Stand Survey & Growth Modeling for the TFL 49 Results-Based Pilot Project: Final Report

Prepared for

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Executive Summary

Riverside Forest Products Ltd. is implementing a results-based Forest Practices Code (FPC) pilot project on TFL 49. This report describes a first approximation method we developed to compare actual with target silviculture performance as part of this FPC pilot. This method uses stand, site, and tree information collected in a new silviculture survey to predict stand merchantable volume 80 years after harvest. The idea is that silviculture obligations are met if the overall average forecasted volume based on stand surveys meets or surpasses the volume predicted using target stand attributes.

Future merchantable volume is predicted using equations based on the mean number of stocked quadrants in sampled stands. Stands are surveyed 10 years after harvest using a combination of *full-measure* and *count-plots* established on a 100 m grid. The *full-measure* plots are established on the 200 m grid where all trees are measured for height, species, and health condition. The *count-plots* are established on a 100 m grid between the full-measure plots where less detailed measurements are taken. Steel pins are used to mark the location of the full-measure plots so they can be relocated and included in subsequent surveys. This will then provide data that can be used to estimate change in these young stands over time.

Acknowledgements

We thank Lorne Bedford, *RPF*, Pat Martin, *RPF*, Barry Snowdon, *MSc RPF*, and Wendy Bergerud, *MMath*, of the B.C. Ministry of Forests for their comments on an earlier draft of this report. We also thank Gary Bouthillier (Resource West Consulting Ltd., Kelowna) for his help at all stages of this project and for his excellent ideas of how to make this survey operationally feasible.

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1. INTRODUCTION

1.1 BACKGROUND

Riverside Forest Products Ltd. is implementing a results-based Forest Practices Code (FPC) pilot project on TFL 49 to explore new ways to regulate the FPC, create efficiency, and save costs for industry and government. A key component of this pilot project is the ability to compare silviculture performance with a predetermined target. Riverside proposed to evaluate silviculture performance in three steps:

1) Use a simple survey to collect information on regenerated stands.
2) Use the stand survey information to predict volume growth.[1]
3) Compare the predicted volume growth for all harvested blocks with a target total for those blocks.

The goal was to design a results-based system that achieved overall silviculture performance goals, but one that avoided the high cost of micro-managing individual blocks and portions of blocks.

1.2 PROJECT OBJECTIVES

The objective of this project was to design the stand survey and growth modeling tools needed to implement Riverside's ideas for a result-based silviculture performance system under the FPC pilot project. Secondary objectives of this project were to: 1) outline how the proposed stand survey could link to other silviculture surveys to estimate growth and yield change in young stands; and 2) develop a first approximation system to estimate log size distributions from the survey information.

1.3 PROJECT OVERVIEW

This project was completed in three phases. The first phase was to design and field-test the stand survey methods. A preliminary survey (version 1) was designed and tested in the fall of 2000 (Appendix I). These methods were subsequently modified and a new survey (version 2) was tested during the summer of 2001 (Appendix II). The final prototype survey design (version 3) is presented in this report (Section 2).

The second phase was to use growth and yield model simulations to help identify stand characteristics that have a significant impact on simulated volume growth. This was done using TASS[2] simulations completed in the 2000/01 fiscal year (Appendix III). TIPSY[3] runs were subsequently completed to determine key variables in setting MAI targets (Appendix IV).

The third and final phase of this project was to design and test modeling systems to predict merchantable volume 80 years after harvest from the stand survey data. TASS simulations and survey simulations were used for this purpose. These simulations and results are described in this report.

[1] The initial target variable was maximum mean annual increment (MAI). In August 2001, this variable was changed to merchantable volume 80 years after harvest in order to allow comparison of volume at a fixed point in time.

[2] TASS (Tree and Stand Simulator) is a computer growth and yield model developed by Ken Mitchell of the MOF Research Branch. This biologically-based model simulates the growth of individual tree in three-dimensions.

[3] TIPSY (Table Interpolation Program for Stand Yield) is the computer program developed by the MOF Research Branch to summarize yield tables developed by TASS.

1.4 TERMS OF REFERENCE

This project was completed by J.S. Thrower and Associates Ltd. (JST) for Riverside of Kelowna, BC. The JST project team was Eleanor McWilliams, *MSc RPF*, Jim Thrower, *PhD RPF,* Dave Affleck, *MSc*, Ian Cameron, *MSc RPF,* and Guillaume Thérien, *PhD*. The Riverside project leader was Shane Browne-Clayton, *RPF*.

Figure 1. Field trip on TFL 49 to review version 1 of the prototype field sampling methods (July 2001). Standing from left to right: Fred Usselman (Spectrum Forest Consulting), Gary Bouthillier (Resource West Consulting Ltd., Kelowna), Bob Johnson (Riverside Forest Products Limited, Armstrong), Bob Bazett (Riverside Forest Products Limited, Kelowna), Shane Browne-Clayton (Riverside Forest Products Ltd., Kelowna), Eleanor McWilliams (J.S Thrower & Assoc. Ltd., Vancouver), Don Wylie (Riverside Forest Products Limited, Armstrong). Kneeling in front: Kathy Swift (Interior Lumber Manufacturer's Assoc., Kelowna), Gerome Girard (Riverside Forest Products Ltd., Kelowna). Photographer: Jim Thrower (J.S. Thrower & Assoc. Ltd., Kamloops).

2. STAND SURVEY

2.1 OVERVIEW

The key components of the stand survey as described in detail below are:

1) All stands are surveyed 10 years after harvest.

2) Sample plots are located on a 100 m grid generated from UTM coordinates.

3) All points on a 100 m grid in harvested stands are sampled.

4) Full-measure plots are located on the 200 m grid points and count plots are located on the 100 m grid points.

5) Both plot types use a 3.99 m radius tree plot (50 m^2) to measure tree attributes and a 5.64 m radius site index plot (100 m^2) to measure site trees. Measurement in all 3.99 m tree plots are recorded by quadrant.

6) Measurements in full-measure plots include: a) species, height (visually estimated) and health of all trees; b) an assessment of stocked or not stocked for each quadrant (for a quadrant to be stocked it must contain at least one healthy free-growing tree); c) an assessment of non-productive area and brush; and d) height and age of one site tree per species. Full-measure plots are marked with a steel pin and GPS coordinates taken for future relocation for including in subsequent surveys.

7) Measurements in count plots are also recorded by quadrant and include only: a) an assessment of stocked or not stocked for each quadrant; b) an assessment of why non-stocked quadrants are such (e.g., brush, non-productive area, health); c) a tally of total trees by species; and d) height and age of one site tree per species.

2.2 SURVEY OBJECTIVES

The goal of the survey is to describe stand characteristics in sufficient detail to predict merchantable volume 80 years after harvest to compare with a target volume for that time, and to predict how that volume is distributed among log size classes. The intent is that the predicted merchantable volume for a stratum (described below under Target Population) is compared to a pre-determined target merchantable volume for that stratum. The goal is to develop target merchantable volumes for each site series and commit to achieving these target volume in higher-level plans.

The objectives of the stand survey are to:

1) Update block maps to define areas where volume should be predicted and where other values take precedence (e.g., wildlife).

2) Measure tree conditions, stand structure, and site productivity (where possible).

3) Produce inventory labels.

4) Identify potential areas for silviculture treatments.

2.3 TARGET POPULATION

The target population to sample in a given year is the net area to be reforested (NAR) created from harvesting 10 years previously. For example, the target population for sampling year 2002 is the NAR resulting from 1992 harvesting. The modeling procedures developed in this project assume stands are surveyed 10 years after harvest. The areas to be sampled will be stratified on the ground by the surveyors based on site index or site series, species composition, density[4], and potential treatments (e.g., brushing, spacing, fill-planting). Merchantable volume will then be estimated for each stratum using the methods described in the next section of this report.

2.4 LINK TO OTHER SURVEYS

The stand survey will be linked with other surveys by using a common sample grid for all surveys. Full measure plots (Section 2.6.2) located on the 200 m grid point will be included in all surveys. This will provide the data to develop a chrono-sequence of measurements over time similar to a permanent sample plot. The 200 m grid points are marked with steel pins and UTM coordinates recorded to assist relocation for subsequent surveys.[5] The permanent markers at these 200 m sample plots should be installed at the first survey completed in a stand.

As an example, the same plot locations could be measured during pay plot surveys following planting, stocking surveys, and a pole-stage survey done at 20 years of age. The same plot size (3.99 m radius) must be used and the same measurements (species, quadrant, estimated heights, damage codes, percent brush cover and brush height[6]) must be taken during each survey. This provides data to track changes over time to give feedback on silviculture treatments, and also provide data to indirectly check predicted merchantable volume by providing growth data to check TASS projections.

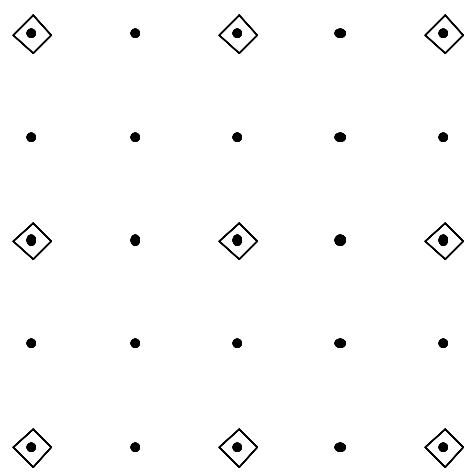

Figure 2. Example of points on a 100 (•), and 200 ( ) m grid.

2.5 OFFICE PROCEDURES

2.5.1 Map & Previous Data

Maps of each block will be available in the GIS. A Silviculture Prescription (SP) map (or equivalent) should be used to develop the plot locations of the stand survey and should be updated following each survey. This map should show block boundaries, non-productive (NP), non-commercial cover (NCC), wildlife tree patches (WTP), riparian management areas (RMA), permanent access structures (PAS), and temporary roads. If permanent sample points have been established in a previous survey (section 2.4), the data should be downloaded to hand-held computers for comparison and error checked during the survey. The surveyor should also be familiar with the block history.

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[4] We suggest initially using two density classes (high with more than 1,600/ha and low with fewer trees).

[5] Appendix II contains information on field testing this procedure in 2001.

[6] If brush is a significant management issue, then surveys should be done at the same time of the year to ensure consistent % cover estimates.

2.5.2 Office Stratification

Each block map should be stratified prior to field sampling to show areas included in the volume estimate (the area equivalent to the current definition of NAR), and areas to be netted-out. Sample plots should only be located in the NAR. Stratification of the surveyed area should then be updated in the field after the survey is complete.

2.5.3 Plot Locations

Sample plots are located on a 100 m grid (Figure 2) using UTM NAD 83 coordinates. These grid points can be generated in the GIS by plotting points evenly divisible by 100 (Table 1). Plot locations should be marked on the map prior to field sampling. All 100 m grid points within the NAR of each block should be sampled.

2.5.4 Sample Size

The sample in each stratum includes full measure plots located on the 200 m grid points (Section 2.6.2) and count plots (Section 2.6.3) located at the 100 m grid between the full measure plots. This gives a sample intensity of one plot/ha, with a full-measure plot every four hectares. We suggest that the minimum strata size is 30 ha to give at least 30 sample plots for analysis (Appendix V). If strata smaller than 30 ha are necessary, the sample size can be increased by adding plots on a 50 m grid between the 100 m grid points.

2.6 FIELD SAMPLING

2.6.1 Field Stratification

Field stratification consists of two components. First, the NAR must be clearly defined and the map updated if necessary. The area surveyed in each block is equivalent to the current definition of NAR. Second, the sampled area must be stratified and mapped for the purpose of estimating future volume by site index (site series), leading species, density,[4] and potential treatments. The updated block maps will provide better information for volume and product modeling, and will help identify areas where additional silviculture treatments may increase volume production or improve product quality.

Table 1. Example Easting and Northing UTM NAD83 coordinates for a 100 and 200 m grid.

Easting	Northing	200 m Grid
317,000	5,603,000	X
317,000	5,603,100	
317,100	5,603,000	
317,100	5,603,100	
317,200	5,603,000	X
317,200	5,603,100	
317,300	5,603,000	
317,300	5,603,100	

Areas to update and identify on maps include:

1) NP (swamps, rocks, shallow soil, etc.) ≥ 0.25 ha.
2) NC brush.
3) Roads (permanent and temporary).
4) WTPs.
5) Partially-cut areas.
6) RMAs (reserves and management zones as necessary).
7) Strata based on site index or site series, leading species, density[4], and potential treatments.

2.6.2 Full Measure Plots

Each full measure plot includes a 50 m^2 (3.99 m radius) plot divided into quadrants along cardinal directions to measure tree attributes and a 100 m^2 (5.64 m radius) plot to collect site tree data (located at the same plot center) (Figure 3). Site index should be estimated for each species in the site index plot where suitable site trees have three or more years height growth above breast height.

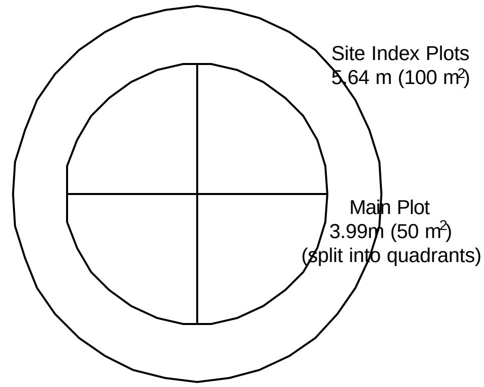

Figure 3. Full measure and count plot design.

Plot Location

Full measure plots are established on the 200 m grid. Plot centers should be permanently marked with a steel pin and GPS coordinates recorded. Plot locations should be documented in the GIS. These sample points should not be visible when walking through the stand to avoid treating the plot area differently than other portions of the stand (which may bias the information from the sample point at subsequent measurements).

Main Plot - 50 m^2

Quadrant Information - Record each quadrant as stocked if it contains at least one healthy tree of an acceptable species that is free of brush competition (according to current free growing regulations). If a non-stocked quadrant could support tree growth, comment on why there are no trees (e.g., type of non-productive ground, missed plantable spots, brush competition, health problems).

Tree Information - Data for each tree in the plot includes:

i) Quadrant number (1-4).
ii) Species.
iii) Height (dm) (measure some for reference and visually estimate others).
iv) Forest health codes – use the same codes used in other silviculture surveys.

Brush Information - In each quadrant record percent cover and average height (nearest decimeter) of brush by species.

NP Area Information - In each quadrant record the type and percent cover of NP area (e.g., rock, water).

Site Index Plots - 100 m^2

Record site index information for one tree of each species from the site index plot (5.64 m radius) located at each plot center. Site trees are:

i) The tallest tree in the 100 m^2 plot for that species.
ii) Undamaged (stem damage resulting in less than 5% reduction in height growth).
iii) Not overtopped by other trees or competing vegetation where height growth may be affected.

The second tallest tree can be measured for site index if the tallest is not suitable. This must be noted on the field card. Information collected for each tree should include:

i) Total height (dm).
ii) Age at breast height (yrs).
iii) Total age (yrs).
iv) Rank in height relative to other trees in the plot of that species (e.g., tallest, 2nd tallest, etc.).

2.6.3 Count Plots

Each count plot includes a 50 m^2 plot to collect stocked quadrant information and a 100 m^2 plot to estimate site index (Figure 3).

Plot Location

Count plots are established at the 100 m grid points between each full measure plot. Count plots are not permanently marked and GPS coordinates are not recorded.

Main Plot - 50 m^2

Quadrant Information - Record each quadrant as stocked if it contains at least one healthy tree of an acceptable species that is free of brush competition (the same as in full-measure plots). For non-stocked quadrants, record whether the quadrant is NP (and what type of NP) or could support tree growth. If a non-stocked quadrant can support tree growth, comment on why there are no trees (e.g., missed plantable spots, brush competition, health problems).

Tree Information - Tally the number of trees by species. This is used in analysis to estimate stand density and species composition.

Site Index Plots - 100 m^2

Measure site index trees as described for full measure plots.

2.7 SURVEY COSTS[7]

The average cost of free-growing surveys in the Kelowna area is approximately $18/ha (Riverside) to $20/ha (other Licensees). The cost of stocking surveys is about 5-10% less than free-growing surveys. The average cost of the survey methods tested on TFL 49 in the year 2001 was $42/ha. These tests were all full-measure plots established on a 100 m grid. Operational implementation will use the full-measure plots only at 200 m grid points and the less costly count plots at 100 m grid points. Thus, we estimate the cost to operationally implement this new survey could be about $25/ha for average sized openings.

[7] This information was provided by Gary Bouthillier, Resource West Consulting Ltd.

3. PREDICTING FUTURE VOLUME

3.1 OVERVIEW

TASS was used to simulate 433 different stand types with varying species composition, stand density, spatial distributions, and ingress patterns. The simulated stands were surveyed using the stem maps generated for a range of young stand ages using the procedures described in Section 2. Survey statistics were compiled and compared to merchantable volumes 80 years after harvest. The single best predictor of future volume was mean number of stocked quadrants (MSQ). A quadrant is considered stocked when it has at least one healthy tree of an acceptable species that is free of brush competition.

Based on these results, a model was developed to predict merchantable volume 80 years after harvest from survey data collected 10 years after harvest. Model inputs include species composition (limited at this time to Pl, Sx, or PlSx), MSQ, site index, and effective total stand age (determined from site index and total average site tree height).

3.2 OBJECTIVES

The goal of predicting future stand merchantable volumes is to compare the estimates with target merchantable volumes to measure silviculture performance. The objectives of the modeling are to:

1) Predict stand merchantable volume 80 years after harvest.
2) Use the least complicated method while accounting for key factors influencing future volume.

3.3 MODEL DEVELOPMENT

3.3.1 TASS Runs

TASS simulations generated a wide range of stand structures to develop and test a model to predict future merchantable volumes from stand survey data. These simulations were completed by the MOF Research Branch (Table 2) and included 433 combinations of planting and natural stand densities, species compositions, spatial, and temporal distributions. The various factors were combined in a factorial structure so that initial[8] stand density ranged from 400 to 9,400/ha and species composition ranged from 100% Pl or Sx and a full range of mixtures.

Table 2. Factors in the matrix of TASS runs used for model development.

Factor	Levels
Site Index	20 m
Species	Pl, Sx
Planting Density (no/ha)	0, 400, 800, 1000, 1200, 1400[a]
Natural Density (no/ha)	0, 400, 800, 1200,1600, 2000, 5000, 8000
Spatial distribution of naturals	Random, Clumped[b]
Ingress period of naturals	TASS default (truncated Normal (2, 1.5)), Poisson (4)[c]

[a] Planting was assumed to occur one year after harvest with 1 year old stock.
[b] Naturals were apportioned 75% to clumps and 25% random, with an average of 25 trees/clump.
[c] Normal (2, 1.5) is a Normal distribution with mean of 2 and standard deviation of 1.5. Poisson (4) is a Poisson distribution with a mean and variance of 4.

[8] The term "initial" is used to indicate the number of trees simulated by TASS prior to mortality.

The height vigor coefficient was included in all simulations. This results in the top height trees tracking the height over age curve for the assigned site index, regardless of stand density. Each TASS simulation was for a 3 ha block (100 x 300 m). No operational adjustment factors were applied, however, the natural clumped distributions with no planting resulted in holes distributed throughout the stands.

The following was generated for each TASS simulation:

1) A standard run summary produced annually from ages 1 – 15 and then every five years to age 120.
2) Merchantable log volumes every 20 years from age 60 to 120. Each tree was bucked into 5 m logs and a top log (< 5 m). For each log, the length, top and bottom diameters inside bark, and volume was output.
3) Stem maps for ages 5, 7, 10, and 13. These included x-y coordinates, species, and heights. Stand density at these ages varied due to the ingress and mortality patterns simulated in TASS.

3.3.2 Simulated Surveys

We simulated the survey in each stand by using the plot procedures described in Section 2. Plots were established on randomly oriented 25 m grids resulting in approximately 48 plots for each simulated survey (a 25 grid gives 16 plots/ha). For each plot, the species and height of each tree in each quadrant was recorded. For each of the 433 TASS simulations, 30 surveys were simulated for each of ages 5, 7, 10, and 13 for a total of 51,960 simulated surveys.

3.3.3 Model Fitting[9]

Summary statistics were calculated for all simulated surveys including mean, standard deviation, and coefficient of variation for tree height, number of trees per quadrant, number of stocked quadrants, and numbers of plots with 0, 1, 2, 3, and 4 stocked quadrants. These variables were compared to merchantable stand volume 70 years later (i.e., the summary statistics for stands "surveyed" at ages 5, 7, 10, and 13 were compared to merchantable volumes at age 75, 77, 80, and 83[10] respectively). Having the different stand ages allowed us to account for different regeneration delays when developing a survey system to be used 10 years after harvest to predict merchantable volumes 80 years after harvest.

Table 3. Mean number of stocked quadrants from 30 simulated surveys at age 10 using TASS with different combinations of planted and natural Pl.

Naturals		Planted Density (no/ha)					
Distributior	Densit (no/ha)	0	400	800	1000	1200	1400
Random	0		1.89	3.39	3.71	3.86	3.91
	400	1.56	2.75	3.62	3.86	3.95	3.96
	800	2.48	3.20	3.79	3.92	3.96	3.98
	1,200	3.02	3.54	3.85	3.95	3.98	3.99
	1,600	3.43	3.71	3.92	3.97	3.99	3.99
	2,000	3.66	3.81	3.95	3.98	4.00	4.00
	5,000	3.99	4.00	4.00	4.00	4.00	4.00
	8,000	4.00	4.00	4.00	4.00	4.00	4.00
Clumped	400	0.95	2.42	3.57	3.83	3.94	3.95
	800	1.60	2.77	3.65	3.89	3.95	3.97
	1,200	2.26	3.06	3.74	3.91	3.98	3.98
	1,600	2.63	3.28	3.79	3.93	3.98	3.98
	2,000	2.96	3.41	3.85	3.95	3.98	3.99
	5,000	3.84	3.91	3.98	3.99	4.00	4.00
	8,000	3.98	3.99	3.99	4.00	4.00	4.00

[9] Further details of the model fitting procedures are provided in Appendix VI.

[10] Volumes for ages 77 and 83 were linearly interpolated between volumes for ages 75 and 80, and ages 80 and 85 respectively.

The best predictor of future merchantable volume was MSQ (Table 3). Several equation forms were tested with the best fit provided by a quadratic equation:

$$PMV = a + b*MSQ + c*MSQ^2$$

Where **PMV** is *predicted merchantable volume*; ***a***, ***b***, and ***c*** are coefficients (Appendix VI); and **MSQ** is the number of *mean stocked quadrants* from the sample of a stand or stratum.

Subsequent testing showed that a set of anamorphic curves (parameters *b* and *c* are held constant) could be fit to the data with separate intercepts (parameter *a*) being fit for each of 12 stand age and species combinations. The four ages were 5, 7, 10, and 13 (Figure 4). The three species groups are pure Pl (≥ 80% Pl based on stand density at the time of the survey), pure Sx (≥ 80% Sx based on SPH at the time of the survey), Pl/Sx mix (21-79% Pl and Sx based on SPH at the time of the survey). Two mixed species groups were tested (one Pl leading and Sx leading) but they did not provide a better fit than a single mixed group.

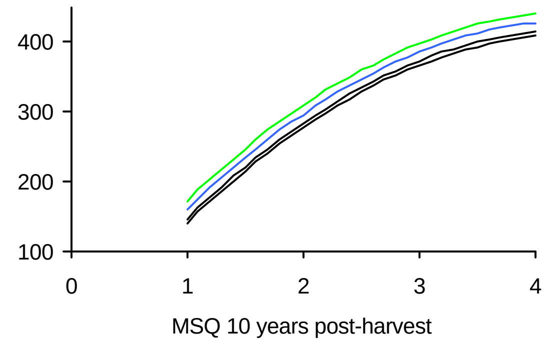

Figure 4. Anamorphic curves showing merchantable volume 80 years after harvest as a function of MSQ 10 years after harvest and effective stand ages (age 5 (—), 7 (—), 10 (—), and 13 (—). These curves are for SI 20 pure Pl.

3.3.4 Site Index

At the beginning of the project the decision was made to use a single site index value for both predicted and target merchantable volumes across all sites. This was done to simplify the procedure. However, since this solution does not identify those sites producing the most volume (and thus, those sites to focus silviculture investment), we incorporated a range of site indices into the predicted volumes.

Fixed Site Index for Target and Predicted Volumes

The objective of the volume comparison is to focus on the impacts that silviculture performance has on volume growth. For each stratum, the same site index estimates should be used to set the target merchantable volume and determine the PMV. The differences in volume are then associated with differences in stand structure, and not on potential differences in site index. Site index estimates should be based on the best available information for each block (e.g. Site Index Adjustment, SIBEC, growth intercepts).[11]

Effective Age – Early Height Growth

Early height growth is a function of many variables including site productivity, stock and planting quality, and brush and health impacts and as a result, early height growth can be highly variable. Implicit in TASS and the prediction models are a set of site curves (height-age curves) that define site tree height growth. Once a site index has been chosen for a stratum, there is a defined height-age curve that the site trees follow. Furthermore, for the purposes of this project, the height-age curve is assumed to represent

[11] Timberline Forest Inventory Consultants are currently working on a site index project for Riverside. This project will be completed by March 31, 2002.

the target height growth pattern. If management practices result in trees growing faster or slower than assumed, then Riverside should be rewarded or penalized accordingly. To achieve this, the following steps can be taken:

1) Determine a site index for the leading species in the stratum.
2) Calculate the average site tree height of the leading species from the survey data.
3) Determine the effective total stand age by using the average site tree height and the appropriate height-age curve.

If management practices are better than assumed in the height-age model, then the effective total stand age is older than the physiological age. The reverse is also true (Figure 5).

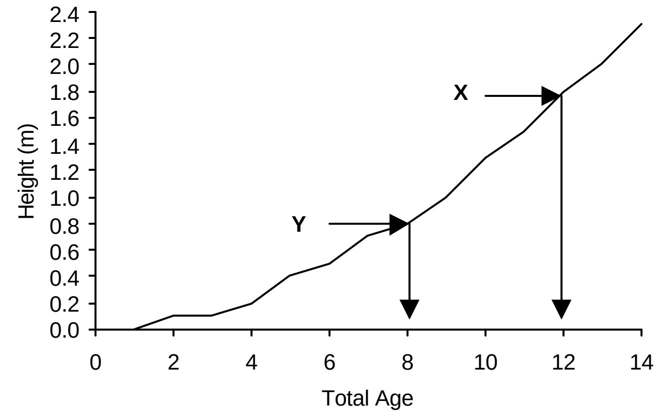

Figure 5. Height-age curve for Sx site index 20 m. Assume the target is set so the stand is 10 years total age 10 years after harvest. For a site index 20 m stand, site trees are assumed to be 1.3 m tall. If the site trees are growing better than expected (X), the effective total stand age is 12 year. If they are poorer than expected (Y), the effective total stand is 8 years.

This method depends on average, realistic site index estimates. If estimated site indices are low, then effective stand ages would be too high on average. These higher ages would not represent better stand management practices, but would be higher because productivity is better than estimated.

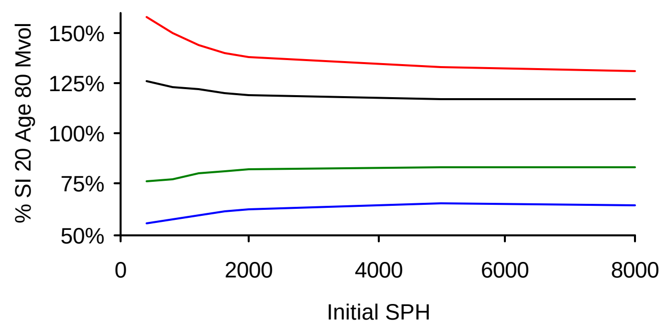

Figure 6. Merchantable volume at age 80 for Pl site index 24 (—), 22 (—), 18 (—), and 16 (—) as a % of merch volume at age 80 for site index 20 across a range of initial SPH. Data are from TIPSY.

This method is proposed as one way to deal with the large variation in years to reach breast height. Ideally, predictions would be based on years above breast height, but many Sx leading stands do not reach breast height by 10 years after harvest.

Table 4. Volume multipliers to adjust target and predicted merchantable volume for different site indices.

	Site Index (m)								
	16	17	18	19	20	21	22	23	24
Multiplier	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4

Volume Adjustment by Site Index

The equations for predicted merchantable volume were fit with data for site index 20. Ideally, separate equations would be fit for the range of site index on the TFL; however, this has not been done. As an alternative, adjustment factors have been developed to correct for different site indices.

Merchantable volumes at age 80 for a range of site indices and initial stand densities were expressed as a percentage of merchantable volume at age 80 for site index 20 (Figure 6). Similar relationships were found for Pl and Sx, and planted and natural stands. The general pattern observed was percent volume increasing (for site index < 20) or decreasing (for site index > 20) below approximately 2,000 SPH and then remaining fairly constant above this density. Table 4 shows the adjustment factors developed using these results. For stands under 2,000/ha these multipliers will slightly under predict volume for site index > 20 m and slightly over predict for site index < 20 m.

3.3.5 Operational Adjustment Factors (OAFs)

Three scenarios were tested to determine the impact that different stand hole patterns have on MSQ. The three scenarios were to remove trees on 15% (4,500 m^2) of the total area from the age 10 stem maps for the 89 pure Pl TASS simulations with the default temporal ingress pattern.[12] The patterns were one 4,500 m^2 hole, five 900 m^2 holes, and ten 450 m^2 holes. For each pattern, the surveys were re-simulated and new MSQ calculated and used in the volume prediction equation. There was little difference between MSQ estimates among the different stand hole patterns. On average, the volume predicted was 94% of the total merchantable volume predicted by TASS for that stand with no holes (values ranged from 88% to 100%). These results show we can assume that MSQ accounts for a portion of the OAF1, but determining additional details of the relationship will require more work.

3.3.6 Brush and Health Impacts

Brush and health impacts will be incorporated into the prediction system by defining whether or not a quadrant is stocked or not. For a quadrant to be stocked, it must contain at least one tree which meets the current free-growing standards for health and brush.

3.4 FINAL MODEL

This section outlines the steps to summarize the survey data and predict merchantable volume 80 years after harvest.

Step 1 – Set the Site Index for the Stratum

The average site index estimate for the stratum should be developed using the best available information (e.g., Site Index Adjustment, SIBEC, growth intercept).

Step 2 – Obtain Site Height Estimate

Calculate average site tree height for the leading species.

Step 3 – Estimate Effective Age

Derive effective stand age using the site index and average site height obtained in steps 1 and 2 (Appendix VII, Table 31 Table 32).

Step 4 – Estimate Mean Number of Stocked Quadrants

Calculate the mean number of stocked quadrants (MSQ) per plot using all full measure and count plots.

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[12] The TASS simulations were not re-run to determine the impact of the holes on the total merchantable volume. Reducing the area by 15% will not necessarily reduce the total merchantable volume by 15% as trees growing on edges of openings may be larger dependent on how effectively their crowns and roots can occupy the open space.

Step 5 – Estimate Species Composition

Determine percent species composition based on SPH using information from all full measure and count plots. Stands that are 80% or greater Pl or Sx are considered pure Pl and pure Sx stands respectively. All other stands are Pl/Sx mix.

Step 6 – Predict Merchantable Volume for Site Index 20

Choose the appropriate volume prediction table based on species composition (Appendix X, Table 33, Table 34, Table 35). Use MSQ and effective stand age to find the predicted merchantable volume 80 years after harvest.

Step 7 – Adjust Volume Prediction for Site Index

Multiply the predicted merchantable volume by the factor given in Table 4. This gives the final predicted merchantable volume 80 years after harvest for entry to the ledger.

3.5 SETTING TARGET MERCHANTABLE VOLUMES

Target merchantable volumes will be defined in a higher-level plan (probably by site series and management zone). The target merchantable volumes will be determined using (currently undefined) species and levels of establishment density, regeneration delay, and genetic worth. The key factors influencing future merchantable volumes are species, establishment density, and regeneration delay (Appendix IV). Target merchantable volumes should be set by defining the target stands and then simulating these in TASS for site index 20 and obtaining merchantable volume 80 years after harvest. For site indices other than 20, the multipliers in Table 4 should be used to maintain consistency with the method used to estimate predicted merchantable volumes.

4. PREDICTING FUTURE PRODUCTS

4.1 OVERVIEW

Predicting future products is more complex than predicting future volume. Two stands with the same merchantable volume can have drastically different log outputs depending on the number and distribution of stems. Riverside stated a preliminary log size distribution target to have 30% of the merchantable volume in 5 m logs with a top diameter greater than 20 cm.

4.2 TASS SIMULATIONS

An additional 354 TASS simulations were completed to examine the distribution of total merchantable volume by log size.[13] Key variables included numbers of planted and natural trees, spatial distribution of naturals, and tree species (Table 5). Repression effects were not included in the highest density runs. Output for each TASS simulation included:

i) A standard run summary.

ii) Merchantable log volumes every 20 years from age 60 to 120. Each tree was bucked into 5 m logs and a top log (< 5 m) using a 30 cm stump and 10 cm top diameter. The length, top, and bottom diameters inside bark, and volume were output for each log.

Table 5. Factors used to define the TASS runs to look at log output.

Factor	Levels
Site Index	20
Species	Pl, Sx
Planting Density (no/ha)	0, 400, 800, 1000, 1200, 1400[a]
Natural Density (no/ha)	0, 400, 800, 1200,1600, 2000, 5000, 8000, 12000, 16000, 20000
Spatial distribution of naturals	Random, Clumped[bd]
Ingress period of naturals	TASS default (truncated Normal (2, 1.5))[c]

[a] Planting was assumed to occur one year after harvest with one year old stock.
[b] Naturals were apportioned 75% to clumps and 25% random, with an average of 25 trees per clump.
[c] Normal (2, 1.5) is a Normal distribution with a mean of 2 and a standard deviation of 1.5.

4.3 ANALYSIS OF LOG OUTPUT

Numerous graphs and summaries were used to examine the distribution of log sizes for different stand types. MSQ values were not available for the simulations of higher stand densities, thus log output was compared to numbers of planted and natural stems and the spatial distribution of the naturals. There was no clear distinctions between planted and natural stands (random or clumped). The number of initial trees was the dominant factor in determining the distribution of log sizes. As a result, summary tables were prepared to show the trends of log distribution for different initial stand densities (Table 6, Table 7, Table 8).

Riverside's initial target of at least 30% total volume in logs with a top diameter greater than 20 cm is met in all initial density classes simulated. However, if the target top diameter was changed to 25 cm or greater, then only Pl stands with 800 or fewer trees/ha, Sx stands with 2000 or fewer trees/ha, and Pl-Sx

[13] These simulations included higher densities after the original 433 simulations showed that most lower stand densities would meet the target to have 30% or more merchantable volume in logs 20 cm and larger.

stands with 1200 or fewer trees/ha would meet the target. This demonstrates the importance of examining the effect of different targets on decisions.

The similar log distributions for all stands above about 5,000/ha initial densities is the result of normal stand dynamics producing stands with similar numbers of trees by age 80. For example, the TASS simulation of 5,000 of random natural Pl trees/ha had 4,752/ha at age 10 and 1,366/ha at age 80. The TASS simulations of 20,000 random natural Pl trees/ha had 17,883/ha at age 10 and 1,464/ha at age 80.

Table 6. Proportion (%) of total merchantable volume by 5 cm log size class and initial stand density for pure Pl stands. Values are averaged over all combinations of planted and natural stands with the same initial stand density.

Initial Stand Density (no/ha)	Log classes by top diameter inside bark (cm)										
	Pulp	10 -15	15-20	20-25	25-30	30-35	35-40	40-45	>= 20	>=25	>=30
400	2.5[a]	12.5	17.5	22.5	22.5	17.5	2.5	2.5	67.5	45.0	22.5
800	2.5	12.5	22.5	27.5	22.5	7.5	2.5	2.5	62.5	35.0	12.5
1,000	2.5	17.5	27.5	32.5	12.5	2.5	2.5	2.5	52.5	20.0	7.5
1,200	2.5	17.5	27.5	27.5	17.5	2.5	2.5	2.5	52.5	25.0	7.5
1,400	2.5	17.5	32.5	27.5	12.5	2.5	2.5	2.5	47.5	20.0	7.5
1,600	2.5	17.5	32.5	27.5	12.5	2.5	2.5	2.5	47.5	20.0	7.5
1,800	2.5	22.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2,000	2.5	22.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2,200	2.5	22.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2,400	2.5	22.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2,600	7.5	22.5	32.5	27.5	7.5	2.5	0.0	0.0	37.5	10.0	2.5
2,800	7.5	22.5	32.5	27.5	7.5	2.5	0.0	0.0	37.5	10.0	2.5
3,000	7.5	22.5	32.5	27.5	7.5	2.5	0.0	0.0	37.5	10.0	2.5
3,200	7.5	22.5	32.5	27.5	7.5	2.5	0.0	0.0	37.5	10.0	2.5
3,400	7.5	27.5	32.5	22.5	7.5	2.5	0.0	0.0	32.5	10.0	2.5
5,000											
5,400											
5,800											
6,000											
6,200											
6,400											
8,000											
8,400											
8,800						No change					
9,000											
9,200											
9,400											
12,000											
13,000											
16,000											
17,000											
20,000											
21,000											

[a] Percentages are given in classes, 2.5 = 0.1–5.0%, 7.5 = 5.1–10%, 12.5 = 10.1–15%, etc

Table 7. Percentage of merchantable volume by log class and initial stand density for pure Sx stands. Values are averaged over all combinations of planted and natural stands with the specified initial stand density.

Initial Stand Density (no/ha)	Log classes by top diameter inside bark (cm)										
	Pulp	10 -15	15-20	20-25	25-30	30-35	35-40	40-45	>= 20	>=25	>=30
400	2.5	7.5	17.5	22.5	22.5	17.5	7.5	2.5	72.5	50.0	27.5
800	2.5	12.5	22.5	22.5	22.5	12.5	2.5	2.5	62.5	40.0	17.5
1,000	2.5	17.5	22.5	27.5	17.5	7.5	2.5	2.5	57.5	30.0	12.5
1,200	2.5	17.5	22.5	27.5	17.5	7.5	2.5	2.5	57.5	30.0	12.5
1,400	2.5	17.5	27.5	22.5	17.5	7.5	2.5	2.5	52.5	30.0	12.5
1,600	2.5	17.5	27.5	22.5	17.5	7.5	2.5	2.5	52.5	30.0	12.5
1,800	2.5	17.5	27.5	22.5	17.5	7.5	2.5	2.5	52.5	30.0	12.5
2,000	2.5	17.5	27.5	22.5	17.5	7.5	2.5	2.5	52.5	30.0	12.5
2,200	2.5	17.5	27.5	27.5	12.5	7.5	2.5	2.5	52.5	25.0	12.5
2,400	2.5	17.5	27.5	27.5	12.5	7.5	2.5	2.5	52.5	25.0	12.5
2,600	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
2,800	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
3,000	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
3,200	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
3,400	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
5,000	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
5,400	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
5,800	7.5	22.5	27.5	22.5	12.5	7.5	0.0	0.0	42.5	20.0	7.5
6,000	7.5	22.5	32.5	22.5	12.5	2.5	0.0	0.0	37.5	15.0	2.5
6,200											
6,400											
8,000											
8,400											
8,800											
9,000											
9,200					No Change						
9,400											
12,000											
13,000											
16,000											
17,000											
20,000											
21,000											

[a] Percentages are given in classes, 2.5 = 0.1–5.0%, 7.5 = 5.1–10%, 12.5 = 10.1–15%, etc.

Table 8. Percentage of total merchantable volume by log class and initial SPH for PlSx stands. Values are averaged over all combinations of planted and natural stands with the specified initial SPH

Initial Stand Density (no/ha)	Log classes by top diameter inside bark (cm)										
	Pulp	10 -15	15-20	20-25	25-30	30-35	35-40	40-45	>= 20	>=25	>=30
800	2.5[a]	12.5	17.5	27.5	22.5	12.5	2.5	2.5	67.5	40.0	17.5
1200	2.5	12.5	22.5	27.5	22.5	7.5	2.5	2.5	62.5	35.0	12.5
1400	2.5	17.5	27.5	27.5	17.5	2.5	2.5	2.5	52.5	25.0	7.5
1600	2.5	17.5	27.5	27.5	17.5	2.5	2.5	2.5	52.5	25.0	7.5
1800	7.5	17.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2000	7.5	17.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2200	7.5	17.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2400	7.5	17.5	32.5	27.5	12.5	2.5	0.0	0.0	42.5	15.0	2.5
2600	7.5	22.5	32.5	22.5	12.5	2.5	0.0	0.0	37.5	15.0	2.5
2800											
3000											
3200					No Change						
3400											
6400											

[a] Percentages are given in classes, 2.5 = 0.1–5.0%, 7.5 = 5.1–10%, 12.5 = 10.1–15%, etc.

5. RECOMMENDATIONS & ISSUES

5.1 FIRST APPROXIMATIONS

The survey and modeling system described in this report are first approximations. Several simplifying assumptions were made in their development. The following sections outline the major assumptions and outstanding issues and provide recommendations for future work.

5.2 SITE INDEX

The predicted merchantable volume equations were fit with data for site index 20 m. Multipliers were then developed to adjust the predicted merchantable volume and target merchantable volume for other site indices (Table 4). These multipliers approximate volumes and for stands under 2000 stems per ha will result in a slight under prediction for site index greater than 20 m and a slight over prediction for site index less than 20 m. To provide more accurate estimates we recommend separate predicted merchantable volume equations be developed for the full range of site indices used to set target merchantable volumes.

5.3 SPECIES

Equations were developed for pure Pl, pure Sx, and Pl-Sx mixtures. Other species were not considered. The same procedures used to develop the equations for Pl and Sx could be used to develop equations for other species and species mixtures. In the interim, we recommend that the Sx and Pl-Sx equations be used for Bl and Pl-Bl respectively.

5.4 NP AREA

There was considerable discussion on how to include the impact of NP areas in the modeling system. The initial proposal was to count a quadrant as stocked if it was NP, as there should not be a volume growth penalty for not growing a tree where it is not possible to grow one. Another idea was to eliminate NP quadrants from the MSQ calculation. The final procedure was to include NP quadrants in the MSQ calculation, but to record the proportion of NP area in each quadrant of full measure plots[14] to quantify the magnitude of the issue. Based on the results of at least one year's surveys, we recommend revisiting this issue to review the method. Of the 294 plots (1,176 quadrants) established in the 2001 test surveys, only seven quadrants had 75% or more non-productive area (Table 13, Appendix II).

An interesting study would be to use TASS to simulate the yield impact of different numbers, sizes, and shapes of NP areas while holding the total NP area constant. For example, the total NP area could be set at 5, 10, or 15% and then this could be assigned as one large NP area and through a range of small NP areas. Additionally the NP areas could be simulated as circles and rectangles to look at the effects of NP edge relative to area.

5.5 MSQ VS WELL SPACED TREES

The question was raised as to whether MSQ or well-spaced trees are better correlated to future volumes. This issue was not addressed in this project. The MOF Research Branch has been given the data from

[14] Information on NP ground could also be recorded in count plots to provide more data.

this project to develop the predicted merchantable volume equations to address this question. One advantage of MSQ is that it is a much simpler variable to measure in the field.

Another question raised is how the stocked quadrant system works if only one tree per quadrant is counted. In this case, it would be equivalent to 800 trees/ha and also be considered fully stocked. Stocked quadrants are a function of SPH and spatial distribution. The case of having only one tree per quadrant would not happen consistently over an entire block. The TASS simulation with 800 trees per ha planted (these are very regularly spaced) only averaged 3.4 stocked quadrants in the simulated surveys. The TASS simulations with 800 random and clumped naturals averaged 2.5 and 1.6 stocked quadrants respectively (Table 3).

5.6 MAXIMUM DENSITY

The current survey and modeling system does not address repression. An overly dense stand would likely have a MSQ of 4.0, a lower than expected height and would be assigned a predicted merchantable volume accordingly. The adjustment for height will only partially account for the full effects of repression. Repression is typically an issue in fire-origin stands where high densities of trees regenerate at the same time. Data from the full measure plots will provide data on SPH and height distribution data and thus the potential for repression. If these plots are re-measured over time they will also provide information on stand development. In addition, high density stands will be stratified out during the survey procedure. We recommend that the data from the full measure plots are analyzed on an on-going basis to assess the potential for repression related impacts on yield.

5.7 CLUSTER PLANTING

Riverside uses cluster planting in heavy cattle use areas and in wet areas. There is some concern that cluster planting will result in low MSQ and therefore predicted merchantable volumes lower than target merchantable volumes. There are several steps that can be taken to address this issue. First, heavy cattle use and wet areas should be stratified during the survey. Second, wet areas are considered NP and recorded accordingly, but the percentage of quadrants lost to cattle trampling should also be recorded during the survey. Third, permanent re-measured plots in these areas will provide data on stand development that can be used in setting appropriate target merchantable volumes.

5.8 RE-SURVEYING AFTER TREATMENT

As part of the survey procedure, areas suitable for treatment will be stratified out. It is quite possible that due to operational considerations only a portion of an identified stratum will be treated. If this is the case then the stratum should be further subdivided into a treated and untreated portion. A new MSQ should then be calculated for the untreated portion based on the plots in that area. The treated portion should be re-surveyed and a new MSQ calculated.

This process has the potential to introduce bias if the portion of area to be treated within the identified “treatment stratum” is chosen on the basis of plot stocked quadrant values alone. However, this is unlikely as other operational factors such as access and laying out areas that are efficient to treat will also come into play.

5.9 FUTURE LOG DISTRIBUTIONS

The initial work on future log distributions shows percentages of total merchantable volume in 5 cm top dib log classes as a function of initial SPH. Potential future refinements include estimating future log distributions as a function of MSQ or other summary statistics calculated from the full measure plots.

5.10 LINK TO OTHER SILVICULTURE SURVEYS

The proposed survey includes permanently marking points on a 200 m grid so that these points can be re-measured in the future to provide data on early stand development. Refinements to this process include clearly defining all surveys installed in young stands under the results based system and marking the permanent points at the first survey so that complete records of early stand development can be obtained. This makes it necessary to include full measure plots similar to those surveys described in this report so that compatible data would be obtained. We recommend the costs and benefits of this approach be examined.

5.11 MONITORING SYSTEM TO CHECK PREDICTED VOLUMES

Accurate projections of future merchantable volumes are critical to the success of the proposed survey and modeling system. Establishing a set of monitoring plots to track actual growth and yield of a representative sample of post-harvest regenerated stands provides data to check predicted volumes. The proposed permanent points (one every four ha on a 200 m grid) provides information on early stand development (approximately ages 0 – 25) if full measure plots are repeatedly established over this period. After age 25, larger plots will be needed to obtain accurate estimates of volume and volume growth. One option to consider is turning a subset of the 200 m grid points into larger 11.28 m radius (0.04 ha) permanent re-measured plots. However, this introduces a new program and associated costs. As a result, all business needs, including the need to check predicted volumes, should be documented and a set of monitoring objectives be developed so that a comprehensive growth and yield monitoring program could be developed.

5.12 DATA COLLECTION AND MANAGEMENT

We recommend that efficient systems to collect and manage the data collected in this survey be developed. The use of hand held data recorders and customized software has been proposed for data collection, as has an ACCESS database to store the data. Both of these options should be pursued. In addition, procedures should be in place to include survey strata and 200 m grid permanent points in Riverside's GIS system.

5.13 PARTIAL CUTTING

The survey and modeling system developed are directly applicable to clear cut blocks only. Refinements will have to be made to address partial cut blocks.

The MOF Research Branch[15] has done some research on the effect that the distribution of leave trees has on regenerated volumes. They found that with different spatial distributions of 10% retained volume, the growth reduction in the regenerated stand (as compared to a clearcut) was related to the linear length of the open crown edges on the remaining trees. The reduction in yield increased as the retained trees

[15] Jim Goudie, personal communication.

were more dispersed. This work could be expanded upon by looking at a range of retained volumes or basal areas with various spatial distributions. A metamodel could then be developed to generate a table of yield reduction factors dependent on retained volume or basal area and open crown edge.

The survey system will also have to be modified to account for retained trees and, if the above modeling system proves successful, determine an estimate of open crown edge.

Any work with partial cut stands will also have to consider ongoing MOF projects looking at refining survey methods in multi-storied stands.

5.14 REVIEW TARGET VOLUMES

We recommend that target volumes be reviewed after the 2002 surveys are complete. In particular, MSQ and associated predicted volumes from all the blocks that have already been declared free-growing should be summarized and compared to initial targets. This will provide a direct comparison between the old and new systems.

6. APPENDIX I – PHASE 1 FIELD TESTING 2000

6.1 OBJECTIVES

The main goal[16] of the first phase (2000) of field-testing was to collect data from TFL 49 to provide the information to develop the prototype stand survey and modeling system. The specific objectives were to:

1) Design a simple survey method to collect the test data.
2) Complete the survey in three stands that represent the range of conditions on TFL 49.
3) Examine the variation in the tree and stand characteristics of interest for modeling MAI.
4) Examine interactions and thresholds of these characteristics where MAI is significantly impacted.

6.2 SAMPLING TO COLLECT TEST FIELD DATA

Three stands were selected by Riverside to represent the range of regenerated stand conditions on the TFL (Table 9). All were Pl leading and seven to nine years old. Sample plots were systematically located in each block on a square grid. The plot at each grid point contained a 20 m^2 (2.52 m radius) main plot and a 100 m^2 site index plot (Figure 7).

Table 9. Blocks surveyed in 2000 for test data.

CP – Block	Location	Net Area (ha)	No. of Plots
25-8	West Kettle	34.5	36
64-2	West Kettle	44.3	42
834-3	Esperon Main	29.3	28

Main Plots (20 m^2)– tree information was collected by quadrant. Data for each tree included: i) quadrant; ii) species; iii) height (m) (some were measured for reference and others were visually estimated); and iv) forest health codes.

Site Index Plots (100 m^2) – the intent was to measure one site tree of each species; however, site index was only estimated in block 834-3 where trees exceeded three years breast height age.

Line Intersect Plots – the line intersect sampling method was used along the compass lines of the sample grid to estimate the number and size of holes[17] in the sample stands. The intent was to measure the total length of the sample transect and the proportion passing through holes in the stand.

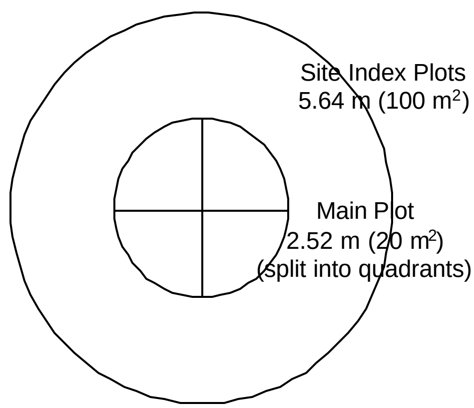

Figure 7. Main and site index plots used in 2000 field testing.

[16] J.S. Thrower & Associates Ltd. 2001. Work Plan: Stand survey and growth modeling for the TFL 49 results-based FPC pilot. Contract report to Riverside Forest Products Ltd., Kelowna, BC. Feb. 20, 2001. 5 pp.

[17] A hole is defined as an area greater than 5 x 5 m that does not contain trees estimated to grow to a merchantable size during the rotation of the stand. This is a very subjective definition that may need to be further refined and developed.

The intent for each sampled stand was to estimate:

1) Site potential (SI).
2) Stand density.
3) Spatial distribution of trees.
4) Species composition.
5) Height distribution of trees (this can be used as a surrogate for the ingress pattern).
6) Health of trees.
7) Size and shape of holes in the stand.

6.3 ANALYSIS OF TEST DATA

Exploratory analyses were completed and the results summarized. This included calculating means, standard deviations, and coefficients of variation (CVs) for total stand density; and number of trees in the 80%, 50%, and 20% or greater of median crop tree height classes (Table 10).[18]

6.3.1 Site Index

Site Index was estimated from field measurements only in block 843-3 because this was the only block with trees that exceeded three years breast height age. The average site index in this block was 22.5 m.

6.3.2 Stand Density

The three surveyed stands showed a wide range of total density from about 3,000 to 12,000 trees/ha (Table 10).

6.3.3 Spatial Distribution

Spatial distribution of trees in the surveyed stands was estimated for different cohorts of trees (height class) using an index of dispersion[19] (Table 10). This index is calculated using the variance of the number of trees among sample plots in relation to the average number of trees in the plots:

$$\text{Index of dispersion} = \frac{s^2}{\bar{x}}(n-1)$$

This index has a Chi-squared (χ^2) distribution, thus tests can be performed to determine if the value is less than one (indicating a uniform distribution of trees), equal to one (random distribution), or greater than one (clumped distribution of trees).

Table 10. Stand density and spatial distribution of trees for blocks surveyed in 2000. Tree height class is based on median crop tree height. For example 20% + is all trees with a height 20% or greater than median crop tree height.

CP-Blk	Tree Height Class	Stand Density (no/ha)				Spatial Pattern
		Avg.	Propor-tion	Std. Dev	CV (%)	
25-8	All	11,819	100%	7,032	60	Clumped
	20%+	10,875	92%	6,723	62	Clumped
	50%+	7,069	60%	4,379	62	Clumped
	80%+	2,125	18%	1,031	49	Random
64-2	All	7,048	100%	4,881	69	Clumped
	20%+	6,536	93%	4,594	70	Clumped
	50%+	4,095	58%	2,333	57	Clumped
	80%+	1,833	26%	908	50	Random
834-3	All	3,161	100%	2,381	75	Clumped
	20%+	2,250	71%	1,357	60	Clumped
	50%+	1,446	46%	671	46	Random
	80%+	1,286	41%	644	50	Random

[18] Median crop tree height was approximated as the average height of the three tallest trees in each plot.

[19] Grieg-Smith, P. 1983. Quantitative plant ecology. University of California Press. Berkeley, California. 359 pp.

The spatial patterns and frequency distribution of tree counts among sample plots (Figure 8) showed that trees in block 25-8 shows the most clumping, followed by 64-2 and 834-3. The trend for all three

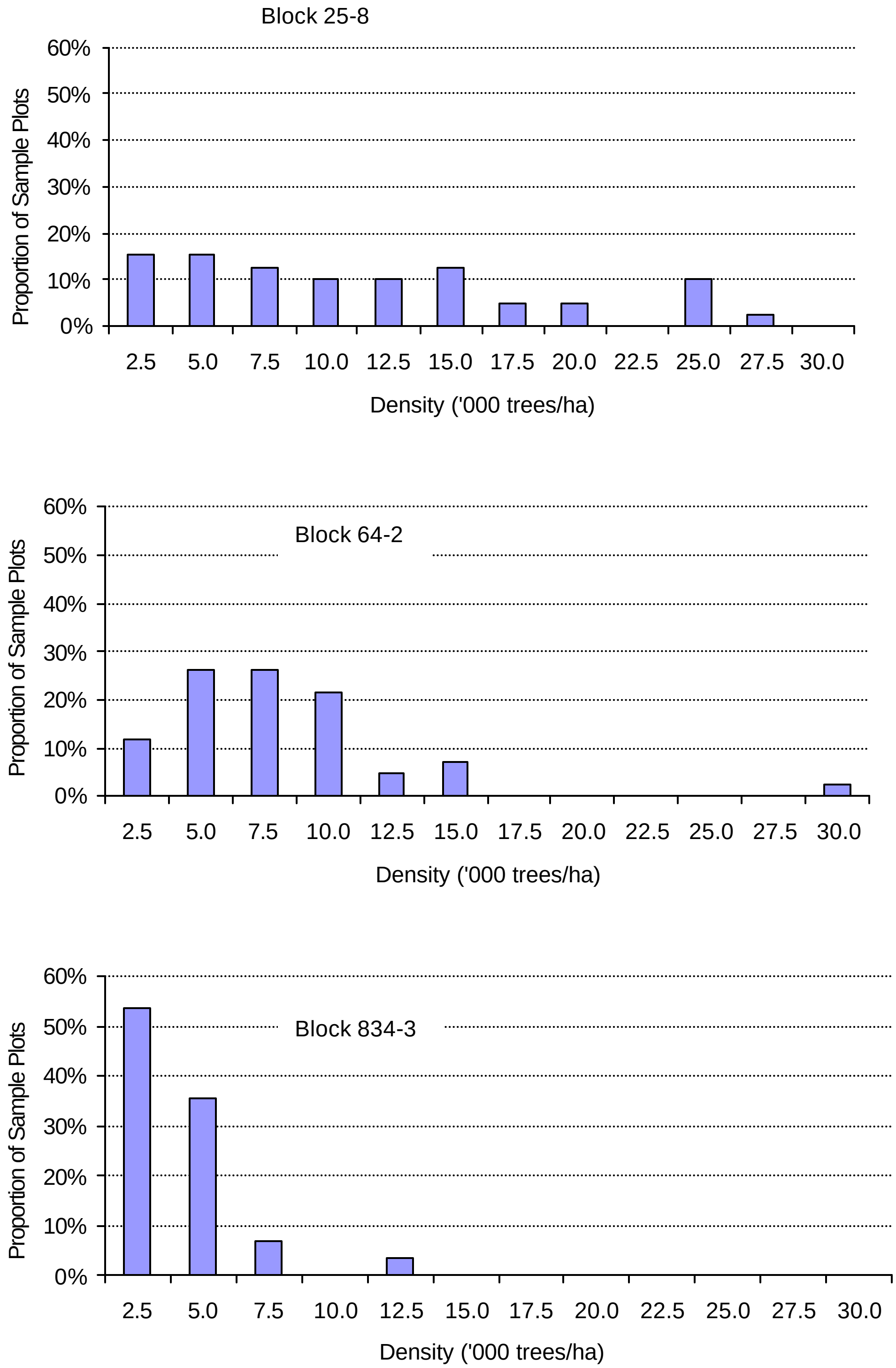

Figure 8. The distribution of stand density (trees/ha) among sample plots for blocks surveyed in 2000.

surveyed blocks was that the largest trees in the stand showed a more random spatial pattern, and smaller trees were more clumped.

6.3.4 Height Distribution

The distribution of stems by height class showed different trends than when basing comparisons only on total stand density. Blocks 25-8 and 64-2 had different total densities, but had similar numbers of trees in the 80%+ height class (Figure 9). This shows that although total stems may differ substantially, the number of dominant trees in the upper canopy may be similar.

In contrast, block 843-3, which has the most uniform spatial distribution of trees, seemed to have the characteristics of a two-storied stand shown by the lack of trees in the 21-50%+ height class (Figure 9).

6.3.5 Tree Health

No significant health problems were reported by the Riverside surveyors. Only one Pl in block 64-2 was noted as having snow/ice damage, and two Pl were dead in one plot in block 834-3.

6.3.6 Holes in the Stand

The Riverside surveyors did not encounter any holes that were in excess of 5 x 5 m in size.

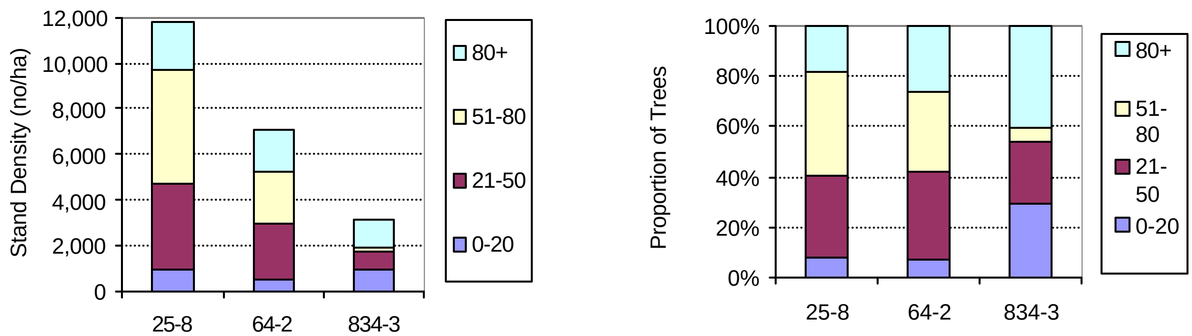

Figure 9. Height distribution of the three stands surveyed in 2000.

7. APPENDIX II – PHASE 2 FIELD TESTING 2001

7.1 OBJECTIVES

The main goal of the second phase of field testing was to collect data from TFL 49 to provide the information to further refine stand survey and modeling system. The specific objectives were to:

1) For clearcut blocks, test the same survey methods used in 2000 (version 1) but with a larger plot size (3.99 m as opposed to 2.52 m). Complete this across a range of block and grid sizes.
2) Examine variation in the tree and stand characteristics of interest for modeling merchantable volume.
3) Obtain cost information on the new survey methods.

7.2 SURVEY PROCEDURES

Surveys were carried out using full measure plots (Section 2.6.2). Count plots were not tested during the 2001 field season.

7.3 SUMMARY OF RESULTS

Ten blocks ranging from 2.3 to 43.2 ha were surveyed during the 2001 field season (Table 11). Information on SPH, species composition (Table 14), non-productive area (Table 13), stocked quadrants (Table 12), and site trees (Table 15, Table 16, Table 17) was used to develop sample size estimates and refine survey and modeling procedures.

Table 11. Description of blocks surveyed in 2001.

CP	BLK	Location	Mapsheet	BioGeo	NAR	Harvested
7	27	29km Stuart Main	82L012-882	MSdm2	76.8	1973
99	92CA	Duo Via Lake	82L002-706	MSdm2	2.3	1993
831	2A	Duo Via Lake	82L012-873A	MSdm2	10.5	1994
831	8A	Terrace-B. Horn	82L002-889A	MSdm2	29.7	1994
834	1	Espron	82L002-887	ESSFdc2	43.2	1987
834	16A	Terrace & Dunwater	82L012-826A	ESSFdc2	2.7	1989
835	10	Terrace Mtn.	82L002-942	ESSFxc	30.2	1988
835	21	Terrace Mtn.	82L002-922	ESSFxc	10.5	1989
839	1	Horseshoe	82E092-828	ESSFdc2	31.4	1994
845	5	Terrace Mtn.	82L012-882	MSdm2	4.6	1994

Table 12. Stocked quadrant summary for blocks surveyed in 2001.

CP-Block	# Plots	MSQ	# Plots with x stocked quadrants 0	1	2	3	4	SE	95% CI MSQ Lower	Upper
7-27	65	3.7	1	1	2	10	51	0.093	3.5	3.9
831-2A	26	3.6		2	1	2	21	0.176	3.3	4.0
831-8A	53	3.8			1	6	46	0.056	3.7	4.0
834-1	42	3.5		2	3	9	28	0.129	3.2	3.8
834-16A	8	3.9				1	7	0.125	3.6	4.0
835-10	29	3.8			2	3	24	0.107	3.5	4.0
835-21	27	3.8		1		2	24	0.120	3.6	4.1
839-1	27	3.7		1	1	4	21	0.141	3.4	4.0
845-5	9	4.0					9	0.000	4.0	4.0
99-92C(A)	8	3.3		1	1	1	5	0.412	2.3	4.0

Table 13. Summary of non-productive (NP) area for the blocks surveyed in 2001.

CP-Block	% of quadrants with % NP area 0%	1-25%	26-50%	51-75%	76-100%	Overall % NP
7-27	91.9	6.2	0.8	0.4	0.8	1.7
831-2A	100.0					
831-8A	73.6	25.9	0.5			2.2
834-1	68.5	29.2	1.2	0.6	0.6	3.5
834-16A	87.5	12.5				0.5
835-10	90.5	9.5				0.6
835-21	88.9	7.4			3.7	4.0
839-1	83.3	13.9	2.8			2.9
845-5	100.0					
99-92C(A)	65.6	34.4				3.1

Table 14. SPH, percent species composition and average height (*m, in italics*) for each species totaling at least 1% of the SPH for the blocks surveyed in 2001.

CP-Block	SPH	Species Pli	Sx	Bl	At	Ac	Fdi
7-27	3631	24	47	28	1	1	
		4.3	*2.0*	*1.8*	*1.3*	*3.1*	
831-2A	5100	76	11	7	5	1	
		2.2	*0.7*	*1.0*	*1.2*	*0.8*	
831-8A	2562	54	24	21			
		1.1	*1.0*	*1.1*			
834-1	1814	66	28	1	4		
		3.5	*1.5*	*1.9*	*1.1*		
834-16A	4100	2	37	61			
		0.8	*1.1*	*1.6*			
835-10	4931	67	9	24			
		1.8	*0.8*	*1.1*			
835-21	4585	34	5	60			1
		1.9	*1.1*	*1.0*			*0.5*
839-1	3793	27	14	59			
		0.6	*0.6*	*0.7*			
845-5	2889	75	20	5			
		0.9	*0.6*	*0.5*			
99-92C(A)	2225	57	12	30			
		1.4	*1.2*	*1.2*			

Table 15. Pl site tree information for blocks surveyed in 2001. Numbers in *(italics)* are numbers of site trees. Blocks not listed had no Pl site trees. Some site trees had both total age and bh age recorded, other site trees just one of the ages recorded, hence the breakdown of average heights of trees with the various age measurements.

	Average Heights				Average Ages		
CP-Block	All	With Total Age	With BH Age	With both ages	Total	BH	Years to BH
7-27	9.6 *(37)*	10.1 *(21)*	9.6 *(34)*	10.3 *(18)*	23.2	16.7	7.3
831-2A	4.3 *(25)*	4.3 *(11)*	4.3 *(25)*	4.3 *(11)*	10.8	5.0	5.9
831-8A	1.9 *(47)*	1.9 *(29)*	2.0 *(38)*	2.0 *(24)*	7.1	1.2	6.0
834-1	5.1 *(30)*	5.2 *(17)*	5.2 *(29)*	5.4 *(16)*	12.9	6.9	6.1
835-10	3.4 *(22)*	3.6 *(16)*	3.4 *(22)*	3.6 *(16)*	10.7	4.1	6.3
835-21	3.3 *(21)*	3.4 *(12)*	3.3 *(21)*	3.4 *(12)*	10.6	4.2	6.1
845-5	1.5 *(8)*	1.5 *(7)*	1.3 *(1)*	1.3 *(1)*	5.6	0.0	6.0
99-92C(A)	2.0 *(5)*	2.0 *(5)*	*(0)*	*(0)*	7.4		

Table 16. Sx site tree information for blocks surveyed in 2001. Numbers in *(italics)* are numbers of site trees. Blocks not listed had no Sx site trees.

	Average Heights				Average Ages		
CP-Block	All	With Total Age	With BH Age	With both ages	Total	BH	Years to BH
7-27	5.9 (20)	6.4 (11)	6.0 (19)	6.4 (11)	24.5	12.3	12.5
831-8A	1.5 (3)	1.4 *(2)*	1.6 *(1)*	*(0)*	8.0	1.0	
834-1	2.7 (12)	2.7 *(5)*	2.7 *(12)*	2.7 *(5)*	12.4	4.2	8.2
834-16A	2.9 (5)	3.5 *(2)*	2.9 *(5)*	3.5 *(2)*	13.0	5.0	7.5

Table 17. Bl site tree information for blocks surveyed in 2001. Numbers in *(italics)* are numbers of site trees. Blocks not listed had no Bl site trees.

CP-Block	Average Heights				Average Ages		
	All	With Total Age	With BH Age	With both ages	Total	BH	Years to BH
7-27	8.6	9.5	8.6	10.0	33.7	17.3	14.0
	(7)	(3)	(6)	(2)			
831-8A	1.8		2.3			2.0	
	(2)	*(0)*	*(1)*	*(0)*			
834-16A	5.9	6.8	5.2	6.8	73.0	12.0	57.0
	(3)	*(1)*	*(2)*	*(1)*			
835-10	2.6		2.6			2.7	
	(3)	*(0)*	*(3)*	*(0)*			

7.3.1 Well Spaced / Free growing trees versus MSQ

At the same plot locations in each block, well spaced and free growing trees were also recorded (Table 18). As expected, as MSQ increases so does the number of well spaced or free growing trees (Figure 10). Block 839-1 has a lower number of well spaced and free growing trees than expected. This is because balsam, which accounts for 59% of the SPH, is an unacceptable species on this block. The balsam was counted in the MSQ and not in the well spaced or free growing numbers. If MSQ is calculated excluding balsam, it drops from 3.7 to 3.2.

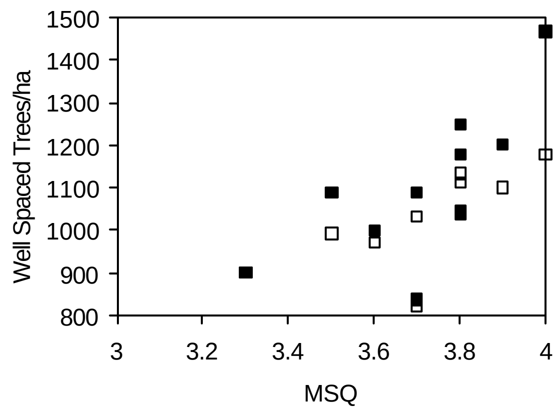

Figure 10. Well spaced trees per ha (with M value, without M value) versus MSQ for the blocks surveyed in 2001.

Table 18. Well spaced and free growing trees/ha for blocks surveyed in 2001.

CP-Block	# Plots	MSQ	Well Spaced/ha		Free growing/ha	
			With M	Without M	With M	Without M
7-27	65	3.7	1031	1089	938	973
831-2A	26	3.6	971	1000	914	943
831-8A	53	3.8	1113	1249	1102	1226
834-1	42	3.5	993	1090	959	1055
834-16A	8	3.9	1100	1200	1000	1075
835-10	29	3.8	1133	1178	1111	1156
835-21	27	3.8	1037	1044	956	956
839-1	27	3.7	822	837	637	644
845-5	9	4.0	1178	1467	1156	1422
99-92C(A)	8	3.3	900	900	675	675

8. APPENDIX III – TASS SIMULATIONS TO IDENTIFY FACTORS IMPACTING MAI

8.1 OBJECTIVES

The goal of this work was to simulate the GY of a range of stand conditions expected on the TFL to identify which tree and stand characteristics should be included in the prototype survey, and which GY modeling system may be appropriate for operational application. The specific objectives were to:

1) Design a matrix of tree and stand conditions representing the range expected on the TFL.
2) Simulate the growth of these conditions using TASS.
3) Summarize the results.
4) Identify the characteristics and levels that significantly impact MAI.

8.2 DESIGN OF TASS SIMULATIONS

8.2.1 Design Matrix

The preliminary TASS simulations included different levels of stand density, number of planted trees, number of ingress trees (naturals), spatial distribution of ingress, and temporal patterns of ingress (Table 19). This combination of stand conditions resulted in 228 different TASS simulations. Summaries were made for all the simulations using only MAI for these preliminary analyses.

Table 19. Factors in the TASS simulation matrix.

Factor	Levels
Stand Density (no/ha)	750, 1,500, 2,000, 2,500, 4,000, 10,000, and 20,000/ha
Trees Planted (no/ha)	0, 750, 1,500, 2,000, and 2,500/ha
Spatial distribution of naturals	Random, Low Clumping, and High Clumping
Ingress period of naturals	Short, Medium, and Long Time Periods

8.2.2 Spatial Distribution

Preliminary TASS simulations were completed to examine the default clumping patterns in TASS and to explore different options for our simulations. We completed 95 simulations that included different stand densities, number of clumps/ha, and dispersion factors defining clump density. The key observation from these simulations was that the default spatial patterns in TASS used to simulate clumped distributions did not establish trees between clumps, and thus was not appropriate for our simulations. Consequently, we worked with Research Branch to modify the spatial patterns to include varying degrees of clumping mixed with varying degree of randomly distributed trees.

8.2.3 Temporal Ingress

Other TASS simulations were done to examine how ingress patterns could be varied to reflect the range that might be expected on the TFL. The default distribution used in TASS to generate the Pl tables for TIPSY is that the number of trees that regenerate is described by a Normal distribution with a mean of two years and standard deviation of one and a half (1.5) years (i.e., N(2, 1.5)) (Figure 11). We also included two other patterns of temporal ingress where the number of trees regenerating was described by a Poisson distribution. These included a Poisson distribution for a short period of natural ingress where the average time of the ingress was four years (P(4)). A slighter longer period of ingress was also included where the average was six years (P(6)).

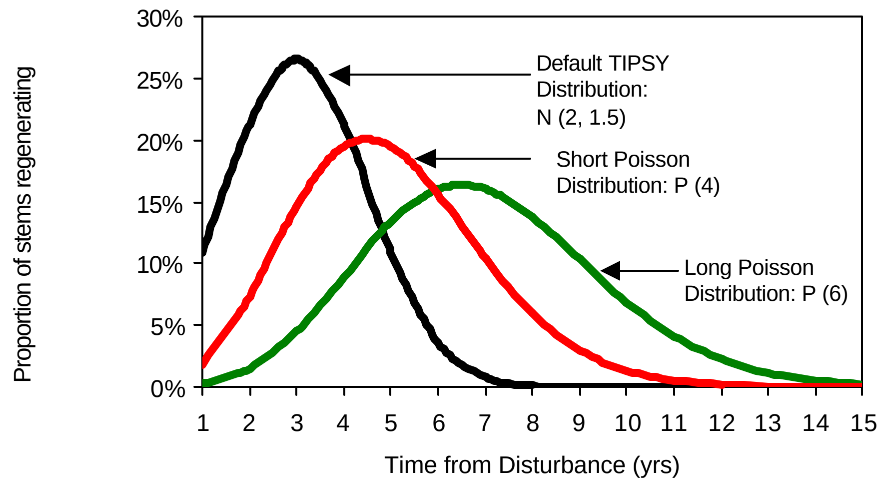

Figure 11. Temporal ingress patterns used in preliminary TASS simulations.

8.3 PRELIMINARY ANALYSIS OF TASS SIMULATIONS

The simulations were evaluated to assess the impact of the various stand characteristics on MAI. The following key observations were made:

1) The amount of ingress does not impact maximum MAI when planting density is 1,500/ha or higher (Table 20).
2) Maximum MAI decreases as clumping increases at lower densities; however, clumping does not significantly impact MAI at higher densities (10,000 and 20,000/ha) (Table 21).
3) Maximum MAI decreases slightly as the length of the ingress period increases at lower densities (below 10,000/ha) (Table 22)

Table 20. Average maximum MAI from TASS simulations for total trees and trees planted (averaged across the different spatial distributions for the naturals).

	Total Stand Density (no/ha) (planted and naturals)							Overall Average
Trees Planted (no/ha)	750	1,500	2,000	2,500	4,000	10,000	20,000	
0	2.1	3.0	3.4	3.6	4.0	4.2	4.3	3.5
750	3.5	3.9	4.0	4.1	4.2	4.2	4.3	4.1
1,500		4.5	4.5	4.5	4.5	4.4	4.4	4.4
2,000			4.5	4.5	4.5	4.4	4.4	4.5
2,500				4.4	4.4	4.3	4.4	4.4
Overall Average	*2.2*	*3.5*	*4.0*	*4.2*	*4.3*	*4.3*	*4.4*	*4.1*

Table 21. Average maximum MAI from TASS simulations for total trees and spatial patterns.

	Total Stand Density (no/ha) (planted or naturals)						
	750	1,500	2,000	2,500	4,000	10,000	20,000
All planted	3.5	4.5	4.5	4.4			
All naturals random	2.8	3.8	4.0	4.1	4.2	4.2	4.4
All naturals low clump	2.0	2.9	3.3	3.6	4.0	4.2	4.3
All naturals high clump	1.5	2.4	2.9	3.2	3.8	4.2	4.3

Table 22. Average maximum MAI from TASS simulations for total trees and ingress period.

Ingress Period	Stand Density (no/ha) (naturals only)						
	750	1,500	2,000	2,500	4,000	10,000	20,000
Short	2.1	3.1	3.4	3.7	4.1	4.3	4.5
Medium	2.1	3.0	3.4	3.6	4.0	4.2	4.3
Long	2.1	3.0	3.3	3.6	4.0	4.2	4.3

9. APPENDIX IV – TIPSY RUNS TO DEMONSTRATE KEY FACTORS TO SET TARGET MAI

9.1 OBJECTIVE

The objective of this process was to identify the key variables in TIPSY influencing the magnitude of MAI.

9.2 METHODS

MAIs and merchantable volume (12.5 cm dbh limit) at age 80 for all 300 combinations of the input parameters (Table 23) were determined using TIPSY. For all TIPSY runs OAF1 = 15, OAF2 = 5, age of planting stock = 1 year, and site index= 20 m. The results were then summarized and analyzed.

Table 23. Input parameters and values.

Input	Values
Species	Pl_{100}, Sx_{100}, $Pl_{50}Sx_{50}$
Establishment Density	700, 1000, 1200, 1500, 2000/ha
Genetic Worth (%)	0, 2, 4, 6
Regen Delay (years)	0, 2, 4, 6, 8

9.3 OVERALL AVERAGES

Across all 300 combinations the overall average MAI was 4.45 and the average culmination age was 79 (Table 24). Relative to the average, the minimum MAI (3.38) was 24% lower and the maximum (5.22) 17% higher.

Table 24. Average and range of MAI and culmination age.

	MAI			Culm. Age		
	Avg	Min	Max	Avg	Min	Max
Overall	4.45	3.38	5.22	79	58	106
Pl	4.34	3.38	5.18	68	58	80
Sx	4.61	3.92	5.22	88	77	106
PlSx	4.39	3.61	5.06	82	68	102

9.4 MAI AND CULMINATION ARE MOST SENSITIVE TO DENSITY AND REGEN DELAY

A base case was defined as establishment density of 1200 trees/ha, genetic worth of 2% and regen delay of 2 years to match current targets used. For each species, the impact of individually varying establishment density, genetic worth, and regen delay (Table 23) while keeping all other inputs constant was examined. The ranges of MAIs caused by varying individual inputs are shown in Table 26. As expected establishment density has the largest impact followed by regen delay and genetic worth. The range of culmination ages caused by varying individual inputs is shown in Table 26. Establishment density and regen delay had the largest impacts on culmination age.

Table 26. Range of culmination ages by individually varying establishment density, regen delay, and genetic worth from base case values.

	Pl	Sx	Pl/Sx
Base case	65	83	82
Stocking	65-71	83-99	75-84
Regen Delay	60-74	79-93	80-88
Genetic Worth	63-67	80-84	80-85

Table 25. Age range where 95% of maximum MAI occurs. For 0 years regen delay and averaged over genetic worth.

Stocking	Pl	Sx	PlSx
700	55-92	75-100	68-100
1000	53-85	72-100	66-100
1200	51-80	71-99	63-96
1500	50-75	69-93	61-91
2000	49-73	68-91	59-87

Table 27. Age range where 98% of maximum MAI occurs. For 0 years regen delay and averaged over genetic worth.

Stocking	Pl	Sx	PlSx
700	59-79	80-100	73-99
1000	58-73	76-94	71-90
1200	56-71	74-92	69-87
1500	55-68	73-87	68-83
2000	54-67	71-84	65-81

The MAI curves (not shown) are relatively flat at the top, thus the range of age when 95% and 98% of maximum MAI occur (Table 25, Table 27) was also analyzed. This shows more overlap than when compared at the absolute age where maximum MAI occurs, however, it still indicates that Pl stands culminate up to 20 years sooner than Sx. This suggests that species composition may not impact overall volume production, but may impact minimum harvest age in timber supply analyses.

9.5 MAI, Establishment Density, and Regen Delay

Given genetic worth has the least impact, graphical displays of MAI as a function of establishment density and regen delay were generated while holding genetic worth at 2% (Figure 13). With MAI being strongly tied to establishment density and regen delay, this is where negotiations on input values will likely occur.

9.6 Variation in Merchantable Volume at Age 80

Over all 300 combinations the average merchantable volume at age 80 was 345 m^3. The minimum was 274 m^3 (23% lower than average) and the maximum was 404 m^3 (19% higher than average). Sx showed a wider range of volumes than Pl (Figure 14).

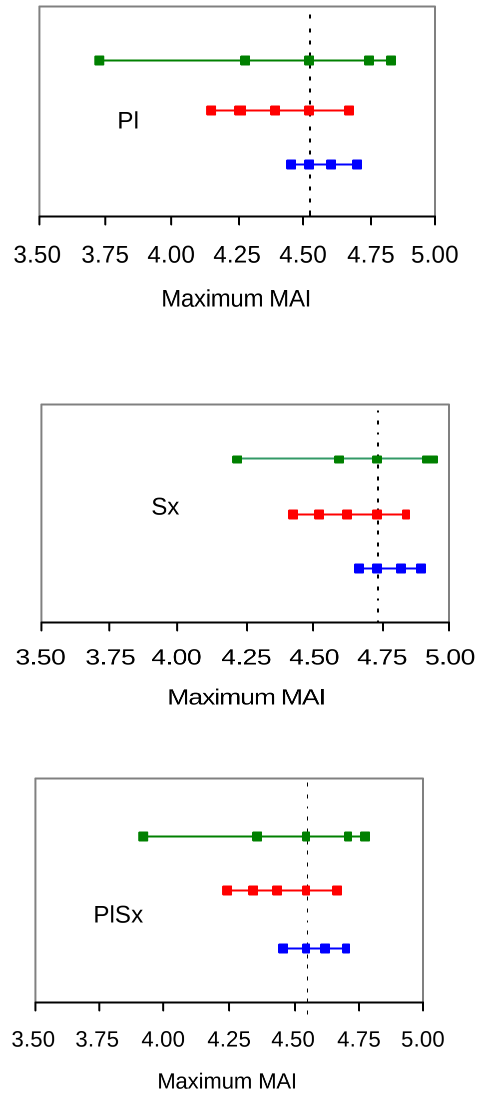

Figure 12. Variation in MAIs by changing establishment density, regen delay, and genetic worth while holding other values at the base case. The vertical dashed line represents the base case for each species. Points on each line represent the MAIs for each level of input. For example, the five points on the green line represent (from left to right) establishment densities of 700, 1000, 1200, 1500 and 2000/ha.

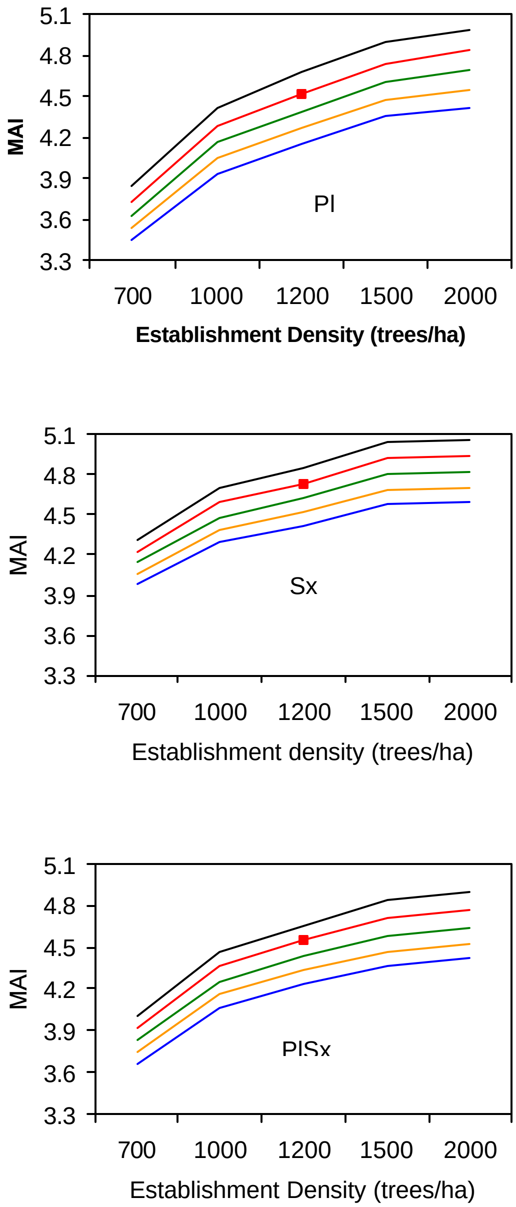

Figure 13. MAI versus establishment density by regen delay. In each graph the five lines represent, from top to bottom, regen delay of 0, 2, 4, 6, and 8 years. Genetic worth set at 2%. The red square on each graph marks the base case MAI value.

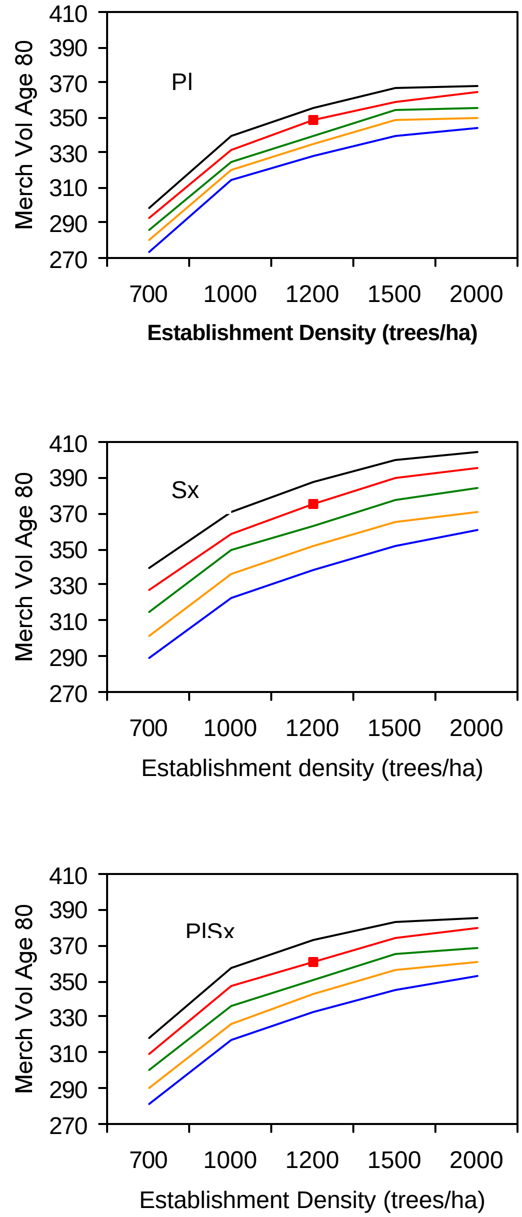

Figure 14. Merchantable volume at age 80 plotted against establishment density by regen delay. The five lines in each graph represent (from top to bottom) regen delay of 0, 2, 4, 6, and 8 years. Genetic worth is 2%. The red square on each graph marks the base case MAI.

10. APPENDIX V – CONFIDENCE INTERVALS ON VOLUME PREDICTIONS

10.1 ERROR SOURCES

There are three sources of error to consider when developing confidence intervals for the volume predictions. These are:

1) Sampling error for the estimate of MSQ.
2) Sampling error for the estimate of effective age.
3) Prediction error from the equations developed to predict merchantable volume as a function of age and MSQ.

10.2 PROCEDURE FOR ESTIMATING 95% CI FOR PREDICTED MERCHANTABLE VOLUME

These three sources of error must be combined to provide a single estimate of standard error for the confidence intervals. The simplified procedure used to do this is as follows:

1) Estimate MSQ and associated 95% confidence interval from the field data.
2) Estimate average site tree height and associated 95% confidence interval.
3) Obtain a lower estimate of effective stand age using the lower bound of the site tree height confidence interval and the appropriate site index curve.
4) Obtain an upper estimate of effective stand age using the upper bound of the site tree height confidence interval and the appropriate site index curve.
5) Obtain a low predicted volume from the appropriate table using the lower estimate of effective stand age and the lower bound of the MSQ confidence interval.
6) Obtain a high predicted volume from the appropriate table using the upper estimate of effective stand age and the upper bound of the MSQ confidence interval.
7) Calculate the difference between the high and low volume prediction, divide this value by 4 and square the result. This will give an estimate of the variance due to sampling.
8) Calculate the prediction variance using equation [1].

[1] $$Varpred(y^* \mid x^*) = MSE\left[1 + \frac{1}{n} + \frac{(x^* - \bar{x})^2}{SXX}\right]$$

Where:

x* = MSQ

MSE = mean square error from the equation = 247.4

n = sample size used in fitting the equation = 51,960

SXX = corrected sums of squares of x from the equation = 17297.32

$\bar{x}$ = mean x from the equation = 3.72

9) Sum the sampling variance and the prediction variance to obtain a total variance. Take the square root of this value to obtain the standard error (SE) to be used in constructing the confidence interval for predicted volume.
10) Calculate the predicted merchantable volume using MSQ and the effective stand age.
11) Calculate a 95% confidence interval as PMV ± 2*SE.

10.3 EXAMPLE 95% CI FOR PREDICTED MERCHANTABLE VOLUME

The above procedure was used to calculate confidence intervals for a range of allowable errors (AE) on MSQ and effective age (Table 28).

Table 28. 95% Confidence intervals for predicted merchantable volume for pure Pl over a range of MSQ and effective age confidence intervals. Similar values were calculated for pure Sx and Pl/Sx.

MSQ	95% CI		Age	95% CI		Low Vol	High Vol	Sampling Variance	Pred Variance	Combined Variance	PMV	95% CI		+/- %
1.5	1.4	1.6	9	8	10	211	247	81.3	247.4	328.7	229	193	266	16%
1.5	1.4	1.6	9	7	11	207	251	123.7	247.4	371.1	229	191	268	17%
1.5	1.4	1.6	9	6	12	204	255	167.7	247.4	415.1	229	189	270	18%
1.5	1.4	1.6	9	5	13	201	260	218.4	247.4	465.8	229	186	273	19%
1.5	1.3	1.7	9	8	10	197	260	252.2	247.4	499.6	229	185	274	19%
1.5	1.3	1.7	9	7	11	192	264	323.5	247.4	570.9	229	182	277	21%
1.5	1.3	1.7	9	6	12	189	269	392.6	247.4	640.0	229	179	280	22%
1.5	1.3	1.7	9	5	13	186	273	468.4	247.4	715.8	229	176	283	23%
1.5	1.2	1.8	9	8	10	182	273	517.3	247.4	764.7	229	174	285	24%
1.5	1.2	1.8	9	7	11	178	277	617.5	247.4	865.0	229	171	288	26%
1.5	1.2	1.8	9	6	12	174	281	711.7	247.4	959.2	229	168	291	27%
1.5	1.2	1.8	9	5	13	171	285	812.6	247.4	1060.1	229	164	295	28%
1.5	1.1	1.9	9	8	10	166	285	876.7	247.4	1124.1	229	162	297	29%
1.5	1.1	1.9	9	7	11	162	289	1005.8	247.4	1253.3	229	159	300	31%
1.5	1.1	1.9	9	6	12	159	293	1125.1	247.4	1372.6	229	155	304	32%
1.5	1.1	1.9	9	5	13	156	297	1251.1	247.4	1498.5	229	152	307	34%
2.5	2.4	2.6	9	8	10	329	356	44.1	247.4	291.4	343	309	377	10%
2.5	2.4	2.6	9	7	11	325	360	76.4	247.4	323.8	343	307	379	10%
2.5	2.4	2.6	9	6	12	322	364	111.8	247.4	359.1	343	305	381	11%
2.5	2.4	2.6	9	5	13	319	368	153.7	247.4	401.1	343	303	383	12%
2.5	2.3	2.7	9	8	10	320	364	123.7	247.4	371.1	343	304	381	11%
2.5	2.3	2.7	9	7	11	315	368	175.0	247.4	422.4	343	302	384	12%
2.5	2.3	2.7	9	6	12	312	372	226.7	247.4	474.1	343	299	387	13%
2.5	2.3	2.7	9	5	13	309	377	285.1	247.4	532.5	343	297	389	13%
2.5	2.2	2.8	9	8	10	310	372	243.6	247.4	491.0	343	299	387	13%
2.5	2.2	2.8	9	7	11	305	376	313.8	247.4	561.2	343	296	390	14%
2.5	2.2	2.8	9	6	12	302	380	381.9	247.4	629.3	343	293	393	15%
2.5	2.2	2.8	9	5	13	299	384	456.7	247.4	704.1	343	290	396	15%
2.5	2.1	2.9	9	8	10	299	379	403.8	247.4	651.2	343	292	394	15%
2.5	2.1	2.9	9	7	11	295	383	492.9	247.4	740.3	343	289	397	16%
2.5	2.1	2.9	9	6	12	291	388	577.4	247.4	824.8	343	286	400	17%
2.5	2.1	2.9	9	5	13	288	392	668.6	247.4	916.0	343	282	403	18%
3.5	3.4	3.6	9	8	10	400	417	18.1	247.4	265.5	409	376	441	8%
3.5	3.4	3.6	9	7	11	396	421	40.5	247.4	287.9	409	375	443	8%
3.5	3.4	3.6	9	6	12	393	425	67.1	247.4	314.5	409	373	444	9%
3.5	3.4	3.6	9	5	13	389	430	100.4	247.4	347.8	409	372	446	9%
3.5	3.3	3.7	9	8	10	395	421	40.5	247.4	287.9	409	375	443	8%
3.5	3.3	3.7	9	7	11	391	425	71.8	247.4	319.1	409	373	445	9%
3.5	3.3	3.7	9	6	12	388	429	106.1	247.4	353.5	409	371	446	9%
3.5	3.3	3.7	9	5	13	385	433	147.1	247.4	394.5	409	369	449	10%
3.5	3.2	3.8	9	8	10	390	424	71.8	247.4	319.2	409	373	445	9%
3.5	3.2	3.8	9	7	11	386	428	111.9	247.4	359.3	409	371	447	9%
3.5	3.2	3.8	9	6	12	382	432	154.0	247.4	401.3	409	369	449	10%
3.5	3.2	3.8	9	5	13	379	436	202.7	247.4	450.0	409	366	451	10%
3.5	3.1	3.9	9	8	10	384	426	112.0	247.4	359.3	409	371	447	9%
3.5	3.1	3.9	9	7	11	380	430	161.0	247.4	408.3	409	368	449	10%
3.5	3.1	3.9	9	6	12	376	434	210.7	247.4	458.1	409	366	452	10%
3.5	3.1	3.9	9	5	13	373	439	267.1	247.4	514.5	409	364	454	11%

We expect most stands will have a MSQ of above 3 and therefore in most cases the 95% confidence interval for predicted merchantable volume will be ± 10% or less.

10.4 REQUIRED SAMPLE SIZES

Based on an allowable error of 10-15% for predicted merchantable volume, the above information, along with variance estimates calculated from blocks sampled in 2001, can be used to determine sample sizes required to estimate MSQ and effective age within acceptable error bounds. For an allowable error of ± 0.3 on MSQ, data from the blocks surveyed in 2001 suggests an average sample size of 27. For an allowable error of 30 cm on Sx site tree height, the 2001 data suggests an average sample size of 15. For an allowable error of 40 cm on Pl site tree height, the 2001 data suggest an average sample size of 26. Both these allowable errors in height (30 and 40 cm for Sx and Pl) translate into approximately ± 2 years in age. Based on these findings a minimum sample size of 30 per stratum was recommended.

11. APPENDIX VI – MODEL FITTING DETAILS

A total of 51,960 (433 TASS runs X 30 surveys X 4 ages) observations were used to fit the equation PMV = a + b*MSQ + c*MSQ^2; summary statistics are presented in Table 29. Parameters b and c from the equation were held constant to produce the set of anamorphic curves. Their estimates were 208.643 and –23.785 respectively. A separate intercept (parameter a) was estimated for each species and age combination (Table 30).

Prior to choosing equation [1] several other model forms including linear, and quadratic polymorphic were tested. Possible impacts of random and clumped spatial distributions on the relationship between predicted merchantable volume and MSQ were also examined. For a given number of stems per ha at year 10, there is a difference in the future volume between random and clumped stands (Figure 15) but this is not the case for a given MSQ at year 10 (Figure 16). MSQ is a function of both stems per ha and the spatial distribution.

Table 29. Summary statistics for the fitted model.

Source	Df	Sum of Squares	Mean Square	F value
Model	13	112762689.2	8674053.0	35066.8
Error	51946	12849268.1	247.4	
Total	51959	125611957.3		
		$R2 = 0.90$	Root MSE = 15.7	

Table 30. Intercept (parameter a) estimates for the equation PMV = a + b*MSQ + c*MSQ^2.

Species Group	Effective Stand Age	a
Pl	5	-44.975
Pl	7	-38.595
Pl	10	-25.688
Pl	13	-13.322
Pl/Sx	5	-39.238
Pl/Sx	7	-28.494
Pl/Sx	10	-12.649
Pl/Sx	13	2.021
Sx	5	-21.470
Sx	7	-12.533
Sx	10	6.548
Sx	13	24.268

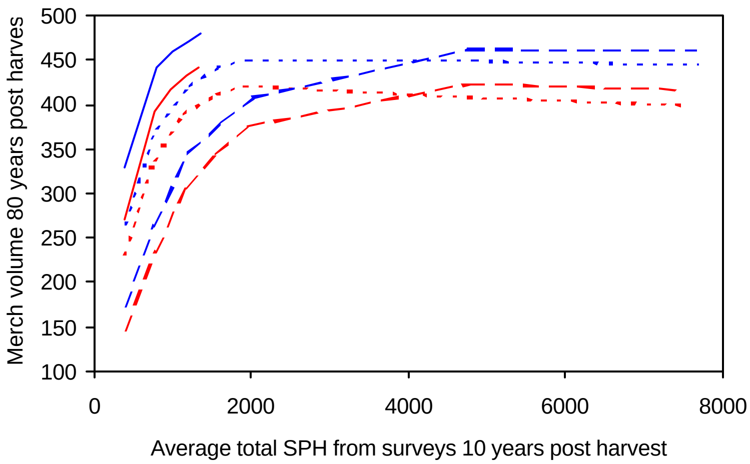

Figure 15. Merchantable volume 80 years post harvest versus average total SPH from surveys completed 10 years post harvest. For pure Pl stands (planted ——, random - - - -, clumped) and pure Sx stands (planted —— , random - - - -, clumped). Values from TASS runs with combinations of planted and natural trees are not shown.

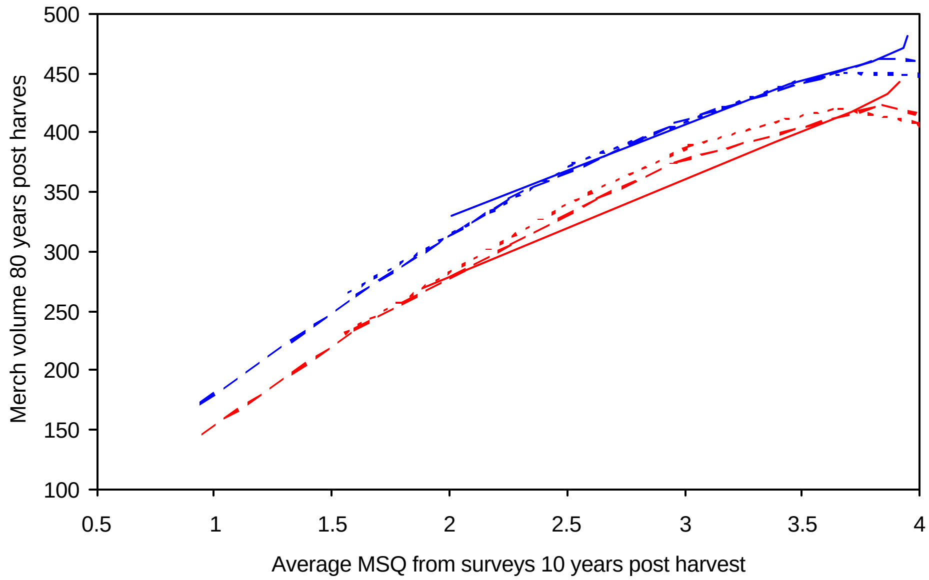

Figure 16. Merchantable volume 80 years post harvest versus average MSQ from surveys completed 10 years post harvest. For pure Pl stands (planted ——, random - - - -, clumped) and pure Sx stands (planted ——, random - - - -, clumped). Values from stands with combinations of planted and natural trees are not shown.

12. APPENDIX VII – TABLES TO ESTIMATE VOLUME AT AGE 80

Table 31. Total height (m) by total age and site index for Pl.[20]

Total age	SI 15	16	17	18	19	20	21	22	23	24	25
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6
4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0
5	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4
6	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8
7	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	2.0	2.1	2.2
8	1.4	1.5	1.6	1.6	1.8	1.9	2.1	2.3	2.4	2.6	2.8
9	1.6	1.7	1.8	2.0	2.1	2.3	2.5	2.7	3.0	3.2	3.4
10	1.9	2.0	2.1	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.1
11	2.1	2.3	2.5	2.7	2.9	3.2	3.5	3.8	4.1	4.4	4.8
12	2.4	2.6	2.9	3.1	3.4	3.7	4.0	4.4	4.7	5.1	5.4
13	2.7	3.0	3.2	3.5	3.8	4.2	4.6	4.9	5.3	5.7	6.1
14	3.0	3.3	3.6	3.9	4.3	4.7	5.1	5.5	6.0	6.4	6.8
15	3.4	3.7	4.0	4.4	4.8	5.2	5.7	6.1	6.6	7.0	7.5
16	3.7	4.1	4.4	4.8	5.2	5.7	6.2	6.7	7.2	7.7	8.2
17	4.1	4.4	4.8	5.2	5.7	6.2	6.7	7.3	7.8	8.3	8.9
18	4.4	4.8	5.2	5.7	6.2	6.7	7.3	7.8	8.4	9.0	9.5
19	4.7	5.2	5.7	6.1	6.7	7.2	7.8	8.4	9.0	9.6	10.2
20	5.1	5.6	6.1	6.6	7.1	7.7	8.3	8.9	9.6	10.2	10.8
21	5.4	5.9	6.5	7.0	7.6	8.2	8.8	9.5	10.1	10.8	11.5
22	5.8	6.3	6.9	7.4	8.0	8.7	9.4	10.0	10.7	11.4	12.1
23	6.1	6.7	7.3	7.9	8.5	9.2	9.9	10.6	11.3	12.0	12.7
24	6.5	7.0	7.7	8.3	8.9	9.6	10.4	11.1	11.8	12.5	13.3
25	6.8	7.4	8.0	8.7	9.4	10.1	10.8	11.6	12.3	13.1	13.8
26	7.1	7.8	8.4	9.1	9.8	10.6	11.3	12.1	12.8	13.6	14.4
27	7.4	8.1	8.8	9.5	10.2	11.0	11.8	12.5	13.3	14.1	14.9
28	7.8	8.5	9.2	9.9	10.6	11.4	12.2	13.0	13.8	14.6	15.4
29	8.1	8.8	9.5	10.3	11.0	11.9	12.7	13.5	14.3	15.1	16.0
30	8.4	9.1	9.9	10.6	11.4	12.3	13.1	13.9	14.8	15.6	16.5
Years to BH	7.2	6.9	6.6	6.4	6.1	5.8	5.5	5.3	5.1	4.9	4.7

[20] These are the site curves currently used in TASS. They are not in the current versions of Site Tools or Tipsy. The Thrower (1994) and Nigh and Love (1999) Pl curves are spliced together by using the Nigh/Love curve below breast height age 0, the Thrower curve above breast height 2, and linearly interpolating heights between breast height age 0 and 2. Nigh, G.D. 1999. Smoothing top height estimates from two lodgepole pine height models. B.C. Min. For., Res. Br., Victoria, B.C. Ext. Note 30. J.S. Thrower and Associates Ltd. 1994. Revised height-age curves for lodgepole pine and interior spruce in British Columbia. Report to the Res. Br., B.C. Min. For., Victoria, B.C. 27 p.

Table 32. Total height (m) by total age and site index for Sx.[21]

Total Age	SI 15	16	17	18	19	20	21	22	23	24	25
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
4	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
5	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5
6	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7
7	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0
8	0.6	0.7	0.7	0.8	0.8	0.8	0.9	1.0	1.1	1.2	1.2
9	0.8	0.9	0.9	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.4
0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.5	1.6	1.7
1	1.2	1.3	1.3	1.3	1.3	1.4	1.5	1.6	1.7	1.8	2.0
2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.8	2.0	2.2	2.4
3	1.4	1.5	1.6	1.7	1.7	1.8	2.0	2.2	2.4	2.6	2.8
4	1.5	1.7	1.8	1.9	1.9	2.0	2.3	2.5	2.7	3.0	3.3
5	1.7	1.8	2.0	2.1	2.2	2.3	2.6	2.9	3.1	3.4	3.7
6	1.9	2.1	2.2	2.4	2.5	2.7	3.0	3.3	3.6	3.9	4.3
7	2.1	2.3	2.5	2.7	2.8	3.0	3.3	3.7	4.0	4.4	4.8
8	2.3	2.5	2.8	3.0	3.1	3.4	3.7	4.1	4.5	4.9	5.3
9	2.5	2.8	3.1	3.3	3.5	3.7	4.2	4.6	5.0	5.4	5.9
0	2.8	3.1	3.4	3.6	3.8	4.1	4.6		5.0	6.0	6.5
1	3.0	3.3	3.7	4.0	4.2	4.5	5.0	5.5	6.0	6.5	7.0
2	3.3	3.6	4.0	4.3	4.6	5.0	5.5	6.0	6.5	7.1	7.6
3	3.6	3.9	4.3	4.7	5.0	5.4	5.9	6.5	7.0	7.6	8.2
4	3.8	4.2	4.7	5.0	5.4	5.8	6.4	7.0	7.6	8.2	8.8
5	4.1	4.6	5.0	5.4	5.8	6.2	6.8	7.4	8.1	8.7	9.4
6	4.4	4.9	5.3	5.8	6.2	6.7	7.3	7.9	8.6	9.3	9.9
7	4.7	5.2	5.7	6.2	6.6	7.1	7.8	8.4	9.1	9.8	10.5
8	5.0	5.5	6.1	6.5	7.0	7.5	8.2	8.9	9.6	10.4	11.1
9	5.3	5.9	6.4	6.9	7.4	8.0	8.7	9.4	10.2	10.9	11.7
0	5.6	6.2	6.8	7.3	7.8	8.4	9.2	9.9	10.7	11.5	12.2
Years to BH	11.5	11.1	10.7	10.4	10.4	10.2	9.7	9.2	8.9	8.5	8.2

[21] These are the site curves currently used in TASS. They are not in the current versions of Site Tools or Tipsy. These curves result from the splicing together of the juvenile height curves by Nigh and Love (2000) and the height-age curves by Goudie (1984). Nigh, G.D. and B.A. Love. 2000. Juvenile height development in interior spruce stands of British Columbia. West. J. Appl. For. 15: 117-121. Goudie, J.W. 1984. Height growth and site index curves for lodgepole pine and white spruce and interim managed stand yield tables for lodgepole pine in British Columbia. B.C. Min. For., Res. Br. Unpubl. Rep. 75 p.

Table 33. Predicted merchantable volumes 80 years after harvest for pure Pl stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	140	143	146	151	155	159	163	167	172
1.1	156	159	162	166	171	175	179	183	187
1.2	171	174	178	182	186	190	195	199	203
1.3	186	189	192	197	201	205	209	214	218
1.4	201	204	207	211	215	220	224	228	232
1.5	214	218	221	225	229	234	238	242	246
1.6	228	231	234	239	243	247	251	255	260
1.7	241	244	247	252	256	260	264	269	273
1.8	254	257	260	264	269	273	277	281	285
1.9	266	269	272	276	281	285	289	293	297
2.0	277	280	284	288	292	296	301	305	309
2.1	288	291	295	299	303	308	312	316	320
2.2	299	302	305	310	314	318	322	326	331
2.3	309	312	315	320	324	328	332	337	341
2.4	319	322	325	329	334	338	342	346	350
2.5	328	331	334	339	343	347	351	356	360
2.6	337	340	343	347	352	356	360	364	368
2.7	345	348	351	356	360	364	368	372	377
2.8	353	356	359	363	368	372	376	380	384
2.9	360	363	366	371	375	379	383	388	392
3.0	367	370	373	378	382	386	390	394	399
3.1	373	376	380	384	388	393	397	401	405
3.2	379	382	386	390	394	398	403	407	411
3.3	385	388	391	395	400	404	408	412	416
3.4	389	393	396	400	404	409	413	417	421
3.5	394	397	400	405	409	413	417	421	426
3.6	398	401	404	409	413	417	421	425	430
3.7	401	405	408	412	416	421	425	429	433
3.8	404	408	411	415	419	424	428	432	436
3.9	407	410	413	418	422	426	430	434	439
4.0	409	412	415	420	424	428	432	437	441

Table 34. Predicted merchantable volumes 80 years after harvest for pure Sx stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	163	168	172	179	185	191	197	203	209
1.1	179	184	188	195	201	207	213	219	225
1.2	195	199	204	210	216	223	229	234	240
1.3	210	214	219	225	231	238	243	249	255
1.4	224	228	233	239	246	252	258	264	270
1.5	238	242	247	253	260	266	272	278	284
1.6	251	256	260	267	273	279	285	291	297
1.7	264	269	273	280	286	293	298	304	310
1.8	277	281	286	292	299	305	311	317	323
1.9	289	294	298	304	311	317	323	329	335
2.0	301	305	310	316	322	329	335	341	346
2.1	312	316	321	327	333	340	346	352	358
2.2	322	327	331	338	344	350	356	362	368
2.3	333	337	342	348	354	361	367	372	378
2.4	342	347	351	358	364	370	376	382	388
2.5	351	356	360	367	373	379	385	391	397
2.6	360	365	369	376	382	388	394	400	406
2.7	368	373	377	384	390	396	402	408	414
2.8	376	381	385	392	398	404	410	416	422
2.9	384	388	393	399	405	412	417	423	429
3.0	390	395	399	406	412	418	424	430	436
3.1	397	401	406	412	418	425	431	437	442
3.2	403	407	412	418	424	431	437	442	448
3.3	408	413	417	423	430	436	442	448	454
3.4	413	417	422	428	435	441	447	453	459
3.5	417	422	426	433	439	445	451	457	463
3.6	421	426	430	437	443	449	455	461	467
3.7	425	429	434	440	447	453	459	465	471
3.8	428	432	437	443	450	456	462	468	474
3.9	430	435	439	446	452	458	464	470	476
4.0	433	437	441	448	454	461	466	472	478

Table 35. Predicted merchantable volumes 80 years after harvest for mixed Pl/Sx stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	146	151	156	162	167	172	177	182	187
1.1	161	167	172	178	183	188	193	198	203
1.2	177	182	188	193	198	203	208	213	218
1.3	192	197	203	208	213	218	223	228	233
1.4	206	212	217	222	228	233	238	243	248
1.5	220	226	231	236	242	247	252	257	261
1.6	234	239	244	250	255	260	265	270	275
1.7	247	252	257	263	268	273	278	283	288
1.8	259	265	270	275	281	286	291	296	301
1.9	271	277	282	287	293	298	303	308	313
2.0	283	288	294	299	304	309	314	319	324
2.1	294	299	305	310	315	321	325	330	335
2.2	305	310	315	321	326	331	336	341	346
2.3	315	320	326	331	336	341	346	351	356
2.4	325	330	335	341	346	351	356	361	366
2.5	334	339	344	350	355	360	365	370	375
2.6	342	348	353	358	364	369	374	379	384
2.7	351	356	361	367	372	377	382	387	392
2.8	358	364	369	375	380	385	390	395	400
2.9	366	371	377	382	387	392	397	402	407
3.0	373	378	383	389	394	399	404	409	414
3.1	379	384	390	395	400	406	410	415	420
3.2	385	390	396	401	406	411	416	421	426
3.3	390	396	401	406	412	417	422	427	432
3.4	395	401	406	411	417	422	427	432	436
3.5	400	405	410	416	421	426	431	436	441
3.6	404	409	414	420	425	430	435	440	445
3.7	407	412	418	423	428	434	439	443	448
3.8	410	416	421	426	431	437	442	447	451
3.9	413	418	423	429	434	439	444	449	454
4.0	415	420	426	431	436	441	446	451	456