Suite 214, 9914 Morrison Street
Fort McMurray, AB T9H 4A4

(780) 799-3947 (Ph)
(780) 714-3081 (Fax)

CUMULATIVE ENVIRONMENTAL MANAGEMENT ASSOCIATION

Analyzing the Relationship between LCCS Ratings and Site Productivity

Working Group: Reclamation Working Group
Final/Approved Report Date: June 23, 2008

Contract # 2008-0015
Consultant: Timberline Natural Resource Ltd.

Suite 214, 9914 Morrison Street
Fort McMurray, AB T9H 4A4

(780) 799-3947 (Ph)
(780) 714-3081 (Fax)

CEMA Disclaimer

Contract Name: Analyzing the Relationship between LCCS Ratings and Site Productivity

Consultant Name: Timberline Natural Resource Ltd.

This report was commissioned by the Terrestrial Subgroup of the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA), in its tasks of updating the Landscape Capability Classification System (LCCS) manual. Specifically, this report was intended to re-analyze the existing relationship between site index and LCCS ratings on reclaimed and natural soils using data from CEMAs long term monitoring reclaimed and natural plots.

This report has been completed in accordance with the terms of reference issued by the RWG. The RWG has closed this project and considers this report final.

The RWG does not fully endorse all of the contents of this report, nor does the report necessarily represent the views or opinions of CEMA or the RWG Members.

The conclusions and recommendations contained within this report are those of the consultant, and have neither been accepted nor rejected by the RWG.

Until such time as RWG issues correspondence confirming acceptance, rejection, or non-consensus regarding the conclusions and recommendations contained in this report, they should be regarded as information only.

For more information please contact CEMA at 780-799-3947.

Briefing Note on

Analysis of the Relationship Between LCCS Rating and Site Index from Permanent Sampling Plots (PSP) in Natural and Reclaimed Areas in the Athabasca Oil Sands Region

Introduction

The Soils and Vegetation Sub-Group (SVSG) is responsible for the production and continued update of the *Land Capability Classification System for Forest Ecosystems in the Oil Sands* (LCCS), currently in its 3rd edition (CEMA, 2006). The LCCS system attempts to classify land based on expected limitations to productive forest use, with an assumption of an idealized generic trend of forest productivity representing 20 % difference in productivity between classes. Part of the ongoing work of the SVSG and its consultants has been to evaluate whether this "idealized generic trend" is in fact realized on both natural and reclaimed sites of different classes. This evaluation has been conducted through the establishment and monitoring of a series of permanent sample plots which include measurements of LCCS parameters and tree growth performance (height over age, or "site index"). The first full re-measurement cycle on the reclaimed component of this plot network was completed in 2007, thus providing the first full and reliable data set on LCCS ratings and tree performance on reclaimed sites. Subsequent to acquiring this data set, the SVSG, through the Forest Productivity Task Group, developed a contract to undertake an assessment of the LCCS and its ability to predict site index on natural and reclaimed lands based on data collected from the long-term soils and vegetation plots. This contract was completed by Timberline Natural Resource Group Ltd. The Timberline analysis incorporated improved site index field-sampling protocols implemented by the SVSG in 2004, new plot-based site index equations developed by Alberta Sustainable Resource Development (ASRD) and the latest LCCS (3rd edition) introduced in 2006.

The purpose of this briefing note is to update members of the SVSG on conclusions and recommendations from the above work. Additional information is provided in the briefing note accompanying the Timberline report, and in the report itself.

This briefing note includes:

- Discussion on the findings of the Timberline report;
- Conclusions; and
- Task Group Recommendations and Follow-up

Discussion

The SVSG Forest Productivity Task Group and consultants reviewed and discussed the results of the report. The group acknowledged that data interpretations are constrained by limitations in the current plot network (small sample size, young tree age and subjective plot location), but agreed that the data was sufficient to undertake the assessment and provide some insights on future directions for the group with respect to LCCS and site index. The group agreed that based on the data from the soil and vegetation long-term monitoring plots from natural and reclaimed sites that trees in the reclaimed sites are growing (i.e., height) at equivalent rates to natural sites. The group discussed the relationship between the LCCS and site index and agreed that based on the data assessed that the LCCS is not effective in predicting Site Index on reclaimed sites. Although the principal reason behind this observation is that the LCCS does not adequately represent the factors that are affecting differentiation in site indices on reclaimed sites, there are a number of potential secondary reasons for this conclusion, as follows:

1. It may be that reclaimed lands occupy a narrower ecological range (in terms of soil moisture and nutrient regimes) than the natural stands used as benchmarks, and that the LCCS is unable to reliably predict differences in site index within this narrower range, due to insufficient variation in controlling soil properties.

2. Although the LCCS attempts to predict forest site productivity, the concepts and underpinnings of this technical field were not fully understood and explored during LCCS development.

3. Site index may be an inadequate or incomplete measure for the purpose of assessing productivity of reclaimed forested lands. Site index does not account for the increases or conversions in below-ground biomass that occur during early development of reclaimed ecosystems.

The group discussed if there would be ways to improve the LCCS to be a better predictor of site index on reclaimed sites and there was agreement that although marginal improvements could likely be achieved, that these improvements would not substantially alter current conclusions, and could deflect effort from moving forward in a constructive manner. Therefore the group decided not to pursue such modifications at this time. The group agreed that the principle focus of LCCS development moving forward was to make the LCCS as good a tool as possible at predicting soil moisture and nutrient regimes and resultant edatopic position of reclaimed sites. The group agreed that the LCCS does integrate a number of fundamental soil quality properties, but that the LCCS could potentially be simplified (by reducing the numbers of parameters contained in the LCCS model) and still achieve its objective The group's recommendations on a path forward are provided below.

Conclusions

1. Evidence collected to date indicates that trees on monitored reclaimed sites are growing at rates (have site indices) equivalent to natural sites. Note that this finding is based on growth observed on juvenile, reclaimed stands. Confirmation of the longer-term validity of this conclusion will require continued monitoring.

2. Evidence collected to date indicates that the LCCS is not effective in predicting site index on reclaimed sites.

3. The Forest Productivity Task Group does not believe that pursuing an improved correlation between LCCS ratings and measured site indices by modifying the LCCS model is a useful endeavour at this time.

4. The LCCS includes assessment and rating of soil and landscape parameters that are known to be fundamental to ecosystem productivity; however, it is possible that the number of variables the LCCS measures could be simplified and focused on measures such as soil nutrient and moisture regimes, which would allow for prediction of edatopic grid prediction. The LCCS can be used as a tool for soil audits.

5. The focus of the SVSG should be expanding the plot network and selecting additional indicators that can better assess equivalent capability on reclaimed landscapes.

Task Group Recommendations and Follow-up

1. The task group will make a recommendation to SVSG that the SVSG issue a statement that indicates the following:

    a. Data collected to date indicate that trees on reclaimed sites are achieving height growth rates equivalent to those measured in natural stands.

    b. A comprehensive analysis of data collected to date indicates that the LCCS does not have value for predicting tree growth performance (site index) on reclaimed sites, and that the LCCS should no longer be viewed as a predictive tool for tree height growth performance. The LCCS should be "de-coupled" from its stated task of predicting forest productivity classes.

    c. Despite this limitation, the LCCS still serves a vital function in ensuring the quality of salvaged soil materials and other growth media, and the appropriate replacement in the reclamation context. The utility of the LCCS to serve this function should be maintained, and improved if possible.

    d. The SVSG does not sanction extrapolation of interpretations in this note and associated reports beyond our explicit statements and conclusions. The implications of these statements and conclusions require further development. For instance, it would not be valid to suggest that all reclamation practices can now be shifted to the minimum treatments required by approvals, and still result in restoration of productive forest ecosystems. There are a number of reasons why variation in soil depths, layering and materials may be important to ultimate reclamation objectives, but these reasons are not fully understood or explored at this time – see item "c" above.

2. The focus of the LCCS should be shifted to making it the best tool possible for estimating and predicting soil moisture and nutrient regimes, and thus resultant edatopic positions of reclaimed sites. This will assist the LCCS in tying in directly to the Revegetation Manual.

3. In the next revision cycle of the LCCS (4^{th} ed., to be produced approx. 2011), the current LCCS system should be explored to evaluate whether the system could be simplified (e.g., by removing variables) and still achieve, or be improved in, its objective of estimating soil moisture and nutrient regimes.

4. The SVSG or Forest Productivity Task Group of the SVSG should continue in its task of developing approaches to evaluate achievement of equivalent capability and forest productivity on reclaimed sites. This approach is likely to incorporate a more holistic definition of forest productivity than single measures such as site index, as follows:

    Long-term ecosystem productivity is the capacity of the site to support forest ecosystems over generations of humans and trees, as measured against some defined reference.

    Assessing restoration of ecosystem productivity on reclaimed sites may include evaluation of a wider suite of productivity indicators (e.g., assessing/modelling carbon assimilation, net primary productivity, below-ground biomass production, etc.).

5. The SVSG should continue its monitoring program, including monitoring of parameters relevant to equivalent capability and forest productivity, on its plot network. This monitoring program should be expanded in intensity in the short term (e.g. establish more plots per unit area reclaimed), to provide more information on reclamation performance. In addition, the monitoring program should be adjusted to incorporate indicators of ecosystem function, as included in the revised (2^{nd} ed,) Revegetation Manual.

6. The SVSG or Forest Productivity Task Group of the SVSG should evaluate the ability of forest ecosystem modelling tools to provide useful prediction of long-term forest productivity on reclaimed sites, as a potential replacement for similar predictions originally intended by the LCCS. A program to do so will be developed as part of the task of evaluating achievement of forest productivity on reclaimed sites, as discussed in item #4, above.

7. Monitoring over time of site index of reclaimed forest stands should be continued as one measure, but not the sole measure, of reclamation performance. The task group will review the sampling protocols for evaluating site index on reclaimed sites. This review will include evaluation of additional recommendations provided by Timberline for implementation in the monitoring network.

8. The implications of the conclusions reported above for the use of the LCCS as an “accounting” tool for post-closure equivalent capability need to be fully explored. This exploration could be initiated as a discussion at the SVSG between regulators, oil sands operators, and other stakeholders.

Analyzing the Relationship Between LCCS Ratings and Site Productivity

Date: June 23, 2008

Submitted to:

Cumulative Environmental Management Association
Reclamation Working Group (RWG)
Soil/Vegetation Subgroup (SVSG)
Suite 214, Morrison Center
9914 Morrison Street
Fort McMurray, Alberta
T9H 4A4

Phone: (780) 799-3947
Fax: (780) 714-3081

Submitted by:

Timberline Natural Resource Group Ltd.
Suite 401 958 West 8th Avenue
Vancouver, BC
V5Z 1E5

Phone: (604) 733-0731
Fax: (604) 733-0634

CEMA Contract No : 2008-0015
TNRG Project No : BC0108252

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 INTRODUCTION

1.1 Terms of Reference

This report was completed by Timberline Natural Resource Group Ltd. (TNRG) for the Soil and Vegetation Subgroup (SVSG) of the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA) in Fort McMurray, Alberta. This report describes the work and results related to deliverable No. 2 listed in the CEMA Contract No. 2008-0015.

This report was prepared by Gyula Gulyas, *MSc* (TNRG). Marty Yarmuch, *MSc*, P.Ag. of Northwind Land Resources Inc. (NWLR) carried out the Land Capability Classification and soil analysis (Appendix I). Rob Vassov *RPF* of Syncrude and Jim Thrower, *PhD*, *RPF* (BC) acted as project technical advisors. The CEMA scientific contact was Veronica Chisholm and the CEMA project manager was Justin Straker, P.Ag. (Chair of the SVSG).

1.2 Background

The reclamation of lands disturbed by mining oil sands in northeastern Alberta is of concern to all stakeholders including Government, the oil and gas industry, the forest industry, First Nations, the public, and environmental non-governmental organizations (ENGOs). The Alberta Government states that operators in the oil sands must use effective conservation and reclamation measures to ensure that disturbed land is reclaimed to meet the goal of equivalent land capability. The intent is that although disturbed and subsequently reclaimed land may not be used for exactly the same purpose, it is capable of the same productivity as prior to disturbance.

The SVSG is developing a process to assess the equivalent capability of reclaimed lands as measured by tree height growth. The core of the process is the Land Capability Classification System (LCCS)[1] and its relationship to site index (as the measure of tree height growth). The idea is to calculate an LCCS rating from soil properties on reclaimed land and predict the site index for that LCCS rating. The reclaimed land is then considered to have equivalent capability if the predicted site index is the same or higher than the average site index expected from the same LCCS rating on undisturbed (natural) land.

There have been numerous analyses of the site productivity and soil data in the recent past by AMEC Earth & Environmental and Paragon Soil and Environmental Consulting Inc. (reports from 2001-2005)[2], Steve Titus (2004)[3] and J.S. Thrower & Associates Ltd. (JST 2004 and 2005)[4,5].

---

[1] Cumulative Environmental Management Association, Reclamation Working Group. 2006. Land capability classification for forest ecosystems in the oil sands. Volume 1: Field manual for land capability determination. Third Edition. 22 pp.

[2] The most recent report describing the work completed to the end of 2004 is: Results from long term soil and vegetation plots established in the oil sands region. Contract report to the Oils Sands Soil and Vegetation Working Group by AMEC Earth & Environmental (Calgary, AB) and Paragon Soil and Environmental Consulting Ltd. (Edmonton, AB). March 2005. 69 pp. +app.

[3] Titus, S.J. 2004. Review of forest productivity estimation in the LCCS calibration study. Contract report to CEMA. Nov. 15, 2004. 6 pp.

[4] J.S. Thrower and Associates Ltd. 2004. A review of site index estimation methods used in land capability calibration sites in the Athabasca oil sands. Contract report to CEMA. Nov. 15, 2004. 8 pp. JST project OTM-046.

The major concerns according to the latest reports are (1) the subjective location of the sample plots which limits the use of statistical methods to help interpret the data; (2) inconsistent site tree selection in the field; and (3) issues related to how site index was calculated and used in the analyses (JST, 2005).

There have been several key developments with regards to site productivity and LCCS since 2005:

- All site productivity data and measurements to 2004 were updated to generally accepted scientific standards. All site index compilations followed a documented and repeatable process.
- New site tree selection and measurement protocols were introduced in 2004 that had been consistently applied to all re-measurements in reclaimed areas. Most PSPs have a re-measurement based on these new protocols. All tree ages were subjected to lab analysis in addition to field counts.
- Most PSPs in reclaimed areas now have older and taller trees providing a more stable site index estimate based on the latest re-measurement.
- New site index equations were created by the Alberta Sustainable Resource and Development (ASRD) in 2006 as part of the development of the GYPSY model (Huang, 2006. Growth and Yield Projection System).
- The Land Capability Classification System was revised in 2006. The new LCCS protocols are considered to be an improvement over the previous scoring system and may show a better relationship to site index.

One of the main objectives of the SVSG in relation to its long term soil and vegetation plot network is to demonstrate the relationship between LCCS and site productivity in natural stands and on reclaimed sites (performance monitoring)[6]. Therefore, the Site Productivity Task Group of the SVSG requested that TNRG re-analyze the potential relationship between site index and LCCS ratings on reclaimed and natural soils based on these latest developments.

1.3 Project Objectives

The overall goal of this project was to re-analyze the existing relationship between site index and LCCS ratings on reclaimed and natural soils using data from CEMA's long term monitoring reclaimed and natural plots.

The specific objectives of this project were to:

1. Recalculate the site index using various site tree selection methods and the latest site index equations used by GYPSY for all available long-term soil and vegetation plots.

[5] J.S. Thrower and Associates Ltd. 2005. Analysis of Site Index Data from PSPs and TSPs in Natural and Reclaimed Areas in the Athabasca Oil Sands Region. Contract report to CEMA. Nov. 2, 2005. 18 pp. JST project CEM-002.
[6] Justin Straker 2007. Notes on SVSG Monitoring Discussion, June 5, 2007.

2. Assign the LCCS ratings based on the 1998[7] and 2006 protocols to all plots with available soil data.

3. Carry out a graphical and statistical analysis of the relationship between site productivity (as measured by site index) and LCCS final land rating.

4. Analyze the relationship between site productivity and all individual soil and landscape components used to calculate the LCCS score.

5. Present the results of this project to CEMA in Fort McMurray in June 2008.

Due to subjective location of the sample plots, statistical inferences to help interpret the data cannot be made without assuming that it has no impact on the underlying sample distribution. This is especially true due to the relatively small number of plots and the observed large variability of site index in young stands. Statistical summaries will include correlation statistics and basic regression analysis with much larger emphasis being placed on the graphical representation of the data.

[7] Leonard A. Leskiw (CAN-AG Enterprises Ltd.) 1998. Land capability classification for forest ecosystems in the oil sands region (Revised Edition). Prepared for the Tailings Sand Reclamation Practices Working Group. 94 pp.

2.0 METHODS

2.1 Data Sources

The data to examine and develop the relationship between LCCS rating and site productivity are being collected from permanent sample plots (PSPs) installed across a range of conditions. This network of PSPs currently includes 50 sample locations in older forest stands growing on undisturbed areas (natural sites), and 53 locations in planted stands growing in reclaimed areas. Detailed soil and vegetation measurements are taken when these plots are established, with the intent to repeat the measurements every five years for reclaimed sites and every 10 years on natural sites. Site index is estimated in plots when trees are old enough (generally greater than 10 years of age) and is related to the LCCS rating for those plots.

We obtained the data for our analysis in several different formats from Harry Ullrich (TNRG's Field Operations Manager, Hinton Office) and from the JST project archives of CEM-002 and CEM-005. The data were not in a consistent format, thus we constructed an Excel spreadsheet and a Microsoft Access 2003 database specifically for this analysis. The combined PSP data included 103 plots of which 28 could not be used, leaving 75 plots for the analysis[8] (Table 1).

Table 1. Number of plots removed from analysis.

Stand type	Original number of plots	Plots removed from the analysis				Plots available for analysis
		Trees are too small	No site trees selected to new standards	Plot was destroyed	Suspect data	
Natural	50	3				47
Reclaimed	53	10	8	3	4	28
Total	*103*	*13*	*8*	*3*	*4*	*75*

We limited the analysis to jack pine (Pj), lodgepole pine (Pl), white spruce (Sw) and aspen (Aw) as there were not enough observations for the other tree species (Table 2). Some plots had multiple tree species selected as site trees, thus there were 62 available site index measurements in 47 natural PSPs and 45 measurements in 28 reclaimed PSPs.

Table 2. Number of plots by tree species and stand type.

Stand type	Tree Species					Total
	Aw	Pj	Pl*	Sw	Other**	
Natural	16	16		19	11	62
Reclaimed	11	8	5	17	4	45
Total	*27*	*24*	*5*	*36*	*15*	*107*

* the latest PSP re-measurements identify the pine site trees as Pl, rather than Pj.
** other species included balsam fir (Fb), balsam poplar (Pb) and white birch (Bw).

[8] The most significant group of plots removed from the analysis was because the trees were either too small (13 plots) or the new field measurement protocols have not yet been implemented (8 plots).

2.2 LCCS Rating

The soil data for each PSP were given in a Microsoft Excel 2000 workbook (Soil Data for S-V Plots 1-103 and repeat 2000-2007.xls). Marty Yarmuch of NWLR carried out the analysis of the soil data using the LCCS 1998 and 2006 systems. All partial and final LCCS ratings were provided to us by plot for the analysis. A brief description and the results of the Soil Analysis can be found in Appendix I. The list of LCCS variables used in our analysis is shown in Table 3. The description of Land Capability Classes is presented in Appendix II.

Table 3. List of LCCS Variables.

LCCS Variable	Description
AWHC	Available water holding capacity (mm)
ADJAWHC	Adjusted AWHC (mm)
SMR	Soil moisture regime index
TOC	Total organic carbon content
TON	Total nitrogen content
CN	C:N ratio
NUTRET	Nutrient retention factor
CUMSNR	Soil nutrient regime cumulative rating
SNR	Soil nutrient regime index
BASE	Soil base rating
TSDED	Top soil deduction
ISR	Interim soil rating
USDED	Upper subsoil deduction
LSDED	Lower subsoil deduction
TOTDED	Total limiting factor deduction
FLR	Final land rating
LCC	Land Capability Class

2.3 Site Index

We estimated a new site index for all natural and reclaimed plots where sufficient data were available. Site index is the height at 50 years breast height age (BH age) that is generally derived from top height[9] (computed as the average height of the largest 100 trees/ha) and BH age. We established the following guiding principles for our analysis:

1. ***Use a consistent approach to estimating site index.***

   Previous analyses mixed a number of site index estimation methods. These included the relaxation of criteria around site tree selection, the use of growth intercept equations and height-age equations simultaneously, the use of total plot age and tree BH age, and even the averaging of site index across species[10] in order to obtain a reasonable number of observations for analysis. Growth intercept measurements and age estimation based on whorl counts were found to be highly suspect in many plots. The latest analysis by JST (2005) concluded that the use of different methods to estimate site index increases the uncertainty in the results.

2. ***Take advantage of the consistent and scientifically-sound field sampling procedures introduced in 2004.***

   The first re-measurement of many reclaimed plots has been done according to new site tree selection protocols that were introduced in 2004. Prior to 2004, site tree selection methods and field sampling protocols changed almost on a yearly basis[11]. There was no consistent approach and therefore the differences found in site index estimates were close to impossible to reconcile.

---

[9] Top height, defined as the average height of the 100 largest diameter trees/ha, is commonly used throughout the world as the height used to estimate site index. Tree size is generally diameter at breast height for larger trees and height for small trees (e.g., less than 6-8 m in height).

[10] Leonard Leskiw 2004. Response to Critiques of LCCS. File Note of December 2004. 4 pp.

[11] AMEC 2005. AMEC's Response to Comments from Consultants re: Soil-Veg and Capability Plot Data. File Note. 6 pp.

The new site index measurement protocols are described in detail in the latest field manual[12] and only some important points are listed here:

- The 400 m^2 plot is split into four 100 m^2 quadrants (10mX10m) for site tree selection inside the plot.

- The three tallest trees by species are selected in each quadrant in the plot. This change allows for assessing the impact of site tree selection on the estimation of site index. In some situations, there could be less than three site trees for a species in the quadrant due to the limited number of suitable site trees.

- The suitable site tree is healthy, free growing, dominant or co-dominant, free of broken or damaged top or any other damage that may have affected height growth. The site trees must also have at least three years' growth above breast height.

- Site trees are identified in the tree data but not permanently marked in the field, as site tree selection is re-assessed at each measurement. This is a very important change as it addresses one of the main concerns related to site index estimation using stem-analysis based equations as described by Magnussen and Penner (1996)[13]. The issue is that site trees selected in mature stands to develop site index equations may not have been dominant/co-dominant site trees at the early stages of stand development and therefore the application of curves derived from these trees may result in significant over-estimation of site index in young regenerated stands. The issue of site tree replacement over time is now being addressed in the modeling as well as in the field sampling protocols.

- Increment cores are taken from the site trees at breast height. The rings are counted in the lab under a microscope. Counting whorls in the field may result in a couple of years of over or underestimation of age. Even a few years of error in age could result in meters of difference in site index in young stands due to being on the 'steep' part of the site index curve.

These protocols have been consistently used for all re-measurements and newly established plots since 2004.

3. ***Assemble a detailed analysis database for future use.***

We took a very detailed look at the latest plot re-measurements to ensure that we deal with the cleanest data possible. This meant the assembly of analysis spreadsheets that collate all information relevant to site index calculation separately for each plot. All site trees were reviewed and compared to the vegetation database records. Most errors were corrected after discussions with field staff (Harry Ullrich, TNRG - Hinton). A few plots that had suspect data were documented and dropped from further analysis. We produced a Microsoft Access database with the site index data for all cleaned and compiled plots and a Microsoft Excel workbook application that brings together all relevant site index and LCCS information under one coherent analysis framework.

[12] Soil and Vegetation Working Group 2007. Installation and Re-measurement of Permanent Sample Plots on Reclaimed Sites: Procedures and Standards for Tree Measurements. Fort McMurray. Alberta. 29 pp.
[13] Magnussen, S. and Penner, M. 1996. Recovering time trends in dominant height from stem analysis. Canadian Journal of Forest Research 26: 9-22.

Following the above guiding principles we decided to examine the three main components of site index estimation in order to assess the sensitivity of those estimates[14].

2.3.1 Site Tree Selection

Site index is based on top height that is the average height of the 100 largest trees per hectare. This means the selection of four site trees in a 400 m^2 plot. Given the plot layout and configuration, this could be done by selecting (A) the tallest site tree in each 100 m^2 quadrant or (B) the four tallest site trees in the plot. Generally speaking, the four tallest site trees in the plot will result in a slightly higher site index (assuming that all trees are planted and are roughly the same age) as the tallest trees in the entire plot are selected[15]. Selecting the tallest trees in each quadrant will yield lower site index estimates, but it may provide a better distribution of site trees in the plot. Alberta's site tree selection method follows the selection of the four tallest site trees in the plot (Shongming Huang ASRD, pers. comm.).

2.3.2 Site Index Equation

Site index can be calculated using several different site index equations (height-age curves). Most of the recent curves developed and applied in Alberta are either derived from stem analysis data (representing individual tree height growth)[16,17] or from PSP-based top height trajectories (representing stand height growth)[18]. The latter approach will generally yield lower estimates and mathematically the equation form may decline in stand height over time allowing for the modeling of stand breakup (individual tree height growth modeling will always result in non-declining, asymptotical functions). The lower site index estimates are partially due to the fact that the plot based top height trajectories may include different sets of site trees over time in the calculations. The re-selection of site trees at each plot measurement is also trying to mitigate the site tree replacement concerns discussed by Magnussen and Penner (1996). We will refer to the stem-analysis based equations as Huang 1997 and the plot based newer equations as Huang 2006 in this document.

2.3.3 Site Index Averaging

Once the site trees and the height-age curve are selected, one can derive an average site index for a species in the plot using two different approaches:

- *Average the input*: This means that the height and BH age of the four selected site trees are averaged first and the average height and BH age are used in the site index equation to arrive at a site index estimate for the plot.

- *Average the output*: The site index for each of the four site trees is calculated using their individual height and age observation. The four site index values are then averaged to arrive at the average site index for the plot.

---

[14] This was done on the reclaimed plots only where the new field sampling protocols allowed such analysis.
[15] For example, all four selected site trees could come from one or two quadrants, 'clumped' in one corner of the plot.
[16] Huang, S., Titus. S. J., and Klappstein, G. 1997. Subregion-based compatible height and site index models for young and mature stands in Alberta: revisions and summaries (Part I). For. Mgmt. Res. Note. Alberta Env. Prot. No. 9. Aug. 1997. Publ. T/389.
[17] Huang, S. 1997. Subregion-based compatible height and site index models for young and mature stands in Alberta: revisions and summaries (Part II). For. Mgmt. Res. Note. Alberta Env. Prot. No. 10. Aug. 1997. Publ. T/390.
[18] Huang, S. 2006. Growth and Yield Projection System (GYPSY) for Natural and Regenerated Pure and Mixed Species Stands. (Parts 1 & 2). Discussion draft for Director's meeting. Unpublished Report.

Although the two methods appear to be quite different, in most situations, they will yield very similar site index estimates for the plot.

2.4 Analysis

We built on the basic analysis that was carried out by JST in 2005 with some additional analyses that were possible with the improved data set.

Firstly, we analyzed the sensitivity of site index estimates based on the different site tree selection methods, equation types and site index averaging methods.

Secondly, we fit separate linear regressions to the site index and LCCS rating for the tree species where we had sufficient data (Pj/Pl, Sw, and Aw). This was done using R (version 2.6) to minimize the sum of the squared site index residuals. We also computed a 95% confidence interval of the estimate and provided descriptive statistics of the data to help portray the reliability of the different relationships between site index and the LCCS ratings. We calculated the Pearson correlation between site index and LCCS rating. Separate regression analysis was carried out for the final land rating and most major components of the LCCS. These analyses were done based on both the LCCS 1998 and the 2006 systems wherever the information was available.

There are several assumptions that must be considered when interpreting the results from these regressions including:

1. The subjective plot location has not biased the relationship between site index and LCCS rating.
2. There are sufficient numbers of observations in the analysis to reveal the true underlying trends.
3. Errors in measuring tree heights and ages had not biased the relationship.
4. The LCCS is measured without error.

Thirdly, we examined the Pearson correlation amongst the LCCS components and site index and also prepared graphical and statistical summaries of site index and LCCS measures in reclaimed site by reclamation prescription and by ecosite on natural sites.

3.0 RESULTS & DISCUSSION

3.1 Sensitivity Analysis

3.1.1 Site Tree Selection

We plotted the site index estimates based on the two site tree selection methods as shown in Figure 1. The X axis represents the site index based on the four tallest site trees in the plot and the Y axis shows the average site index based on the tallest tree in each of the four quadrants[19]. The graphical analysis was done for both the Huang 1997 and Huang 2006 site index equations. The red line represents the perfect correlation between the two methods.

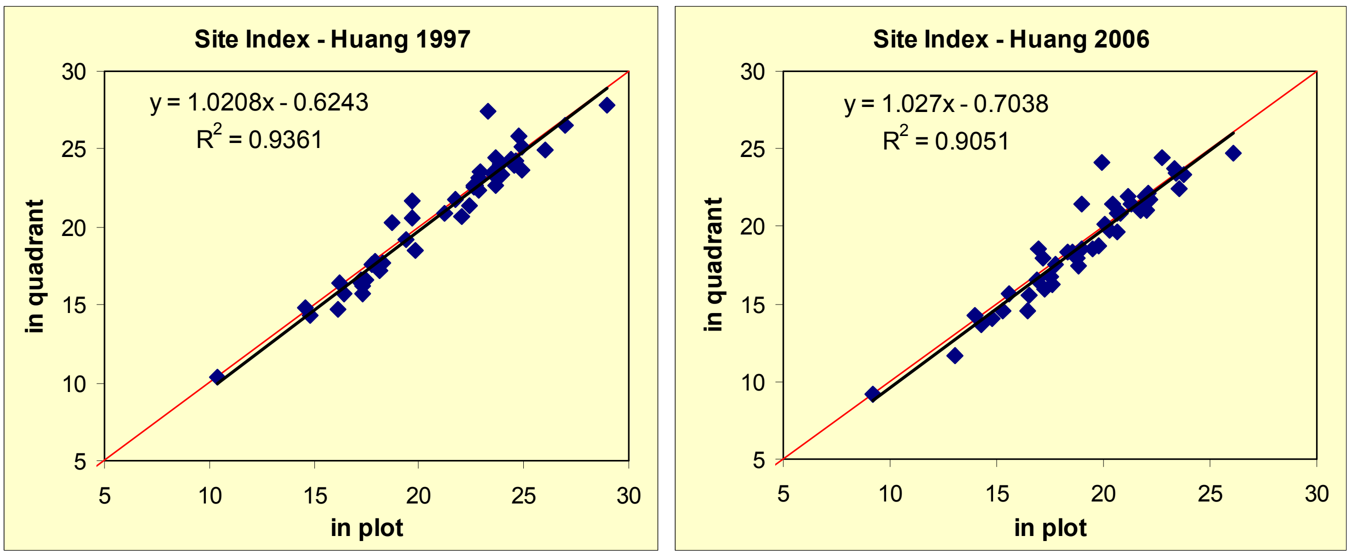


Figure 1. The effect of site tree selection method on site index estimates.

Both regressions are highly significant[20] at 95% confidence (p=0.000 for both methods) where the slope is close to one and the intercept is not significantly different from zero. The majority of the points are slightly below the red line indicating that the four tallest trees selected in the plot will generally yield a higher site index estimate, however the age differences of the selected site trees could result in higher site index estimates for the 'in quadrant' selection in certain situations. We examined the effect by species but could not find any obvious trend in the data. The site index equation does not appear to influence the relationship between the two site tree selection methods.

3.1.2 Site Index Equation

We plotted the site index estimates based on the two site index equations as presented in Figure 2. The X axis represents the site index calculated from Huang 2006 (plot top height trajectory) and the Y axis shows the average site index based on Huang 1997 (stem-analysis based). The graphical analysis

[19] We used the 'average the output' site index calculation method for this analysis.
[20] Unless otherwise noted, all references to statistical significance in this document are at the 95% level of confidence.

was done for both the in-plot and in-quadrant site tree selection methods. The red line represents the perfect correlation between the two equations.

Both regressions are highly significant (p=0.000 for both equations) where the slope is close to one and the intercept is not significantly different from zero. The majority of the points are above the red line indicating that the stem analysis based equations (Huang 1997) will yield a higher site index estimate than the plot top height trajectory based equations (Huang 2006). We examined the effect by species but could not find any trend in the data. The site tree selection method does not seem to affect the relationship between the two site index equations. The Huang 1997 equation yields higher site index estimates. However, its relationship to LCCS might not differ from Huang 2006 as it appears that the two equations have a highly significant linear correlation with very similar slopes (i.e., the regression lines are parallel to each other).

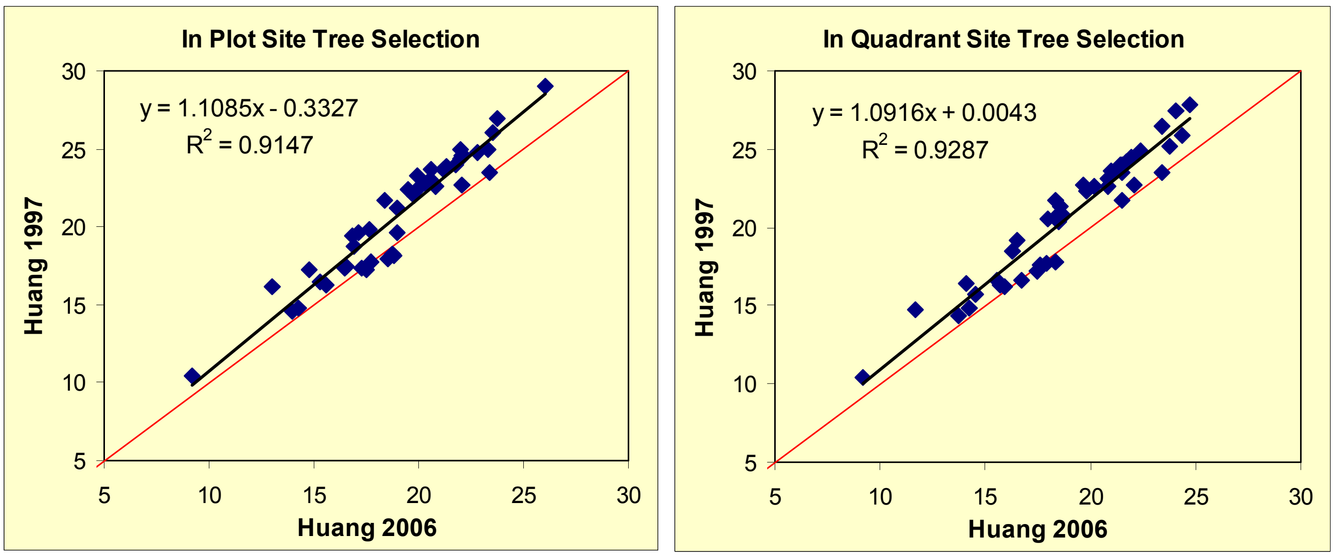


Figure 2. The effect of site index equation on site index estimates.

3.1.3 Site Index Averaging

We plotted the site index estimates based on the two averaging methods as presented in Figure 3. The X axis represents the site index calculated from averaging the input variables (height and BH age) and the Y axis shows the site index based on averaging the output (site index)[21]. The graphical analysis was done for both the in-plot and in-quadrant site tree selection methods. The red line represents the perfect correlation between the two averaging methods.

Both regressions are highly significant (p=0.000 for both methods) where the slope is very close to one and the intercept is not significantly different from zero. We can safely conclude based on the observed results that the averaging method is not a significant factor in the estimation of site index.

[21] We used the Huang 2006 equation in this analysis, but the other site index equation yields similar results.

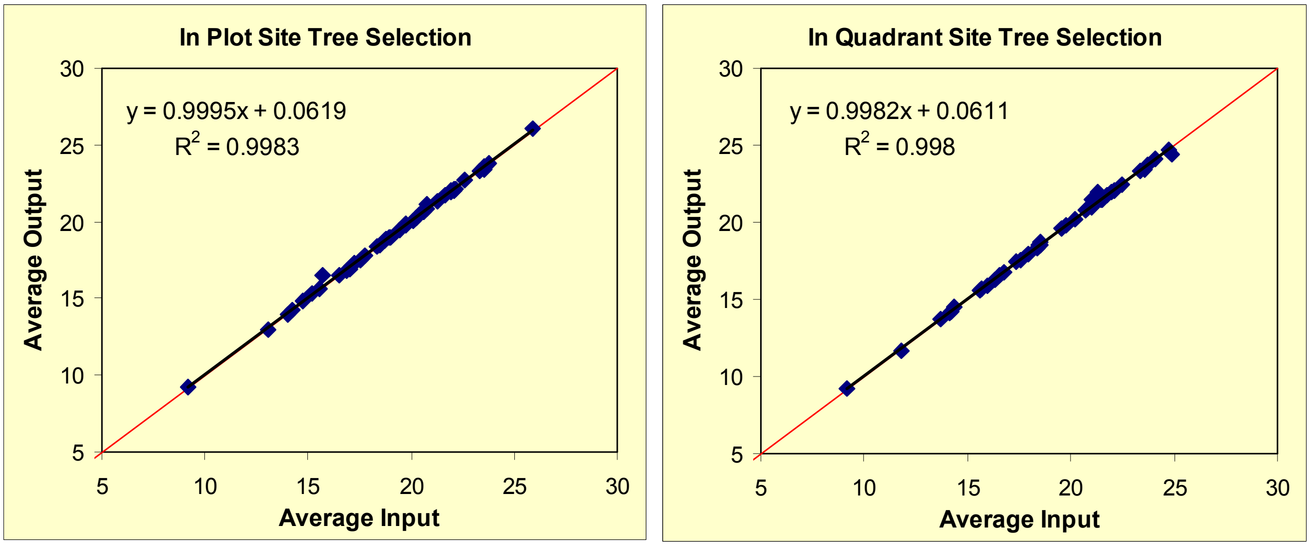


Figure 3. The effect of site index averaging on site index estimates.

3.2 Regression Analysis

As per the results of the sensitivity analysis, we decided to base our analysis on the average output site index calculation method[22], use the in plot site tree selection as it is closer to the current standards used in Alberta and use the latest plot based site index equations by Huang (2006). We also conducted all the other analyses of various site index estimation methods and the analysis results were put into an interactive spreadsheet application for future reference. Most of the results presented in here are related to the LCCS 2006 system as that was the major focus of this work. However, results related to the LCCS 1998 analysis are also available in the interactive Excel spreadsheet application. The regression analysis results for the Final Land Rating (FLR) and Land Capability Class are discussed by species in the following sections. The results of the regression analyses of the other LCCS components are presented in Appendix III.

3.2.1 Jack Pine & Lodgepole Pine

These two species are difficult to differentiate in the field at a very young age and the plot re-measurements often ‘switched’ the code from one to the other as the trees were getting older. Since the site index equations are similar for these two species, we analyzed them together. However, we also made the option of separating them in our interactive Excel tool.

3.2.1.1 Natural Areas

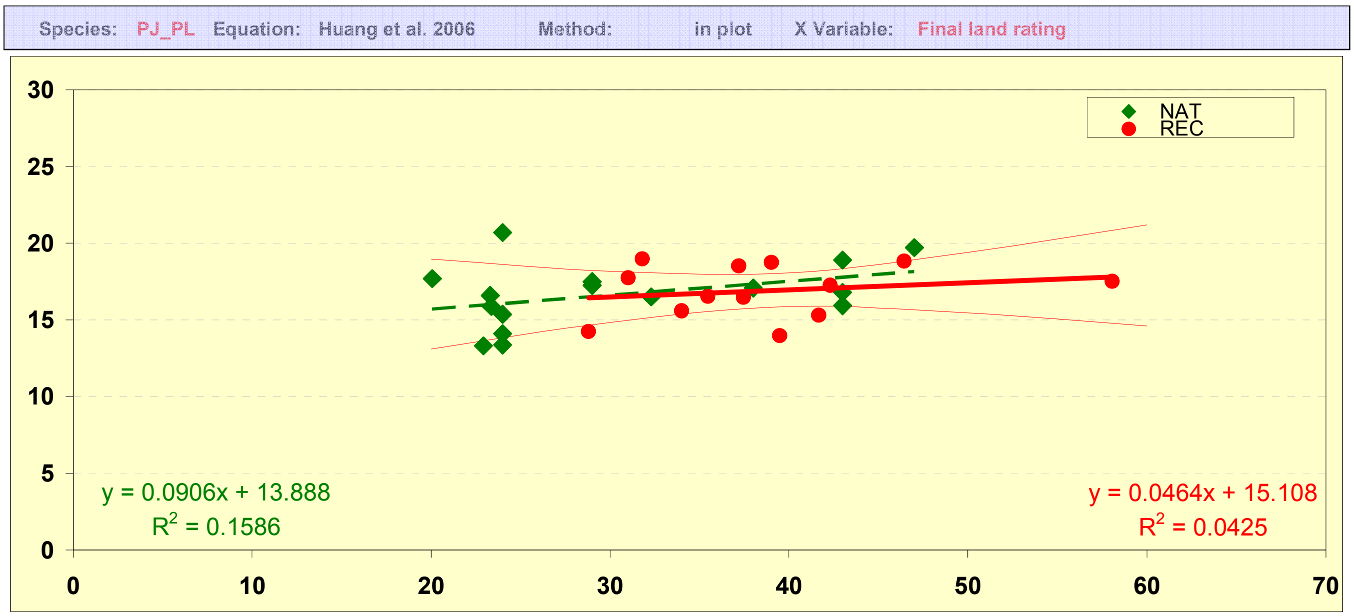
The 16 site index observations for natural plots where Pj or Pl site trees were present show a positive but weak relationship with the LCCS Final Land Rating (FLR) (Figure 4 and Figure 5). The linear regression has a slope of 0.091, which is not statistically significant (p=0.127).

[22] There was virtually no difference between the two averaging methods. The natural plots were originally calculated based on this averaging method so we decided to use it for consistency. The new site index estimates for natural plots were re-calculated based on the Huang 1997 and Huang 2006 plot based site index equations.

The pine plots span a range of LCCS classes 3 and 4 (ratings 20-60). The LCCS class average pine site index is 16.3 m for class 4 and 17.8 m for class 3. These plots are subjectively located thus there is limited interpretation that can be drawn from this range. Natural plots were selected in ecosites that were also targeted in the reclamation plans therefore it was expected that the reclaimed plots will also display a similar range.

3.2.1.2 Reclaimed Areas

The results show no significant relationship between pine site index and the FLR (Figure 4 and Figure 5) for the 13 site index observations. The indicated slope of 0.046 is not statistically different from zero (p=0.500).



Statistics for Final land rating and Site index: Land Capability Classification System: LCCS 2006

Site Type	Site index (Y)					Final land rating (X)					Correlation
	Avg	StDev	N	CV%	S.E.	Avg	StDev	N	CV%	S.E.	
Natural	16.7	2.1	16	12%	0.52	30.6	9.1	16	30%	2.28	0.40
Reclaimed	16.9	1.7	13	10%	0.48	38.7	7.6	13	20%	2.12	0.21

Figure 4. Graphical comparison of site index and Final Land Rating for Pj and Pl plots.

3.2.1.3 Differences

Comparison of the pine relationships shows no statistical or practical difference between site index expected on natural or reclaimed areas for a given FLR (Figure 4 and Figure 5). This could indicate that there is no real difference, or that the LCCS system does not reflect the factors that are related to or that influence the height growth of pine trees in these areas. The two thin red lines around the regression line represent the 95% confidence interval of the reclaimed plots.

Species:	PJ_PL	Equation:	Huang et al. 2006	Method:	in plot	X Variable:	FLR

NATURAL SITES

Regression Statistics	
Pearson correlation	0.398
R Square	0.159
Standard Error	1.968
Observations	16
Degrees of Freedom	14
F value	2.6385
Significance of F	0.1266

	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	13.8883	1.778	7.810	0.0000	***
Slope, X	0.0906	0.056	1.624	0.1266	

RECLAIMED SITES

Regression Statistics	
Pearson correlation	0.206
R Square	0.042
Standard Error	1.757
Observations	13
Degrees of Freedom	11
F value	0.4877
Significance of F	0.4995

	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	15.1080	2.616	5.775	0.0001	***
Slope, X	0.0464	0.066	0.698	0.4995	

*** significant at alpha=0.05

Figure 5. Linear regression analysis of site index and Final Land Rating for Pj and Pl plots.

3.2.2 White Spruce

3.2.2.1 Natural Areas

Results for the 19 observations for natural Sw show a much stronger positive relationship between site index and FLR (Figure 6 and Figure 7) than shown for the natural pine plots. The regression shows a slope of 0.092, which is statistically significant (p=0.005).

The Sw plots span a range of LCCS classes 1, 2, 3 and 4 (ratings 20-100). The LCCS class average Sw site index is 15.7 m for class 4, 18.6 m for class 3, 18.2 m for class 2 and 22.1 m for class 1. These plots are subjectively located thus there is limited interpretation that can be drawn from this range. Natural plots were selected in ecosites that were also targeted in the reclamation plans therefore it was expected that the reclaimed plots will also display a similar range.

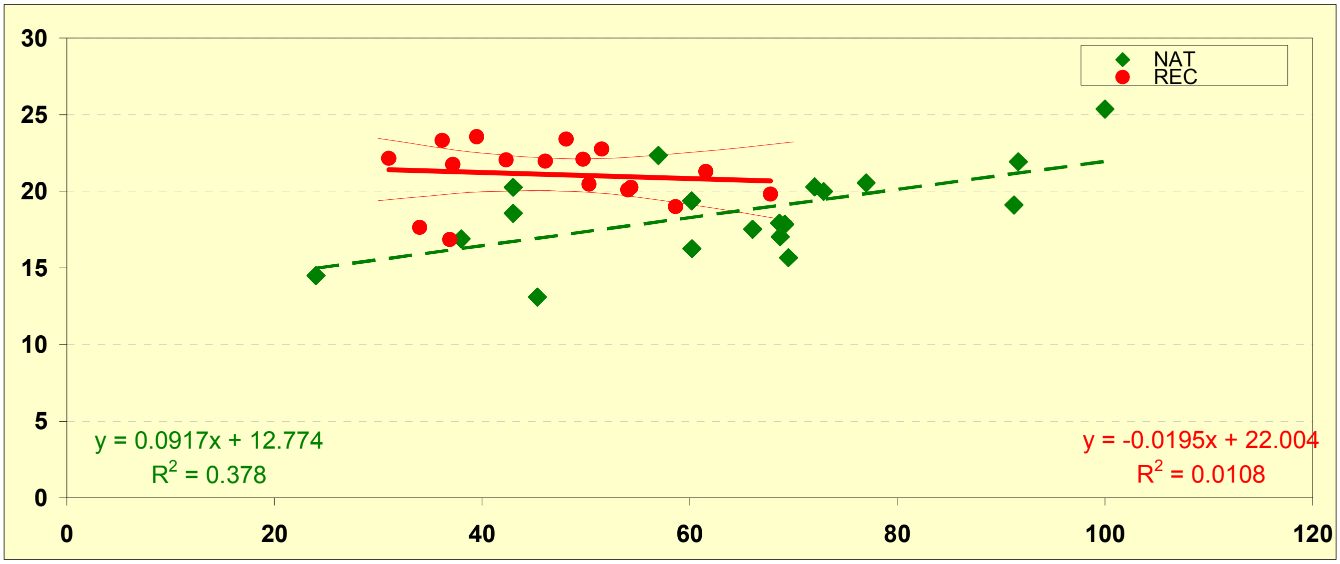
3.2.2.2 Reclaimed Areas

The 17 observations of Sw site index on reclaimed areas show a negative relationship between site index and LCCS rating with a slope of –0.020 (Figure 6 and Figure 7). This slope is not statistically significant (p = 0.691) and thus the appropriate interpretation is that there is little or no relationship between Sw site index and the FLR on these areas.

3.2.2.3 Differences

These data show that the overall site index of Sw on reclaimed areas is about 2-3 m higher than what is expected on natural areas for the same LCCS rating (Figure 6 and Figure 7). Again, it is not possible to know if this is a real difference or if it is caused by the subjective location of plots. The two thin red lines around the regression line represent the 95% confidence interval of the reclaimed plots. The range of reclaimed sites planted with Sw seem to represent a much narrower range of conditions than in natural areas indicating perhaps that spruce is planted only under more favorable site condition in reclaimed areas.

Species: SW Equation: Huang et al. 2006 Method: in plot X Variable: Final land rating



Statistics for Final land rating and Site index: **Land Capability Classification System:** **LCCS 2006**

Site Type	Site index (Y)					Final land rating (X)					Correlation
	Avg	StDev	N	CV%	S.E.	Avg	StDev	N	CV%	S.E.	
Natural	18.7	2.9	19	16%	0.67	64.1	19.4	19	30%	4.46	0.61
Reclaimed	21.1	2.0	17	9%	0.48	47.0	10.4	17	22%	2.53	**-0.10**

Figure 6. Graphical comparison of site index and Final Land Rating for Sw plots.

Species: SW Equation: Huang et al. 2006 Method: in plot X Variable: FLR

NATURAL SITES

Regression Statistics	
Pearson correlation	0.615
R Square	0.378
Standard Error	2.355
Observations	19
Degrees of Freedom	17
F value	10.3310
Significance of F	0.0051 ***

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	12.7744	1.907	6.697	0.0000 ***
Slope, X	0.0917	0.029	3.214	0.0051 ***

RECLAIMED SITES

Regression Statistics	
Pearson correlation	-0.104
R Square	0.011
Standard Error	2.014
Observations	17
Degrees of Freedom	15
F value	0.1642
Significance of F	0.6910

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	22.0041	2.320	9.485	0.0000 ***
Slope, X	-0.0195	0.048	-0.405	0.6910

*** significant at alpha=0.05

Figure 7. Linear regression analysis of site index and Final Land Rating for Sw plots.

3.2.3 Aspen

3.2.3.1 Natural Areas

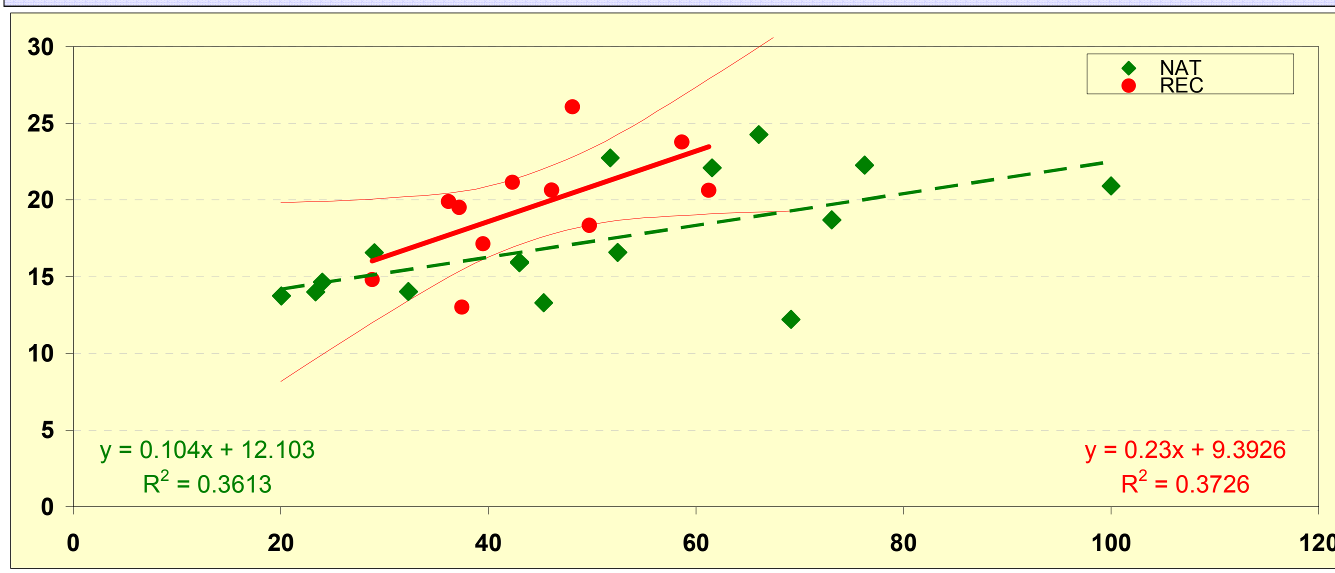
Results for the 16 observations for natural Aw show a much stronger positive relationship between site index and FLR (Figure 8 and Figure 9) than shown for the natural pine plots. The regression shows a slope of 0.104, which is statistically significant (p=0.014).

The Aw plots span a range of LCCS classes 1, 2, 3 and 4 (ratings 20-100). The LCCS class average aspen site index is 14.6 m for class 4, 16.9 m for class 3, 19.9 m for class 2 and 20.9 m for class 1. These plots are subjectively located thus there is limited interpretation that can be drawn from this range.

3.2.3.2 Reclaimed Areas

The 11 observations of Aw site index on reclaimed areas show a positive relationship between site index and FLR with a slope of 0.230 (Figure 8 and Figure 9). This slope is statistically significant (p = 0.046) at the 95% confidence level.

Species: AW Equation: Huang et al. 2006 Method: in plot X Variable: Final land rating



Statistics for Final land rating and Site index: **Land Capability Classification System:** **LCCS 2006**

Site Type	Site index (Y)					Final land rating (X)					Correlation
	Avg	StDev	N	CV%	S.E.	Avg	StDev	N	CV%	S.E.	
Natural	17.4	3.9	16	22%	0.98	50.7	22.6	16	45%	5.64	0.60
Reclaimed	19.5	3.7	11	19%	1.12	44.1	9.9	11	22%	2.97	0.61

Figure 8. Graphical comparison of site index and Final Land Rating for Aw plots.

3.2.3.3 Differences

These data show that the overall site index of Aw on reclaimed areas is about 1-2 m higher than what is expected on natural areas for the same LCCS rating (Figure 8 and Figure 9). The two thin red lines around the regression line represent the 95% confidence interval of the reclaimed plots.

Species:	AW	Equation:	Huang et al. 2006	Method:	in plot	X Variable:	FLR

NATURAL SITES

Regression Statistics		
Pearson correlation	0.601	
R Square	0.361	
Standard Error	3.229	
Observations	16	
Degrees of Freedom	14	
F value	7.9188	
Significance of F	0.0138	***

	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	12.1034	2.038	5.939	0.0000	***
Slope, X	0.1040	0.037	2.814	0.0138	***

RECLAIMED SITES

Regression Statistics		
Pearson correlation	0.610	
R Square	0.373	
Standard Error	3.099	
Observations	11	
Degrees of Freedom	9	
F value	5.3455	
Significance of F	0.0461	***

	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	9.3926	4.488	2.093	0.0659	
Slope, X	0.2300	0.099	2.312	0.0461	***

*** significant at alpha=0.05

Figure 9. Linear regression analysis of site index and Final Land Rating for Aw plots.

3.3 Correlation Analysis

We examined the Pearson correlation amongst the LCCS components listed in Table 3 and site index by species for the natural and reclaimed sites. The correlation statistics of the LCCS components against site index are shown in Table 4. Negative correlations are presented in red and they indicate that an increasing value of the particular index is associated with decreasing site index.

Table 4. Correlation of LCCS 2006 components against site index by species and site type.

LCCS Components	Pine		Spruce		Aspen	
	Natural	Reclaimed	Natural	Reclaimed	Natural	Reclaimed
AWHC	0.48	0.24	0.31	0.27	0.86	0.55
ADJAWHC	0.48	0.17	0.36	0.29	0.88	0.57
SMR	0.41	0.19	0.52	0.18	0.69	0.54
TOC	0.32	**-0.20**	0.61	**-0.16**	0.45	**-0.15**
TON	0.35	**-0.01**	0.54	**-0.09**	0.34	**-0.19**
CN	**-0.02**	**-0.45**	**-0.11**	0.07	**-0.51**	0.47
NUTRET	0.46	0.27	0.32	0.27	0.84	0.63
CUMSNR	0.25	0.20	0.39	**-0.17**	0.75	**-0.13**
SNR	0.39	0.01	0.45	**-0.36**	0.71	0.01
BASE	0.44	0.17	0.52	0.08	0.72	0.50
TSDED	0.32	**-0.02**	**-0.07**	0.00	0.48	**-0.24**
ISR	0.41	0.19	0.55	0.08	0.71	0.58
USDED	0.13	0.11	0.01	0.27	0.72	0.33
LSDED	0.30	0.09	**-0.03**	0.23	0.61	0.21
TOTDED	0.34	0.08	**-0.04**	0.21	0.67	0.14
FLR	0.40	0.21	0.61	**-0.10**	0.60	0.61
LCC	**-0.34**	**-0.13**	**-0.50**	**-0.01**	**-0.60**	**-0.58**

The general observation about the data presented in Table 4 is that the correlation of LCCS components to site index is not very strong and that is especially true for reclaimed areas. Aspen shows a stronger correlation for most LCCS components than the other species. When considering both natural and reclaimed plots, SMR and AWHC have positive correlations to site index indicating that moisture conditions are considered to be one of key factors in forest soil productivity. With respect to SNR, natural soils have a stronger correlation to site index than reclaimed soils. The principles of carbon and nitrogen dynamics that have been incorporated into the LCCS are predominantly based on natural ecosystems, thus the discrepancy may be that these principles don't apply to reclaimed soils. One issue may be that peat mix material may contain a similar percentage of carbon and nitrogen as natural LFH horizons, but their forms (and ultimately availability) may be different. Therefore, it may not be correct to assume peat mix and natural LFH horizons are directly comparable (Marty Yarmuch pers. comm.).

The capability class (LCC) is negatively correlated to site index indicating that the less capable the site is (i.e., the higher the class) the lower the site index across all species. The final rating is positively correlated to site index with the exception of white spruce in reclaimed areas where there is essentially no correlation. Nutrient retention and available water holding capacity correlate very well with site index for aspen. The final land rating appears to correlate to site index reasonably well in natural areas. This is likely because the LCCS was largely built based on our better understanding and more historical information with respect to natural systems as compared to the reclaimed soils of the oil sands mine industry (Marty Yarmuch pers. comm.).

It is interesting to note that the limiting factor deductions for the TS, US and LS horizons did not necessarily improve the correlation values between site index and FLR from the base rating for some species. We would expect that after applying these limiting factors that a truer value of a soil's productivity would be determined, which would result in a higher FLR correlation compared to the base rating's correlation value. The various deductions do not seem to impact this correlation, in fact some of the deductions due to soil structure and consistence, pH, salinity and sodicity may not necessarily be limiting to the same degree in every stand type. This may also suggest that the current approach to limiting factor deductions (using the most limiting in each horizon) may not be adequate for capturing site productivity. Moreover, these deductions and thus the final land rating could be different for different species as they may respond to limiting factors in different ways as they are not all equally adaptable to the range of moisture and nutrient regimes present, and will likely respond differently to different soil-based limitations.

We also calculated the Pearson correlation statistics amongst the individual LCCS components. Given that the LCCS is not species specific, we could use all 103 plots for this step as the soil analysis was completed for the entire PSP data set. We present the correlation statistics for the 50 natural plots and 53 reclaimed plots in Table 5 and Table 6, respectively. For presentation purposes, we dropped the adjusted AWHC and the interim soil rating as they were found to be very closely correlated to AWHC and the base rating providing no additional relevant information.

Most of the results presented in Table 5 and Table 6 are expected as they are based on the internal logic of the LCCS. However, they also reveal some interesting observations that could potentially provide some insight into the underlying relationships of the LCCS. The correlation statistics appear to be much stronger in natural systems than in reclaimed areas. For example, SMR and SNR are not as strongly correlated in reclaimed soils as natural soils. This is expected as the limiting factors of the TS, US and LS horizons are usually greater in reclaimed soils compared to natural soils. All the evaluated parameters (structure/consistence, pH, salinity and sodicity) are generally more limiting in reclaimed soils, which would lower the correlation of the SMR and SNR to the final rating (Marty Yarmuch pers. comm.).

Again, these observations are somewhat affected by the subjective location of the plots. Soil moisture regime is very highly correlated with the final rating of the LCCS 2006 (r=0.95) in natural areas. The presented correlation statistics could also be used as a first step in quantifying the impact of individual LCCS components on the final LCCS score.

Table 5. Correlation of the LCCS 2006 components in natural areas (n=50).

LCCS Comp	AWHC	SMR	TOC	TON	CN	NUT RET	CUM SNR	SNR	BASE	TS DED	US DED	LS DED	TOT DED	FLR	LCC
AWHC		0.94	0.74	0.56	-0.43	0.99	0.91	0.94	0.96	0.67	0.80	0.92	0.87	0.88	-0.86
SMR	0.94		0.70	0.47	-0.26	0.89	0.85	0.87	0.99	0.43	0.51	0.67	0.62	0.95	-0.93
TOC	0.74	0.70		0.67	-0.07	0.64	0.75	0.76	0.73	0.09	0.21	0.39	0.26	0.78	-0.72
TON	0.56	0.47	0.67		-0.43	0.56	0.73	0.72	0.54	0.16	0.25	0.48	0.34	0.52	-0.47
CN	-0.43	-0.26	-0.07	-0.43		-0.32	-0.49	-0.45	-0.31	-0.14	-0.26	-0.32	-0.27	-0.27	0.28
NUTRET	0.99	0.89	0.64	0.56	-0.32		0.91	0.92	0.92	0.44	0.61	0.73	0.69	0.83	-0.82
CUMSNR	0.91	0.85	0.75	0.73	-0.49	0.91		0.98	0.90	0.37	0.55	0.72	0.63	0.83	-0.83
SNR	0.94	0.87	0.76	0.72	-0.45	0.92	0.98		0.93	0.40	0.56	0.72	0.65	0.86	-0.85
BASE	0.96	0.99	0.73	0.54	-0.31	0.92	0.90	0.93		0.43	0.53	0.70	0.64	0.95	-0.94
TSDED	0.67	0.43	0.09	0.16	-0.14	0.44	0.37	0.40	0.43		0.66	0.37	0.81	0.19	-0.20
USDED	0.80	0.51	0.21	0.25	-0.26	0.61	0.55	0.56	0.53	0.66		0.74	0.94	0.26	-0.28
LSDED	0.92	0.67	0.39	0.48	-0.32	0.73	0.72	0.72	0.70	0.37	0.74		0.81	0.52	-0.54
TOTDED	0.87	0.62	0.26	0.34	-0.27	0.69	0.63	0.65	0.64	0.81	0.94	0.81		0.36	-0.39
FLR	0.88	0.95	0.78	0.52	-0.27	0.83	0.83	0.86	0.95	0.19	0.26	0.52	0.36		-0.98
LCC	-0.86	-0.93	-0.72	-0.47	0.28	-0.82	-0.83	-0.85	-0.94	-0.20	-0.28	-0.54	-0.39	-0.98	

Table 6. Correlation of the LCCS 2006 components in reclaimed areas (n=53).

LCCS Comp	AWHC	SMR	TOC	TON	CN	NUT RET	CUM SNR	SNR	BASE	TS DED	US DED	LS DED	TOT DED	FLR	LCC
AWHC		0.82	0.02	0.14	-0.01	0.74	0.34	0.33	0.80	0.08	0.49	0.35	0.43	0.66	-0.60
SMR	0.82		0.08	0.11	0.02	0.69	0.42	0.38	0.97	0.13	0.64	0.52	0.59	0.78	-0.68
TOC	0.02	0.08		0.43	-0.42	-0.16	0.31	0.27	0.14	-0.19	0.23	0.32	0.12	0.08	-0.14
TON	0.14	0.11	0.43		-0.20	-0.20	0.64	0.58	0.24	-0.11	0.28	0.34	0.21	0.14	-0.15
CN	-0.01	0.02	-0.42	-0.20		-0.02	-0.30	-0.27	-0.05	-0.02	-0.01	-0.06	-0.04	-0.03	0.13
NUTRET	0.74	0.69	-0.16	-0.20	-0.02		0.28	0.30	0.68	0.19	0.48	0.22	0.43	0.54	-0.50
CUMSNR	0.34	0.42	0.31	0.64	-0.30	0.28		0.92	0.59	0.06	0.44	0.51	0.45	0.40	-0.38
SNR	0.33	0.38	0.27	0.58	-0.27	0.30	0.92		0.58	0.14	0.41	0.42	0.45	0.38	-0.38
BASE	0.80	0.97	0.14	0.24	-0.05	0.68	0.59	0.58		0.14	0.67	0.56	0.63	0.78	-0.69
TSDED	0.08	0.13	-0.19	-0.11	-0.02	0.19	0.06	0.14	0.14		0.07	-0.13	0.59	-0.29	0.35
USDED	0.49	0.64	0.23	0.28	-0.01	0.48	0.44	0.41	0.67	0.07		0.68	0.79	0.22	-0.22
LSDED	0.35	0.52	0.32	0.34	-0.06	0.22	0.51	0.42	0.56	-0.13	0.68		0.65	0.19	-0.23
TOTDED	0.43	0.59	0.12	0.21	-0.04	0.43	0.45	0.45	0.63	0.59	0.79	0.65		0.00	0.02
FLR	0.66	0.78	0.08	0.14	-0.03	0.54	0.40	0.38	0.78	-0.29	0.22	0.19	0.00		-0.91
LCC	-0.60	-0.68	-0.14	-0.15	0.13	-0.50	-0.38	-0.38	-0.69	0.35	-0.22	-0.23	0.02	-0.91	

3.4 Other Analyses

We constructed a ‘tornado chart’ to provide some insight into the overall differences of the LCCS components by site type. Figure 10 shows the average values of the LCCS components side-by-side for natural and reclaimed plots.

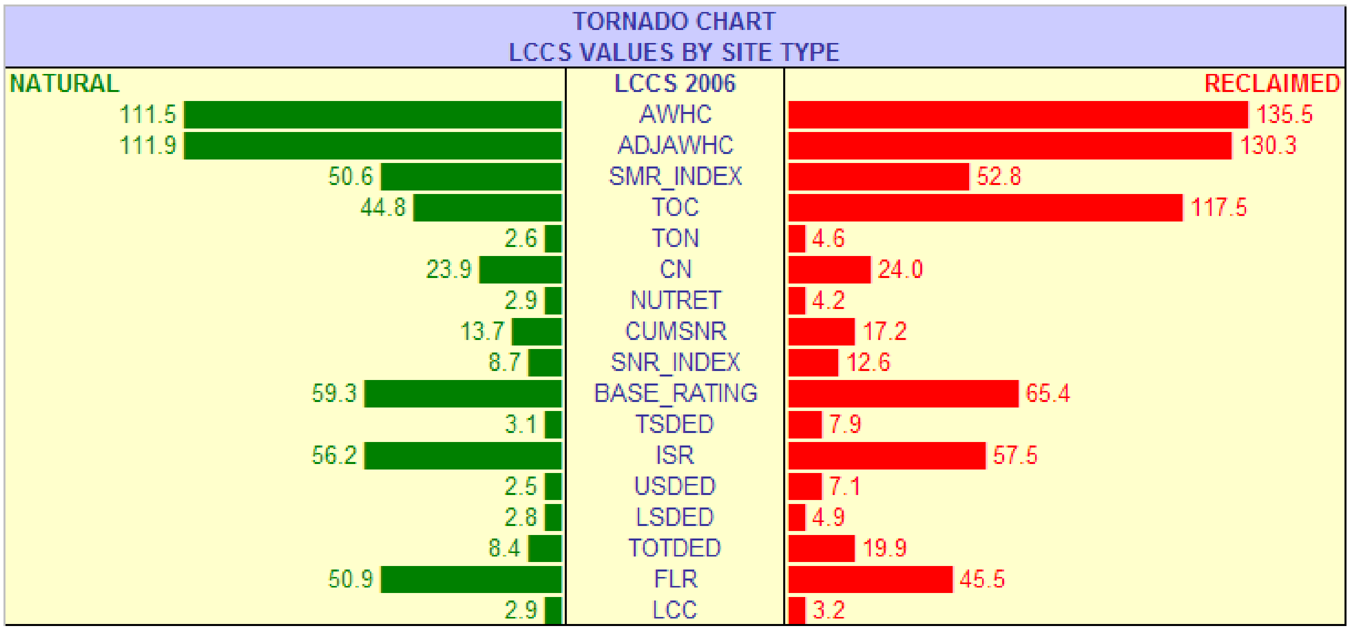


Figure 10. Average values of the LCCS 2006 components by site type.

The reclaimed sites have almost three times as much organic carbon. The nitrogen content is also higher in the reclaimed areas. Nitrate levels however are decreasing over time on reclaimed soils with peat mineral mix and after 15 years they are similar to those in natural areas (AMEC 2005).

Soil moisture regimes appear to be similar, however on the natural sites almost half the plots (n=24) carry the X subclass notation indicating very dry conditions. While the soil base rating is slightly higher on reclaimed sites, the final rating is lower than the natural sites due to limiting factor deductions. These deductions are mainly due to soil reaction (pH), and structure and consistence, but there are several reclaimed plots with high salinity in their profile. Earlier analysis by AMEC (2005) found that phosphorus levels in tailings sand are very low and may become limiting in the future and sulfate levels are considerably higher in reclaimed areas than on natural sites. Most of these results could be explained by the fertilization practice and reclamation prescriptions (Table 7) applied in the reclaimed areas.

Table 7. Reclamation prescriptions.

Series	Description
A	Peatmix/Secondary/Tailing Sand
B	Direct Placement/Tailing Sand
E	Peatmix/Secondary/Overburden
F	Direct Placement/Overburden
H	Peatmix/Tailing Sand
I	Peatmix/Overburden
M	Peatmix/Secondary/Clearwater

The plots were subjectively located to represent a range of prescriptions (reclaimed areas) and ecosites that were targeted in reclamation plans (natural areas). We calculated the average site index values by species and series/ecosite in natural and reclaimed areas as presented in Figure 11. The number of plots that represents the averages varies depending on the species. All reported site index values are based on the plot-based Huang 2006 height-age equations. Pine was found in natural ecosites a and b that generally are on coarse textured soils with very low carbon content on upland sites, thus their nutrient retention is very low as compared to the reclaimed areas where most prescriptions involve some form of top dressing with peat mix that has a much higher organic carbon mass. Pine seems to perform better on reclaimed areas where Peatmix/Secondary are placed over tailings sand or overburden (A and E prescriptions). Peatmix over tailings sand (H) prescriptions have comparable site index values and nutrient retention to that of the natural sites. They have the lowest nutrient retention and SMR and water holding capacity amongst all prescriptions. For spruce and aspen, natural e ecosites located in the floodplain areas have the most productive sites. In addition to prescriptions A and E it appears that spruce performs reasonably well on direct placement over tailings sand (B) however these results are based on only a few plots of data. Actual performance of growth and productivity by reclamation prescription can only be captured based on a controlled experiment that enables the separation of the effects due to prescription from the growth that would have occurred under normal conditions.

Site Type	Series/ EcoSite	Pine	Spruce	Aspen
NATURAL	a	15.7		
	b	17.1	17.3	14.6
	d		18.4	19.6
	e		20.7	21.6
RECLAIMED	A	18.8	20.4	21.1
	B	15.9	23.4	20.4
	E	18.7	22.0	20.4
	F		21.5	19.5
	H	16.6	17.6	13.0
	I	16.3	20.9	19.1

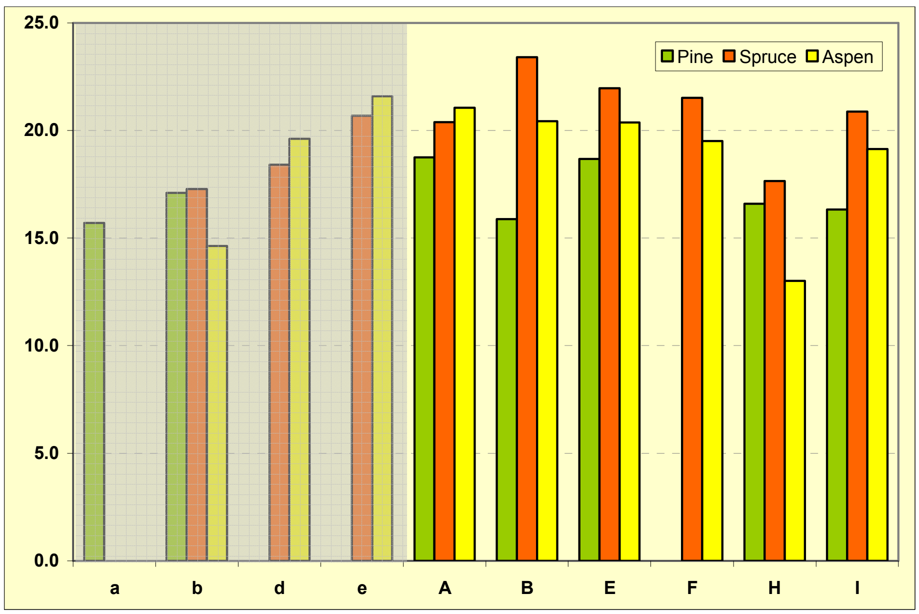


Figure 11. Average values of site index series/ecosite and site type.

4.0 SUMMARY AND CONCLUSIONS

We re-analyzed the relationship between site index and LCCS while addressing several concerns mentioned in previous studies:

1. **We took advantage of the scientifically sound and consistent field sampling protocols.**

   The new field protocols for site index were introduced in 2004. These protocols provided a solid base for estimating site productivity. We also had better data due to the trees being older and taller thus providing a more stable site index estimate.

2. **We used a consistent approach to estimating site index.**

   Site index was estimated based on a consistent selection of site trees, site index equation and averaging method. We avoided the combination of various site index estimation methods, especially the use of growth intercept measures as they were found to be highly suspect (JST 2005). As site index is a species-specific measure, we kept all relevant analysis at the species level.

3. **We used the best available site index equations.**

   The latest site index equations developed by Huang (2006) are based on the stand top height trajectories of re-measured PSPs. These equations address some of the concerns raised by Magnussen and Penner (1996) about the replacement of site trees over time, a known issue of the stem-analysis based equations such as Huang 1997.

4. **We compiled the land capability ratings based on the latest system.**

   All soil data were compiled to LCCS 2006 standards by soil experts (Marty Yarmuch, Northwind). The LCCS 2006 is considered an improvement over previous systems. We stored the final ratings and all component scores in a database. We also calculated the LCCS 1998 scores for comparison purposes.

5. **We assembled an interactive tool that combines all soil and site index data.**

   We developed a user-friendly Microsoft Excel interactive application that houses all compiled site index and LCCS data. The application allows knowledgeable soil and forestry experts to examine the data, explore underlying relationship and help with the interpretation of the results.

The major conclusions of this study are:

1. **The subjective location of the plots makes it difficult to interpret the results.**

   The subjective location of the sample plots results in not being able to use statistical inference to interpret the data. This would likely be less of an issue if the relationship between site index and LCCS rating was strong. The weak relationships shown in this study, and the potential for a few influential points to change the interpretation results in low confidence in the indicated trends.

2. **There is a positive relationship between LCCS and site index on natural sites.**

   We found a positive relationship between LCCS and site index in natural areas for all major tree species. The relationship is statistically significant for spruce and aspen at the 95% confidence level. Pine appears to be weakly correlated with a slope that is not significant (p=0.127).

3. **There is no apparent relationship between LCCS and site index in reclaimed areas.**

   The results do not show any meaningful relationship between LCCS rating and site index in reclaimed plots for pine and spruce; however the slope appears to be weakly significant for aspen (p=0.046). Pine and spruce seem to occupy a narrow range of site conditions in reclaimed areas. Pine is planted in areas with the capability scores ranging from 30 to 50 while spruce can be found on sites with the range of 40-70 suggesting that these species are planted under site and soil conditions that are better suited for the particular species. The use of fertilization techniques, reclamation prescriptions that tend to favor finer textures, initial spacing, vegetation control and the use of better growing stock all contribute to a potential lift in early height growth. This height increase combined with the relatively narrow range of capabilities might explain the observed results.

4. **The site index is the same or higher in reclaimed areas than in natural areas.**

   The general observation in many studies in BC and Alberta is that trees grow significantly better on disturbed sites than on natural ecosystems in the same area. A recent study by the Foothills Growth and Yield Association found that lodgepole pine had a 24% increase in site index in harvested areas as compared to the same sites prior to harvest (Dempster, 2004)[23]. It was found that height growth was affected by site, particularly soil nutrient regime.

   The increase in site index provide some evidence that the reclamation efforts have been successful in providing equivalent capability for forest production; however most reclaimed areas are still very young. The real question is if increases in site index will be sustained in the future. Only long term monitoring will help answer this question. We may also need to separate the effects of site (soil nutrient regime) from the effects of reclamation prescriptions, fertilization techniques, vegetation control and initial spacing of the planted trees. These can only be done under a controlled experiment.

5. **Site index estimates are not overly sensitive to site tree selection methods.**

   We tested two widely used methods in our study. The tallest 100 trees/hectare were selected based on the four tallest trees in the 400 m^2 plot (in-plot method) and based on the tallest tree in each 100 m^2 quadrant (in-quadrant method)[24]. The in-plot method generally yield higher site index estimates as it ensures that the four tallest trees are selected in the entire plot. The new field sampling protocols allow for a consistent application of either of these methods.

6. **Site index estimates are not overly sensitive to averaging methods.**

   One can derive an average site index for a species in the plot using two different approaches. The 'average input' method takes the average height and average BH age of the selected site

[23] W.R. Dempster 2004. Comparison of pre-harvest and post-harvest site indices. Technical Report. Prepared for the Foothills Growth and Yield Association regenerated Lodgepole Pine Project. Hinton, Alberta. 22 pp.
[24] The site tree selection methods already assume that there was a consistent set of criteria for suitable site trees.

trees and those averages are used in the site index equation as input to arrive at the site index estimate. The ‘average output’ method calculates the site index for each site tree based on its height and age and then averages the resulting site indices. We found no substantial difference between these two methods in reclaimed sites.

7. Site index estimates vary greatly based on the applied site index equation.

We calculated the site index using Huang’s 1997 stem analysis based equations and 2006 plot-based equations. The stem analysis based equations were consistently 1-3 m higher for all species; however it appears that their relationship to LCCS is not affected. In other words, the general trend and conclusions about the relationship between LCCS and site index is very similar regardless of the equation used, only the magnitude will be different.

5.0 RECOMMENDATIONS

Based on our findings in this study we recommend the following:

1. **Review the current design of the CEMA PSP program.**

   The subjective location of the plots is a major issue when it comes to interpretation of the results. We suggest that the objectives of the PSP program should be revisited and a statistically designed plot network should be considered. Such programs are routinely used in Alberta and BC to monitor the growth and yield of forestlands.

2. **Use the latest plot-based site index equations.**

   The latest equations by Huang (2006) address previous concerns about site tree replacement and they fit well within the current field measurement protocols. If better site index equations are being developed, the analysis must be re-run for the entire data set to ensure consistency.

3. **Use the 'in-plot' site tree selection method.**

   Selecting the four tallest trees in the 400 m^2 plot is compatible with the current Alberta site index estimation protocols. The definition of suitable site trees should remain consistent with the field sampling protocols implemented in 2004. The current protocol also allows for the selection of one site tree per quadrant. This practice should be re-visited once a round of re-measurements is completed on all reclaimed plots to minimize potential redundancy.

4. **Use the 'average the output' method for site index estimation.**

   We suggest the calculation of site index for the individual site trees and the averaging of those site indices to arrive at an estimate. Under no circumstances should site index be averaged across species.

5. **Provide clear guidelines in the manual when to switch to DBH-based site tree selection.**

   Current field protocols define site trees as the tallest three trees per species in a quadrant. There should be very clear guidelines when the field crew should switch to selecting the fattest (largest DBH) trees. The current protocols suggest this to happen when the site trees reach about 6 to 8 m in height.

6. **Monitor the change in site index over time by species.**

   The observed higher site indices in reclaimed areas suggest that reclamation efforts have been successful; however the sustainability of such growth over time is being questioned. Only long term monitoring will provide an answer. Consistent and well-documented re-measurement protocols, especially regarding the selection and re-measurement of site trees for top height and BH age are crucial for effective monitoring of change in site index.

7. **Monitor the change in site tree replacement rates.**

   Site trees are identified in the tree data but not permanently marked in the field, as site tree selection is re-assessed at each measurement. This is a very important as it addresses one of the main concerns related to site index estimation using stem-analysis based equations as described by Magnussen and Penner (1996). The issue is that site trees selected in mature stands to develop site index equations may not have been dominant/co-dominant site trees at the early stages of stand development and therefore the application of curves derived from these trees may result in significant over-estimation of site index in young regenerated stands. Using the latest plot-based site index equations (Huang, 2006) combined with the current field sampling protocols provide a potential solution to this problem; however monitoring the change in site trees over time will help assess if this is a crucial issue in reclaimed areas.

8. **Engage soil and forestry experts in the interpretation of the results.**

   In addition to this report, a user-friendly consolidation of the compiled site index and soil (LCCS) data are distributed within the SVSG members for review and feedback. Knowledgeable soil experts, forestry professionals and tree physiologists may provide some valuable insight into the compiled results that are now easily accessible for exploratory analysis.

9. **Re-analyze the relationship between LCCS and site index once a complete round of re-measurements is available in 2010.**

   We worked out an analysis framework and compilation protocols that should provide a solid foundation for examining the change in the relationships over time. Soil analysis should be done by a qualified soil professional and the site productivity information should be compiled by a qualified forestry professional. Interpretation of the results however should be done collectively to utilize the experience and local knowledge of professional staff, researchers and consultants. The data now allows for the potential analysis and monitoring of the underlying relationships between several soil and site factors.

10. **All the compiled data of this study should be housed in a secure database**

    Current development efforts to create a secure database for CEMA PSPs should include provisions for storing the cleaned and compiled site index and LCCS data. It would also be preferable to implement the automatic calculation of site index for all PSPs based on the suggested protocols. This would enable easy changes to the protocols (e.g., new site index equation) and the re-estimation of site index values for the entire plot database.

Appendix I

Soil Analysis

By Marty Yarmuch M.Sc., P.Ag., NorthWind Land Resources Inc.

1.0 INTRODUCTION

NorthWind Land Resources Inc. was commissioned by Timberline Natural Resource Group Ltd. to complete the Land Capability Classification System (LCCS) ratings for 103 permanent sample plots (PSP's) located in the boreal forest region of Northern Alberta and reclaimed oil sands mine lease soils in the Fort McMurray area.

The LCCS is used to determine the capability of an area for potential forest productivity. A base rating is determined using the Soil Moisture Regime (SMR) and the Soil Nutrient Regime (SNR). The SMR is determined using the available water holding capacity (AWHC), landscape variables (slope, aspect) and the ability for water to move through the profile (impermeable layers or layering of fine and coarse material). The SNR is determined using the total organic carbon, total nitrogen, carbon to nitrogen (C:N) ratio, and nutrient retention (based on soil texture). Points are deducted from the base rating based on four variables for each layer of the soil (topsoil [0-20 cm], upper subsoil [20-50 cm] and lower subsoil [50-100 cm]). These four variables are: aggregate structure and consistence, soil pH, salinity (EC), and sodicity (SAR). A final land rating (FLR) is calculated and a land capability class is determined based on the range the FLR fits in. There are five different classes; Class 1 is the most productive and Class 5 is the least productive (see Appendix II).

The primary objective of the exercise was to update the 1998 and 2006 LCCS ratings for the Soil and Vegetation Monitoring plots and compare them to site index information collected from these sites. The sample data includes 50 natural plots in the boreal forest region of Northern Alberta and 53 reclaimed plots on oil sands mine leases in Fort McMurray.

The detailed scores and LCCS ratings for each plot along with the soil data are provided in the Soil Analysis Data Package.

2.0 METHODS

Data was provided for 103 Soil and Vegetation Monitoring plots in the boreal forest region of Northern Alberta and oil sands mine leases in the Fort McMurray area. In total, there were 50 natural plots and 53 reclaimed plots. The data from the Soil and Vegetation Monitoring plots were entered into the 1998 and the 2006 LCCS calculators developed on behalf of CEMA. There were some data gaps in the database and assumptions were made based on our professional judgment and experiences. A list of the data parameters entered into each program is provided in Tables 1 and 2.

The 1998 LCCS required deductions to be entered manually for each site. These deductions were based on the chemistry, physical soil and site conditions. Table 8 and Table 16 of the 1998 LCCS manual (Leskiw, 1998) provides the criteria for the deductions.

2.1 LCCS Calculator Assumptions

The LCCS calculator was unable to calculate a valid LCCS rating if data fields requiring information remained empty. Analysis for total organic Carbon (TOC), total nitrogen (TN) electrical conductivity (EC), and sodium absorption ratio (SAR) were typically only determined for those horizons containing the visible presence of elevated organic materials. These organic materials include LFH and O horizons in natural sites, and peat-mineral mix (Ptmix) in reclaimed sites. If there were no data available for the mineral horizons below the organic layers, a value of zero was entered in for TOC, TN, EC and SAR, since the underlying mineral horizons do not contribute a great amount to the final TOC and TN relative to organic enriched horizons. If there was an organic layer below the upper organic layer (i.e., LFH over Om, or Ptmix (0-20cm) over (Ptmix (20-50)), then the values such as TOC, EC and SAR from the upper layer were applied to the lower layer. In cases where the lower horizons or layers were re-sampled and analyzed, the re-sampled analyses data were used. If any Ptmix horizons had a TOC greater than 17%, then the horizon description was converted to read O for organic. This was done because the LCCS manual does not classify reclaimed horizons with >17% TOC as Ptmix horizons.

If data were missing for pedon characteristics such as: consistence, structure, size, or texture, then values were added based on professional experience, previous site information collected (Yarmuch, 2003) and general soils knowledge for the northern boreal region. In situations where there were horizons with no data available, the chemistry of the most similar overlain or underlain horizon was applied (e.g., Bt1 and Bt2 horizons). Also, soils classified as heavy clay texture were changed to clay as the program does not recognize heavy clay as a texture class.

In the reclaimed sites, some plots had a thin layer of wind blown tailings sand on the surface. If no chemical analysis had been performed on this layer, the chemistry data determined for the lower subsoil tailings layer was applied to the topsoil layer. In this case, it was assumed that the tailings sand materials were relatively similar as a result of the bitumen extraction process.

2.1.1 Assumptions and Procedures for the 1998 LCCS Calculator

Data was entered into the Data Forms in the LCCS calculator. The 1998 version allowed the flexibility to enter pH values in one of two forms – H_2O based (pH_{H2O}) or a $CaCl_2$ based (pH_{CaCl2}). The data provided had some plots with pH_{H2O}, while others were determined in pH_{CaCl2}. In some instances, the method of pH analysis changed within a single profile (i.e., Topsoil had pH_{CaCl2} while the lower subsoil had a pH_{H2O}). In these instances the pH values were converted to pH_{CaCl2} (Table 3). This was necessary because, while the program allowed variations between plots, the entire profile needed to have a consistent pH base.

Once these assumptions were established the data gaps were filled in and the dataset was validated; FLR and LCCS ratings were calculated. Assumptions are listed in Table 4.

2.1.2 Assumptions and Procedures for the 2006 LCCS Calculator

Data was entered into the 2006 LCCS program by pasting values into the individual worksheets (i.e., "Site", "Horizon (lab)", and Horizon (field)"). The only assumptions that were made in this version, which were different than the 1998 version, were the pH values. The 2006 LCCS calculator assumes that all pH values are water based (pH_{H2O}). Since many of the reclaimed pH values were pH_{CaCl2}, they had to be converted to pH_{H2O} (Table 3) using the reverse method that was used to convert the pH_{H2O} to pH_{CaCl2} for the 1998 program.

3.0 REFERENCES

Dudas, M.J. 1997. Soils 450: Soil Environmental Chemistry notes. Dept of Renewable Resources, University of Alberta, Edmonton, Alberta.

Leskiw, L.A. (CAN-AG Enterprises Ltd.) 1998. Land capability classification for forest ecosystems in the soil sands region (Revised Edition). Prepared for the Tailings Sand Reclamation Practices Working Group. 94. pp.

AMEC Earth & Environmental and Paragon Soil and Environmental Consulting Ltd. 2005. Results from long term soil and vegetation plots established in the oil sands region. Prepared for the Oil Sands Soil and Vegetation Working Group. 69. pp. +app

Yarmuch, M. 2003. Measurement soil physical parameters to evaluate soil structure quality in reclaimed oil sands soils, Alberta, Canada. Master of Science Thesis. University of Alberta, Edmonton, Canada. 134. pp.

Table 1. Data fields and descriptions for LCCS 1998.

Category (worksheet tab)	Variable	Description	Location of Data (AMEC and Paragon, 2005)
Data Header	ID	Detailed ID based on a combination of soil type, site ID, polygon and location.	Internal Programming column.
	Soil Type	Natural or Reclaimed	Appendix I
	Site ID	Plot ID	Appendix I
	Polygon	Polygon location	Not Applicable
	Location	Plot location	Not Applicable
	Assessor	Assessor	Not Applicable
	Date	Date of collection	Not Applicable
	Depth to WT	Water table depth (cm)	Based on Appendix I, Soil Moisture regime
	Company	Company or individual collecting data	Not Applicable
	SMR	Soil Moisture regime	Appendix I
	SNR	Soil Nutrient regime	Appendix I
	Slope (%)	Percent slope	Appendix I
	Position	Position of slope (crest, upper, mid, lower, toe, depression, level)	Appendix I
	Aspect	Slope aspect in degrees	Appendix I
	Erosion	Range from none to extreme	Appendix I
	Notes	Notes	Not Applicable
	ClayBanding	Presence of clay banding identified in the field.	
Data Layers	ID	Detailed ID based on a combination of soil type, site ID, polygon and location.	Internal Programming column.
	Horizon	Horizon nomenclature (O, LFH, A, B, etc.)	Appendix II
	Impermeable	Impermeable layers identified within 100 cm of the soil surface	Appendix II
	Top	Top of horizon depth (cm)	Appendix II
	Bottom	Bottom of horizon depth (cm)	Appendix II
	Stone/Gravel	Volume Percent (%) of stones or gravel in horizon.	Appendix II
	Structure	Horizon structure	Appendix II
	Size	Horizon aggregate size (mm)	Appendix II
	Consistence	Horizon consistence of aggregates	Appendix II
	Texture	Horizon texture based on percent of sand, clay and silt.	Appendix III
	TOC	Total organic carbon (%)	Appendix IV
	Dry Colour	Colour based on Munsell colour charts.	Appendix II
	pH	pH - either pH_{H2O} or pH_{CaCL2}	Appendix IV
	EC	Electrical Conductivity (EC) of horizon (dS/m)	Appendix IV
	SAR	Sodium Adsorption Ratio (SAR) of the horizon	Appendix IV
	SAT	Percent base saturation	Appendix IV
	CEC	Cation Exchange Capacity of horizon (cmol/kg)	Appendix IV
	Horizon Indicator	Specific to reclaimed soils. Choose if horizon is either peat-mineral mix (Ptmix) or Tailings sand (TSS)	Appendix III
	TN	Total Nitrogen (%)	Appendix IV
	BulkDens	Bulk Density (g/cm^3)	Appendix III
	PctPeat	Percentage of Peat in Ptmix	Not Applicable

Table 2. Data fields and descriptions for LCCS 2006.

Category (worksheet tab)	Variable	Description	Location of Data (AMEC and Paragon, 2005)
Site	SITEID	Plot ID	Appendix I
	TYPE	Natural or Reclaimed	Appendix I
	DATE	Date of collection	Not Applicable
	ASSESSOR	Assessor (individual or company)	Not Applicable
	SMR	Soil Moisture regime	Appendix I
	SLOPEPCT	Percentage of slope	Appendix I
	SLOPEPOS	Position of slope (crest, upper, mid, lower, toe, depression, level)	Appendix I
	ASPECT	Slope aspect in degrees	Appendix I
	DEPTHTOWATER	Water table depth (cm)	Based on Appendix I, Soil Moisture regime
	NOTES	Notes	
Horizon (field)	SITEID	Plot ID	Appendix I
	HORIZON	Horizon nomenclature (O, LFH, A, B, etc.)	Appendix II
	IMPERMEABLE	Impermeable layers identified within 100 cm of the soil surface	Appendix II
	TOP	Top of horizon depth (cm)	Appendix II
	BOTTOM	Bottom of horizon depth (cm)	Appendix II
	KIND	Horizon structure	Appendix II
	SIZE	Horizon aggregate size (mm)	Appendix II
	CONSISTENCE	Horizon consistence of aggregates	Appendix II
	PCTSTONE	Volume Percent (%) of stones or gravel in horizon.	Appendix II
	SAMPLEID	Unique ID combining Site ID and Horizon.	Internal Programming column.
	HORIZON_ INDICATOR	Specific to reclaimed soils. Choose if horizon is either peat-mineral mix (Ptmix) or Tailings sand (TSS)	Appendix III
Horizon (Lab)	SAMPLEID	Unique ID combining Site ID and Horizon.	Internal Programming column.
	TOCPCT	Total organic carbon (%)	Appendix IV
	TONPCT	Total Nitrogen (%)	Appendix IV
	BULKDENS	Bulk Density (g/cm^3)	Appendix III
	CLAYPCT	Percentage of clay in soil horizon.	Appendix III
	SANDPCT	Percentage of sand in soil horizon.	Appendix III
	SILTPCT	Percentage of silt in soil horizon.	Appendix III
	TEXTURE	Texture class based on percent of sand, clay and silt.	Appendix III
	PH	pH – pH_{H2O}	Appendix IV
	EC	Electrical Conductivity (EC) of horizon in (dS/m)	Appendix IV
	SAR	Sodium Adsorption Ratio (SAR) of the horizon	Appendix IV
	NOTES	Additional notes	

*Table 3. Conversion of pH_{H2O} to pH_{CaCl2}. **

pH_{H2O}	pH_{CaCl2}
8.0	8.0
7.0	7.0
6.0	5.5
5.0	4.0
4.0	2.5

*Dudas, M.J. 1997. Soils 450: Soil Environmental Chemistry notes. Dept of Renewable Resources, University of Alberta, Edmonton, Alberta.

Table 4. List of changes and assumptions to each plot entered into the LCCS programs.

Type	Site ID	Notes 2006	Notes 1998
Reclaimed	1	Used Resampled TOC and TN data	Zeros entered into TOC, EC and SAR columns to obtain LCCS ratings.
Natural	2	Assumed no EC and SAR deduction because C horizon EC and SAR were low pH - Based on LFH CaCl2 pH (5.3), Ae CaCl2 pH (4.2), Bm CaCl2 pH (5.1), Bt CaCl2 pH (6.6) No TN data - assumed a ten point rating for SNR Changed Bm bulk density - 2.5 is unreasonable	Entered Zeros for TOC, EC and SAR where no data is available
Reclaimed	3	Used TOC and TN resampled data	Zeros entered into TOC column to obtain LCCS ratings.
Natural	4	pH and pedon data from Yarmuch 2003 Site data. Classified AB as Subangular blocky, 10-20, Firm; Bt changed to firm; Cca 20-50 size and firm Entered 0 for EC and SAR data above Cca	Entered Zeros for TOC, EC and SAR where no data is available Changed Bt to Firm instead of Friable
Reclaimed	5	Used resampled TOC and TN data LS - 20-50 size	Zeros entered into TOC column to obtain LCCS ratings. LS - entered 20-50 size
Natural	6	Data from other research program (Yarmuch, 2003)	Entered Zeros for TOC, EC and SAR where no data is available Entered 20-50 mm and Firm for Cca Entered Clay for Cca BC (H20) pH 6.6, entered 6.6 for BC and Cca
Reclaimed	7	Used resampled TOC and TN data	Zeros entered into TOC column to obtain LCCS ratings. LS2 - 20-50 size
Natural	8	Data from other research program (Yarmuch, 2003)	Entered Zeros for TOC, EC and SAR where no data is available Entered 5.5 pH for Bt (Yarmuch 2003) Entered 6.5 pH for BC (pH for H2O is 6.5)
Reclaimed	9	No TN data - assumed C:N of 25	Zeros entered into TOC column to obtain LCCS ratings. Entered 10-20 for US and LS

Type	Site ID	Notes 2006	Notes 1998
Natural	10	No TN data - assumed a C:N of 30 No H20 pH data, converted CaCl2 pH for LF Ae and Bm	Entered Zeros for TOC, EC and SAR where no data is available Entered 6.8 pH for BC (H2O pH)
Reclaimed	11	Used resampled TN and TOC data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	12	Used resampled TOC and TN data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	13		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	14	Used resampled TOC, TN and Ptmix texture data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	15	Used resampled data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	16	Used resampled TOC and TN data	Zeros entered into TOC column to obtain LCCS ratings. Ptmix 20-33 - TOC equal to 0-20 ptmix
Reclaimed	17		Zeros entered into TOC column to obtain LCCS ratings. Ptmix 20-60 - TOC equal to 0-20 ptmix
Natural	18	Converted CaCl2 pH data for LFH (5.1), Ae (5.1), Bt1 (4.9) and Bt2 (4.9) to H2O pH	Entered Zeros for TOC, EC and SAR where no data is available Used Bt1 pH for Bt2
Natural	19	Om TOC, TN, pH data - same as LFH Converted CaCl2 pH data for LFH (5.1), Ahe (4.6), Bmg (5.4) to H2O pH Cg - structure assumed to be 10-20 Assumed 1 for Bmg TOC, 25 C:N	Entered Zeros for TOC, EC and SAR where no data is available Used LFH pH and TOC for Om
Natural	20	Cca - assumed 20-50 size and firm consistence pH - LFH pH CaCl2 (4.3) converted to pH H2O; No pH data for Ae and Btj, assumed 5.5 pH	Entered Zeros for TOC, EC and SAR where no data is available Cca - entered 20-50 for size, firm for consistence IIBC - entered 5.5 for pH (H2O pH 5.9) Cca - entered 7.4 for pH (H2O pH 7.4) Ae, Btj - entered 5.5 for pH (equal to IIBC) - not entirely correct, but no data
Natural	21	Entered Zeros for EC and SAR where no data is available Ccas - entered 20-50 for size pH: LFH CaCl2 pH (4.5), Ae CaCl2 pH (4.3), Bt CaCl2 pH (4.2)	Entered Zeros for TOC, EC and SAR where no data is available Ccas - entered 20-50 for size BC - entered 4.2 (H2O pH was 5.2) Ccas - entered 7.5 (H2O pH was 7.5)
Natural	22	Entered Zeros EC and SAR where no data is available pH: LFH CaCl2 pH (3.9), Ae CaCl2 pH (3.4), Bm CaCl2 pH (4.2)	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 7.5 (H2O pH was 7.5)
Natural	23	Entered Zeros for EC and SAR where no data is available Cca - entered 10-20 for size Ahe - entered pH 7.0 (equal to Ae) pH: LFH CaCl2 pH (6.7), Ae CaCl2 pH (7), Bt - entered pH 7.3 (between Ae and BC) Ahe TOC, TN, pH and texture data taken from Ae	Entered Zeros for TOC, EC and SAR where no data is available Cca - entered 10-20 for size Ahe - entered pH 7.0 (equal to Ae) Bt - entered pH 7.3 (between Ae and BC) BC - entered 7.6 (H2O pH 7.6) Cca - entered 7.5 (H2O pH 7.5)

Type	Site ID	Notes 2006	Notes 1998
Reclaimed	24	Zeros entered into EC and SAR columns to obtain LCCS ratings. LFH pH taken from Ptmix horizon Resampled data has LS for ptmix	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	25	Resampled data has SL for ptmix	Zeros entered into TOC column to obtain LCCS ratings.
Natural	26	Entered Zeros for EC and SAR where no data is available pH: LFH CaCl2 pH (4.8), Ae CaCl2 pH (5.1), Bm pH (5.1)	Entered Zeros for TOC, EC and SAR where no data is available
Natural	27	Entered Zeros for EC and SAR where no data is available pH: LFH CaCl2 pH (3.9), Ae CaCl2 pH (4.0), Bm CaCl2 pH (5.0)	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 5.6 pH (H2O pH was 6.1)
Reclaimed	28	TS1 TOC and TN data used for TS2 LS - 20-50 size Field notes say ptmix is ptSL and resampled data shows SL (put in SL)	Zeros entered into TOC column to obtain LCCS ratings.
Natural	29	Entered Zeros for EC and SAR where no data is available pH: LFH CaCl2 pH (5.2), Ae CaCl2 pH (4.3), Bm CaCl2 pH (4.6), BC selected between Bm and C	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 4.3 (between Bm and C pH) C - entered 4.0 pH (H2O pH was 5.0)
Reclaimed	30		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	31	US and LS textures from Resampled data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	32	TOC, TN from resampled data	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	33	TOC, TN from resampled data. Resampled data has SL for ptmix	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	34	TOC, TN from resampled data. US2 - entered 10-20 size LS - entered 20-50 size US2 - pH, EC, SAR, SAT equal to US1	Zeros entered into TOC column to obtain LCCS ratings. US2 - entered 10-20 size LS - entered 20-50 size US2 - pH, EC, SAR, SAT equal to US1
Reclaimed	35	Zeros entered into TOC and TN for TS1 (TSS) TOC, TN data from resampled data used for TS2 and US Zeros entered for EC and SAR columns with no data. Used TSS data for TS1 (blown in TSS)	Zeros entered into TOC , EC and SAR columns to obtain LCCS ratings. Used TSS data for TS1 (blown in TSS)
Reclaimed	36	TOC, TN data resampled data used. Resampled Ptmix texture is C	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	37	Zeros entered into TOC column to obtain LCCS ratings. No data for TS1 (blown in TSS) - used data from LS of site 11 (TSS) Resampled ptmix texturedata is SL	Zeros entered into TOC column to obtain LCCS ratings. No data for TS1 (blown in TSS) - used data from LS of site 11 (TSS) and C from site TS TSS of site 35

Type	Site ID	Notes 2006	Notes 1998
Reclaimed	38	Used LS TSS for TS1 (blown in TSS)	Zeros entered into TOC column to obtain LCCS ratings. Used LS TSS for TS1 (blown in TSS)
Reclaimed	39		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	40		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	41	No data for TSS - put in 7.5 (arbitrary) and 0 for EC and SAR	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	42	Zeros entered into TOC column to obtain LCCS ratings. Used lower TSS data for TS1 (blown in TSS)	Zeros entered into TOC column to obtain LCCS ratings. Used lower TSS data for TS1 (blown in TSS)
Reclaimed	43	TOC, TN data from resampled data. Entered 20-50 size Resampled ptmix texture is SL	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	44	Resampled ptmix texture SL	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	45	TOC, TN from resampled data Used Site 48 overburden resampled data (approximately 250 m from each other) Resampled ptmix texture is SCL	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	46		Zeros entered into TOC column to obtain LCCS ratings. Changed LS1 texture from HC to C.
Reclaimed	47	Used Resampled data for TSS	Zeros entered into TOC column to obtain LCCS ratings. Used Resampled data for TSS
Reclaimed	48	Used resampled data for LS2 (overburden) Resampled ptmix texture is SL	Zeros entered into TOC column to obtain LCCS ratings. Used resampled data for LS2 (OB)
Natural	49	Entered Zeros for EC and SAR where no data is available pH: LFH CaCl2 pH (4.7), Ae CaCl2 pH (4.2), Bm CaCl2 pH (4.4)	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 4.6 pH (H2O pH was 5.4)
Natural	50	Entered Zeros for EC and SAR where no data is available Bt, BC, Cca - entered 10-20 for size pH: LFH CaCl2 pH (5.8), Ae2 CaCl2 pH (5.3), Bt CaCl2 pH (5.8) Ae1 - entered 5.3 (equal to Ae2) BC and Cca - entered 7.8 (equal to Cca)	Entered Zeros for TOC, EC and SAR where no data is available Bt, BC, Cca - entered 10-20 for size Ae1 - entered 4.5 (equal to Ae2) BC and Cca - entered 7.8 (equal to Cca H2O pH)

Type	Site ID	Notes 2006	Notes 1998
Natural	51	Entered Zeros for EC and SAR where no data is available BC - entered 20-50 for size pH: LFH CaCl2 pH (6.2), Ae CaCl2 pH (6.2), Bt1 CaCl2 pH (5.6) Bt2 - pH between Bt1 and BC	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 20-50 for size Bt2 - pH between Bt1 and BC BC - entered 5.8 (H2O pH was 6.2)
Natural	52	Entered Zeros for EC and SAR where no data is available pH: LF CaCl2 pH (4.8), Ae CaCl2 pH (4.7), Bm CaCl2 pH (5)	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 5.6 pH (H2O pH was 6.1)
Natural	53	Entered Zeros for EC and SAR where no data is available pH: LF CaCl2 pH (4.9), Ae CaCl2 pH (4.3), Bm CaCl2 pH (4.8)	Entered Zeros for TOC, EC and SAR where no data is available BC - entered 5.9 pH (H2O pH 6.3)
Natural	54	Entered Zeros for EC and SAR where no data is available Cca - entered 20-50 for size pH: LFH CaCl2 pH (5.1), Ae CaCl2 pH (4.7), Bt1 CaCl2 pH (4.6), Bt2 - entered 6.6 (between Bt1 and Cca)	Entered Zeros for TOC, EC and SAR where no data is available Cca - entered 20-50 for size Bt2 - entered 6.2 (between Bt1 and Cca) Cca - entered 7.8 pH (H2O pH was 7.8)
Natural	55	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. Cca - entered 20-50 for size pH: LFH CaCl2 pH (4.7), Ae CaCl2 pH (4.1), Bt1 CaCl2 pH (4.8), Bt2 - entered 6.8 (between Bt1 and Cca)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Cca - entered 20-50 for size Bt2 - entered 6.4 (between Bt1 and Cca) Cca - entered 8 (H2O pH was 8.0)
Natural	56	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. BC - entered 20-50 size pH: LFH CaCl2 pH (5), Ae CaCl2 pH (4.4), Bt1 CaCl2 pH (4.4), AB - entered 5.2 pH (same as Ae and Bt), Bt2 - entered 5.2 pH (equal to Bt2)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. AB - entered 4.4 pH (same as Ae and Bt) Bt2 - entered 4.3 pH (between BC and Bt1) BC - entered 4.1 pH (H2O pH was 5.1)
Natural	57	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. BCgj - entered 20-50 size pH: LFH CaCl2 pH (5.5), Ae CaCl2 pH (4.5), Btgj CaCl2 pH (5), AB - entered 5.5 pH (between Ae and Btgj1), Btgj2 - entered 6.4 pH (between Btgj1 and BCgj)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. BCgj - entered 20-50 size AB - entered 4.8 pH (between Ae and Btgj1) Btgj2 - entered 6 pH (between Btgj1 and BCgj) BCgj - entered 7.0 pH (H2O pH 7.0)
Natural	58	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (5.5), Ae CaCl2 pH (4.7), Bm CaCl2 pH (4.8), C - same as BC	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. BC and C - entered 5.9 pH (H2O pH was 6.3)
Natural	59	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (4.8), Ae CaCl2 pH (4.4), Bm1 CaCl2 pH (4.5), Bm2 - 5.7 pH entered (between Bm1 and BC)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Bm2 - 5.1 pH entered (between Bm1 and BC) BC - 5.6 pH entered (H2O pH 6.1)

Type	Site ID	Notes 2006	Notes 1998
Natural	60	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LFH CaCl2 pH (4.4), Ae CaCl2 pH (5.1), Btj pH (5.2), Bm - entered 6.9 pH (between Btj and Cca)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Ae, Bm, Cca - entered <10 for size Bm - entered 6.5 pH (between Btj and Cca)
Natural	61	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. BC - entered 10-20 for size Cca - entered 20-50 for size pH: LFH CaCl2 pH (5.2), Ae CaCl2 pH (4.6), Bt CaCl2 pH (5.1), BC - entered 6.8 pH (between Bt and Cca)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. BC - entered 10-20 for size Cca - entered 20-50 for size BC - entered 6.4 pH (between Bt and Cca) Cca - entered 7.8 (H2O pH was 7.8)
Natural	62	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (4.5), Ae CaCl2 pH (5.1), Bm CaCl2 pH (5.5)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. BC - entered 6.4 pH (H2O pH was 6.6)
Natural	63	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (5.1), Ae CaCl2 pH (5.3), Bm CaCl2 pH (5.2)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. BC - entered 6.4 pH (H20 pH was 6.6)
Natural	64	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (4.5), Ae CaCl2 pH (3.7), Btjgj CaCl2 pH (4.2), IIBmgj - entered 5.4 (between Btjgj and IIBCgj)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. IIBmgj - entered 4.6 (between Btjgj and IIBCgj) IIBCgj - entered 4.9 pH (H2O pH was 5.6)
Natural	65	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LF CaCl2 pH (5), Ae CaCl2 pH (4.3), Btj CaCl2 pH (4.1), Bm - entered 5.3 (between Btj and BC)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Bm - entered 4.4 (between Btj and BC) BC - entered 4.6 (H2O pH was 5.4)
Natural	65.02	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: H CaCl2 pH (6.8), Ae CaCl2 pH (4.2), Bm CaCl2 pH (5.2)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating.
Natural	66	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. pH: LFH CaCl2 pH (5.8), Ahe CaCl2 pH (5.4) IIBCk - 7.5 pH because it is calcareous	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Btjgj - entered 5.2 pH (H2O pH was 5.8) IIBCk - entered same pH as Btjgj - probably higher because of k horizon
Reclaimed	67	Used resampled chemistry data	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. LS - entered 6.6 pH (US H2O and CaCl2 pH were the same - 6.6) and LS H2O was 6.6
Natural	68	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. Ahj - <10 size Bm, IIC1, IIC2 - entered 10-20 size pH: LFH CaCl2 pH (6.7), Ahj CaCl2 pH (5.4), IIC1 CaCl2 pH (6.1), Bm - entered 6 pH (between Ahj and IIC1)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Ahj - <10 size Bm, IIC1, IIC2 - entered 10-20 size Bm - entered 5.6 pH (between Ahj and IIC1) IIC2- entered 6.1 (H2O pH was 6.4)

Type	Site ID	Notes 2006	Notes 1998
Natural	69	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. Ahj - entered <10 for size C1 and C2 - entered 10-20 for size pH: LFH CaCl2 pH (6.9), Ahj CaCl2 pH (7), C1 CaCl2 pH (6.9)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Ahj - entered <10 for size C1 and C2 - entered 10-20 for size C2 - entered 7.1 for pH (H2O pH was 7.1)
Natural	70	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. Ahj - entered <10 for size IIC and IIIC - entered 10-20 for size pH: LFH CaCl2 pH (6.2), Ahj CaCl2 pH (6.6), IIC CaCl2 pH (6.8)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. Ahj - entered <10 for size IIIC - entered 10-20 for size IIIC - entered 7.2 pH (H2O pH 7.2)
Natural	71	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: Ahj CaCl2 pH (7.1), C CaCl2 pH (7.2), IIC CaCl2 pH (7.3), LFH - selected arbitrarily	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating.
Natural	72	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. C - entered 10-20 for size IICgj - entered 20-50 for size pH: LFH CaCl2 pH (7.0), Ahj CaCl2 pH (7.0), C CaCl2 pH (7.0)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. C - entered 10-20 for size IICgj - entered 20-50 for size IICgj - entered 7.9 pH (H2O pH was 7.9)
Natural	73	Zeros were entered into the EC and SAR columns to obtain the LCCS rating. pH: LFH CaCl2 pH (6.8), Ahj CaCl2 pH (7.3), Btjgj CaCl2 pH (7.5)	Zeros were entered into the TOC, EC and SAR columns to obtain the LCCS rating. IIBCg - entered 7.6 pH (H2O pH was 7.6)
Reclaimed	74	pH: TS CaCl2 pH (7.3)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. TS - 7.3 pH (CaCl2 pH was 7.3)
Reclaimed	75	Entered LS as massive and 20-50, no values were entered previously. No TN data for C:N ratio	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. Entered LS as massive and 20-50, no values were entered previously. Assumed LS consistence was very firm
Reclaimed	76	Entered 20-50 size for TS and size 10-20 for LS - arbitrarily. No TN data for C:N ratio	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. Entered size for TS and massive and size for LS.
Natural	77	Zeros were entered in the EC and SAR columns to get the LCCS rating.	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.
Natural	78	Zeros were entered in the EC and SAR columns to get the LCCS rating. No structure type, assumed Granular to fine blocky - no deduction regardless	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. No structure type, assumed Granular to fine blocky - no deduction regardless
Natural	79	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LFH CaCl2 pH (6.1), C1 CaCl2 pH (6), C2 CaCl2 pH (6.7)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.

Type	Site ID	Notes 2006	Notes 1998
Natural	80	Zeros were entered in theEC and SAR columns to get the LCCS rating. pH: LFH CaCl2 pH (6.2), C1 CaCl2 pH (4.7), C2 pH (4.4)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.
Natural	81	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (4.6), Ae CaCl2 pH (4.1), Bm CaCl2 pH (4.8)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.
Natural	82	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (4.3), Ae CaCl2 pH (3.8), Bm CaCl2 pH (4.8)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.
Natural	83	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (5.2), Ae CaCl2 pH (4.9), Bm CaCl2 pH (5.4)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating.
Reclaimed	84	LS - 20-50 size added	Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	85		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	86		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	87		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	88		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	89		Zeros entered into TOC column to obtain LCCS ratings.
Natural	90	Zeros were entered in the EC and SAR columns to get the LCCS rating. Ae - BD and pH same as Bm pH: LF CaCl2 pH (5.4), Bm CaCl2 pH (6), BC CaCl2 pH (5.7)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. Ae - 5.2 pH (same as Bm) C - 5.8 pH (H2O pH was 6.2)
Natural	91	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (3.5), Ae CaCl2 pH (4), Bm CaCl2 pH (4.5) LF bulk density selected as 0.15 g/cm^3	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. BC - 6.1 pH entered (H2O pH was 6.4)
Natural	92	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 ph (4), Ae CaCl2 pH (3.6), Bm CaCl2 pH (4.4) bulk density of LF selected as 0.15 g/cm^3	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. BC - 6.2 pH (H2O pH was 6.5)

Type	Site ID	Notes 2006	Notes 1998
Natural	93	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (5.2), Ae CaCl2 pH (3.9), Bm CaCl2 pH (4.8) LF bulk density selected as 0.15 g/cm^3	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. BC - 6.0 pH (H2O was 6.3)
Natural	94	Zeros were entered in the EC and SAR columns to get the LCCS rating. pH: LF CaCl2 pH (3.1), Ae CaCl2 pH (4.2), Bm CaCl2 pH (4.8)	Zeros were entered in the TOC, EC and SAR columns to get the LCCS rating. BC - 6.2 pH (H2O pH was 6.5)
Reclaimed	95	Coke classified as Sand texture class	Zeros entered into TOC column to obtain LCCS ratings. Coke classified as Sand texture Class
Reclaimed	96		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	97		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	98	LS - 20-50 size Says lean oil sand - might be impermeable; if so, AWHC (and capability) will be lower	Zeros entered into TOC column to obtain LCCS ratings. LS - 20-50 size
Reclaimed	99	LS - 20-50 size Says OB is lean oil sand - might be impermeable; if so, AWHC (and capability) will be lower	Zeros entered into TOC column to obtain LCCS ratings. LS - 20-50 size
Reclaimed	100		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	101		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	102		Zeros entered into TOC column to obtain LCCS ratings.
Reclaimed	103		Zeros entered into TOC column to obtain LCCS ratings.

Appendix II

Land Capability Classes

Source: Cumulative Environmental Management Association, Reclamation Working Group. 2006. Land capability classification for forest ecosystems in the oil sands. Volume 1: Field manual for land capability determination. Third Edition. 22 pp.

There are five classes of land recognized in the LCCS, rated according to potential and limitations for productive forest use. Classes are based on adjusted Canada Land Inventory categories, with Classes 1, 2 and 3 being capable of supporting commercial/productive forests, and Classes 4 and 5 being non-commercial/lower-productivity forest lands. The classes are an approximate assessment of the degree or intensity of limitation. For example, Class 3 land has limitations that are more severe than Class 2.

Class 1 High Capability (Final land rating 81 to 100): Land having no significant limitations to supporting productive forestry, or only minor limitations that will be overcome with normal management practices.

Class 2 Moderate Capability (Final land rating 61 to 80): Land having limitations which in aggregate are moderately limiting for forest production. The limitations will reduce productivity or benefits, or increase inputs to the extent that the overall advantage to be gained from the use will still be attractive, but appreciably inferior to that expected on Class 1 land.

Class 3 Low Capability (Final land rating 41 to 60): Land having limitations which in aggregate are moderately severe for forest production. The limitations will reduce productivity or benefits, or increase inputs to the extent that the overall advantage to be gained from the use will be low.

Class 4 Conditionally Productive (Final land rating 21 to 40): Land having severe limitations; some of which may be surmountable through management, but which cannot be feasibly corrected with existing practice.

Class 5 Non-Productive (Final land rating 0 to 20): Land having limitations that appear so severe as to preclude any possibility of successful forest production.

Appendix III

Regression Analysis of Individual LCCS Components

<provided in a separate interactive Excel application>