau have been undertaken through various research programs (Carey 2008, 2011). These measurements (Figure 3) highlight the progressive development of LAI from 2006 through to 2011 (7 years after placement). The gradual growth of LAI is consistent with the development of the vegetation canopy with increased transpiration and plant growth. It is important to note that once the LAI reaches a value of approximately 2.7, the majority of available potential evapotranspiration will be directed towards transpiration rather than surface evaporation due to near continuous vegetation cover.

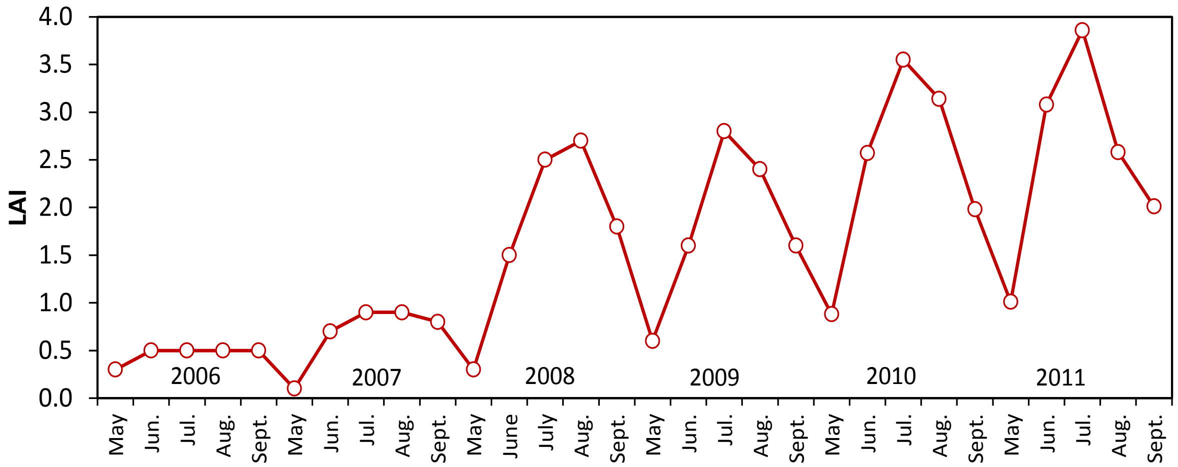


Fig. 3. The change of LAI during growing season in different years. Data from Carey (2011).

3.2.2 Water Contents

A typical set of soil water content dynamics at different depths within the three covers is presented in Figures 4a to 4c. The monitoring data is only presented for days in which the cover temperatures were greater than $O^{o}C$ (i.e. unfrozen day). Estimates of water contents associated with field capacity and wilting point in each material are also added to the figures although it is important to note that changes in texture or density can cause these values to differ from these estimates. This is a particular problem in the shale overburden which can be quite heterogeneous, ranging from clay to lean oil sands.

The soil water contents in the upper peat-mineral mixture show strong rapid responses to rainfall and evapotranspiration for all of the different covers, while the soil water contents in the lower secondary layer have generally muted responses to climatic conditions. At some depths, such as the depth 115 cm at the Plateau, the monitored water content for the secondary is nearly constant throughout the unfrozen period from 2006 to 2011. The only cover location to demonstrate persistent changes in water content within the shale in response to climatic conditions was at the D2 cover.

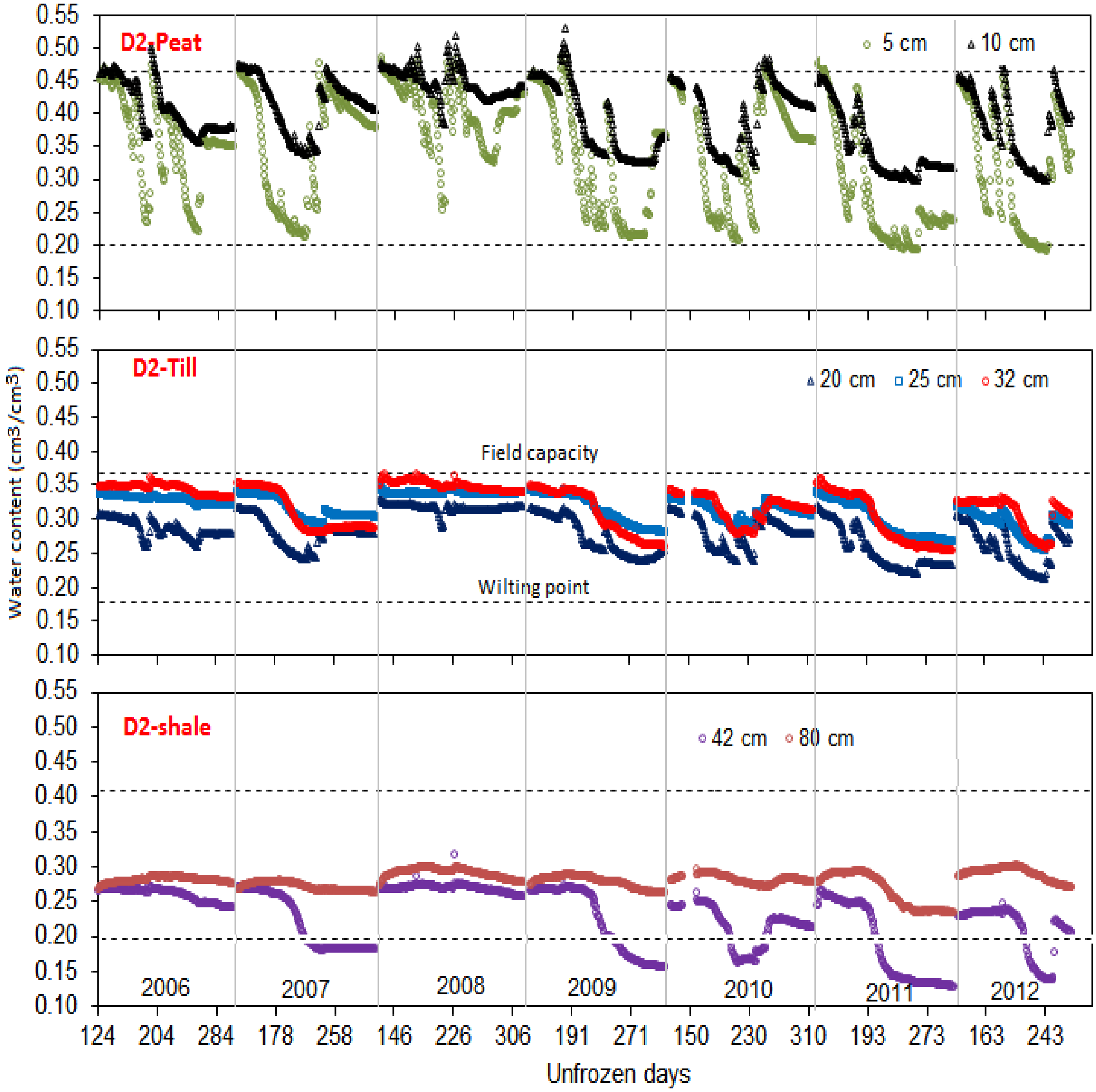


Fig. 4a. The measured water contents at different depths on days in which the soil temperature is greater than 0°C for D2 (37 cm total capping depth). Dashed lines represent the estimated water content at field capacity and wilting point.

The low water content at the 42 cm sensor at the D2 cover and at 125 cm sensor at the Plateau cover may be due to the presence of a somewhat coarser material at this location since the minimum water content is much lower than the WP of the shale. Although not reported here, Ken van Rees (reference not availalbe) did find that there was a greater percentage of root biomass with the secondary (clay) layer at two plateau sites than there was along the slope at

D3. In the case of the thicker covers (D3 and Plateau) there is little to no contribution from the shale to the water balance in the covers. It is also important to note that the water contents at the base of the secondary in the thicker covers are consistently high (approximately 35-40%) and higher than those of the thinner cover (as low as 25%). Previous research by Kessler (2007) and Kelln (2008) have all noted the fact these higher water contents appear to enable higher rates of salt diffusion from the shale into the cover.

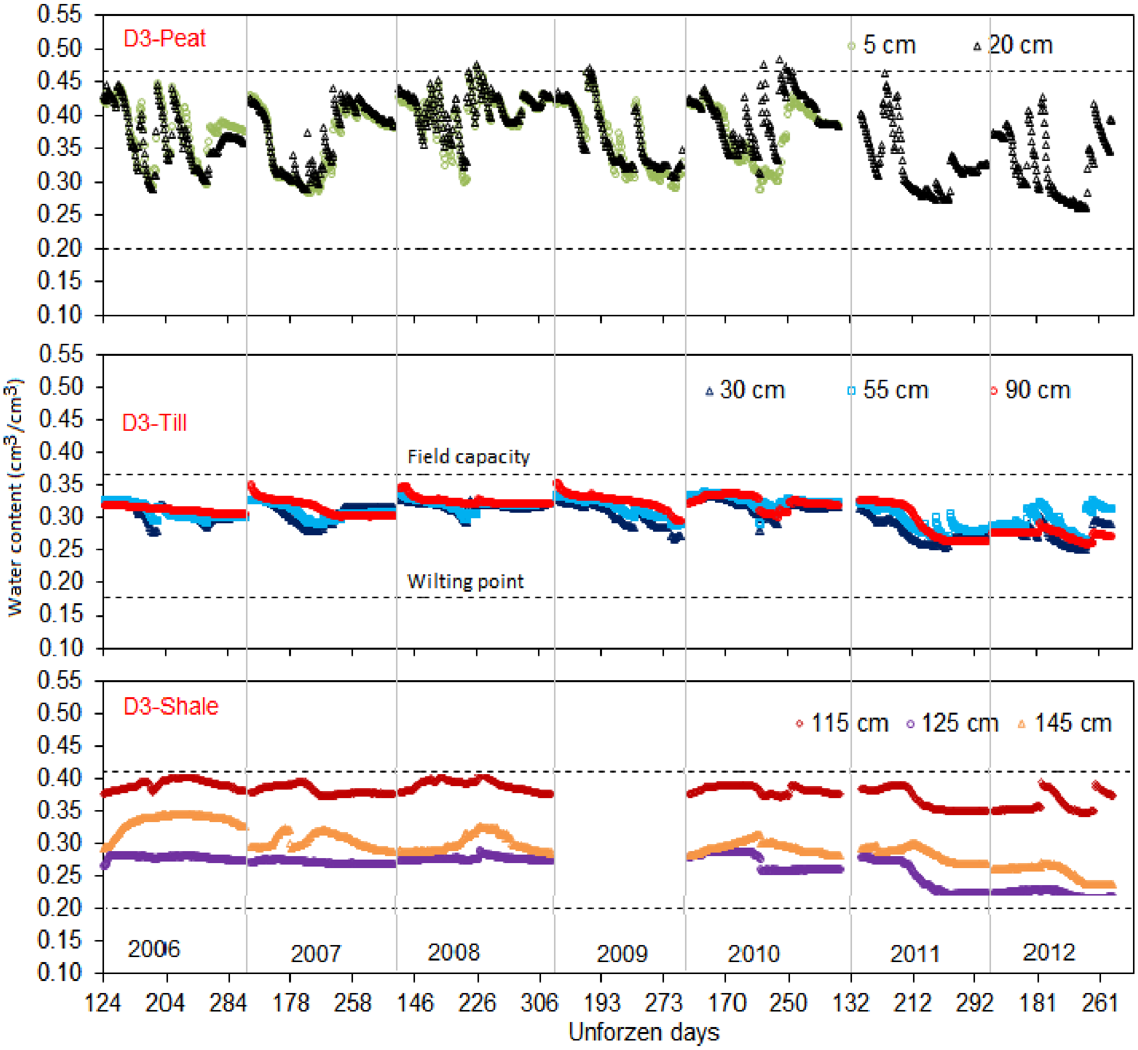


Fig. 4b. The measured water contents at different depths on days in which the soil temperature is greater than 0°C for D3 (100 cm total capping depth). Dashed lines represent the estimated water content at field capacity and wilting point.

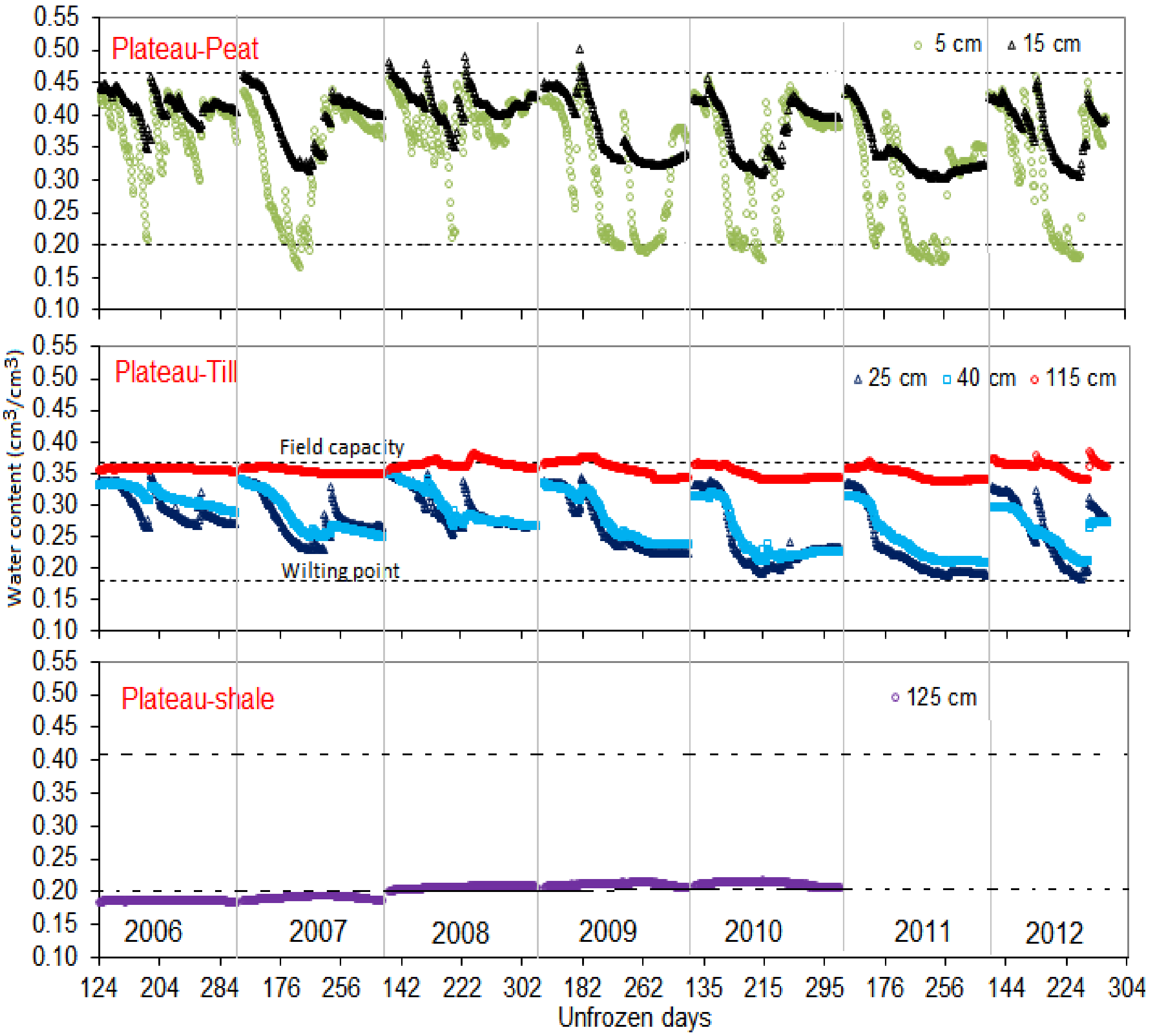


Fig. 4c. The measured water contents at different depths on days in which the soil temperature is greater than 0°C for Plateau (120 cm total capping depth). Dashed lines represent the estimated water content at field capacity and wilting point.

3.2.3 Matric Suction

The monitored suctions for selected years are shown in Figures 5a to 5c. The sensors are not able to reliably measure suction above a few thousand kPa; consequently high suctions (e.g. > 1,000 kPa) should be understood to be qualitative rather than quantitative. In a similar manner, suctions below 10 kPa confirm the presence of low suctions (or even saturated conditions with positive pressures) but are not quantitative.

These figures highlight how the suction within the peat/mineral layer ranges from field capacity (or wetter) to near wilting point conditions for nearly all of the covers. Deeper within the secondary layer, the range of suctions for the thinner cover continues to extend from field capacity to wilting point conditions while the deeper covers and depths appear to cycle from field capacity (or possibly even saturation) to suctions generally less than wilting point. The suction within the shale below the deepest covers (100 and 120 cm) rarely even exceeds field capacity while in the thinnest cover (35 cm) the suction within the shallow shale exceeds wilting point nearly every year.

One anomaly in these general patterns was the period of high suctions that developed in all layers within the 35 and 100 cm covers by the end of 2011, an extremely dry year. It is known that these very dry conditions persisted into 2012. It is important to note that the sensor readings are not considered to be accurate at suctions greater than 1000 kPa; however; high suctions are reflective of very dry soil moisture conditions. These dry cycles are reflected in the water content readings for the 35 and 100 cm covers (Figures 4a and 4b) but appear to be much less severe than is represented by the suction readings.

The water content data can also be cross-plotted against suction for various sensor locations to evaluate a general trend for the volumetric water content (VWC) for the various soils (Figures 6a to 6c). These types of cross-plotted data have considerable scatter because of differences in the specific location, representative volume, response time, and hysteresis of the measured suction and water content. They do, however, provide a ‘cloud’ of data which should encompass the VWC used for modeling purposes.

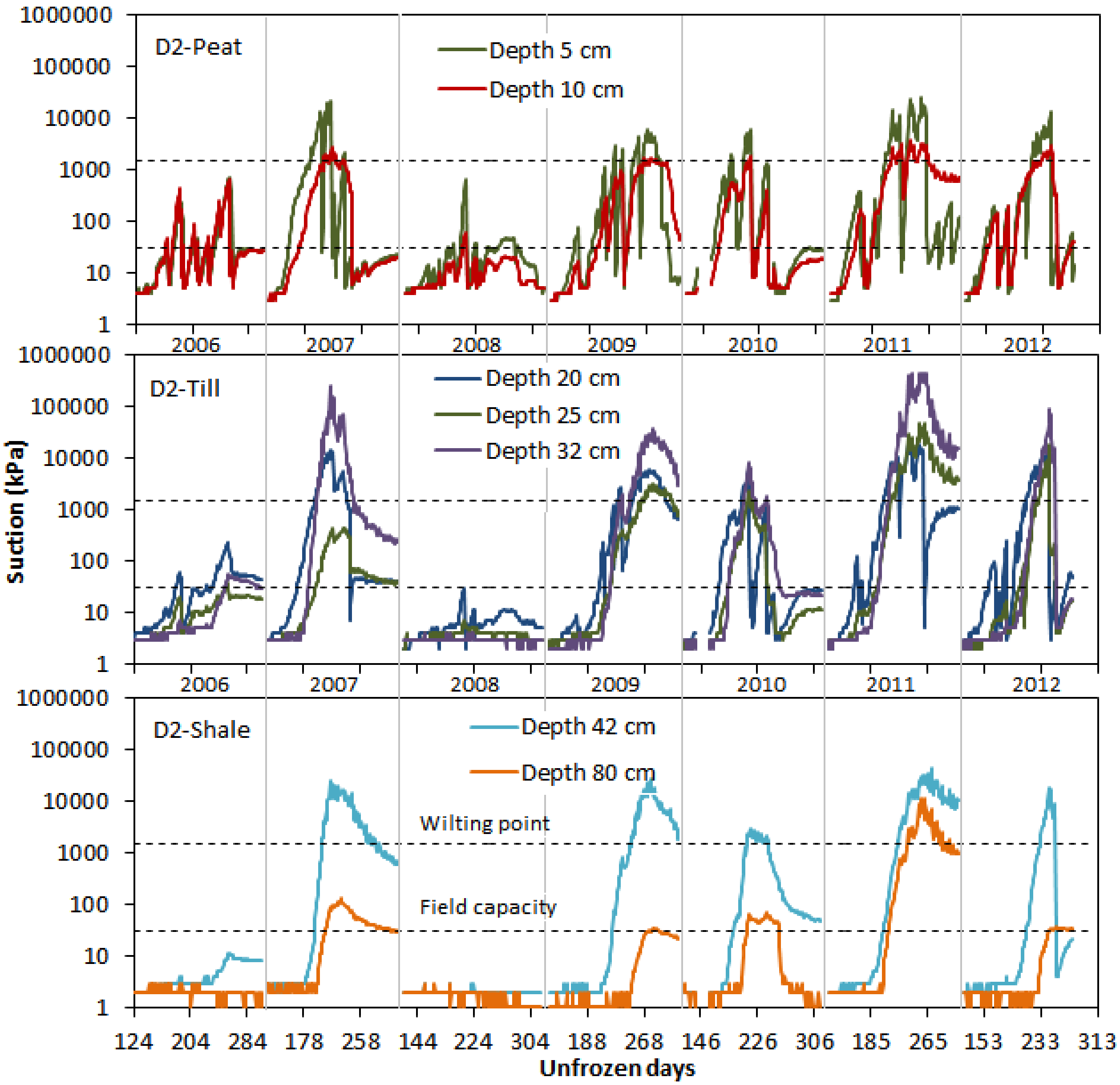
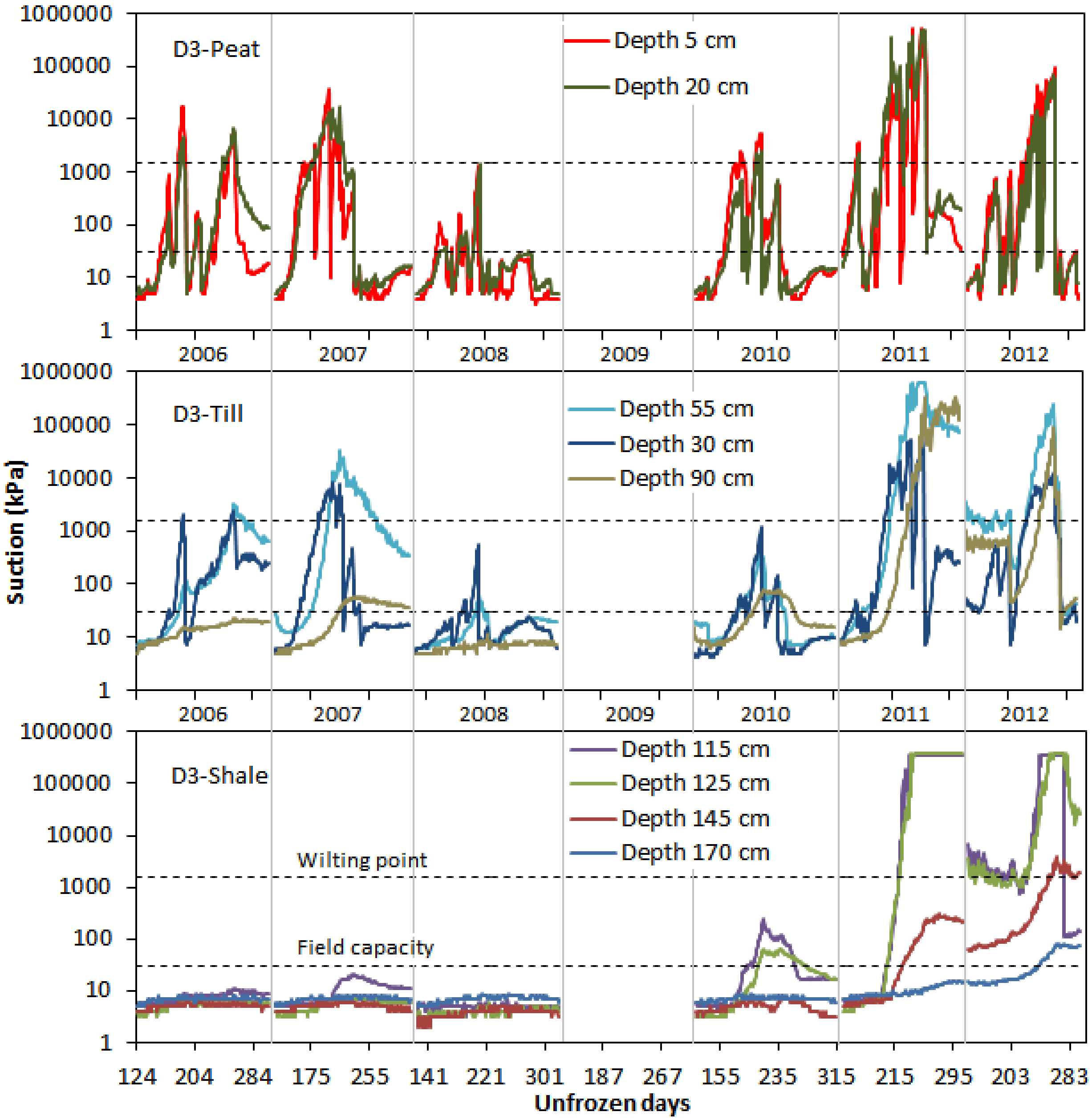


Fig. 5a. The measured suctions at different depths on days in which the soil temperature is greater than 0°C for D2 (37 cm total capping depth). Dashed lines represent the estimated suction at field capacity and wilting point.



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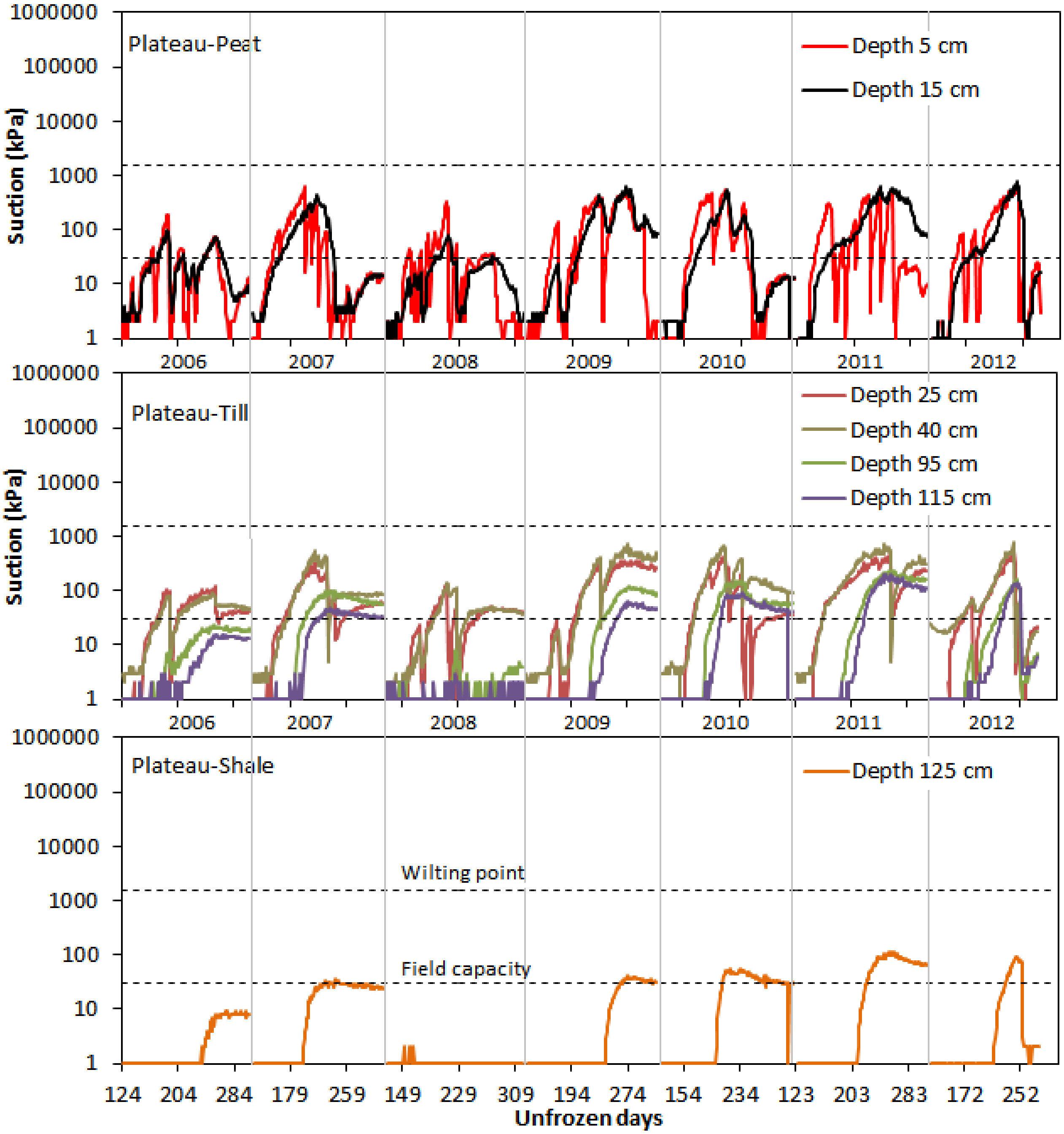


Fig. 5c. The measured suctions at different depths on days in which the soil temperature is greater than 0°C for Plateau (120 cm total capping depth). Dashed lines represent the estimated suction at field capacity and wilting point.

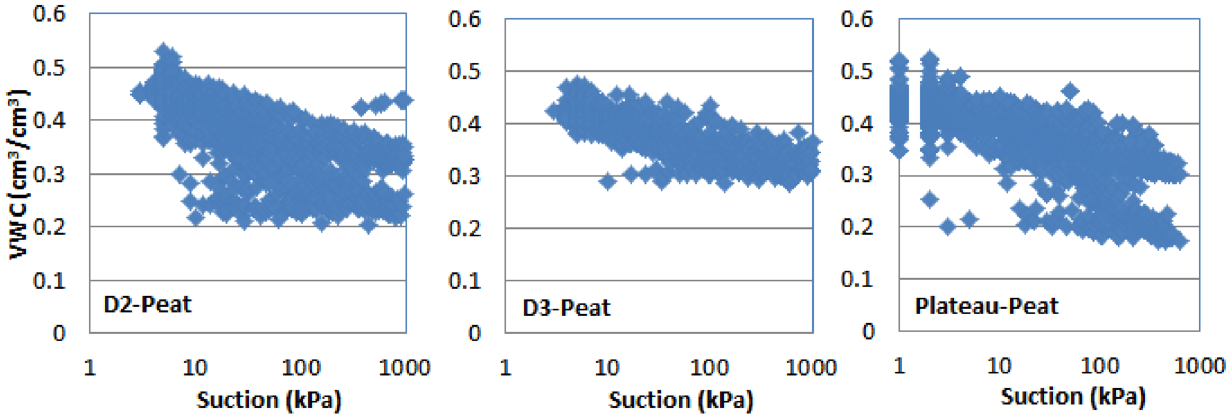


Fig. 6a. The measured volumetric water content vs. matric suction for peat at three covers.

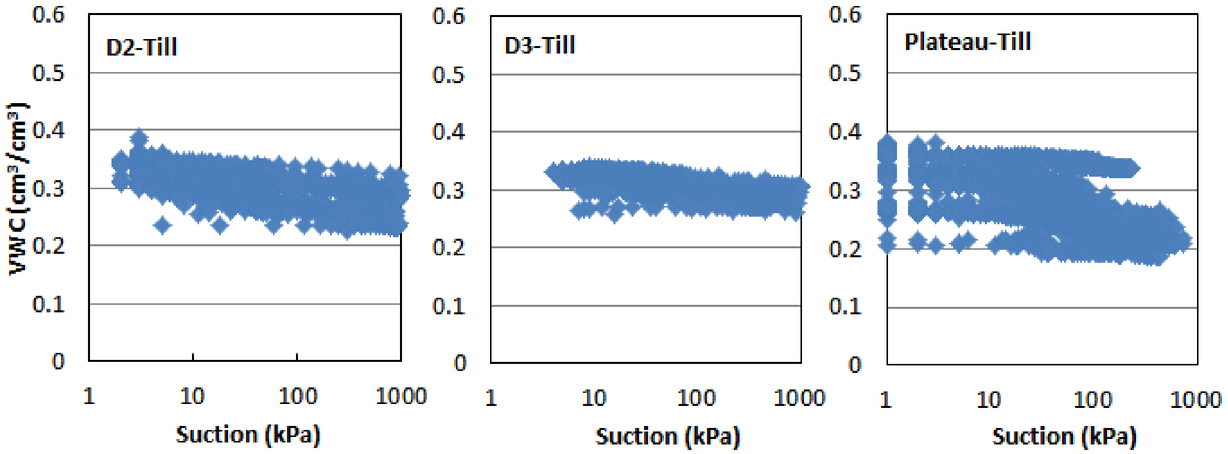


Fig. 6b. The measured volumetric water content vs. matric suction for till at three covers.

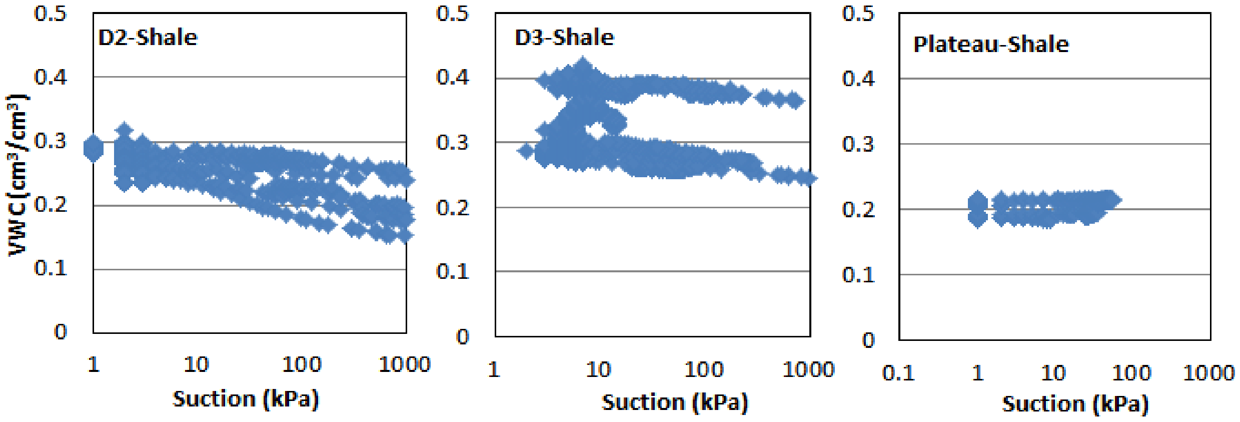


Fig. 6c. The measured volumetric water content vs. matric suction for shale at three covers (Total capping depths: D2 – 37cm, D3 – 100 cm and Plateau – 120 cm).

3.3 Numerical Modeling

3.3.1 Governing Equation

Simulation of water flow through the cover requires some conceptual model as to how the cover should be characterized in regard to its hydraulic properties. The most common options are to consider the soil as an equivalent porous media (EPM) in which one set of hydraulic properties describes all soil behavior, or to attempt to characterize a 'dual porosity' system which allows for the possibility of fracture-dominated preferential flow through macropores as well as flow and storage within the matrix porosity between the macropores. There is evidence of preferential flow through the SBH covers under specific conditions. These might include high antecedent water contents or high intensity infiltration rates as were applied by Allaire et al. (2009) during field dye tracer tests. Preferential flow was also considered to be likely during snowmelt infiltration when the matrix is frozen but the macropores are drained (Kelln, 2008). A dual porosity characterization of the soil properties has been adopted in this modeling in order to not constrain the soil characterization excessively.

The dual-porosity model assumes that water flow is restricted to the fractures (or macropores), and that water in the matrix (intra-aggregate pores) does not move at all. In a dual-porosity model, the liquid phase is partitioned into mobile, θ_m, and immobile, θ_{im}, regions.

$$\theta = \theta_{im} + \theta_m \qquad [1]$$

The exchange of water between the two regions is usually calculated by means of a first-order process (Gerke and van Genuchten, 1993).

The dual-porosity model for water flow can be based on a mixed formulation of the Richards equation to describe water flow in the fractures, and a mass balance equation to describe moisture dynamics in the matrix as follows (Simunek et al. 2003):

$$\frac{\partial \theta_m}{\partial t} = \frac{\partial}{\partial z}[K(h_m)(\frac{\partial h_m}{\partial z}+1)] - S_m - \Gamma_w$$
$$\frac{\partial \theta_{im}}{\partial t} = -S_{im} + \Gamma_w \quad [2]$$

Where t is time [T]; z is the vertical coordinate (positive upwards) (L); h_m is pressure head in mobile region (L); $K(h_m)$ is the unsaturated hydraulic conductivity function ($L\ T^{-1}$) in mobile region ; S_m and S_{im} are sink term for both regions; and Γ_w is the transfer rate for water from the fractures to the matrix pores and is calculated as follows (Gerke and van Genuchten, 1993):

$$\Gamma_w = \omega_w(h)(h_m - h_{im}) \quad [3]$$

where, Γ_w is assumed to be proportional to the difference in pressure heads between the two pore regions; ω_w is a first-order mass transfer coefficient (1/LT); and h_{im} is pressure head in the intra-aggregates pores. Since pressure heads are now needed for both regions, this approach requires estimating the WRC for both regions.

Eq. [2] is solved numerically using Galerkin-type linear finite-element schemes in HYDRUS-1D version 4.15 (Simunek et al. 2012) with specific initial and boundary conditions.

3.3.2 Initial and Boundary Conditions

The field monitoring data suggests that seasonal wetting and drying of the shale only occurs below the thinnest cover. In order to include this observation within the model calibration study, it was decided to include a thickness of shale within the model for the thinnest cover alone. A 'unit gradient' boundary is applied to the base of this shale to allow deep drainage to occur through the shale if excess water is available at the base of the cover.

In the case of the thick covers, it was assumed that the lower boundary of the model was the base of the secondary and that this layer was free to drain in the event that positive pressures developed within this layer (e.g. ponded water). The presence of ponding on the shale surface has been observed in the D3 (100 cm) cover, and interflow (down slope of water movement along the secondary / shale interface) has been observed within all the covers on the north slope (D1, D2, and D3). The model does not attempt to simulate the transient, time dependent drainage of ponded water from the base of the covers but allows any water that does pond to be removed and consequently not included in the water balance. The lower boundary condition was set to be free seepage for D3 and zero flux for the Plateau.

For all covers, the upper boundary condition was the micro-meteorological boundary, and the potential evapotranspiration was calculated using the Penman-Monteith equation.

3.3.3 Soil Hydraulic Parameters

The unsaturated hydraulic properties for the fractures and intra-aggregate pores were both described using the van Genuchten-Mulaem equations (1980):

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \qquad [4]$$

$$K(h) = \begin{cases} K_s S_e^{1/2}[1-(1-S_e^{1/m})^m]^2 & h < 0 \\ K_s & h \geq 0 \end{cases} \qquad [5]$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad [6]$$

where S_e is the effective saturation; θ is the volumetric water content [$L^3 L^{-3}$]; subscripts *r* and *s* refer to residual and saturated volumetric water contents, respectively; α[L^{-1}], *n*, and *m* are van Genuchten (VG) equation parameters, and m=1-1/n; and K_s is the saturated hydraulic conductivity [$L T^{-1}$].

3.3.4 Root Water Uptake

The sink term in Eq. [2] represents the volume of water taken up by plant roots per unit bulk volume of the soil per unit time. The rate at which water is removed from soil is limited by the potential transpiration rate, T_p, by the rate at which soil can supply water to roots, $\alpha(h)$, and the root distribution function, b(z). The HYDRUS-1D model incorporates these relationships and results in a root water uptake function as follows (Feddes et al. 1974):

$$S(h) = \alpha(h) \frac{b(i)}{\sum_{i=1}^{\ell} b(i)} T_p \qquad [7]$$

where $\alpha(h)$ is the root water uptake stress response function. Eastman and Camm (1995), Dang et al. (1997), and Kimball et al. (1997) found that the discrete function based on two pressure heads was effective for spruce and trembling aspen as follows:

$$\alpha(h) = \begin{cases} 1, & h \geq h_1 \\ \dfrac{h_2 - h}{h_2 - h_1}, & h_2 < h < h_1 \\ 0, & h \leq h_2 \end{cases} \qquad (8)$$

The two pressure heads (h_1 and h_2) were determined based on previous studies reported in the literature. For white spruce, the reported value was 500 and 1,500 kPa for h_1 and h_2, respectively (Eastman and Camm, 1995), and the related values are 500 and 2,300 kPa for trembling aspen (Bond-Lamberty et al., 2005; Kimball et al., 1997). In this study, the average values of 500 kPa and 1,900 kPa for h_1 and h_2 were used, respectively.

The root distribution function, b(z), used for this study is shown in Figure 7 for each cover based on the field measurements described by Shurniak (2003). The recently measured root distributions presented by Ken van Rees (Soil Science, University of Saskatchewan) have not been incorporated into this model since they were not available at the time of these simulations. Although it is known from previous root surveys that roots do penetrate the shale surface in small amounts. It is assumed for the purposes of this modeling that 100% of the root mass is contained within the cover layers.

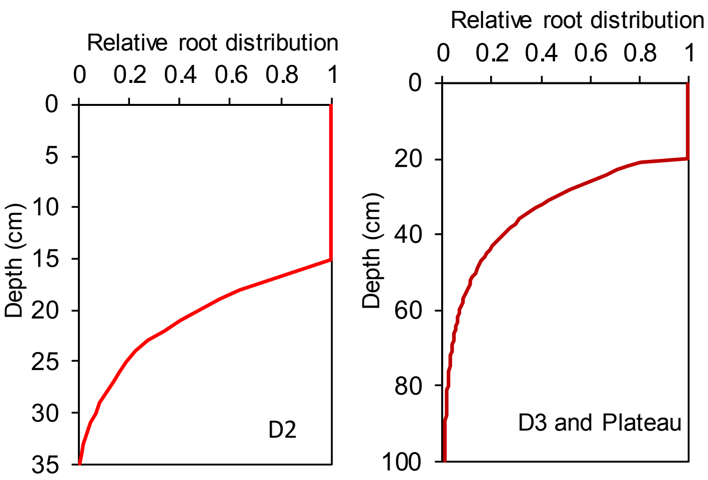


Fig. 7. The root distribution functions for the three covers.

3.3.5 Daily Potential Transpiration and Evaporation

The daily PET value calculated using the Penman-Monteith equation is partitioned into potential soil evaporation (PSE) and potential plant transpiration (PPT) using the leaf area index (LAI) as follows:

$$PPT = PET(1 - e^{-\mu LAI}) \qquad [9]$$

$$PSE = PETe^{-\mu LAI} \qquad [10]$$

where μ is an empirical parameter varying from 0.50-0.75 for trees (Ritchie 1972). When the LAI is larger than 2.7, the PSE is approximately equal to 0.

In this study, an average value of 0.62 was used for partitioning PET into PSE and PPT from LAI. For the cover plateau, the measured LAI values shown in Figure 3 were used for the simulation, while the LAI values for D2 and D3 were determined by comparing the photos taken among the three covers during the growing seasons.

3.3.6 Rainfall Interception

In HYDRUS-1D, Braden's (1985) equation is used for interception estimation:

$$I = aLAI(1 - \frac{1}{1 + \frac{bP}{aLAI}}) \qquad [11]$$

$$b = 1 - e^{-\mu LAI} \qquad [12]$$

Where I is the rainfall interception, P is rainfall, and a is a parameter equal to 0.25 cm. The range of simulated interception rates were compared to those measured for the plateau by Sean Carey to check that they were reasonable.

3.3.7 Model Calibration and Validation

The HYDRUS-1D modeling has been divided into three parts. The first part is the calibration process to obtain the soil parameters of two regions for three materials. The model was calibrated against the observed soil moisture data at D2 using an inverse procedure. Water flow in the dual-porosity model requires five parameters: Θ_{rm}, Θ_{sm}, α_m, n_m, and K_s in the mobile region, and five other parameters in the immobile region: Θ_{rim}, Θ_{sim}, α_{im}, n_{im}, and ω_w for each material. In the calibration process, the parameters of α_m, $n_{m,}$ Θ_{sm}, α_{im}, n_{im}, and ω_w were optimized. The value of Θ_{rm} was equal to 0 for all materials, while the value of Θ_{rim} for each material was determined by the WRC at high suctions (Figure 2). The value of Θ_{sim} was determined based on the Shurniak' (2003) results. For each material, the values of Θ_{rim} and Θ_{sim} are shown in Table 2.

The potential values of the five optimized parameters were only weakly constrained to be within a realistic range based on literature values such as Shurniak's (2003). For parameters, where literature references were unavailable or inconclusive, a relatively wide range of values was permitted to account for the behavior of fractured soils.

The second part is the validation process. In this section, the calibrated parameter values for the peat/mineral and secondary layers were used to simulate water contents at D3 to evaluate the model accuracy. This final set of parameters was then used to simulate the water content dynamics at the plateau site. During the calibration, validation, and simulation processes, the K_s value was not fixed and needed to be optimized by the inverse procedure in each year for all covers, while the parameter values of Θ_r, Θ_s, α, and n in Eq. [4] for two regions are fixed. It should be noted that because the freeze-thaw or wet-dry cycling impacts the development of fractures, this might result in changes in Ks values for the three materials in different years due to different climatic characteristics.

Table 2 The fixed and optimized van Genuchten (VG) parameters for the three materials

VG parameters	Value sources	Peat	Till	Shale
Mobile				
Θ_{rm} (cm^3/cm^3)	Constant	0	0	0
Θ_{sm} (cm^3/cm^3)	Optimized	0.106	0.098	0.125
α_m (1/cm)	Optimized	0.0207	0.0214	0.0207
n_m	Optimized	2.032	2.076	2.60
Immobile				
Θ_{rim} (cm^3/cm^3)	Measured	0.105	0.062	0.120
Θ_{sim} (cm^3/cm^3)	Measured	0.4543	0.344	0.310
α_{im} (1/cm)	Optimized	0.0086	0.0177	0.0171
n_{im}	Optimized	1.268	1.159	4.139
ω_w (1/cmd)	Optimized	9.76e-4	2.46e-2	7.03e-3

3.4 The Long-Term Simulations

The calibrated and validated parameters were used to simulate the long-term performance of a series of hypothetical covers with varying thickness using the 60 years of climate data available from the Fort McMurray airport weather station. The effects of vegetation and cover thickness on the variation in long-term transpiration released from covers were analyzed, while the annual maximum transpirations in different climatic years were estimated for each cover.

3.4.1 Six Hypothetical Covers

The six hypothetical covers are presented in Figure 8. The thickness of the six covers was 35, 50, 75, 100, 125, and 150 cm, respectively. The thickness of the upper peat-mineral layer was 15 cm for D35, and 20 cm for the other covers. In order to ensure that the comparison of available water within the covers for use in transpiration was straightforward, it was decided to simulate only the cover layers themselves such that no water could be drawn from the underlying shale and any ponded water on the shale surface was allowed to drain away. This assumption maximizes the release of water to interflow or deep percolation and hence is conservative relative to the estimate of plant available water.

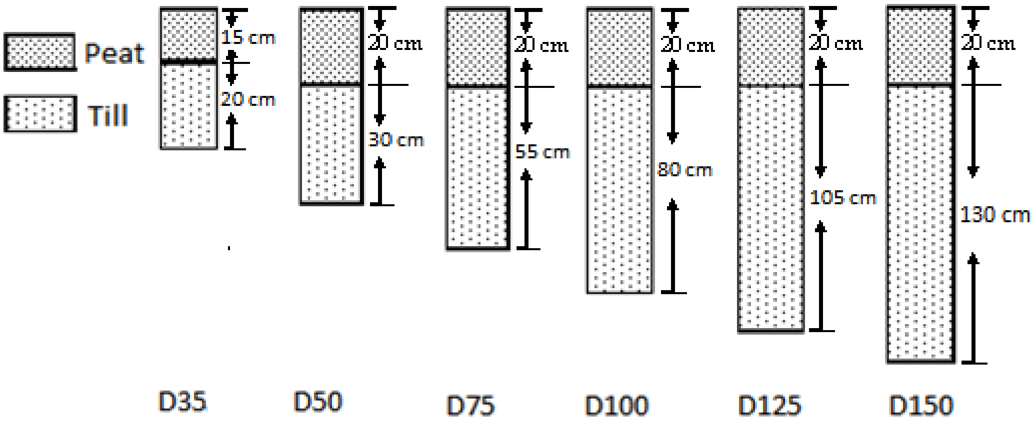


Fig. 8. Six hypothetical covers.

3.4.2 The Long-Term Climatic Data

Daily climatic data from 1952 to 2011 was collected from the Fort McMurray airport weather station, including maximum and minimum temperatures, relative humidity, wind speed, dew temperature, precipitation, etc. The Penman-Monteith equation was used to calculate daily PET, and then daily PET was partitioned into PSE and PPT using Eqs. [9] and [10]. The rainfall interception was calculated using Eqs. [11] and [12] for each rainfall event.

Any precipitation falling as snowfall, minus an assumed annual sublimation, was accumulated during the winter period. The annual sublimation was calculated based on the relative difference in the measured values of snow water equivalent (SWE) between Fort McMurray airport weather station (FMAWS) and SBH. During the period of 2003 to 2011, the average relative difference was 7.1% of the SWE at FMAWS, which value was assumed equal to the annual sublimation. The total snowpack volume was converted into liquid water during the first week of spring when the soil was unfrozen.

The average annual PET, annual total amount of rainfall during unfrozen periods, and snowpack volume were 496 mm, 311 mm, and 116 mm, respectively. Their frequency distributions are presented in Figure 9.

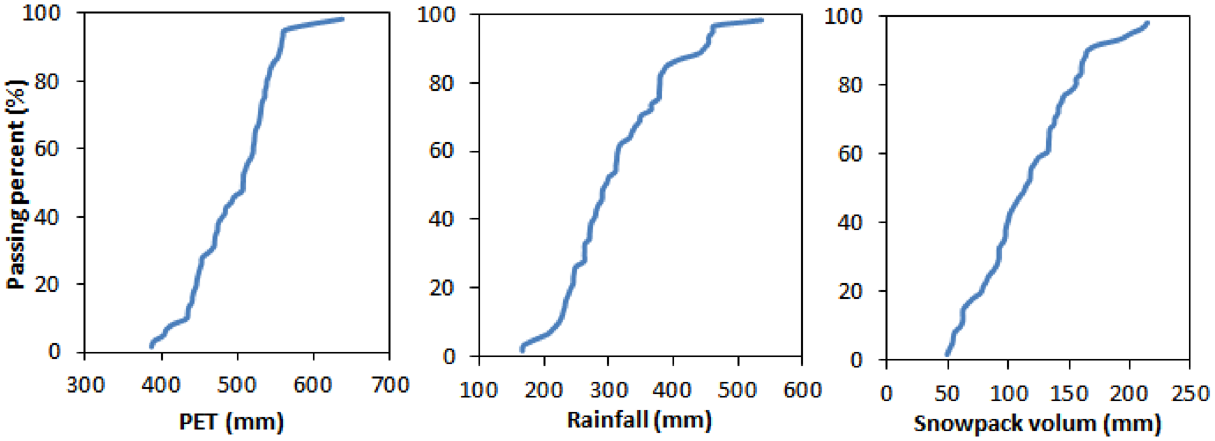


Fig. 9. Frequency distributions of annual PET, rainfall during unfrozen periods, and snowpack volume from 1952 to 2011.

3.4.3 Vegetation cover scenarios

In order to investigate the effect of vegetation cover on hydrological behavior, four seasonal patterns of LAI were applied to each cover (Figure 10). In the models employed here, LAI is specified and is not adjusted in response to transpiration rates. A separate evaluation of the maximum sustainable LAI (and subsequent transpiration rates) will be made later in this report based on the results of the simulations.

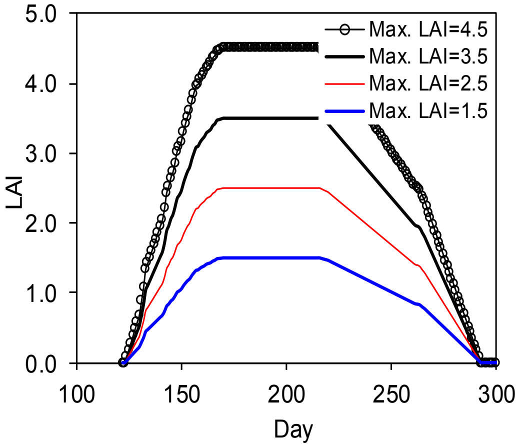


Fig. 10. Assumed LAI values and their variation during the growing season.

A simple linear root system distribution in the second cover layer was used for long-term simulation (Figure 11), while the root was not assumed to penetrate into the shale.

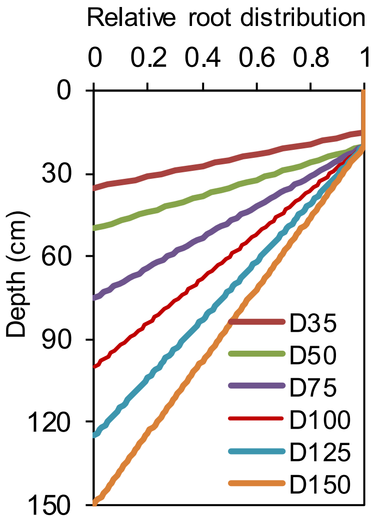


Fig. 11. The linear root system distribution for each cover.

3.4.4 Boundary condition and modeling parameters

All hypothetical covers are assumed to have free drainage at the lower boundary. This might be conceptualized as covers placed over sloping overburden or covers in which deep percolation through the shale is sufficient to remove any ponded water following snow melt infiltration. Restricting deep percolation and allowing ponding on the shale surface at plateau locations would increase the plant available water at these sites. However; in order to simulate a conservative case (most restricted plant available water) and to limit the number of simulation cases it was assumed that any water that reaches the base of the covers is free to drain.

The calibrated and validated van Genuchten parameters for two regions were used for long-term simulation, while the K_s value for each material was determined using the median of K_s optimized for D2, D3, and Plateau covers from 2006 to 2011.

4. Results and Discussion

4.1 The VG Equation Parameters

The calibrated and validated VG parameters for mobile and immobile regions are shown in Table 2, while the estimated water retention curves (WRC) from the optimized parameters are presented in Figure 12. A comparison of the measured in lab, measured in field, and calibrated WRC for the peat-mineral and secondary are shown in Figure 13 suggests that the optimized VG equation parameters are consistent with field measurements. It is important to note that the maximum water content (i.e. porosity) of the mobile pores is approximately 10% while work by Kelln (2008) suggested that the macropore porosity was likely closer to 3-4%. The 10% mobile porosity is an artifact of the numerical scheme since it was difficult to obtain numerical convergence for values less than 10%.

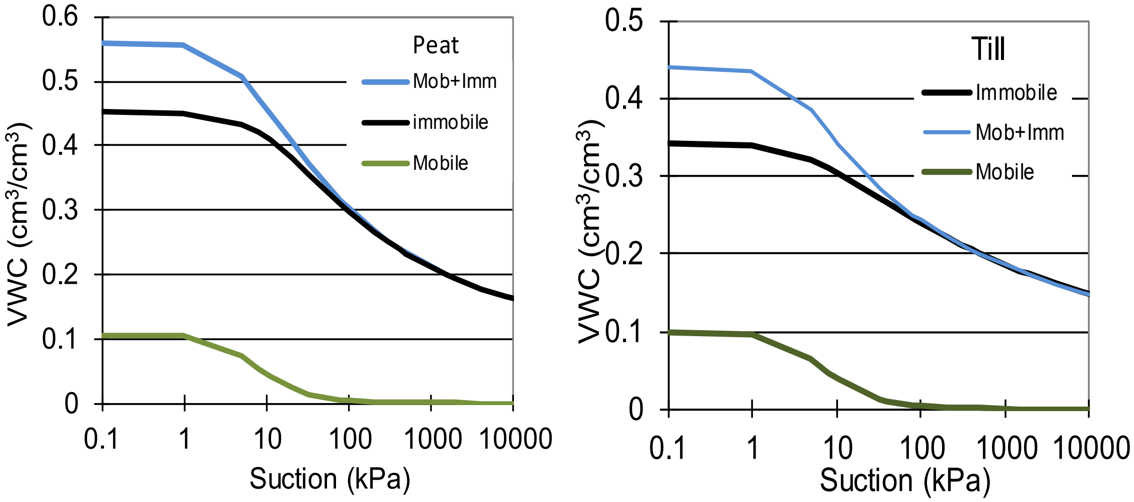


Fig. 12. The estimated water retention curves for Peat and Till from the optimized VG equation parameters.

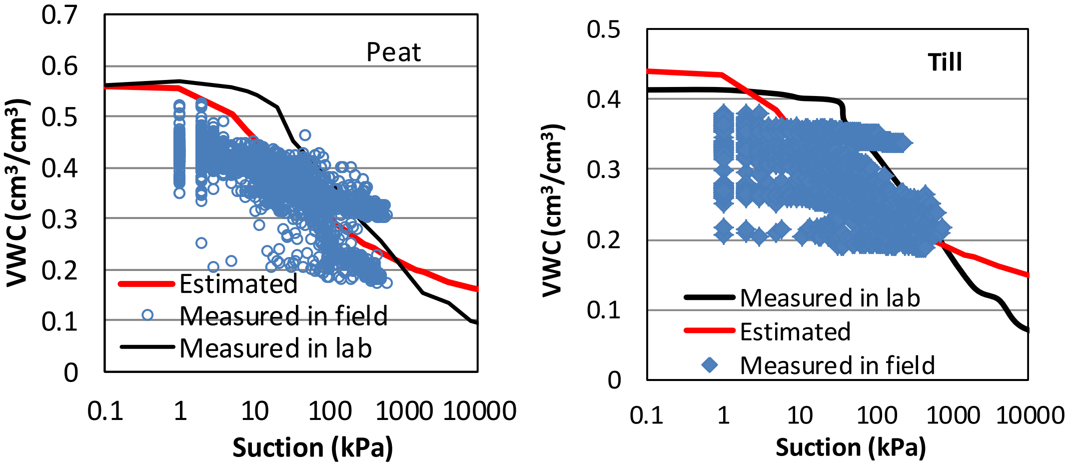


Fig. 13. Comparison of the measured in lab, measured in field, and estimated WRCs for Peat and Till.

4.2 Simulation of Water Storages in Covers

Figure 14a shows the simulated water storage within the D2 cover based on the parameters. Of particular note is the drop in stored water volume that occurs during the springs of 2006, 2007, 2008, 2009, and 2011. The simulation does not always match the rate of this drop but captures the overall loss of water. The differences in the rate of decrease between the simulation and observation may result from the effect of mulches on ground surfaces. There were many types of mulches on ground surface, which act to reduce soil evaporation. During the spring, the LAI values were very low, and soil evaporation was the dominant factor for water loss. Since HYDRUS-1D model could not consider the effect of mulch on evaporation, the simulated water storage in the whole profile was less than the measured values as occurs during springs of 2007 and 2008. In other seasons, the simulated water storage is in good agreement with the measured values. In general, the simulated results appear to provide a reasonable representation of the variation of water storage in each single layer and the whole cover profile. The low root mean square error (RMSE) value of 6.9 mm for the peat layer, 6.4

mm for the till layer, and 11.1 mm for the whole profile indicate that the parameters shown in Table 2 could be used to simulate daily water balance for D2.

Figure 14b and Figure 14c present the simulated water storage in D3 and the Plateau using the optimized parameters from the D2 simulations. The measurements in D3 and Plateau are used to validate the model, while the measurements in Plateau are used to assess the calibrated and validated model. With the exception of 2010, the simulated water storage within both the individual layers and the whole profile appear to match the measured values. In 2010 the simulation underestimated the storage in the secondary layer in the 100 cm cover early in the growing season but overestimated the storage in the plateau secondary layer. The reason for these anomalous responses is not known.

The low RMSE of 7.5 mm for peat layer, 10.9 mm for till layer, and 14.4 mm for the whole profile indicate that the optimized parameters provide a reasonable simulation of the daily water balance in D3. In the case of the Plateau; the low RMSE of 7.9 mm for peat-mineral layer, 17.0 mm for the secondary layer, and 17.9 mm for the whole profile indicate that the model provides a reasonable simulation of water storage and dynamics.

The optimized Ks values for three materials during the studied period are presented in Figure 15. Most of them varied over approximately 2 order of magnitude difference. It is possible that this may be an artifact of the Ks optimization process. In HYDRUS-1D, an inverse solution is used for Ks estimation based upon the minimization of the discrepancy between the observed values and simulated results. Since the value of Ks was only loosely constrained (i.e. allowed to vary from 0 to 10000 cm/day) this method might lead to large differences in optimized Ks in order to minimize the ‘error’ between measured and observed water contents in a particular year.

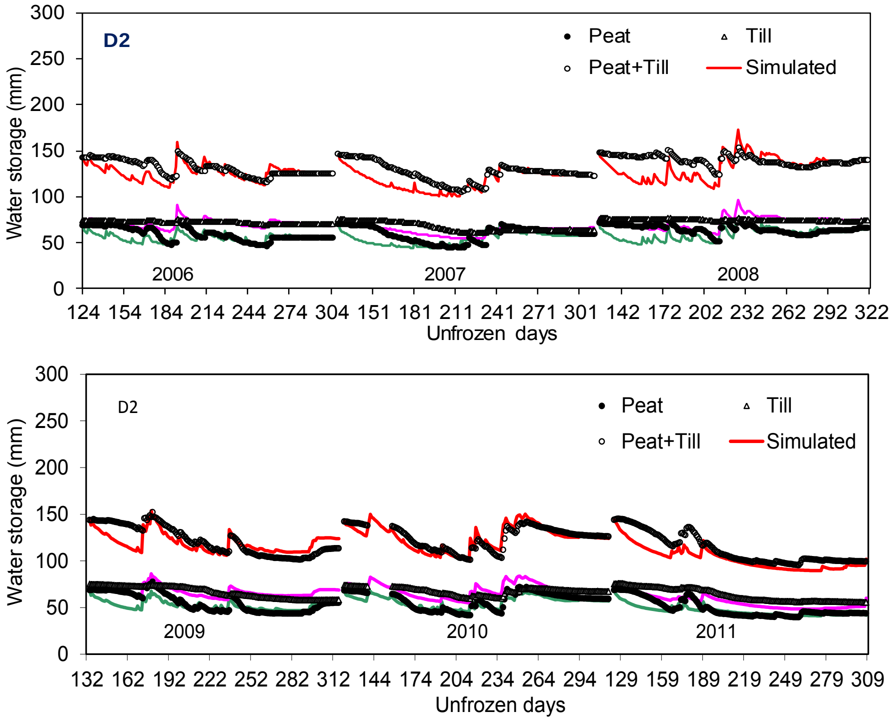


Fig. 14a. Comparison of the measured and simulated water storages on days in which the soil temperature is greater than 0°C for D2 (37 cm total capping depth).

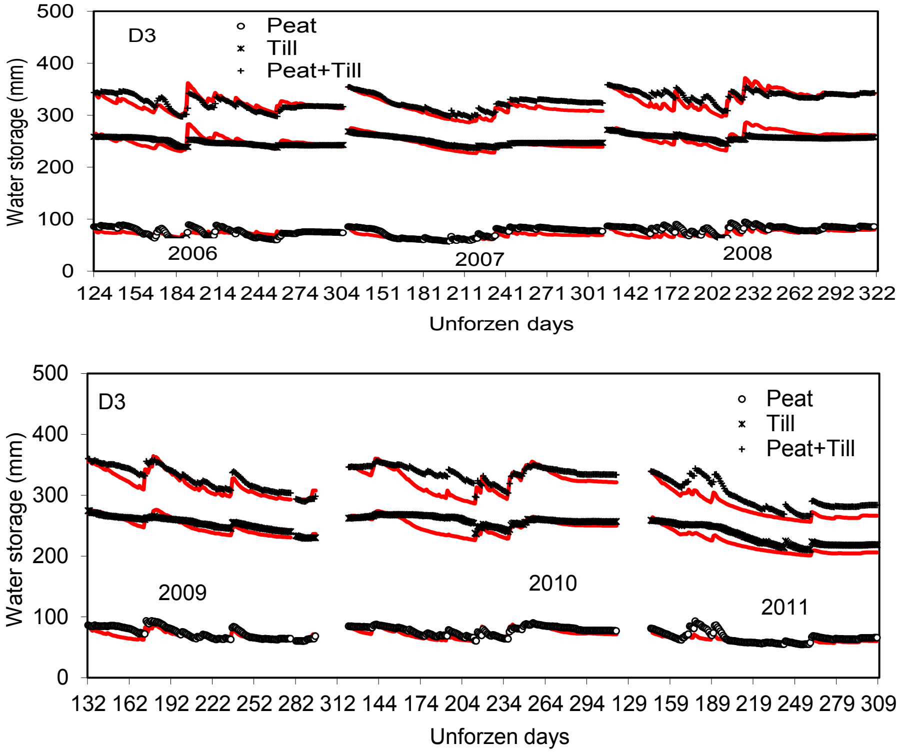


Fig. 14b. Comparison of the measured and simulated water storages on days in which the soil temperature is greater than 0°C for D3 (100 cm total capping depth).

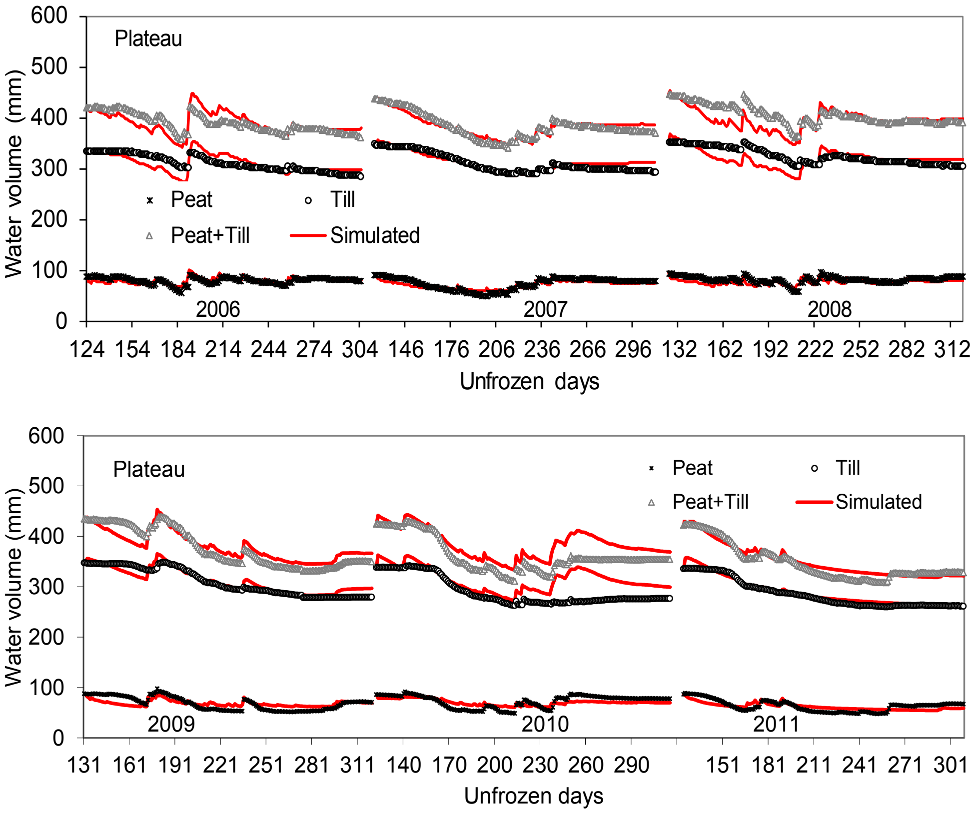


Fig. 14c. Comparison of the measured and simulated water storages on days in which the soil temperature is greater than 0°C for Plateau (120 cm total capping depth).

4.3 The Frequency Distribution of the Optimized Ks Values

Interestingly, the median of the optimized Ks values is close to the measured values for each material (Table 3). These field values obtained by Meiers et al. (2011) were based on repeated measurements of Ks over a five year period using a Guelph permeameter. Once the Ks values stabilized, the average K_s for the peat-mineral mixture, secondary and shale were 5.0e-5 m/s, 1.0e-6 m/s, and 3.0e-8 m/s respectively. These values are similar to the optimized median values of 1.04e-5 m/s for the peat-mineral, 1.05e-6 m/s for the secondary, and 2.95e-8 m/s for the shale respectively.

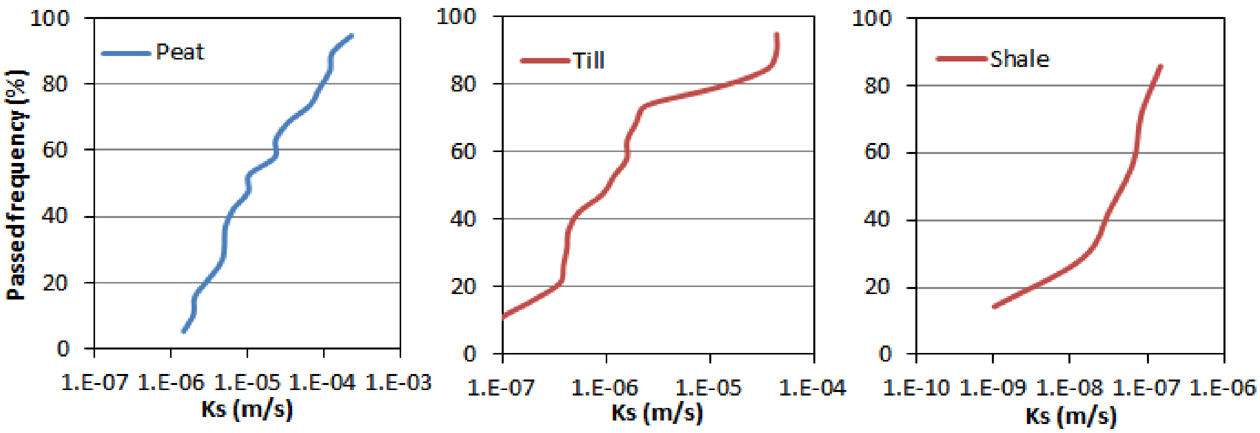


Fig. 15. The frequency distribution of optimized Ks value for each material during studied period.

Table 3 The comparison of the optimized and measured (by Guelph permeameter) Ks values

	Peat (m/s)	Till (m/s)	Shale (m/s)
Mean for all covers (Meiers et al. 2011)	5.0e-5	1.0e-6	3.0e-8
Optimized median	1.04e-5	1.05e-6	2.95e-8

4.4 Response of Cumulative Tr to Different Covers

The dual-porosity model with the VG parameters in Table 2 and the median values of Ks in Table 3 were used to simulate the transpiration (Tr) for the different covers. The amount of cumulative Tr increased with cover thickness, while the increase in Tr with increasing cover thickness diminished once the cover thickness exceeded 75 cm until there was no appreciable difference in Tr between the D125 and D150 covers (Figure 16). The same trend was obtained regardless of the LAI values. Since the Tr value is directly related to biomass production this result suggests that increasing the cover thickness from 125 cm to 150 cm would not significantly improve vegetative productivity.

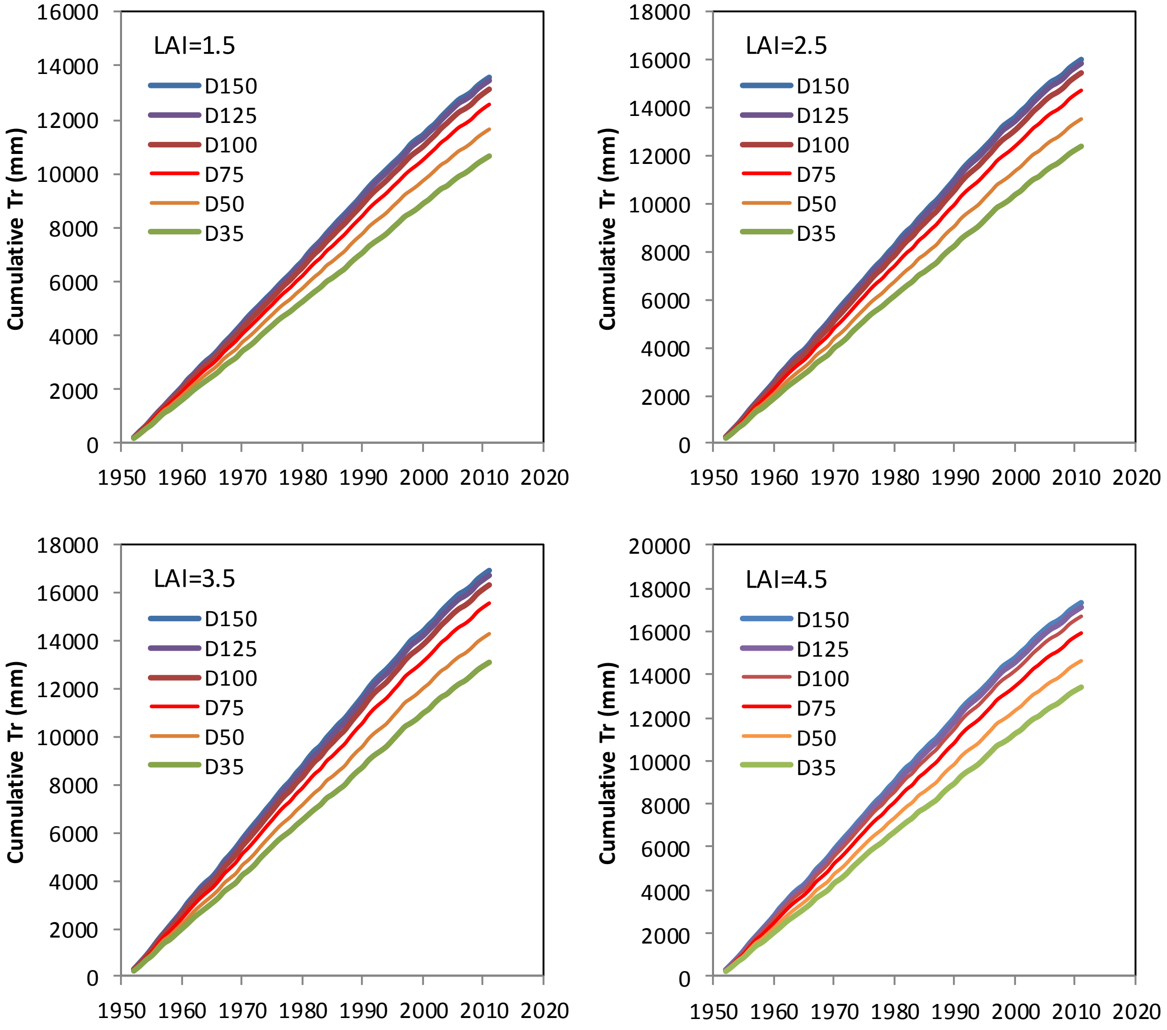


Fig. 16. Response of cumulative Tr to different covers with different LAI values.

4.5 Tr Frequency Distribution for Long-Term Simulation

Figure 17 shows the frequency distribution of annual Tr value for each cover with different LAI values. The magnitude, and the range, of annual Tr that can be produced by any particular cover decreases with decreasing cover thickness. For example, the annual Tr only varied from 142 mm to 299 mm in the 35 cm cover with an LAI=3.5 while it range from 148 mm to 350 mm for the 100 cm cover for the same LAI value. When the cover thickness increased from 125 cm to 150 cm, however, the range of annual Tr value did not appear to change.

The simplest interpretation of the differences in annual Tr between the covers appears to be primarily related to the ability of the cover to store snow melt infiltration since any precipitation during the growing season appears to be fully utilized by the covers for transpiration, regardless of their thickness. Consequently, the enhanced Tr from thicker covers can be credited in large part to their enhanced ability to store snow melt waters. The volume of this water; however, is limited. Consequently, continuing to increase cover thickness beyond that which is required to store snow melt water does not provide any additional benefit in terms of Tr. In fact, it is possible that some water might even be lost if the water moves deep enough through the cover such that it is difficult for the roots of some trees (e.g. Spruce) to access it.

Based on the climate data used in this study, the snowpack volume varied from 49 to 215 mm, with an average of 116 mm. To store all of this water within a layer of secondary, assuming a field capacity of 0.342 cm^3 cm^3 would require only 33.4 cm of secondary. Any water that could not be stored by the cover would then report as surface runoff (including interflow) or net percolation. This makes it clear that a potential downside of very thick reclamation covers is the loss of water release to adjacent surface water (e.g. wetlands).

The magnitude and range of annual Tr values increases with increasing LAI. For example, the annual Tr value varied from 126 mm to 266 mm for the D100 with an LAI equal to 1.5 but if the LAI is increased to 3.5 the annual Tr value increased to 148 mm to 350 mm. The higher vegetative cover directed more radiation energy to plant transpiration resulting in more soil water use with less water available for percolation (Table 4). No significant difference in frequency distribution was found for annual Tr between 125 cm and 150 cm cover with different LAI values (Figure 17).

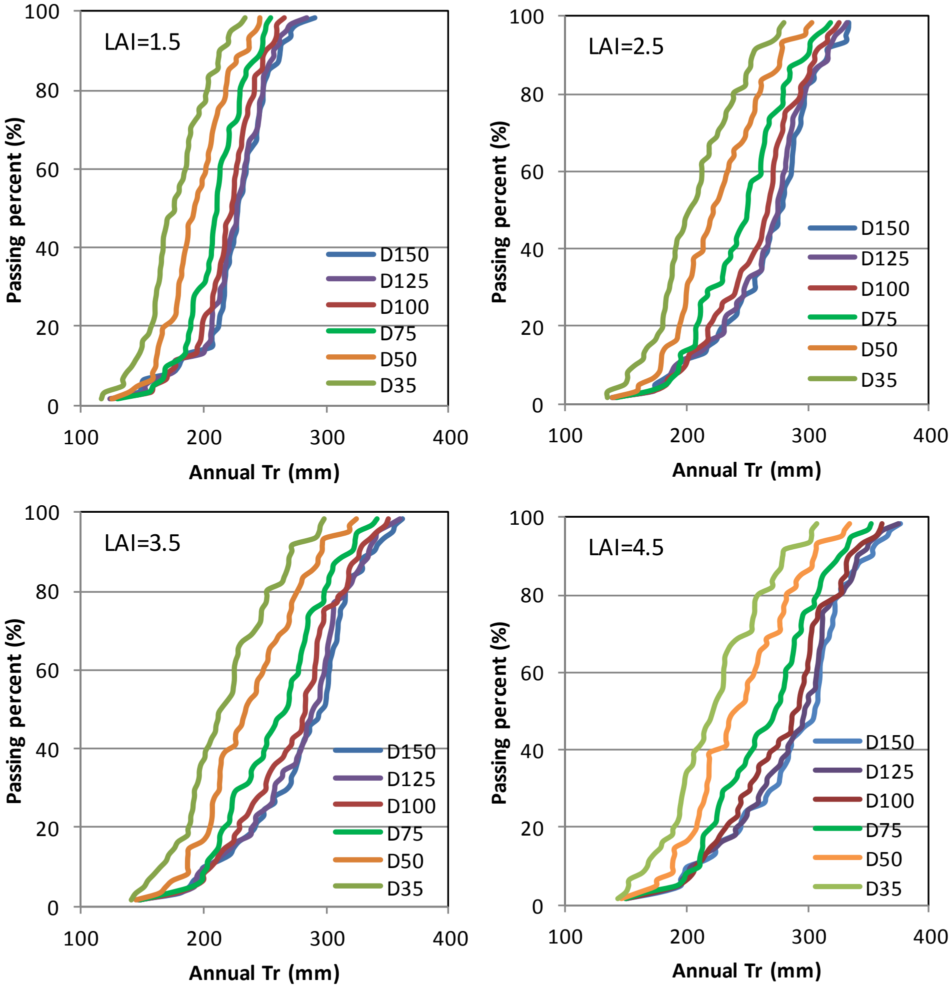


Fig. 17. The frequency distribution of annual Tr for different cover thickness.

4.6 Water Balance Components

The average precipitation during the unfrozen period was 426.2 mm (310.6 mm as rainfall and 115.6 mm as snowmelt water) (Table 4). The average PET was 495.8 mm. The ratio of actual evapotranspiration (Tr and Es) to precipitation varied from 63% to 84%, while canopy interception varied from 46.0 mm with an LAI of 1.5 to 81.6 mm with a LAI of 4.5. The ratio of Tr to precipitation varied from 42% to 68%. Both of these values vary with LAI and cover thickness. In this study, the estimated Es value might be overestimated since: (1) the effect of mulch on soil evaporation was not considered in this study; (2) the method calculating soil

Table 4 The average components of water balance

	Cover depth	Rainfall (mm)	Snowmelt volume (mm)	Interception (mm)	Tr (Actual transpiration, mm)	Es (Actual evaporation, mm)	ET (Tr+Es, mm)	Percolation + Runoff (mm)	ΔS(change in soil water storage, mm)
LAI=4.5	35 cm	310.6	115.6	81.6	223.5	46.6	270.1	75.8	-0.8
	50 cm	310.6	115.6	81.6	243.9	46.7	290.6	55.6	-1.1
	75 cm	310.6	115.6	81.6	265.3	45.9	311.2	36.5	-1.7
	100 cm	310.6	115.6	81.6	278.3	45.5	323.8	24.6	-2.2
	125 cm	310.6	115.6	81.6	285.2	45.9	331.1	16.7	-2.8
	150 cm	310.6	115.6	81.6	288.8	47.4	336.2	13.3	-3.4
LAI=3.5	35 cm	310.6	115.6	75.0	218.4	56.9	275.3	77.0	-0.8
	50 cm	310.6	115.6	75.0	238.3	57.4	295.7	57.0	-1.1
	75 cm	310.6	115.6	75.0	259.6	56.9	316.5	37.9	-1.7
	100 cm	310.6	115.6	75.0	272.3	56.4	328.7	26.3	-2.2
	125 cm	310.6	115.6	75.0	278.9	56.8	335.7	18.6	-2.8
	150 cm	310.6	115.6	75.0	282.3	58.7	341.0	14.9	-3.3
LAI=2.5	35 cm	310.6	115.6	64.3	206.6	78.9	285.5	77.5	-0.8
	50 cm	310.6	115.6	64.3	225.5	80.1	305.6	57.7	-1.1
	75 cm	310.6	115.6	64.3	245.5	80.1	325.6	39.1	-1.6
	100 cm	310.6	115.6	64.3	257.6	79.8	337.4	27.8	-2.2
	125 cm	310.6	115.6	64.3	264.2	80.5	344.7	20.2	-2.8
	150 cm	310.6	115.6	64.3	266.9	83.2	350.1	16.1	-3.3
LAI=1.5	35 cm	310.6	115.6	46.0	177.6	123.3	300.9	80.3	-0.7
	50 cm	310.6	115.6	46.0	194.2	126.0	320.2	61.4	-1.1
	75 cm	310.6	115.6	46.0	209.5	127.5	337.0	45.5	-1.6
	100 cm	310.6	115.6	46.0	218.9	127.4	346.3	36.7	-2.1
	125 cm	310.6	115.6	46.0	224.3	128.1	352.4	30.8	-2.7
	150 cm	310.6	115.6	46.0	226.2	131.5	357.7	26.2	-3.3

evaporation in HYDRUS-1D might result in Es overestimation (A similar result was reported by Sutanto et al. 2012). The total of runoff and percolation was around 41 mm, and varied with LAI and cover thickness. This value is similar to the measured runoff at four weirs located at different sites of 30 Dump (Table 5).

In general, the magnitude and distribution of the components of the water balance for the covers shown in Table 4 are consistent with their ratios reported by Lawrence et al. (2007). Further comparison of these model results can also be made to monitoring undertaken by Sean Carey and/or Kevin Devito on adjacent reclaimed or natural sites.

Table 5 The measured runoff at four weirs located at different sites of 30 Dump

	Volume				Water depth			
	Peat pond inlet weir, PPI (m^3)	Peat pond outlet weir, PPO (m^3)	Golden pond weir 2, GP2 (m^3)	Golden pond, GP (m^3)	Peat pond inlet weir, PPI (mm)	Peat pond outlet weir, PPO (mm)	Golden pond weir 2, GP2 (mm)	Golden pond, GP (mm)
2003	5150	4841			46.8	29.0		
2004	5091	9341		30362	46.3	55.9		48.9
2005	19351	15269		49288	175.9	91.4		79.4
2006	2629	2855		9732	23.9	17.1		15.7
2007	12330	9510	16920	25240	112.1	56.9	34.5	40.6
2008	1933	2071	6478	10774	17.6	12.4	13.2	17.3
2009	2983	4016	20996	25579	27.1	24.0	42.8	41.2
2010	492	1052	2875		4.5	6.3	5.9	
2011	1192	2487	6834		10.8	14.9	13.9	
2012	248	68	142		2.3	0.4	0.3	
Average					46.7	30.8	18.5	40.5

4.7 Annual Tr Estimation for Each Cover

In these simulations, one of the limitations of the model is that the LAI cannot be adjusted based on the pattern of Tr developed in any one year. In order to try to illustrate how the annual values of Tr can be linked to LAI, and hence to net productivity, the relationships among the LAI, ET, and annual net primary productivity (ANPP) as reported by Huang et al. (2011) were applied to the model results.

The first step was to identify a more realistic annual value of Tr for each cover based on an estimate of the maximum sustainable LAI that could be supported from the simulated Tr. Rosenzweig (1968) developed a linear relationship between log(ANPP) and log(ET_a) for terrestrial communities as:

$$Log(ANPP) = 1.66Log(ET_a) - 1.66 \qquad [13]$$

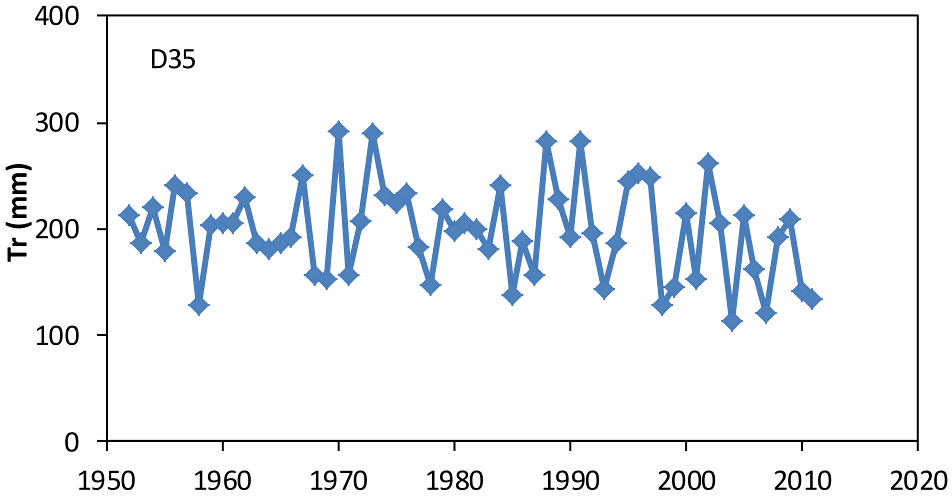
where ET_a is actual evapotranspiration (mm). A linear equation between ANPP and LAI was reported by Huang et al. (2011) as:

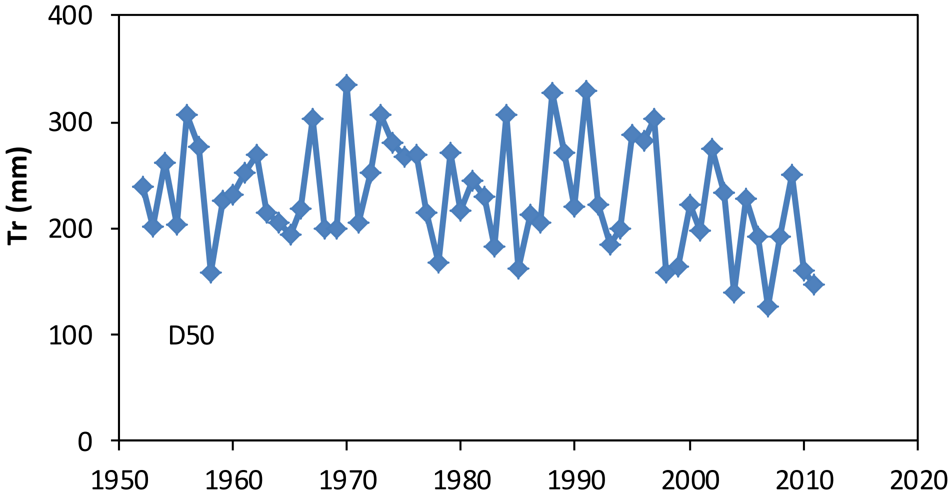
$$ANPP = 110.1LAI + 8.72 \qquad [14]$$

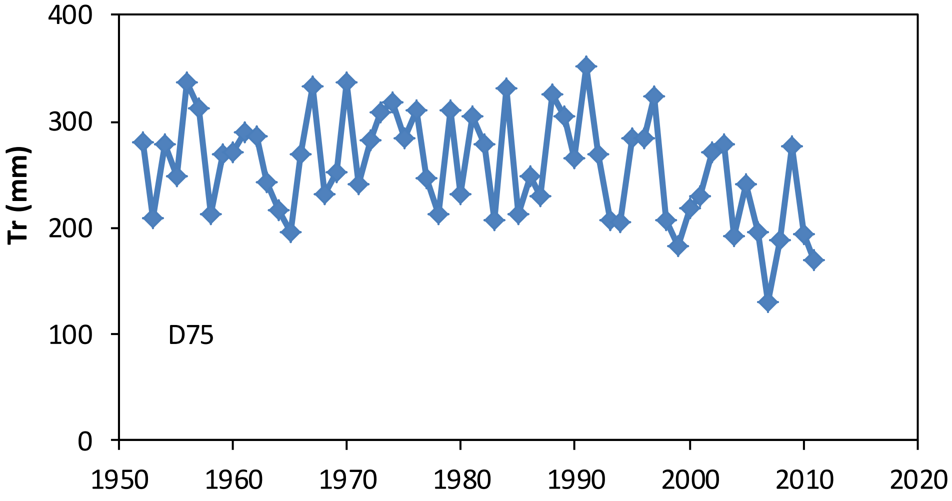
The combination of Eq. [13] and Eq. [14] can be link annual Tr value and the maximum sustainable LAI. Based on this method, the appropriate Tr for each year could be estimated from the family of Tr vs LAI graphs for that cover. The variation in maximum sustainable LAI for each cover is presented in Figure 18 below and the frequency distributions of 'actual' Tr are presented in Figure 19. The impact of this screening is that the frequency distributions for the thicker covers remain similar to those of the largest LAI while the distribution for the thinner covers become somewhat wider (e.g. lower Tr in driest years)

This is easier to visualize in Figure 20 where the actual Tr distributions for the 35 and 100 cm covers are superimposed over the simulated Tr for a range of LAI values. It is interesting to note how in the case of the thinnest cover, the 'actual' Tr distribution adjusts from low LAI value of 1.5 in the driest years to a maximum sustainable LAI of between 2.5 and 3.5 in the highest Tr year. In contrast, the thicker cover (100 cm) consistent utilizes high LAI values, regardless of the year.

The average Tr values are 198, 230, 257, 273, 280, and 284 mm for D35, D50, D75, D100, D125, D150, and these values reflect the vegetative productivity that the six hypothetic covers could actually support, respectively. It is clear that the there is little separation in the average Tr values once the cover thickness is greater than 75 cm.


D35
Tr (mm)
0
100
200
300
400
1950
1960
1970
1980
1990
2000
2010
2020


D50
Tr (mm)
0
100
200
300
400
1950
1960
1970
1980
1990
2000
2010
2020


D75
Tr (mm)
0
100
200
300
400
1950
1960
1970
1980
1990
2000
2010
2020

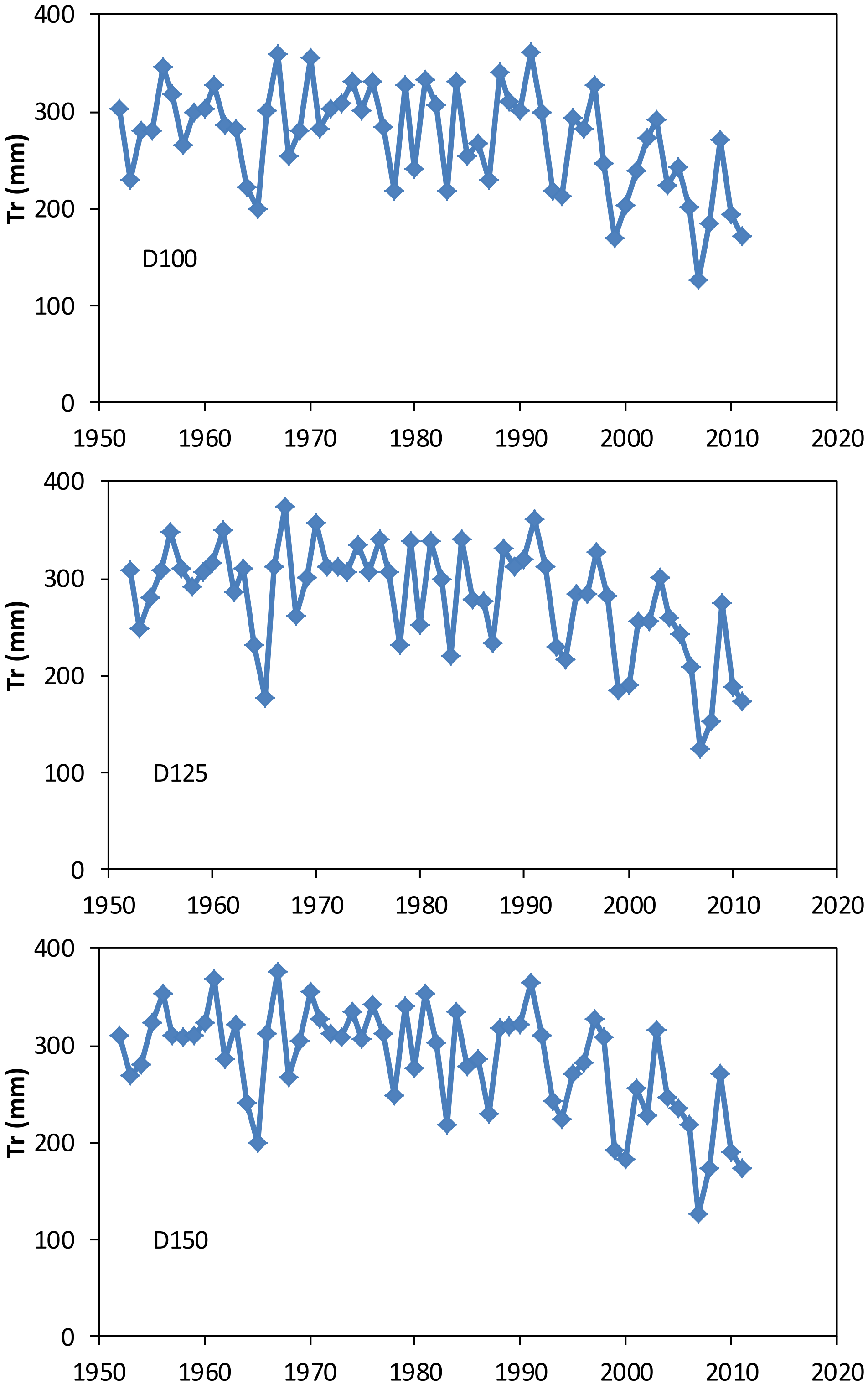


Fig. 18. Estimated Tr and its yearly variation for each cover.

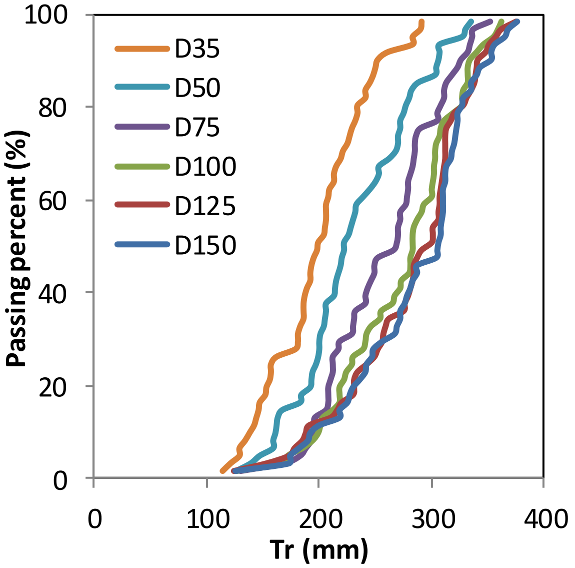


Fig. 19. The frequency distribution of the estimated Tr values for each cover.

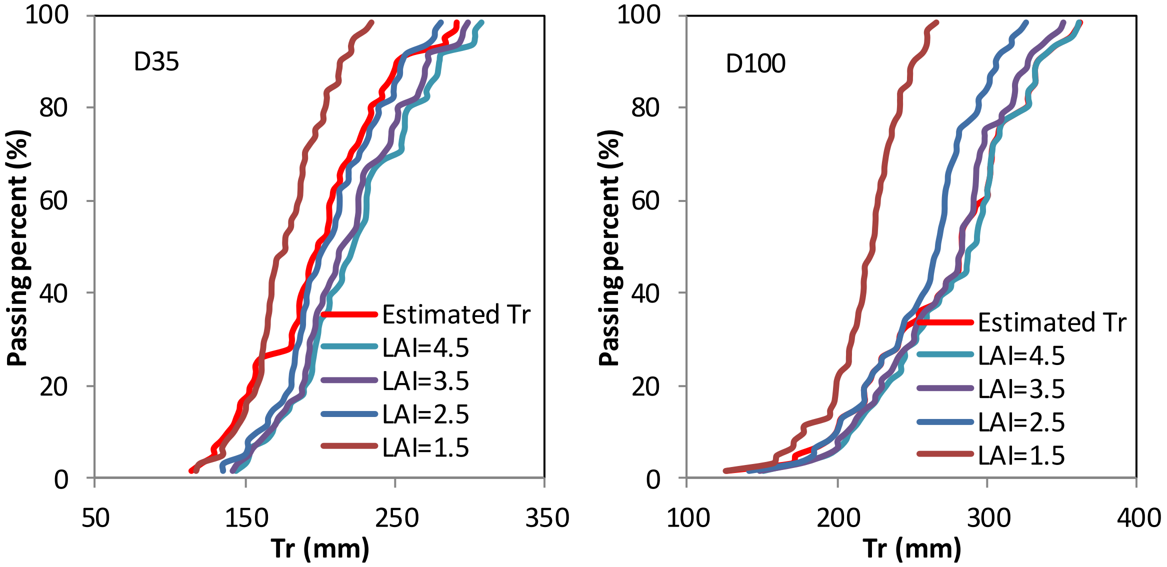


Fig. 20. Comparisons of frequency distribution among the estimated Tr and the simulated Tr from constant LAI values for D35 and D100.

5. Conclusions

The measured soil water contents from the D2 (35 cm), D3 (100 cm) and plateau (120cm) monitoring locations were used to calibrate and validate a dual-porosity model in HYDRUS-1D. The optimized parameters and the dual-porosity model provided a reasonable representation of the hydrological behavior for three covers.

The calibrated and validated model was then used to evaluate the influence of cover thickness and climatic variability on plant available water for forest growth. The frequency distributions of Tr for six cover treatments with a range of LAI cases were developed. These Tr frequency distributions reflected the differences of plant water consumption among the six cover treatments and 4 LAI values.

These Tr frequency distributions were then modified by coupling Tr and LAI. Although not a rigorous approach to estimating productivity, it illustrates how the thinner cover productivity is affected by dry year cycles in which the maximum available Tr leads to limitations in LAI which further restrict Tr and productivity. This approach provides some insight into the influence of cover thickness on plant available water and consequently on vegetative productivity.

The modified frequency distributions for annual Tr value for the six simulated cover thickness highlight the strong non-linearity between the distribution of Tr over a long-term (60 year) climate cycle in that incremental increases in cover thickness do not produce proportional increases in Tr. In fact, once the cover thickness exceeds 75 cm, there is little incremental increase in the median value of Tr over the 60 year climate cycle.

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APPENDIX G
RESEARCH TEAM BACKGROUND AND PROJECT ROLE

SYNCRUDE CANADA LTD.

Research Team Background and Study Role

Marty Yarmuch

Mr. Marty Yarmuch, MSc, PAg, is a soil scientist working with Syncrude in its Environmental Research Division. Marty has 15 years of experience in soils related reclamation and research activities. Marty was the project lead for the SBH Research Synthesis and provided technical support and review for all aspects of the project.

Elisa Scordo

Ms. Elisa Scordo, MSc, PAg, GIT, is a hydrologist with BGC Engineering Inc. (BGC) Elisa has 10 years of experience in surface water hydrology, geomorphology, water resources management and mine closure planning. Elisa worked for two years at Syncrude as a reclamation scientist.

Elisa worked as the BGC project manager for the completion of surface water design, groundwater design, and closure surface design for the 2011 Mildred Lake and Aurora North Closure and Reclamation Plan. Elisa provided technical support to the research group.

Gord McKenna

Dr. Gord McKenna, PhD, PEng, PGeo, is a senior geotechnical engineer with BGC. Gord has 26 years of experience in the mining industry, including 17 years working at Syncrude Canada's Mildred Lake oil sands operation.

Gord has been involved with reclamation research at Mildred Lake throughout his employment at Syncrude and has continued working with reclamation research as a consultant. Gord has been involved with SBH since the beginning of construction of the landform. He provided guidance, technical support, and a technical review for the compilation report.

Julian McGreevy

Mr. Julian McGreevy, BASc, EIT, is a junior geological engineer with BGC. Julian has one year of experience in construction monitoring and reclamation design and research. Julian provided technical support to the research group.

Justin Straker

Mr. Justin Straker, MSc, PAg, is a forest ecologist and soil scientist and has 17 years of experience in applied terrestrial ecology. Justin's primary areas of focus are the terrestrial reclamation of industrial disturbances, the assessment of the interaction of human land uses and ecosystems, and terrestrial environmental effects research. Justin was one of the authors of the current version of the Land Capability Classification System and Revegetation Manual for the Athabasca Oil Sands regions.

Justin performed a field assessment of the overstory vegetation performance, prepared a report summarizing his findings and provided technical review for the compilation report.

Joel Hilderman

Mr. Joel Hilderman, MSc, PEng, is a senior geoenvironmental engineer with Klohn Crippen Berger. Joel has 8 years of experience primarily in hydrogeology for mining applications.

Joel prepared his MSc thesis on the transport of salts in the SBH soil cover. Joel used stable isotopes of water to estimate net percolation rates for the cover. He prepared the soil salinity research report and provided the group with guidance regarding soil salinity issues. Joel also provided a technical review of the compilation report.

Ken Van Rees

Dr. Ken Van Rees, PhD, is a professor of forest soils and Agri-Food Innovation Chair in Agroforestry and Afforestation at the University of Saskatchewan. Ken has over 30 years of experience working with forest soils and studying root systems.

Ken first became involved with SBH in 2003 and he has been involved with graduate students examining the root distributions of planted boreal vegetation on reclamation covers. He has also been involved in research on the possible impacts of salt profiles and soil physical properties on root development. Ken oversaw the rooting research and prepared the report as well as providing a technical review for the compilation report.

Lee Barbour

Dr. Lee Barbour, PhD, PEng, is a professor at the University of Saskatchewan in the Department of Civil and Geological Engineering. Lee has 30 years of experience in research and education and his primary area of expertise is water and mass transport in saturated/unsaturated soils, with particular interest/expertise on the application of numerical models to these problems.

Lee has been involved on SBH since 1998 with the setup of the initial instrumented watersheds. Lee has since been involved with monitoring and modeling of soil-water dynamics, salt generation and release, infiltration and interflow through frozen soils, and the use of stable water isotopes to monitor net percolation and interflow processes. Lee is the NSERC/Syncrude Canada Ltd. Industrial Research Chair in Hydrogeological Characterization of Oil Sands Mine Closure Landforms. The goal of the chair is to research the movement of groundwater through constructed upland structures at oil sands operations. Lee prepared the water-balance modeling and report and provided technical support and review for the salinity research and the compilation document.

Robbie Price

Mr. Robbie Price, BSc, is a soil scientist working with NorthWind Land Resources Inc. Robbie manages Syncrude's pre-disturbance soil salvage survey and soil reclamation programs at Mildred Lake and Aurora North mines. He has conducted soil sampling and assessments for a wide variety of research and operational programs at Syncrude over the last 9 years. Robbie performed the field sampling for the salinity and rooting research programs. Robbie also provided the team with guidance regarding the 2012 soil cover placement practices of Syncrude.

Sean Carey

Dr. Sean Carey, PhD is an associate professor at McMaster University in the School of Geography and Earth Sciences. Sean has 13 years of experience as a professor in hydrology primarily focusing on cold-region hydrological processes, soil atmosphere interaction and reclamation hydrology.

Sean has been involved in research at SBH since 2002 when he installed the initial eddy covariance tower on the site. Sean has since been involved with monitoring surface atmosphere exchanges at the site. Sean prepared the Evapotranspiration and Net Ecosystem Exchange report and provided guidance to the team regarding the history of SBH and the typical performance of boreal forest ecosystems. He also provided a technical review of the compilation report

Sophie Kessler

Ms. Sophie Kessler, MSc, is a geo-scientist with O'Kane Consultants Inc. Sophie is the Oil Sands Reclamation and Performance Compliance group leader for O'Kane and provides instrumentation installation, and data interpretation services to the oil sands industry.

Sophie prepared her MSc thesis on salinity patterns developing in the reclaimed soils at SBH. Sophie's thesis was the first to quantify the height of ingress of soil salinity into the SBH covers. Sophie has been involved with instrumentation installation, monitoring, and research at SBH since 2002. She assisted NorthWind Land Resources Inc. with the salinity research program and provided guidance to the team regarding the history of SBH

APPENDIX H
SUMMARY OF PUBLISHED RESEARCH PERFORMED BY RESEARCH TEAM AT SOUTH BISON HILL

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Summary of Published Research Performed by Research Team at South Bison Hill

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APPENDIX I
SOUTH BISON HILL HISTORICAL PHOTOS

Figure I-1. Aerial view of SBH (Top Right) looking northeast during the construction phase. Photo taken between 1996 – 1999.

Figure I-2. Aerial view of SBH looking southeast during construction. Peat Pond was developed out of the recessed area in the middle of the photograph. Photo taken between 1996 and 1999.

Figure I-3. Aerial view of SBH pre-cover placement. West-in Pit is visible in the back of the photograph and the South Haul Road can be seen in the foreground. Photo taken between 1997-2000.

Figure I-4. Aerial view looking south during the construction phase of SBH. Photo taken between 1997-1998

Figure I-5. View of S1 dump. Looking northwest to the back of the photograph is West-in-pit. Photo taken between 1996 – 1998.

Figure I-6. Photo of South Bison Hills (1995). The view is westward, looking towards the east slope of SBH.

Figure I-7. View looking west, post-construction (2001). Peat Pond can be seen on the left and weirs D1, D2 and D3 of capping study are located on the right beside the road. Base Mine Lake can be seen in the background.

Figure I-8. Post-construction with view looking west (2001). Weirs D1, D2 and D3 of capping study are visible, as well as Peat Pond on the left.

Figure I-9. South facing view of the three test covers on SBH (2001).

Figure I-10. Aerial view of covers D1, D2 and D3 of capping study (right to left; 2001).

Figure I-11. Photograph of the main swale weir of SBH plateau, with Peat Pond visible in the immediate background followed by West-in-pit (2001).

Figure I-12. Main swale weir of SBH plateau with Peat Pond and West-in-pit in the background (2001).

Figure I-13. Southwest aerial view showing Peat Pond, South Bison Pond, and West-in-pit all visible (2001).

Figure I-14. South Bison Hills post-construction looking southwest (2001).

Figure I-15. View looking west of South Bison Hills (2001).

Figure I-16. North slope of South Bison Hills looking southwest. Photo taken in 2001.

Figure I-17. Photograph of Bill’s Lake, looking in the northwest direction (2001).

Figure I-18. Covers D1, D2, and D3 (right to left; 2001).

Figure I-19. Cover D2, note weir hut and weather station on the slope (2001).

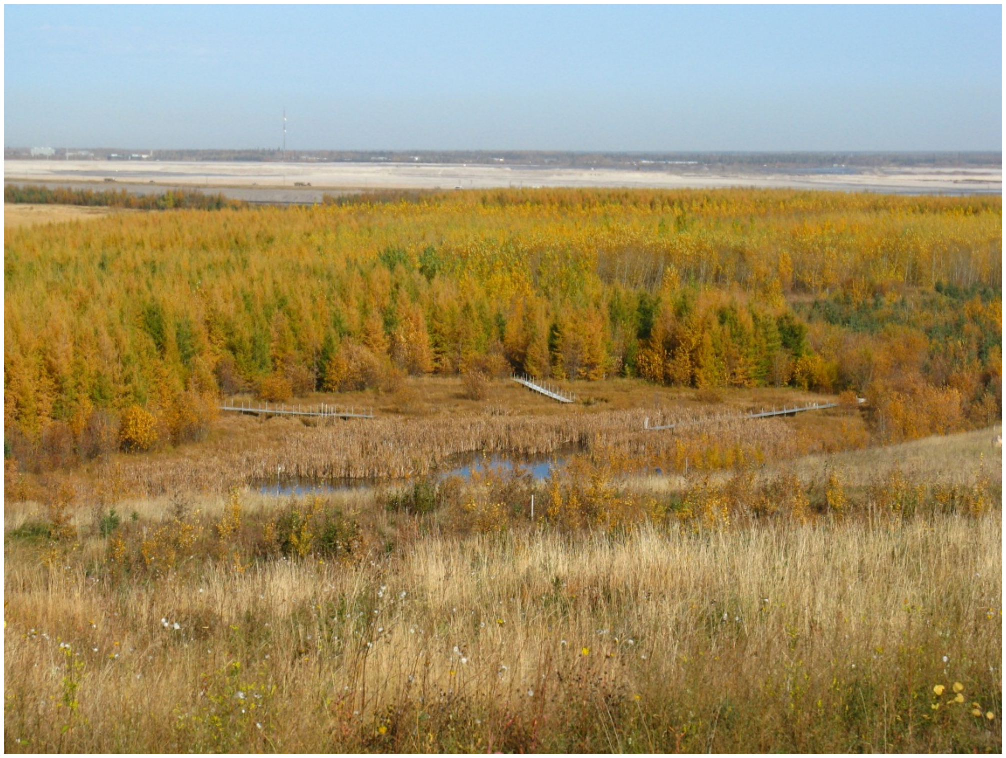


Figure I-20. Bill’s Lake looking from the east slope of SBH, SW29 dump in the background. Photo taken in an undetermined year.

Figure I-21. Aerial view of SBH looking southeast. Photo taken between 2001-2002.

Figure I-22. An eastward view towards Bill’s Lake with South Bison Pond in the background. Photo taken in an undetermined year.

Figure I-23. Weir (2004).

Figure I-24 Eddy covariance tower (2012).

Figure I-25 South Bison Hill Plateau (2012).

DRAWINGS

SYNCRUDE CANADA LTD.

Syncrude

BGC

Integral Ecology Group

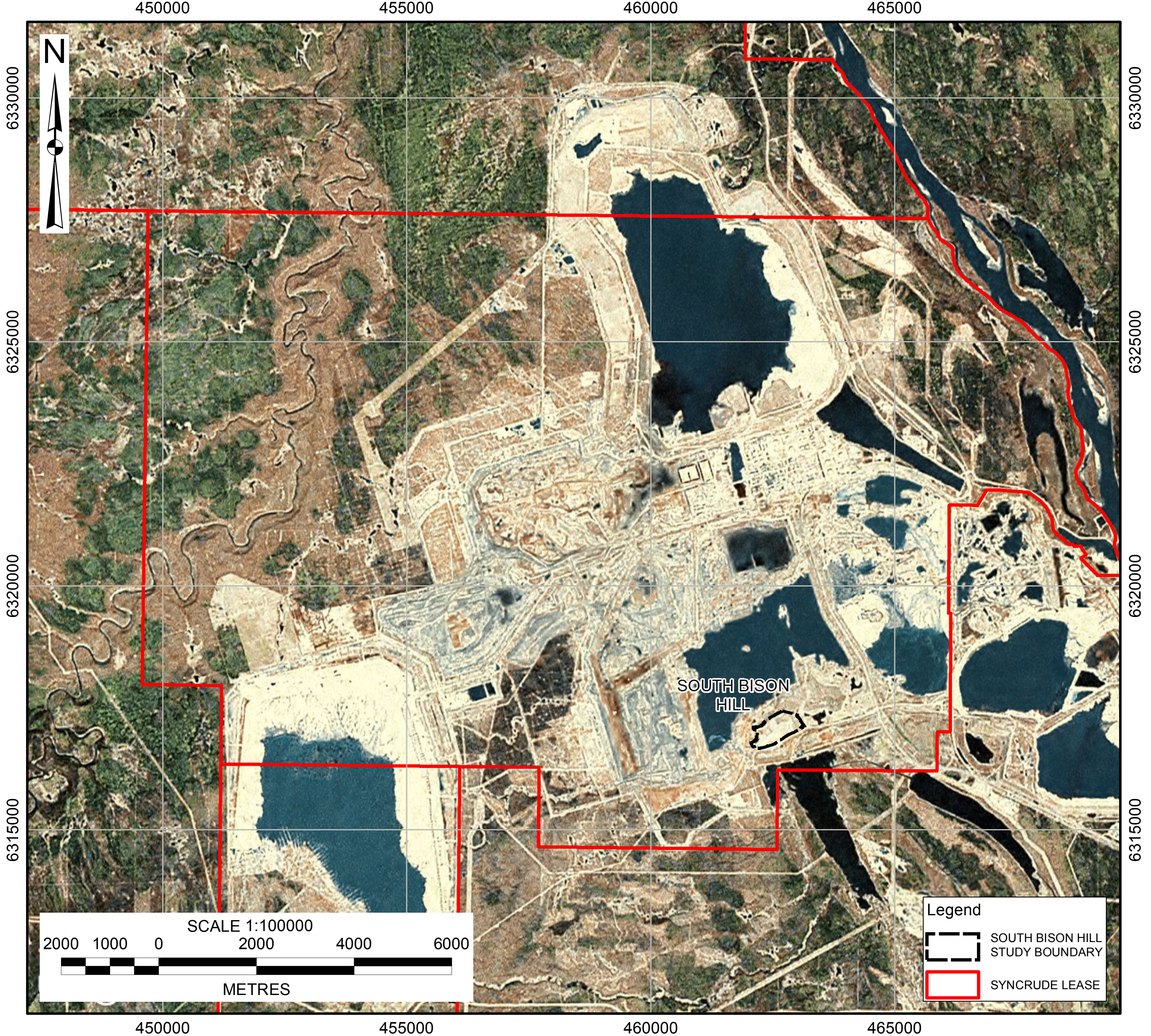
McMaster University

Klohn Crippen Berger

O'Kane Consultants Inc.

University of Saskatchewan

NorthWind Land Resources Inc.



2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

SOUTH BISON HILL RESEARCH SYNTHESIS DRAWING PACKAGE

Drawing Number	Drawing Title
00	Cover Sheet
01	Mildred Lake Overburden Substrate Reclamation Material Placement
02	South Bison Hill Study Overview
03	Capping Study Instrumentation And Tree Health Survey Locations
04	Digital Elevation Model
05	As Built Soil Placement Dates and Areas
06	Measured Reclamation Material Thickness (2012)
07	Construction Timeline
08	Historical Orthophotos
09	Revegetation Dates and Areas
10	2012 Field Program Transect Cross Sections
11	2012 Sampling Transects 1, 2, and 3 - Cross Sections
12	2012 Sampling Transects 4, 5, and 6 - Cross Sections
13	2012 Sampling Transects 7, 8, and 9 - Cross Sections
14	Topography Position Index

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APPROVED:	TGH

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Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
COVER SHEET

PROJECT No.:	DWG No.:	REV.:
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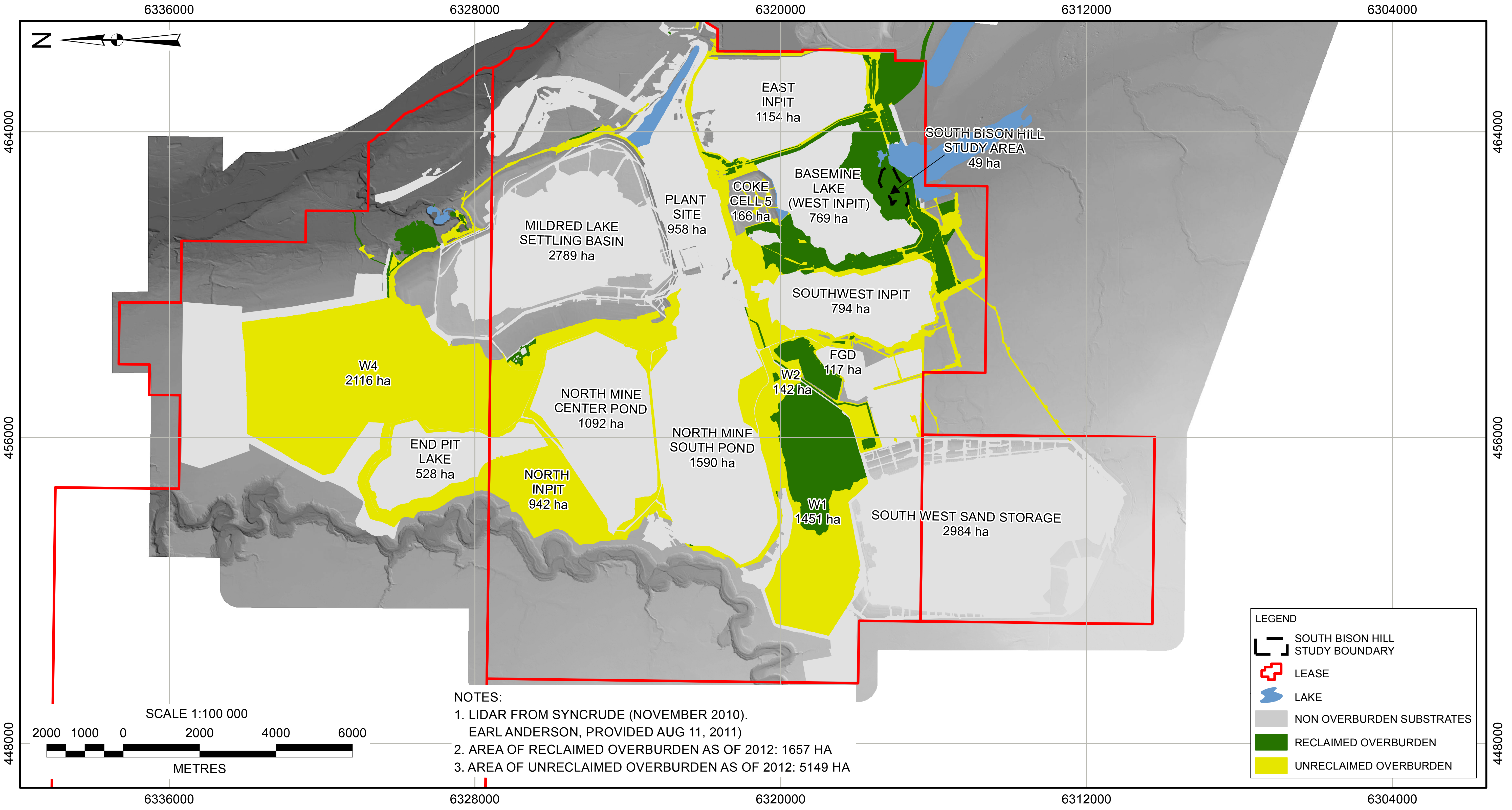

NOTES:
1. LIDAR FROM SYNCRUDE (NOVEMBER 2010).
   EARL ANDERSON, PROVIDED AUG 11, 2011)
2. AREA OF RECLAIMED OVERBURDEN AS OF 2012: 1657 HA
3. AREA OF UNRECLAIMED OVERBURDEN AS OF 2012: 5149 HA

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

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DATE: FEB 2013
DRAWN: RC
DESIGNED: JM
CHECKED:
APPROVED:

PROFESSIONAL SEAL:

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CLIENT: Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
MILDRED LAKE OVERBURDEN SUBSTRATE
RECLAMATION MATERIAL PLACEMENT

PROJECT No.: 0534107
DWG No.: 01
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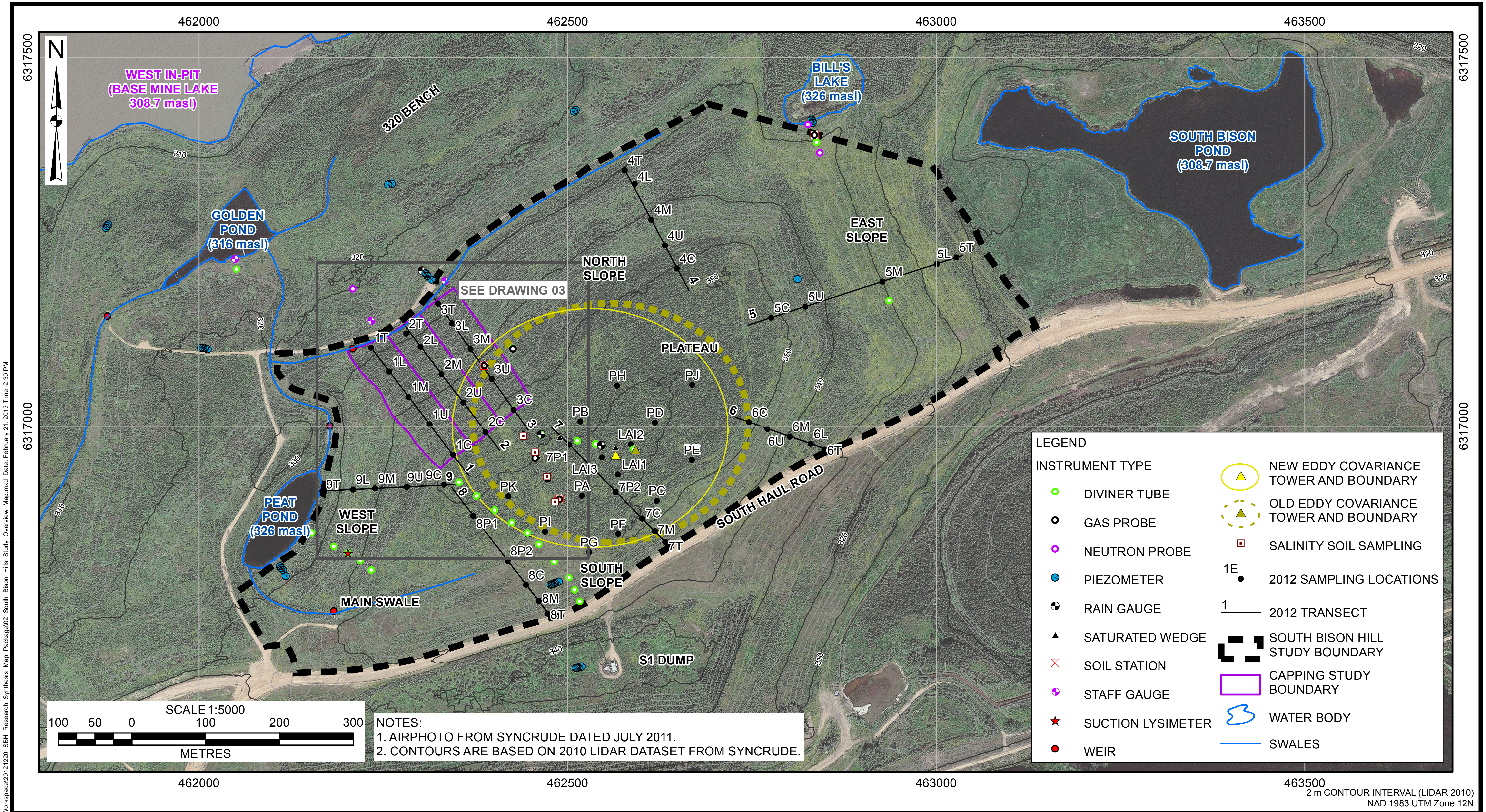

NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

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DATE: FEB 2013
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DESIGNED: ES, JM
CHECKED: GM, ES
APPROVED: TGH

PROFESSIONAL SEAL:

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PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
SOUTH BISON HILL STUDY OVERVIEW

PROJECT No.: 0534107
DWG No.: 02
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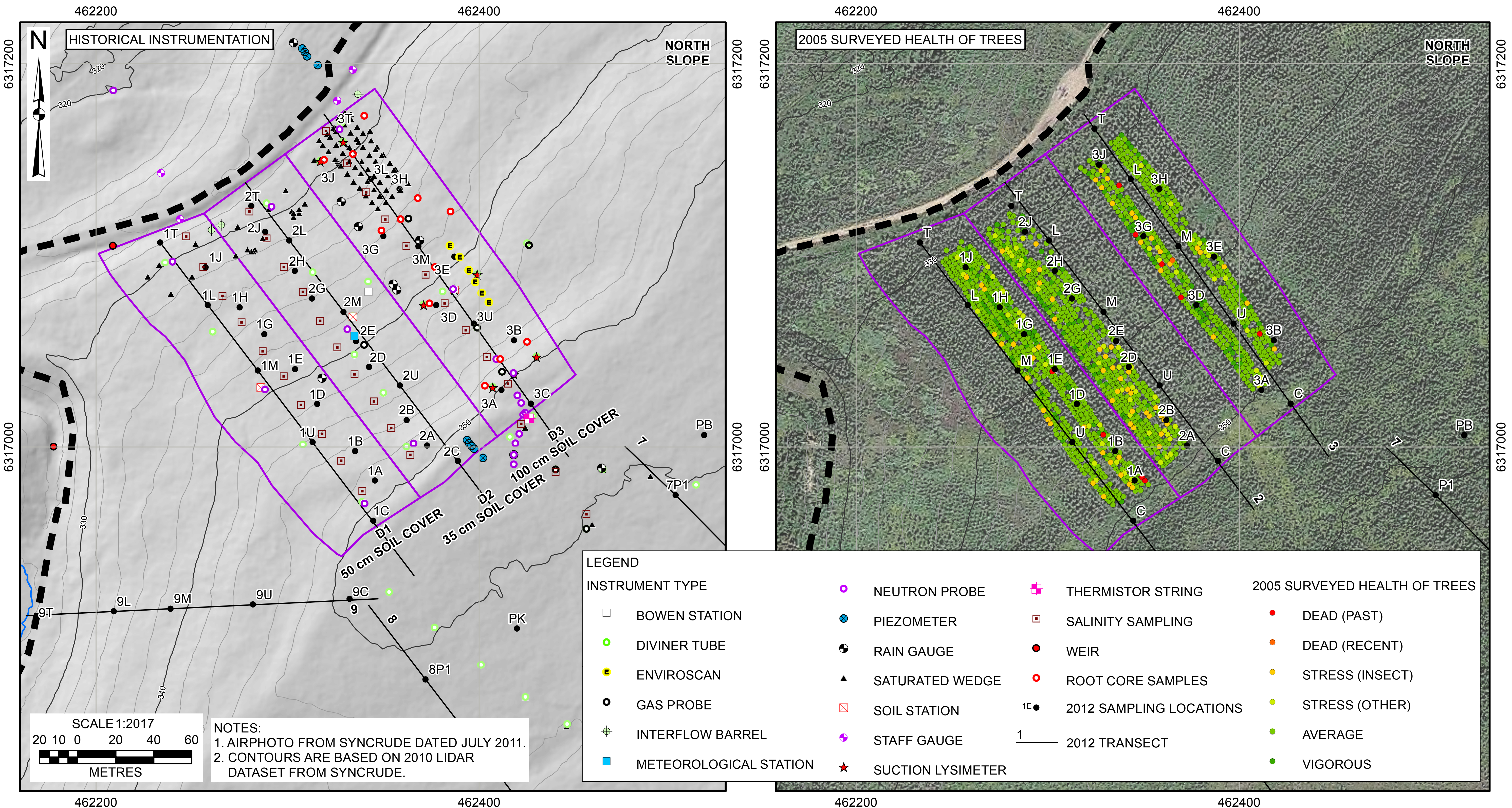

HISTORICAL INSTRUMENTATION

2005 SURVEYED HEALTH OF TREES

NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

LEGEND

INSTRUMENT TYPE

☐	BOWEN STATION	○	NEUTRON PROBE	⊞	THERMISTOR STRING
○	DIVINER TUBE	⊗	PIEZOMETER	⊡	SALINITY SAMPLING
E	ENVIROSCAN	◕	RAIN GAUGE	●	WEIR
○	GAS PROBE	▲	SATURATED WEDGE	○	ROOT CORE SAMPLES
⊕	INTERFLOW BARREL	☒	SOIL STATION	1E●	2012 SAMPLING LOCATIONS
■	METEOROLOGICAL STATION	◕	STAFF GAUGE	1 ───	2012 TRANSECT
		★	SUCTION LYSIMETER		

2005 SURVEYED HEALTH OF TREES

●	DEAD (PAST)
●	DEAD (RECENT)
●	STRESS (INSECT)
●	STRESS (OTHER)
●	AVERAGE
●	VIGOROUS

2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

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DESIGNED:	ES, JM
CHECKED:	ES
APPROVED:	TGH

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PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
CAPPING STUDY INSTRUMENTATION AND TREE HEALTH SURVEY LOCATIONS

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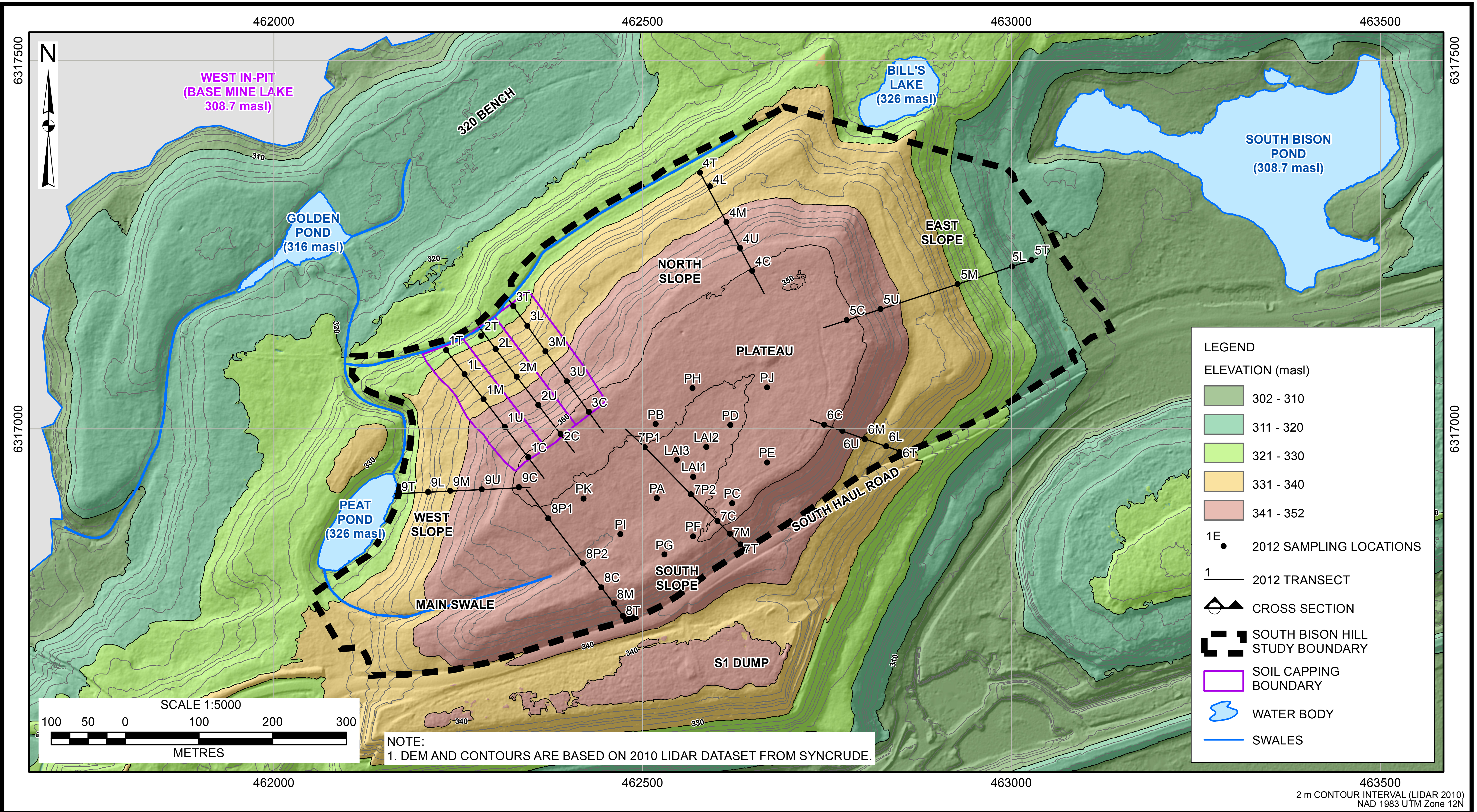

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1. DEM AND CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

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DESIGNED:	ES, JM
CHECKED:	ES
APPROVED:	TGH

PROFESSIONAL SEAL:

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BGC ENGINEERING INC.
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CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
DIGITAL ELEVATION MODEL

PROJECT No.:	DWG No.:	REV.:
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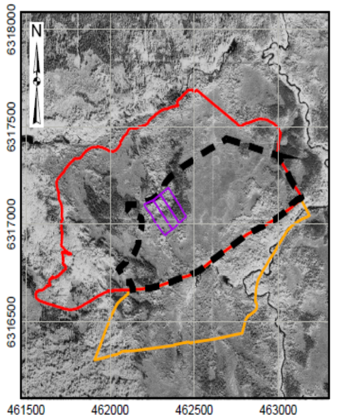
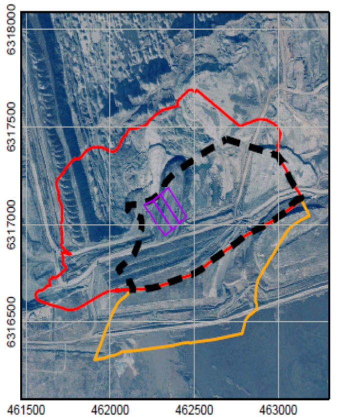
Syncrude SOUTH BISON HILLS CONSTRUCTION TIMELINE



1967



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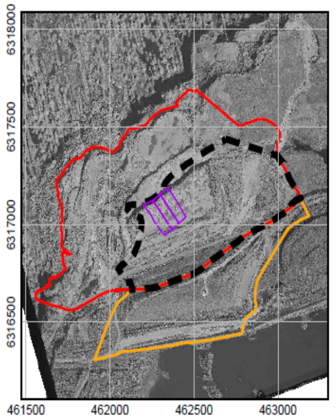

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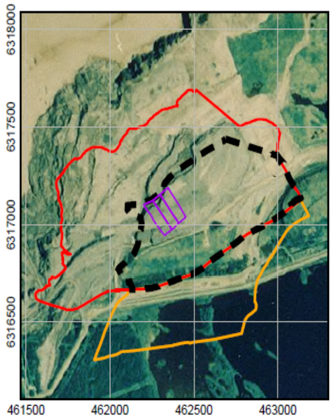

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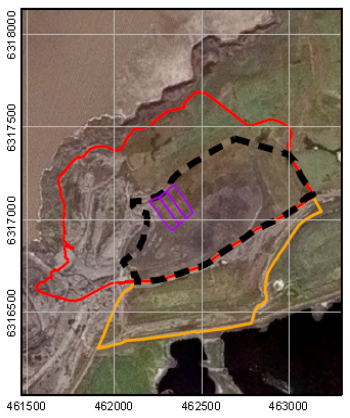
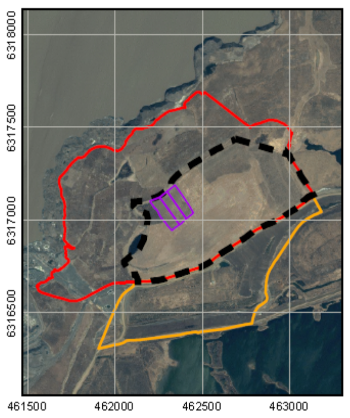


2001



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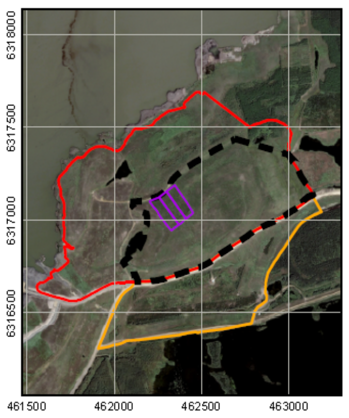
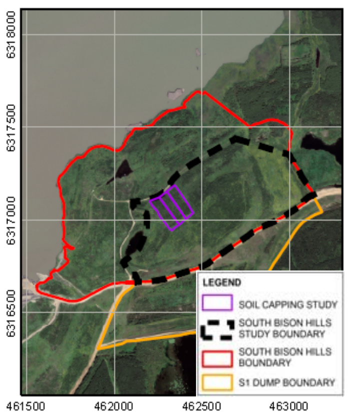
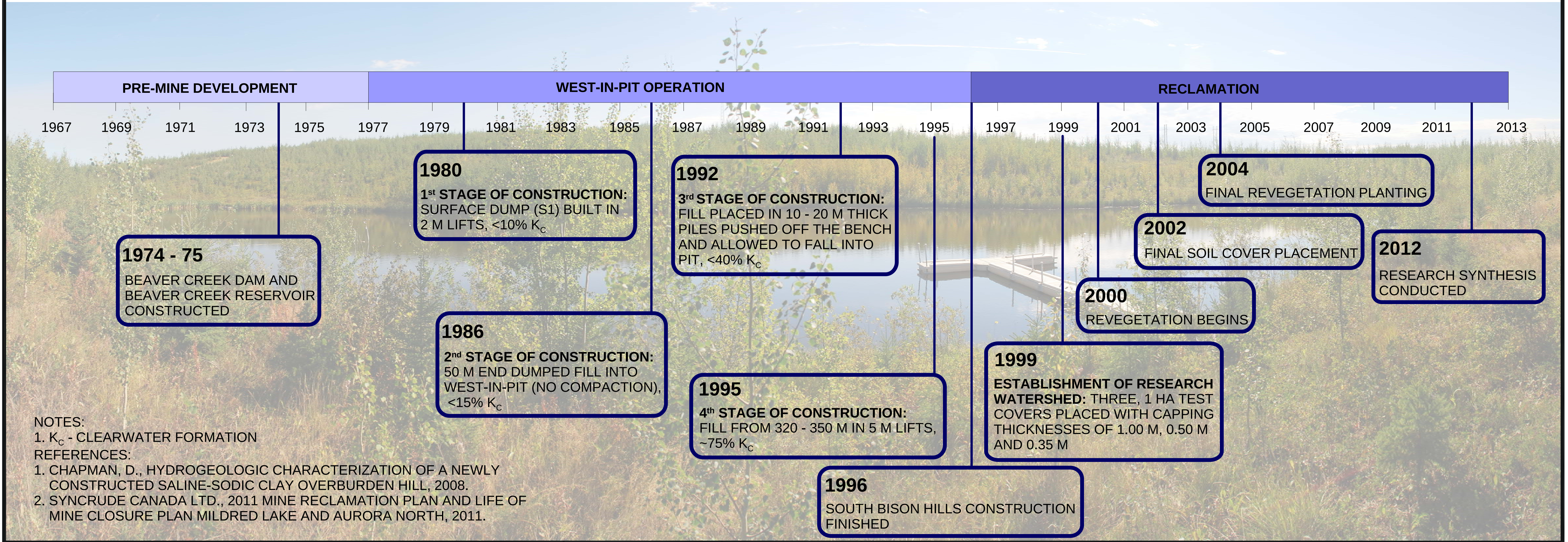


2007



2011



PRE-MINE DEVELOPMENT	WEST-IN-PIT OPERATION	RECLAMATION
1967 1969 1971 1973 1975	1977 1979 1981 1983 1985 1987 1989 1991 1993 1995	1997 1999 2001 2003 2005 2007 2009 2011 2013

1974 - 75
BEAVER CREEK DAM AND BEAVER CREEK RESERVOIR CONSTRUCTED

1980
1st STAGE OF CONSTRUCTION: SURFACE DUMP (S1) BUILT IN 2 M LIFTS, <10% K_C

1986
2nd STAGE OF CONSTRUCTION: 50 M END DUMPED FILL INTO WEST-IN-PIT (NO COMPACTION), <15% K_C

1992
3rd STAGE OF CONSTRUCTION: FILL PLACED IN 10 - 20 M THICK PILES PUSHED OFF THE BENCH AND ALLOWED TO FALL INTO PIT, <40% K_C

1995
4th STAGE OF CONSTRUCTION: FILL FROM 320 - 350 M IN 5 M LIFTS, ~75% K_C

1996
SOUTH BISON HILLS CONSTRUCTION FINISHED

1999
ESTABLISHMENT OF RESEARCH WATERSHED: THREE, 1 HA TEST COVERS PLACED WITH CAPPING THICKNESSES OF 1.00 M, 0.50 M AND 0.35 M

2000
REVEGETATION BEGINS

2002
FINAL SOIL COVER PLACEMENT

2004
FINAL REVEGETATION PLANTING

2012
RESEARCH SYNTHESIS CONDUCTED

NOTES:
1. K_C - CLEARWATER FORMATION

REFERENCES:
1. CHAPMAN, D., HYDROGEOLOGIC CHARACTERIZATION OF A NEWLY CONSTRUCTED SALINE-SODIC CLAY OVERBURDEN HILL, 2008.
2. SYNCRUDE CANADA LTD., 2011 MINE RECLAMATION PLAN AND LIFE OF MINE CLOSURE PLAN MILDRED LAKE AND AURORA NORTH, 2011.

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DESIGNED: JW/JM
CHECKED: ES
APPROVED: GM

PROFESSIONAL SEAL:
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CLIENT: Syncrude

PROJECT: SOUTH BISON HILLS RESEARCH SYNTHESIS
TITLE: CONSTRUCTION TIMELINE
PROJECT No.: 0534107
FIG No.: 05
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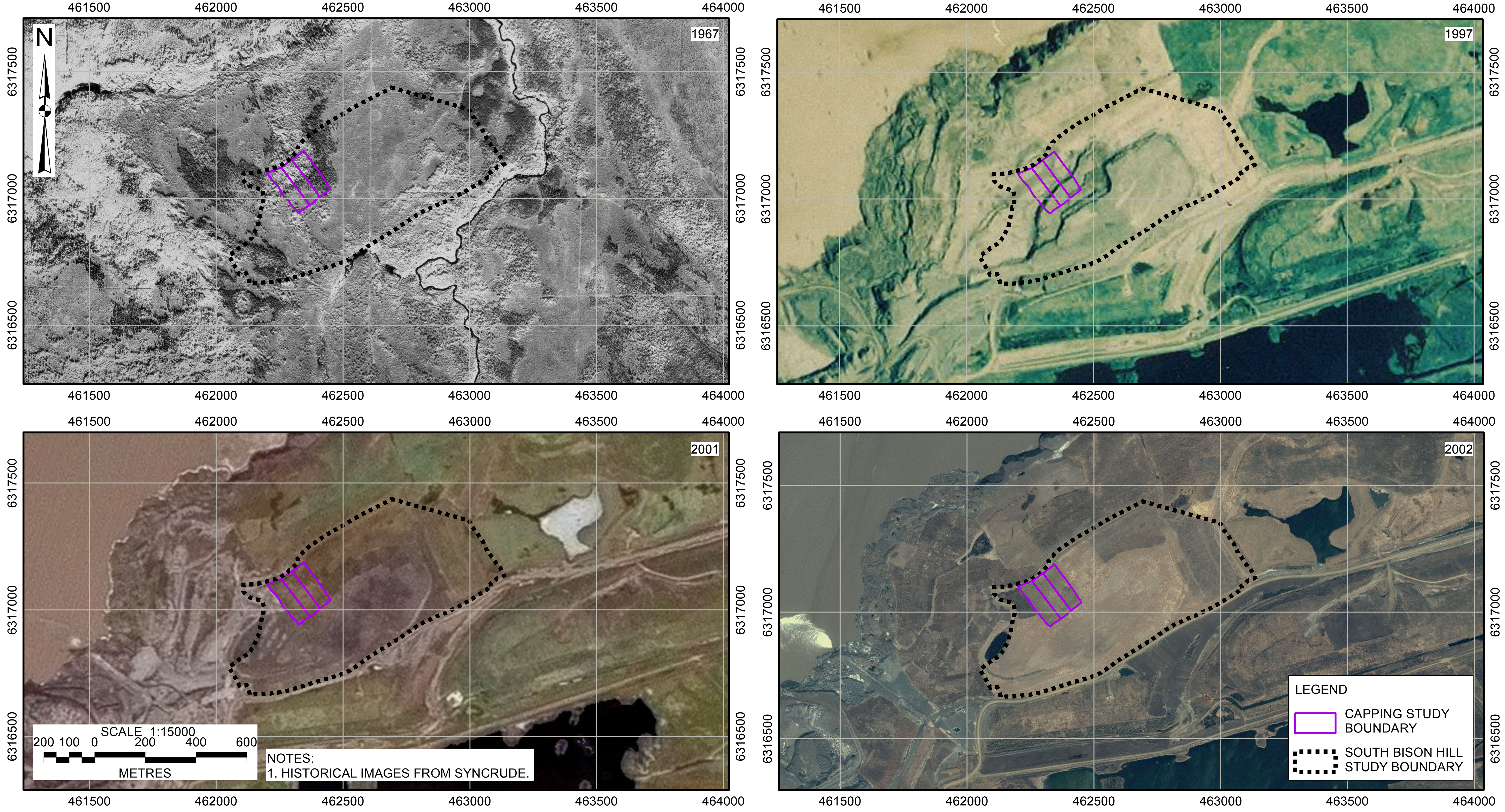

NOTES:
1. HISTORICAL IMAGES FROM SYNCRUDE.

NAD 1983 UTM Zone 12N

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APPROVED: TGH

PROFESSIONAL SEAL:

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BGC ENGINEERING INC.
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CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
HISTORICAL ORTHOPHOTOS

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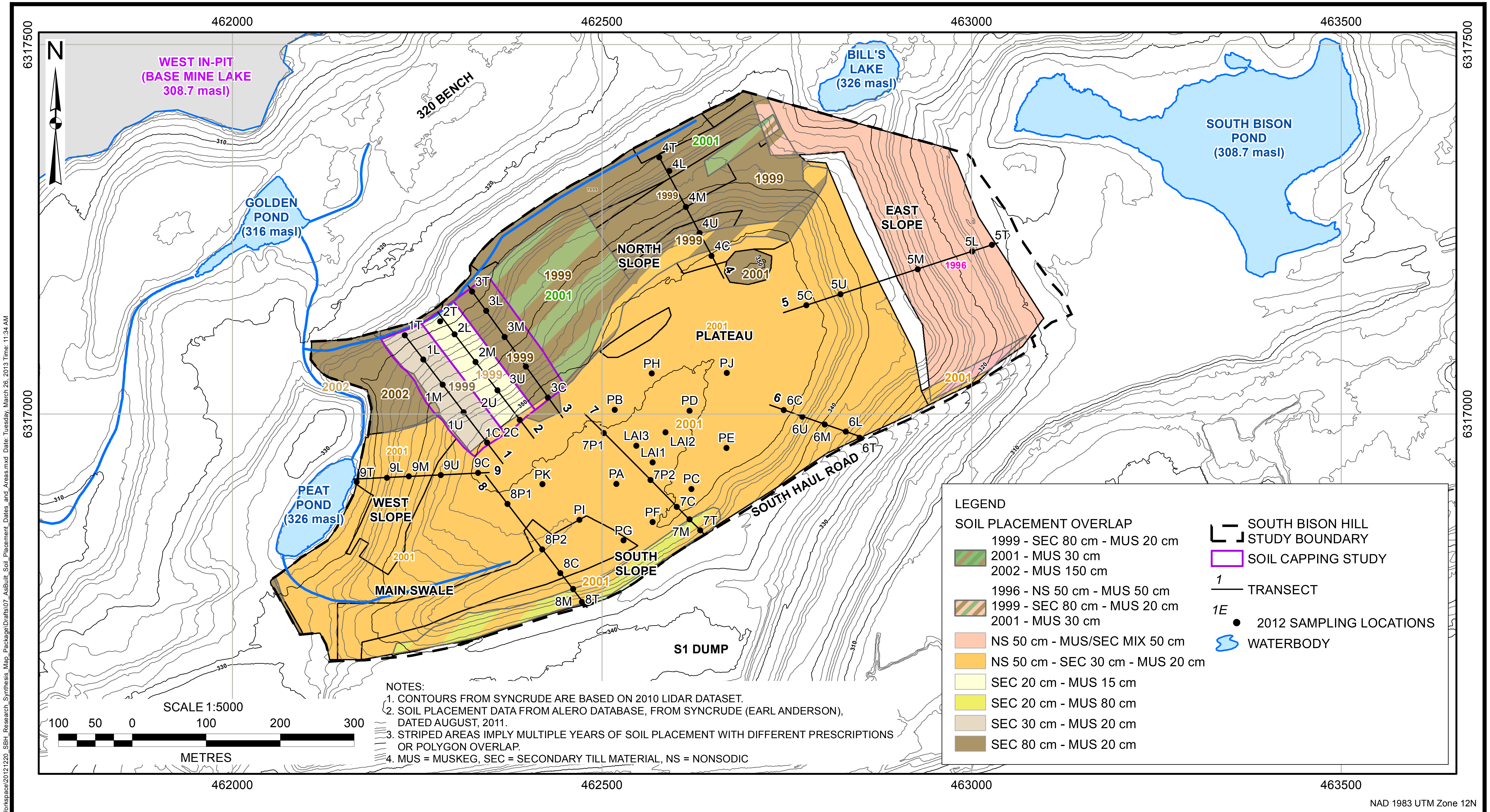

LEGEND

SOIL PLACEMENT OVERLAP

▨	1999 - SEC 80 cm - MUS 20 cm 2001 - MUS 30 cm 2002 - MUS 150 cm
▨	1996 - NS 50 cm - MUS 50 cm 1999 - SEC 80 cm - MUS 20 cm 2001 - MUS 30 cm
■	NS 50 cm - MUS/SEC MIX 50 cm
■	NS 50 cm - SEC 30 cm - MUS 20 cm
■	SEC 20 cm - MUS 15 cm
■	SEC 20 cm - MUS 80 cm
■	SEC 30 cm - MUS 20 cm
■	SEC 80 cm - MUS 20 cm

⌐ ┘	SOUTH BISON HILL STUDY BOUNDARY
□	SOIL CAPPING STUDY
1	TRANSECT
1E ●	2012 SAMPLING LOCATIONS
~	WATERBODY

NOTES:
1. CONTOURS FROM SYNCRUDE ARE BASED ON 2010 LIDAR DATASET.
2. SOIL PLACEMENT DATA FROM ALERO DATABASE, FROM SYNCRUDE (EARL ANDERSON), DATED AUGUST, 2011.
3. STRIPED AREAS IMPLY MULTIPLE YEARS OF SOIL PLACEMENT WITH DIFFERENT PRESCRIPTIONS OR POLYGON OVERLAP.
4. MUS = MUSKEG, SEC = SECONDARY TILL MATERIAL, NS = NONSODIC

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APPROVED: TGH

PROFESSIONAL SEAL:

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CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
AS BUILT SOIL PLACEMENT
DATES AND AREAS

PROJECT No.: 0534107
DWG No.: 07
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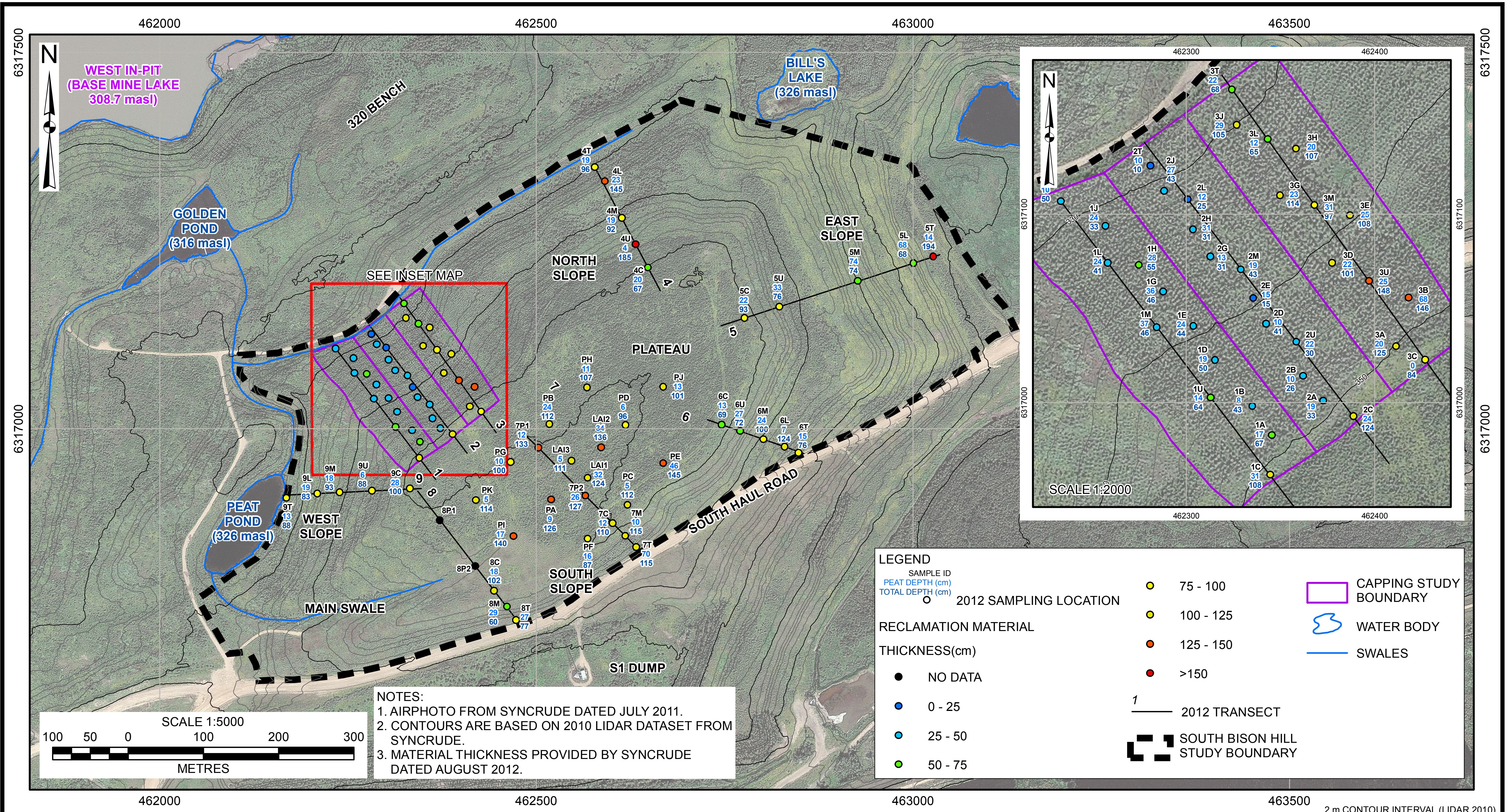

LEGEND

SAMPLE ID
PEAT DEPTH (cm)
TOTAL DEPTH (cm)
○ 2012 SAMPLING LOCATION

RECLAMATION MATERIAL THICKNESS(cm)

- ● NO DATA
- ● 0 - 25
- ● 25 - 50
- ● 50 - 75
- ● 75 - 100
- ● 100 - 125
- ● 125 - 150
- ● >150

1 2012 TRANSECT

SOUTH BISON HILL STUDY BOUNDARY

CAPPING STUDY BOUNDARY

WATER BODY

SWALES

NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.
3. MATERIAL THICKNESS PROVIDED BY SYNCRUDE DATED AUGUST 2012.

2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

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DESIGNED:	ES, JM
CHECKED:	ES
APPROVED:	TGH

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
MEASURED SOIL COVER THICKNESS (2012)

PROJECT No.:	DWG No.:	REV.:
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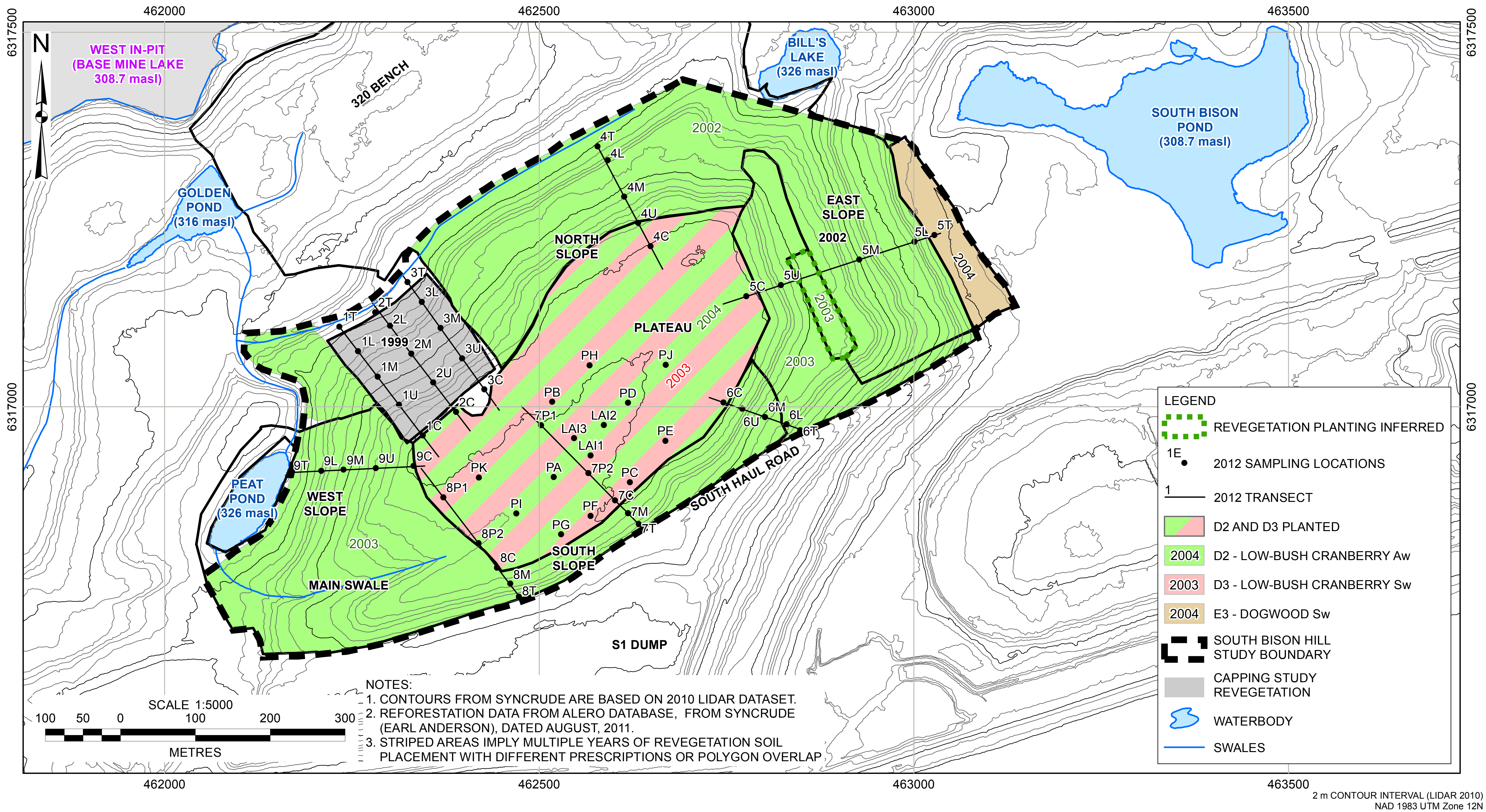

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1. CONTOURS FROM SYNCRUDE ARE BASED ON 2010 LIDAR DATASET.
2. REFORESTATION DATA FROM ALERO DATABASE, FROM SYNCRUDE (EARL ANDERSON), DATED AUGUST, 2011.
3. STRIPED AREAS IMPLY MULTIPLE YEARS OF REVEGETATION SOIL PLACEMENT WITH DIFFERENT PRESCRIPTIONS OR POLYGON OVERLAP

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PROFESSIONAL SEAL:

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS
TITLE: REVEGETATION DATES AND AREAS
PROJECT No.: 0534107
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REV.:

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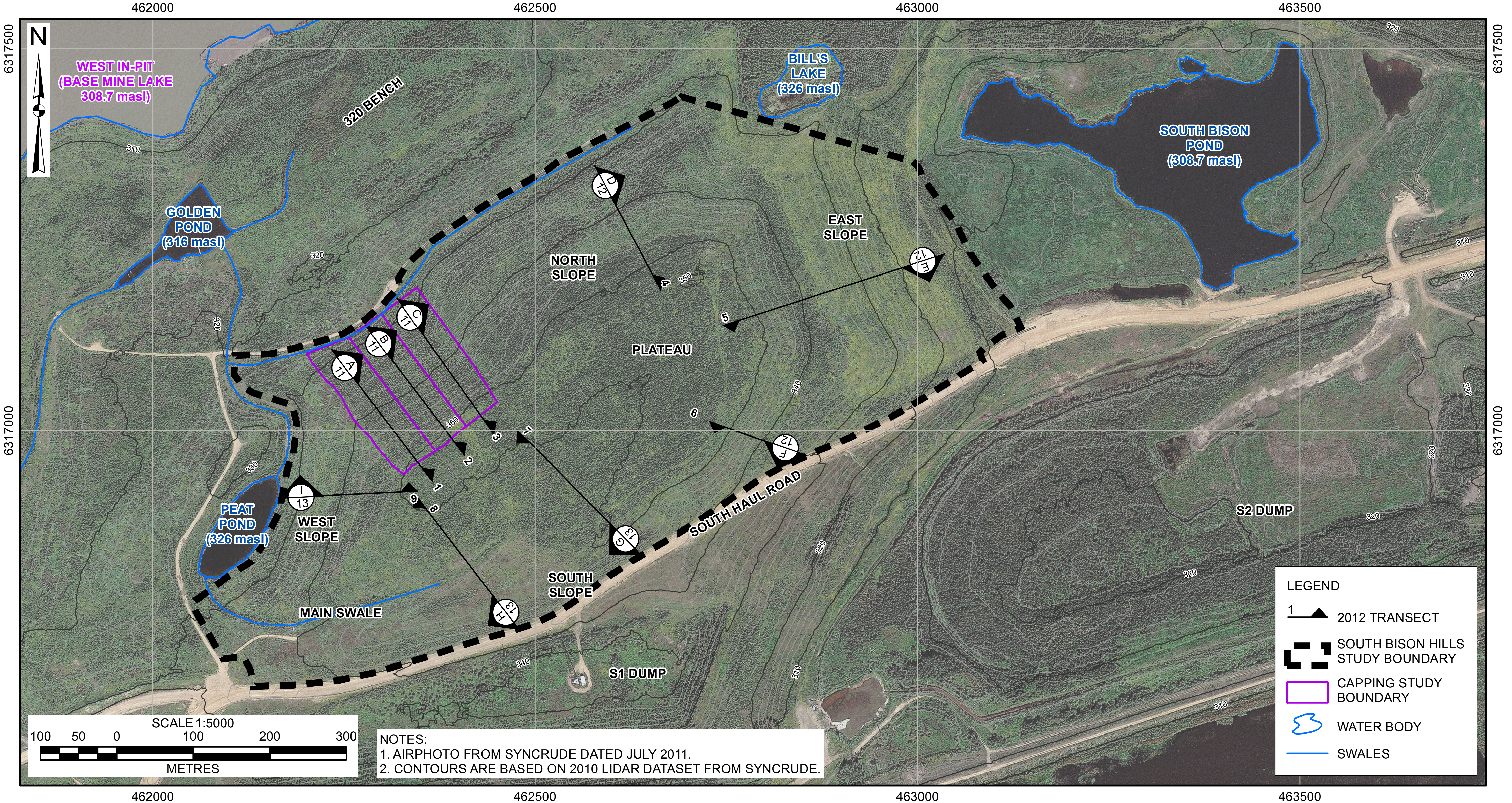


NOTES:
1. AIRPHOTO FROM SYNCRUDE DATED JULY 2011.
2. CONTOURS ARE BASED ON 2010 LIDAR DATASET FROM SYNCRUDE.

2 m CONTOUR INTERVAL (LIDAR 2010)
NAD 1983 UTM Zone 12N

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: 1:5000
DATE: FEB 2013
DRAWN: RC, IL
DESIGNED: ES, JM
CHECKED: ES
APPROVED: GM

PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

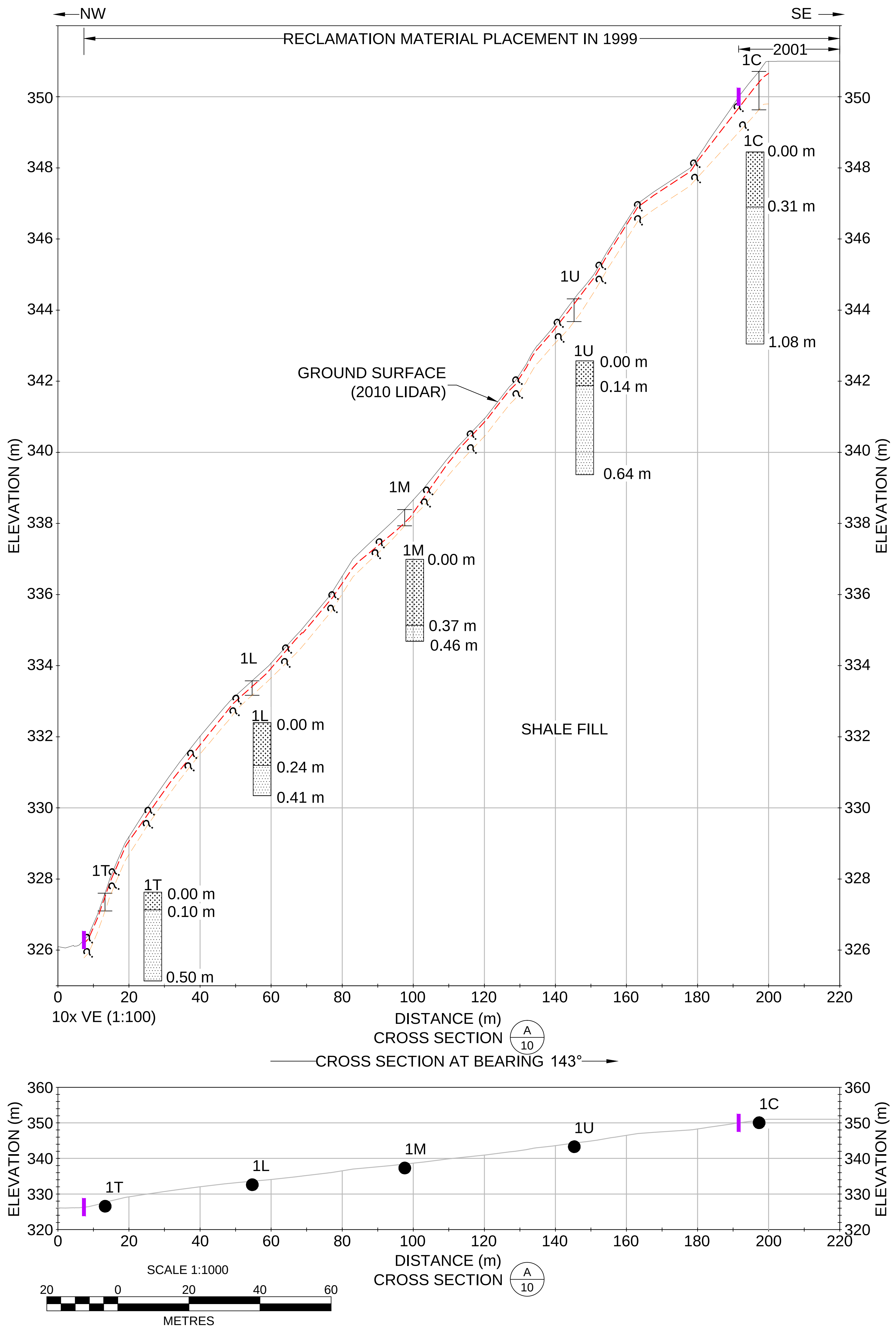
PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
2012 FIELD PROGRAM TRANSECT CROSS SECTIONS

PROJECT No.: 0534107
DWG No.: 10
REV.:

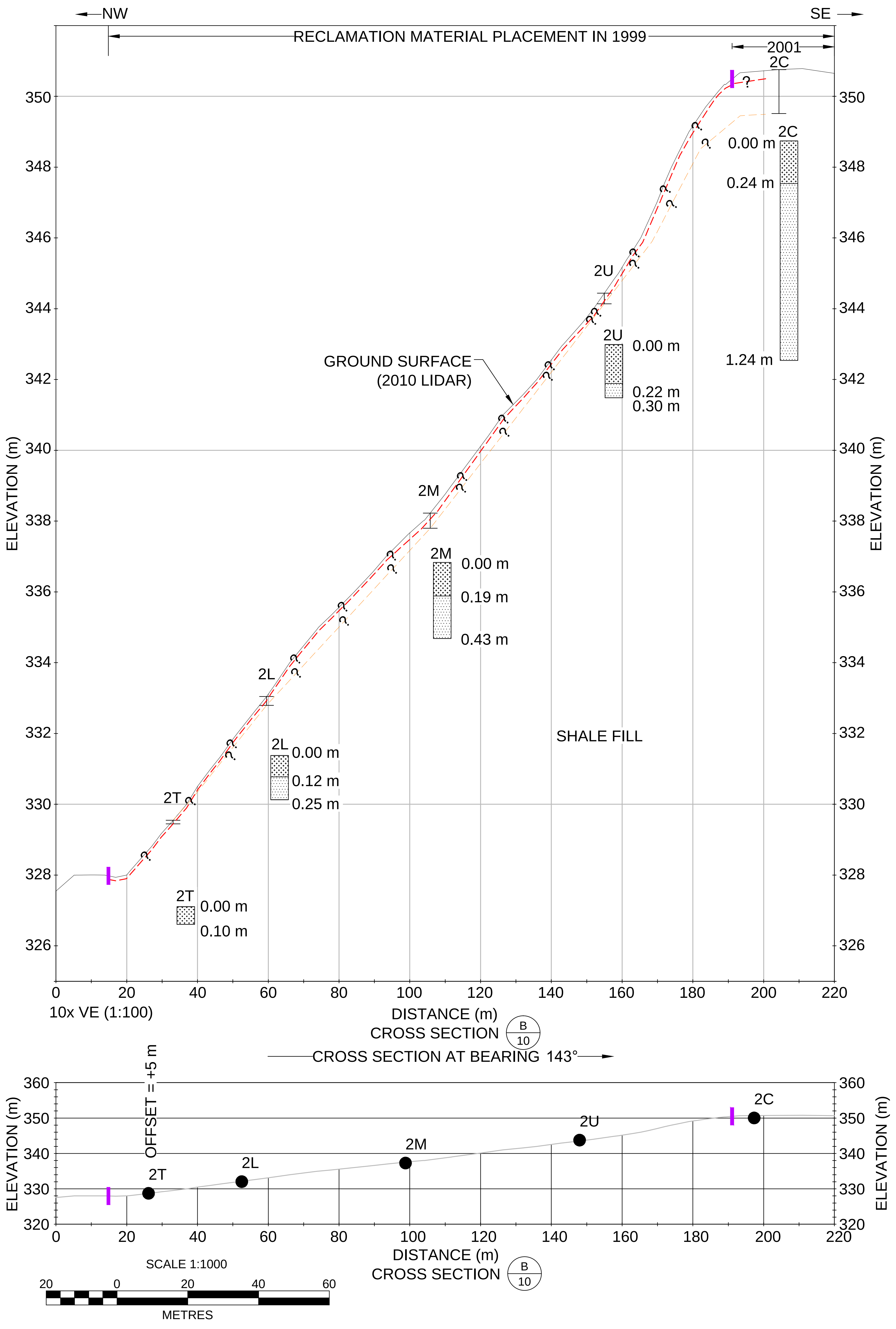
TRANSECT 1

D1 - 0.50 m COVER: 0.20 m PEAT, 0.30 m TILL



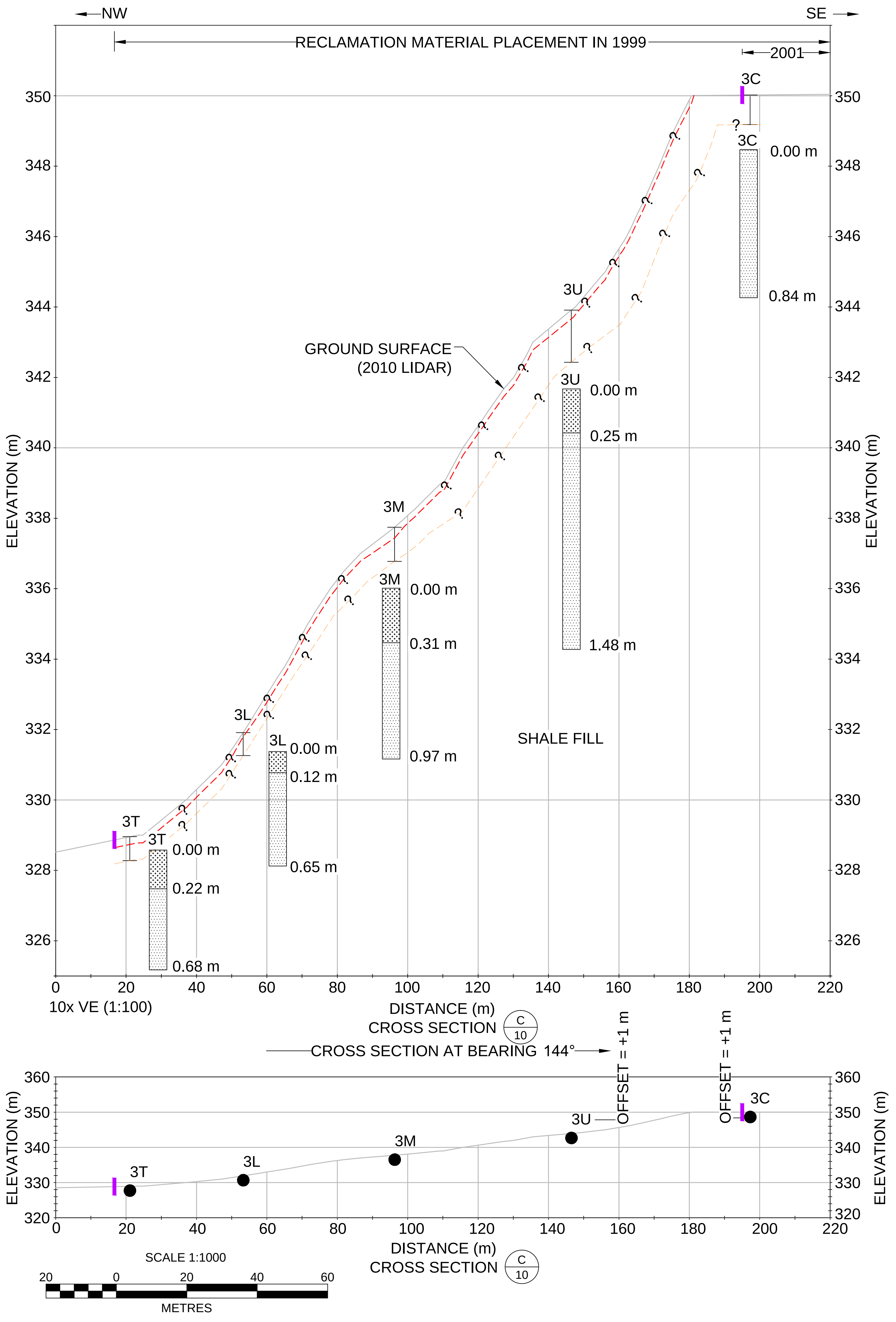
TRANSECT 2

D2 - 0.35 m COVER: 0.15 m PEAT, 0.20 m TILL



TRANSECT 3

D3 - 1.0 m COVER: 0.20 m PEAT, 0.80 m TILL



LEGEND

—	GROUND SURFACE (LIDAR 2010)	—	CAPPING PRESCRIPTION BOUNDARY
—?—	INFERRED PEAT-TILL INTERFACE	●	SAMPLING LOCATION
—?—	INFERRED TILL-SHALE INTERFACE	⊥	SAMPLING INCREMENT
		▩	PEAT
		▤	TILL

1T SAMPLING LOG
SCALE: 1:20
NO VERTICAL EXAGGERATIONS

NOTES:
1. OFFSET IS THE DISTANCE PERPENDICULAR TO THE CROSS SECTION LINE: +OFFSET IS OUT OF THE PAGE, - OFFSET IS INTO THE PAGE.
2. INTERPOLATION OF COVER LAYER SURFACES ACHIEVED BY PROJECTING THE KNOWN GROUND SURFACE TOPOGRAPHY TO THE HEIGHTS OF DIFFERENT LAYERS AND MATCHING CONSECUTIVE DATA POINTS.
3. SAMPLING LOGS ARE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY AT A SCALE OF 1:20 WITH NO VERTICAL EXAGGERATION.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: FEB 2013
DRAWN: AH
DESIGNED: JW
CHECKED: ES
APPROVED: -

PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
2012 SAMPLING TRANSECTS 1, 2, AND 3 - CROSS SECTIONS

PROJECT No.: 0534107
DWG No.: 11
REV.:

X:\Projects\0534_Syncrude\107_SouthHills\Workspace\20121015_DWG_SOUTH_BISON_HILL_RESEARCH_SYNTHESIS\11_2012_SAMPLING_TRANSECTS_1,_2_AND_3_-_CROSS_SECTIONS.dwg Layout: Layout1 Plot Date Feb 26 13 Time: 3:35 PM

LEGEND

—	GROUND SURFACE (LIDAR 2010)	▬	CAPPING PRESCRIPTION BOUNDARY
—?—	INFERRED PEAT-TILL INTERFACE	●	SAMPLING LOCATION
—?—	INFERRED TILL-SHALE INTERFACE	⌶	SAMPLING INCREMENT
		▩	PEAT
		▨	TILL

1T SAMPLING LOG
SCALE: 1:20
NO VERTICAL EXAGGERATIONS

NOTES:
1. OFFSET IS THE DISTANCE PERPENDICULAR TO THE CROSS SECTION LINE: +OFFSET IS OUT OF THE PAGE, - OFFSET IS INTO THE PAGE.
2. INTERPOLATION OF COVER LAYER SURFACES ACHIEVED BY PROJECTING THE KNOWN GROUND SURFACE TOPOGRAPHY TO THE HEIGHTS OF DIFFERENT LAYERS AND MATCHING CONSECUTIVE DATA POINTS.
3. SAMPLING LOGS ARE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY AT A SCALE OF 1:20 WITH NO VERTICAL EXAGGERATION.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: FEB 2013
DRAWN: AH
DESIGNED: JW
CHECKED: ES
APPROVED: -

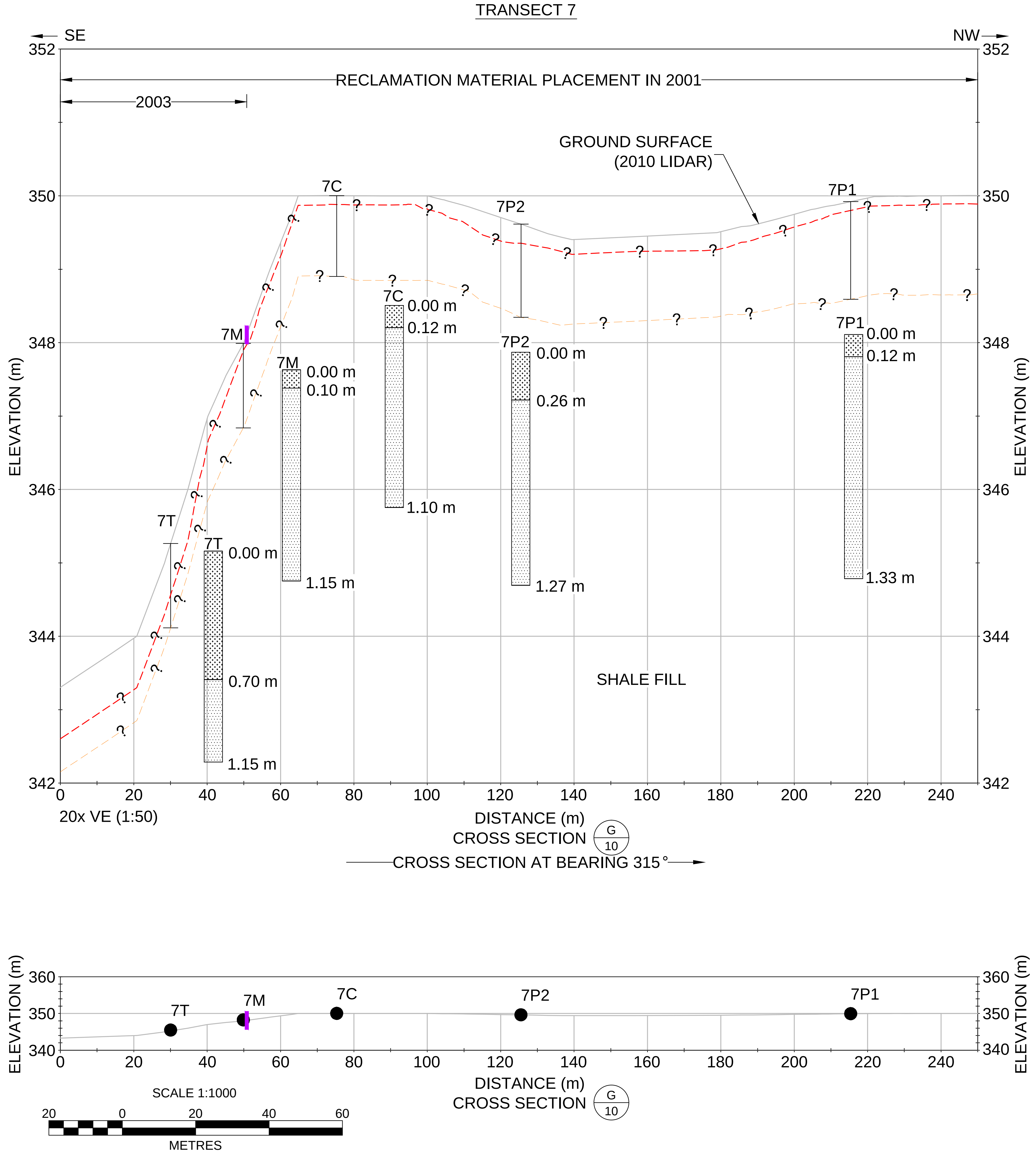
PROFESSIONAL SEAL:
DRAFT

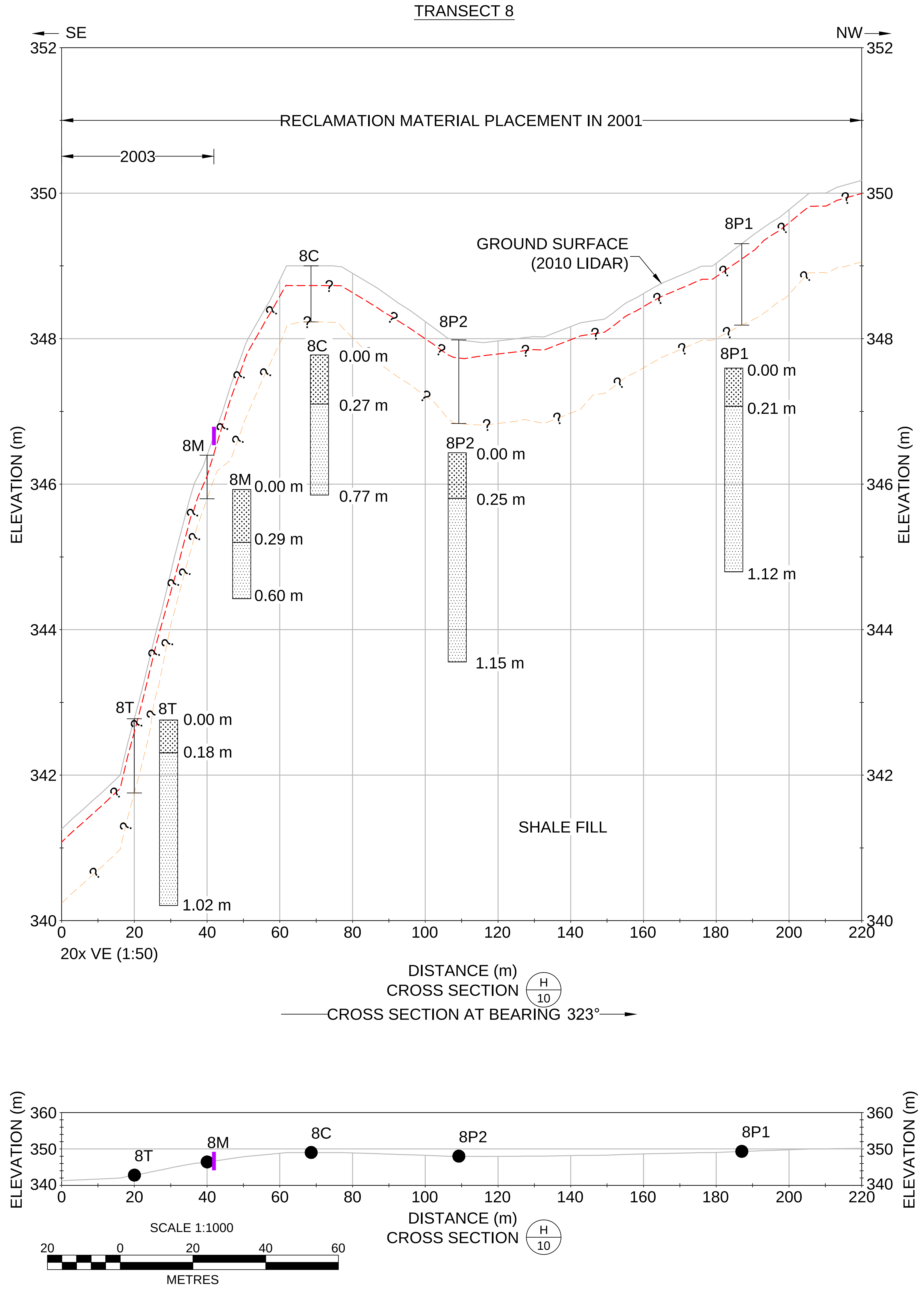
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

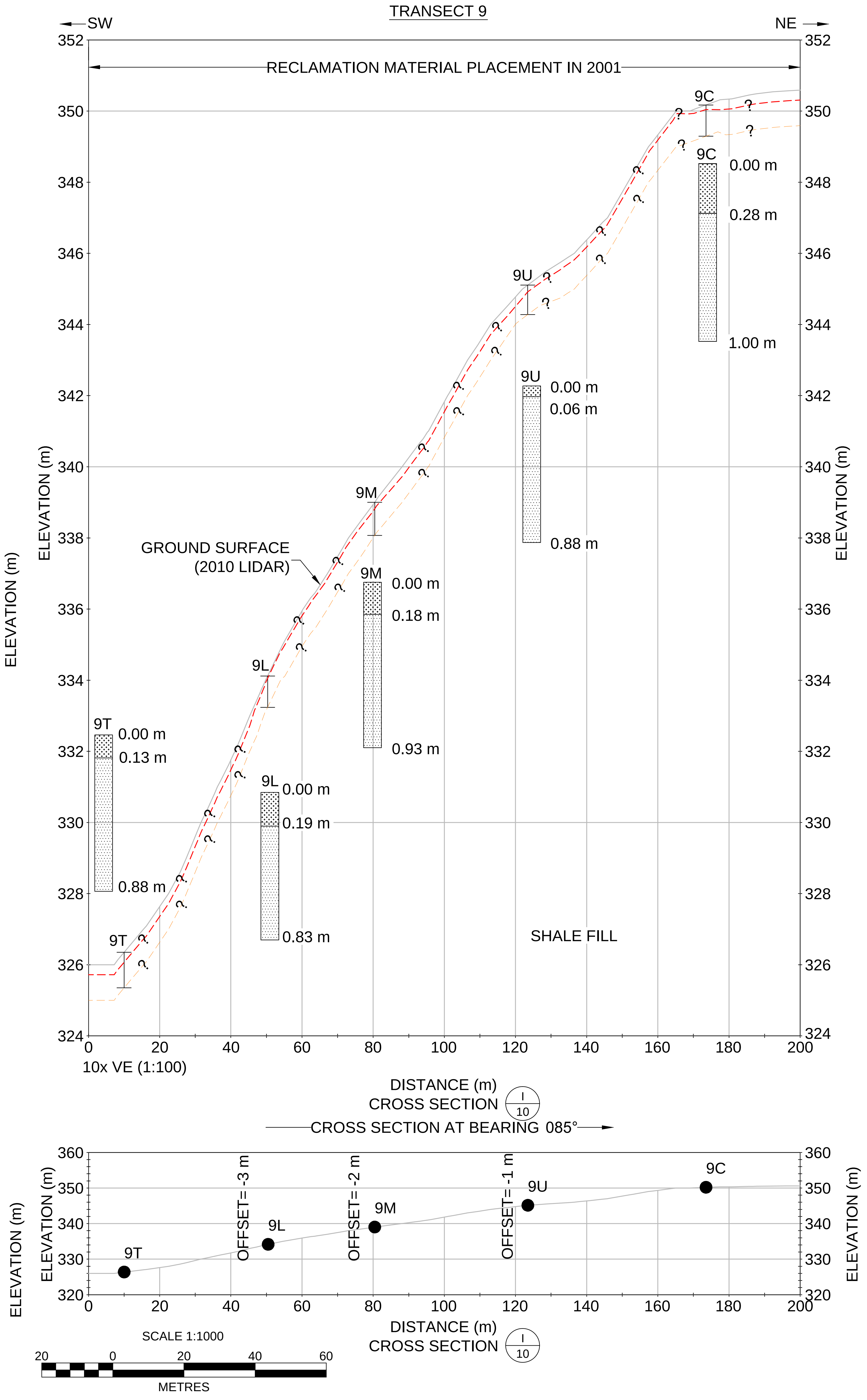
CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS
TITLE: 2012 SAMPLING TRANSECTS 4, 5, AND 6 - CROSS SECTIONS
PROJECT No.: 0534107
DWG No.: 12
REV.:

X:\Projects\0534_Syncrude\107_SouthHills\Workspace\20121015_DWG_SOUTH_BISON_HILL_RESEARCH_SYNTHESIS\12_2012_SAMPLING_TRANSECTS_4_5_AND_6_-_CROSS_SECTIONS.dwg Layout: Layout1 Plot Date Feb 26 13 Time: 3:34 PM







LEGEND

GROUND SURFACE (LIDAR 2010)	CAPPING PRESCRIPTION BOUNDARY	1T	SAMPLING LOG
INFERRED PEAT-TILL INTERFACE	● SAMPLING LOCATION		SCALE: 1:20
INFERRED TILL-SHALE INTERFACE	SAMPLING INCREMENT		NO VERTICAL EXAGGERATIONS
	▨ PEAT		
	▨ TILL		

NOTES:
1. OFFSET IS THE DISTANCE PERPENDICULAR TO THE CROSS SECTION LINE: +OFFSET IS OUT OF THE PAGE, - OFFSET IS INTO THE PAGE.
2. INTERPOLATION OF COVER LAYER SURFACES ACHIEVED BY PROJECTING THE KNOWN GROUND SURFACE TOPOGRAPHY TO THE HEIGHTS OF DIFFERENT LAYERS AND MATCHING CONSECUTIVE DATA POINTS.
3. SAMPLING LOGS ARE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY AT A SCALE OF 1:20 WITH NO VERTICAL EXAGGERATION.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	FEB 2013
DRAWN:	AH
DESIGNED:	JW
CHECKED:	ES
APPROVED:	-

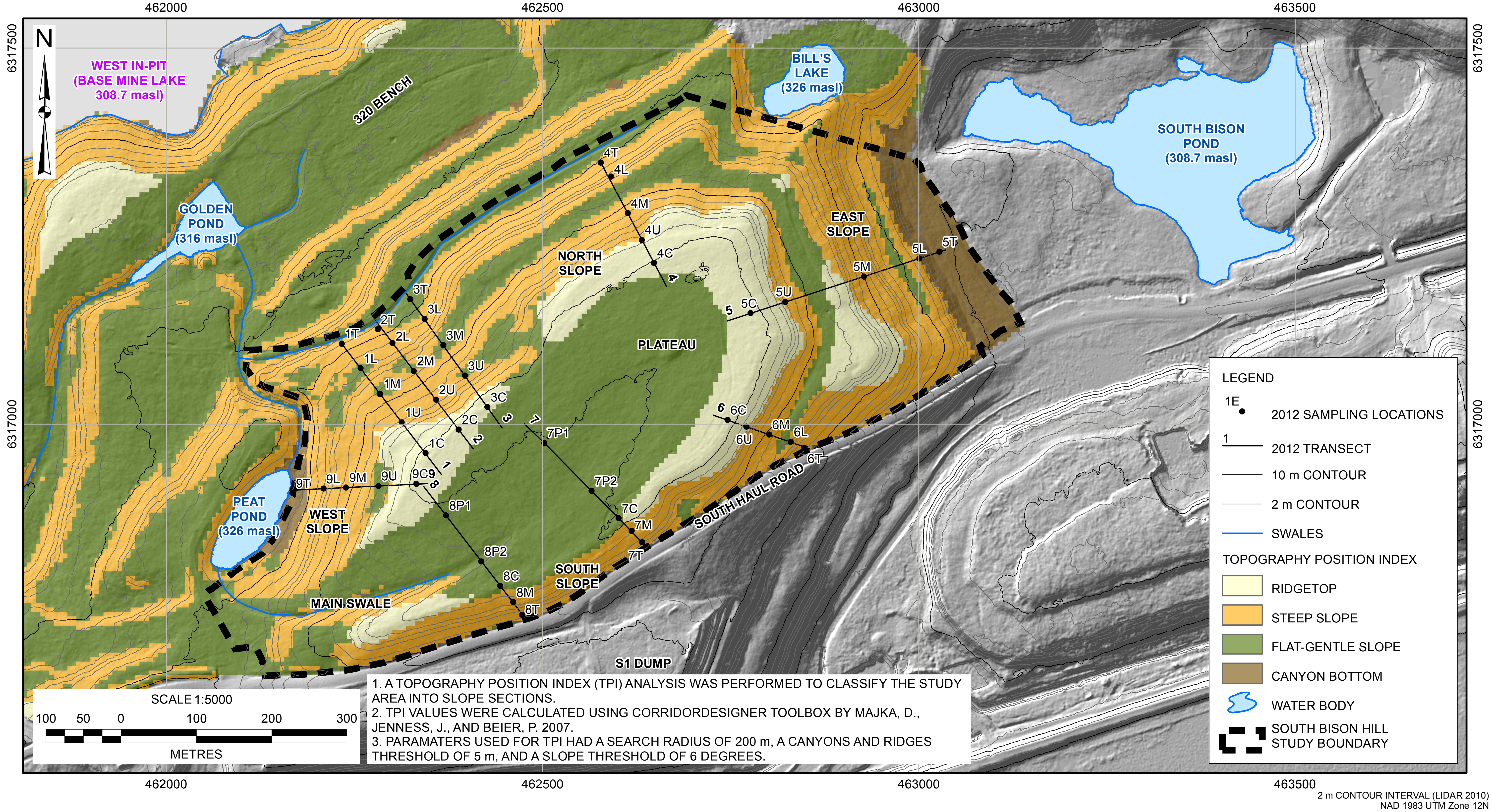
PROFESSIONAL SEAL:
DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Syncrude

PROJECT: SOUTH BISON HILL RESEARCH SYNTHESIS
TITLE: 2012 SAMPLING TRANSECTS 7, 8, AND 9 - CROSS SECTIONS

PROJECT No.:	DWG No.:	REV.:
0534107	13	



1. A TOPOGRAPHY POSITION INDEX (TPI) ANALYSIS WAS PERFORMED TO CLASSIFY THE STUDY AREA INTO SLOPE SECTIONS.
2. TPI VALUES WERE CALCULATED USING CORRIDORDESIGNER TOOLBOX BY MAJKA, D., JENNESS, J., AND BEIER, P. 2007.
3. PARAMATERS USED FOR TPI HAD A SEARCH RADIUS OF 200 m, A CANYONS AND RIDGES THRESHOLD OF 5 m, AND A SLOPE THRESHOLD OF 6 DEGREES.

X:\Projects\0534_Syncrude\107_SouthHillsWorkspace\20121220_SBH_Research_Synthesis_Map_Package\14_Topography_Position_Index_Map.mxd Date: February 26, 2013 Time: 2:45 PM

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: 1:5000
DATE: FEB 2013
DRAWN: RC
DESIGNED: ES, JM
CHECKED: ES
APPROVED: TGH

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Syncrude

PROJECT:
SOUTH BISON HILL RESEARCH SYNTHESIS

TITLE:
TOPOGRAPHY POSITION INDEX

PROJECT No.: 0534107
DWG No.: 14
REV.: