

Arrowsmith TSA

Silviculture Strategy (Type 2)

Prepared For:

**Vancouver Forest Region, Forest Practices
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We also wish to acknowledge Ralph Winter, Forest Practices Branch, whose vision and support made this project possible.



Summary

This report documents a forest-level modeling study that examines the implications of silviculture regime options proposed by the South Island Forest District for implementation on the Arrowsmith TSA. The objective of the project is to provide strategic direction to the district silviculture staff in the design of their silviculture program.

Benefits are evaluated against the TSR base case

A silvicultural planning model was developed using the Woodstock (Remsoft, 1997) modeling language that is consistent with the current TSR model and base case for the TSA, and also fully represents the additional forest-level objectives and silvicultural activities required for silvicultural planning. The landbase and management parameters, described in AAC Rationale for Arrowsmith TSA (December 1996), are the basis of the silviculture planning model implemented for this study. Using the TSR base case as the point of departure ensures that benefits from incremental silviculture are modelled in a management context consistent with the Chief Forester's assumptions when he set the AAC.

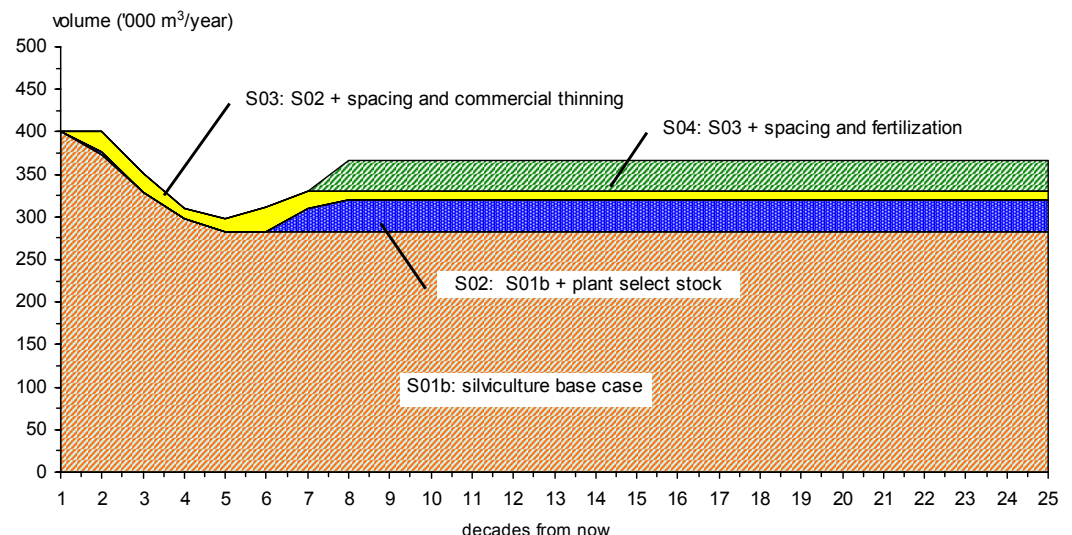
Quantity and quality objectives are evaluated

Scenarios were evaluated for their impacts on three forest-level management objectives: maximizing total timber supply, maximizing the supply of larger dimension logs, and maximizing the supply of solid-clear wood.

28% increase in harvest in long term

Figure S-1 shows the impact of intensification of management on timber supply. In the long term, planting select stock will increase harvest levels by 13%, and spacing and fertilization increase the harvest level by 11%. Commercial thinning contributes 4% to the long-term cut but has a larger impact (up to 10%) in the short term and early mid term.

Figure S-1. Impact of planting select stock, commercial thinning, spacing and fertilization on the forecast harvest





The model puts the highest priority on maximizing harvest levels in decade 2, then in the mid term (decades 3-15), and finally in the long term (decades 16-25). Therefore the model implements commercial thinning to bring timber forward in the harvest queue in order to reduce falldown in decade 2 and fill the mid-term trough. Fertilization and genetic gain produce timber quantity benefits in the late mid term and early long term which are conveyed forward in the harvest queue by commercial thinning.

Double harvest of
65+ cm logs

The analysis showed that volume harvested in the long term of stems 65+ cm can be doubled by lengthening rotation ages past culmination age — but at a cost of reducing the long-term harvest level by 19%. In addition to longer rotations, there was a shift to spacing to lower densities.

9% of cut in solid-clear
wood

An aggressive program of pruning can increase the long-term harvest of solid-clear wood from zero to 9% of the total harvest.

First decade priorities:
commercial thin,
fertilize, then space

Silvicultural activities were ranked by constraining the areas to be treated in decade 1, and then sorting the associated shadow prices in ascending order. In the first decade, commercial thinning and fertilization activities rank the highest, followed by juvenile spacing. Note that juvenile spacing is intrinsic to most of the fertilization and commercial thinning activities. These rankings assume that the operable management objective is to maximize the harvest according to the schedule of priorities described above.

The main limitations of the study are issues regarding the validity of the TASS managed stand yield tables, the difficulty of incorporating the silvicultural history in the landbase dataset, and the scope and accuracy of the representation of the silvicultural regimes in the model.

This study quantifies the change in productive capacity of the Arrowsmith TSA with intensification of management, various levels of expenditure, and alternative management objectives. It does not specify which management objectives should be pursued, and therefore does not prescribe a desirable intensity of forest management.

Prescriptive studies
should follow
confirmation of the
descriptive model

The critical components of the physical production model (yield curves, silviculture history, and regime diagrams) should be confirmed before addressing the question of the appropriate level of silviculture investment.



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Section 1 — Introduction

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1.0 Introduction

This report documents a forest-level modeling study that examines the implications of silviculture regime options proposed by the South Island Forest District for implementation on the Arrowsmith TSA. The objective of the project is to provide strategic direction to the district silviculture staff in the design of a silviculture program.

A silvicultural planning model was developed that is consistent with the current TSR model and base case for the TSA, and also fully represents the additional forest-level objectives and silvicultural activities required for silvicultural planning.

The TSR base case is the appropriate "point of departure" for the silviculture analysis because it:

- reflects the management unit's current land base, inventory, growth and yield, and management practices;
- is the schedule of timber supply from the base case data set that conforms to Ministry of Forests' conventions regarding harvest flow, and any departures from the standard harvest flow conventions that may have been deemed appropriate by the TSR;
- ensures that the silvicultural planning model is based on the timber supply assumptions for the TSA that the Chief Forester considered (or will consider) in setting the AAC for that TSA.

A major difference between the TSR analyses and this analysis is the choice of forest-level model. The TSR uses the simulation model FSSIM while this analysis was undertaken with a linear programming (LP) model developed using the Woodstock (Remsoft, 1997) modeling language. The LP formulation was selected because of its flexibility and comprehensiveness in representing silviculture activities, its ability to incorporate complex and multiple objectives, and its facility and consistency with economic reasoning. The LP model is referred to in subsequent sections of this report as the Arrowsmith Silviculture Planning Model (ASPM).

After this introduction, Section 2.0 of this report describes the information requirements for the analysis with special emphasis on changes to the TSR data base and additional information required for the silvicultural analysis. The next section (Section 3.0) describes the results of modelling the scenarios constructed to explore the implications of intensification of management. Section 4.0 reports the long-term silviculture strategy for the TSA-- the regimes selected to achieve the forest-level objectives -- and the silvicultural activities that are feasible in the first decade.

The validity of this study depends substantially on the accuracy of the managed-stand yield tables, the representation of TSA's silvicultural history in the modeled landbase, and the specification and modelling of the silvicultural regimes. These limitations are discussed in Section 5.0.



2.0 Data and Management Assumptions

This section describes the data and assumptions used in this analysis that differ from those documented TSR1 or are additional inputs that are required for the silvicultural analysis. Other forest management assumptions-- including forest cover requirements, utilization levels and standards, unsalvaged losses and green-up assumptions-- are unchanged from the TSR1 timber supply analysis.

2.1 Changes to the TSR1 Landbase

Revised as per AAC Rationale 1996, and Clayoquot Sound removed

The data set provided to the project team by Timber Supply Branch comprised 68 672 ha of operable forest, including backlog NSR and Timber Licences (which will revert to Crown management in the future). Note that this land base differs significantly from the TSR1 land base reported in *Arrowsmith TSA Timber Supply Analysis, 1995* (Table 2-1). The reduction in landbase (6 573 ha) is concentrated on the western zones (14% reduction) with a small reduction in the eastern zones (2% reduction).

Table 2-1. Timber harvesting land base.

Classification	TSR1 ¹	TSR1 revised ²	Net of Clayoquot Sound ³
Current THLB	75 244	68 672	63 166
NSR	1 446	196	196
Timber Licences	7 544	196	196

1 Source: Arrowsmith TSA Timber Supply Analysis, 1995

2 Source: Timber Supply Branch, November 9, 1998

3 Source: AAC Rationale for Arrowsmith TSA, 1996 estimated the CS portion of the THLB as 5506 ha

The AAC *Rationale for Arrowsmith TSA* (December 1996) notes that the land base was updated and corrected prior to the AAC determination. It is assumed that the landbase provided to this project reflects those changes.

The landbase was subsequently adjusted to reflect the exclusion of Clayoquot Sound subsequent to the 1995 TSR timber supply analysis.

Future roads, trails and landings are not removed from the THLB

Loss of productive land to future roads, trails and landings are modelled explicitly with the ASPM, in that a specified percentage of land harvested for the first time is removed from the productive land base. Losses to roads and landings occur at a rate of 3% from the conventional harvest zones and 1% from the unconventional zone.



2.2 Silviculture Analysis Units

The 17 analysis units defined for TSR1 were aggregated by District staff into 10 silviculture analysis units (SAUs) deemed appropriate for the silviculture regimes contemplated for the TSA (see Table 2-2). Mean site index (metres at 50 years) for each SAU was calculated as the area weighted average of the indices of its constituent TSR1 analysis units.

Table 2-2. Definition of the silvicultural analysis units

SAU # ¹	TSR1 AU # ²	Types	Site Class	TSR1 Area (ha)	Revised Area (ha) ³	Area net of CS ⁴	Mean Site Index ⁵
1	1,4,11	Fd	G	8,712	8,289	8,224	34.77
2	2,5,12	Fd	M	13,140	12,918	12,918	27.88
3	3,6,13	Fd	P	6,938	7,064	6,928	19.60
4	7	Other Conif	all	1,583	1,633	1,619	21.77
5	14	HwBa West	G,M	4,980	6,543	4,257	21.77
6	15	HwBa West	P	3,876	4,464	3,312	13.69
7	16,17	Cw West	G,M	11,615	8,469	7,045	23.40
8	18	Cw West	P	20,219	16,353	16,098	14.03
9	19	Ba/Ss West	all	735	722	655	22.29
10	21	Heli West	all	3,446	2,217	2,218	16.42
Total				75,244	68,671	63,166	

Notes

1. SAUs for this study were defined by Dean Stewart, South Island Forest District.
2. TSR1 analysis unit areas are from the Arrowsmith TSA Timber Supply Analysis, August 1995.
3. Revised Area is obtained from the FSSIM data files supplied to this project by Timber Supply Branch.
4. Source: AAC Rationale for Arrowsmith TSA, 1996
5. Mean site indices are the area-weighted average site indices of the TSR1 analysis units.

2.3 Silvicultural State of the Landbase

The silviculture state of a stand records the information that the manager needs in order to determine what silviculture activities are immediately feasible (not including operational considerations such as harvesting restrictions, accessibility, terrain, or markets). For example, species mix, age, density, basal area, crown closure may be the variables that the silviculturalist considers when deciding the treatment of a stand. These state variables change over time with the development of the stand (growth, competition, mortality) and with silviculture actions (e.g., juvenile spacing).

The TSR timber supply analysis differentiates between stands that are in natural and managed states in order to assign appropriate yield curves. A silvicultural analysis requires a more complex definition of the silvicultural state of each stand



in order to determine feasible management actions and appropriate managed stand yield curves.

Describing the silvicultural state in terms of the variables utilized by the silviculturalists may be appropriate for operational (tactical), program-level planning, but is too detailed for strategic planning with a forest-level model. For the purposes of this project, the silviculture state of (aggregations of) forest stands was developed from the ISIS and MLSIS data bases and is described in Appendix A.

2.4 Management Practices

In addition to the harvesting methods included in the TSR analysis (clearcutting-conventional and helicopter), this study explicitly models commercial thinning.

Harvesting operability responds to silviculture

However, instead of assigning a minimum harvest age for clearcutting, minimum operable volumes were calculated from the height, diameter and volume criteria described in the TSR analysis report. Specifying minimum operable volumes allows the model to reduce harvesting ages in response to volume benefits of intensification of management.

Commercial thinning is single entry, 3 possible ages

The development of stands post commercial thinning was simulated with TASS, according to residual stand criteria (trees per hectare, target volume removal) and method (single entry, from below, leaving the largest well-spaced trees) supplied by the district. The district specified one age of entry; after reviewing the results of the TASS simulations, two more ages of entry were added, typically 10 and 20 years after the age specified by the district. Alternate ages of entry were included in order to provide additional flexibility in re-ordering the harvest queue.

1st decade harvest profile is imposed on the model

The harvest profile for the first decade is imposed on the silviculture model to ensure that silviculture activities selected by the model reflect current operations. The distribution of the first-decade harvest shown in Table 2.3 was constructed from an analysis of recent forest development plans for the Arrowsmith TSA.

Base case scenario assumes basic silviculture

The base case scenario for this study assumes basic silvicultural practices and models these practices in a manner identical to the TSR timber supply analysis. The remaining scenarios of this study require the simulation of complex silvicultural regimes including spacing, pruning, fertilization and commercial thinning.

Alternative management regimes incorporating these incremental silviculture activities and commercial thinning were specified for each SAU by District staff. And regime diagrams were constructed that delineate the alternative silvicultural states of each SAU and the feasible transitions between these states. These regime diagrams are useful for communicating the possible development states implied by sets of alternative regimes, and for specifying yield tables required for stands in harvestable states. The regime diagrams for each SAU are included in Appendix B.



Arrowsmith TSA Silviculture Strategy Analysis

Section 2 — Data and Assumptions

Table 2-3. Harvest profile (% volume harvested) in the first decade.

SAU Description	SAU	SI	% Total Harvest Volume	
			Conventional	Commercial Thin
Fd, G	SAU01	35	13%	30%
Fd, M	SAU02	28	10%	70%
Fd, P	SAU03	20	5%	
Conif	SAU04	22	0%	
H/B West, GM	SAU05	22	10%	
H/B West, P	SAU06	14	13%	
C/H West GM	SAU07	23	23%	
C/H West P	SAU08	14	17%	
B/S West	SAU09	22	0%	
Unconven West	SAU10	16	8%	
			100%	100%

Confirmed by Dean Stewart, South Island Forest District.

Managed stand yield tables are simulated with TASS

Each harvesting activity represented in the regime diagrams requires a yield table corresponding to the silvicultural state that it is acting on. Managed stand yield tables were created by Research Branch using TASS. Yield tables for existing natural stands (state N) and TSR1 managed stands (state A) were obtained directly from the TSR1 data files. The yield tables for each SAU are included in Appendix E.

Costs and labour requirements for implementing the silvicultural treatments are listed in Table 2.4.

Table 2-4. Cost and labour assumptions for silviculture treatments.

Activity	\$/ha	P-day/ha
plant	800	3
space - east	800	2
space - west	1700	4
prune - east	1100	6
prune - west	2200	8
fert	200	0.1

Source: Arrowsmith TSA Workshop, June 18-19, 1998



2.5 Select Stock and Genetic Gain

The benefits from planting select stock in the Arrowsmith TSA are evaluated in this study. The genetic gain for each planting mix specified by the District is listed in Table 2.5 and the calculation of these gains is detailed in Appendix C.

Table 2-5. Genetic gain assumptions for the Arrowsmith TSA.

Species Planted	Genetic Gain
Fdc	10.5
Fdc75Cw25	11.9
Cw5Bg3Hw2	8.8
Hw7Cw2Ba1	11
Cw7Hw2Ba1	10.7
Ba6Hw2Cw2	5.9

Source: R. Plandon, MoF Tree Improvement Branch.



Arrowsmith TSA Silviculture Strategy Analysis



3.0 Analysis Results

This section presents the results of the analysis of eight scenarios designed to quantify the impact of silvicultural practices under different assumptions and objectives. The scenarios are described in detail in Appendix D.

3.1 Base Case

Only two silviculture activities are included in the base case – harvesting and planting, including basic silviculture. No incremental silviculture (spacing, pruning, or fertilization) or commercial thinning is included.

The base case is modelled for two reasons. It demonstrates the consistency of the TSR representation of the TSA's timber supply with that of the silviculture model used in this study. With the validity of the silviculture model established, scenarios with intensified management or different management objectives can be compared to the base case results and differences can be quantified and attributed to management assumptions.

Base Case Harvest Forecast

Figure 3-1 compares base case harvest forecasts determined for this study with the TSR1 base case harvest forecast.

Figure 3.1
S01a TSR1 landbase

The harvest schedule labeled S01a corresponds to the base case management assumptions applied to the TSR1 landbase supplied to this project. It traces the TSR1 harvest schedule from the initial harvest level (AAC, December 1996), along a steeply declining path (7%, 12%, 12% and 12% in decades 2, 3, and 4 respectively) until decade 10, when it rises about 10% above the TSR1 harvest schedule. The S01a schedule maintains this level (272 000 m³ per year) through decade 19, when it rises another 3% and maintains this level (280 000 m³ per year) to the planning horizon.

Figure 3.1
S01b Silvicultural
history landbase

The harvest schedule labeled S01b corresponds to the base case management assumptions applied to the silvicultural history landbase (described in Appendix A). The silvicultural history landbase more accurately represents the silvicultural state of existing managed stands. This schedule closely follows the TSR1 schedule through decade 4 but subsequently maintains a harvest level of 283 000 m³ per year out to the planning horizon.

The differences between the S01a and TSR1 base case harvest schedules may be due to aggregation of the landbase into different analysis units with different associated yield tables. Also, the land base described in the rationale report also differed from the land base supplied to this project, and the project was warned by the original analyst (Mike Clarkson, pers. com.) of the difficulties of working with this data set.

Figure 3-1. Base Case harvest forecasts.

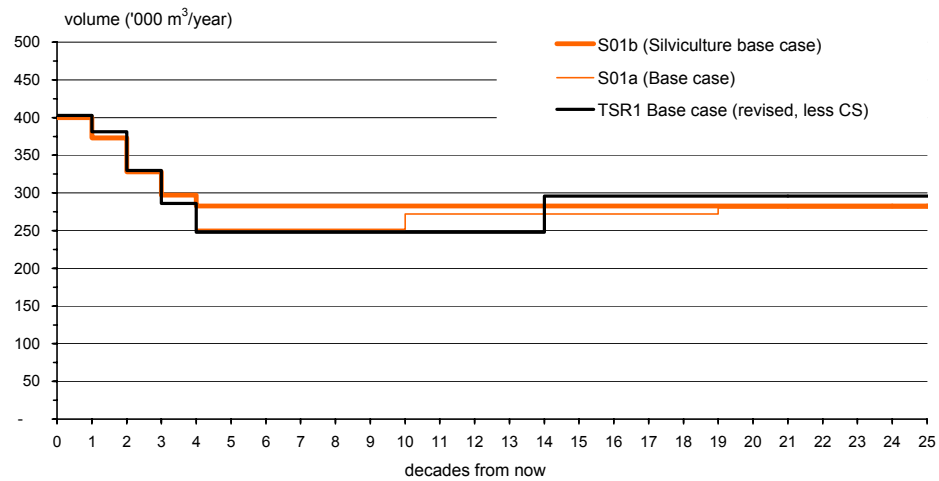


Figure 3-2. Composition by leading species of forecast harvest, silviculture base case (S01b).

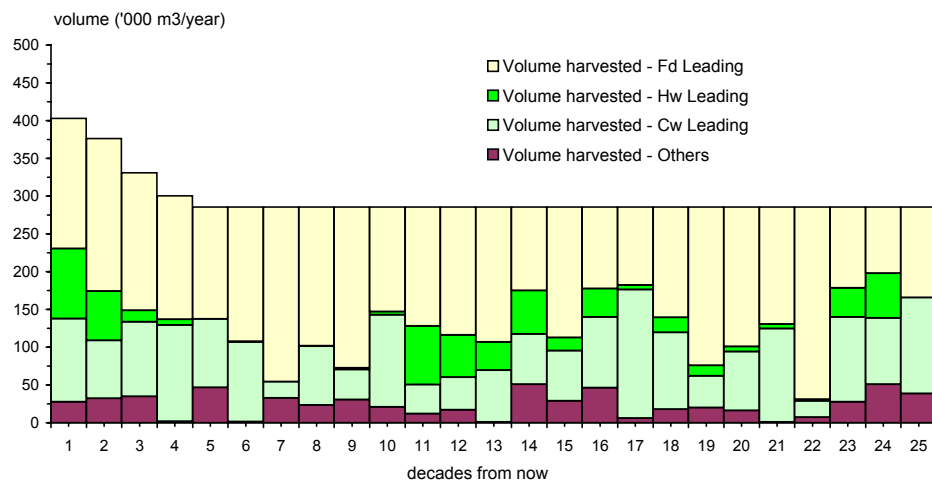
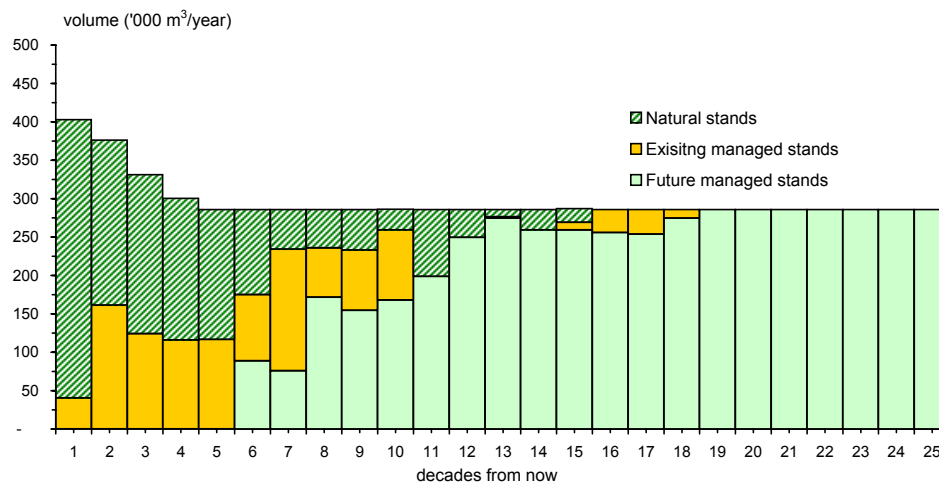


Figure 3-3. Composition by existing natural and managed stands of forecast harvest, silviculture base case (S01b).





Arrowsmith TSA Silviculture Strategy Analysis

Section 3 — Analysis Results

Schedule S01b, based on the silvicultural history landbase, forecasts a harvest level that exceeds the S01a schedule substantially in decades 4-10, and less so in decades 11-19. This difference suggests that the existing managed stands in this study are assigned yield curves of higher productivity than are assumed in TSR1. Both S01a and S01b show increases over the TSR1 schedule in the mid-term trough (decades 4-14) while under-performing TSR1 in the long term (by 5%). This is partly due to the model solution process, which assigns a higher priority to the maintenance of the initial harvest level for as long as possible and the reduction of depth of the mid-term trough, and a lower priority on maximizing the long-term harvest level.

S01b is the silvicultural base case harvest schedule

After consideration of these issues, the schedule S01b was accepted as the basis for evaluating the harvest volume effects of incremental silviculture, and will be subsequently referred to as the silvicultural base case.

Figure 3-2

Figure 3-2 shows the composition of the base case harvest by leading species. The harvest in decade 1 reflects the harvest profile specified by the District (section 2.4) but the mix of species in subsequent decades is determined by the model.

Figure 3-3

Figure 3-3 shows the composition of the base case harvest in terms of natural stands, existing managed stands, and future managed stands. The harvest is composed of existing stands until decade 6, and is not totally dependent on managed stands until decade 16.

Response framework

The end of the transition to managed stands (decade 15) is referred to in this study as the end of the mid-term, and the beginning of the long term. The short term is arbitrarily set as decades 1 and 2.

Figures 3-4, 3-5

The composition of the forecast harvest of managed stands by grade and diameter limit are plotted in Figures 3-4 and 3-5, respectively. In both figures the harvest from natural stands is not differentiated by grade or diameter due to limitations of the yield tables. Note also that the quadratic mean diameter of the harvested managed stands, plotted against the right-hand axis on Figure 3-5, remains relatively constant between 33-35 cm out to the planning horizon.

Figure 3-6

Figure 3-6 plots the area harvested on the left-hand axis, and the harvest volume per hectare on the right-hand axis. The trend in volume per hectare is negative over the first 10 decades, but appears level in the long term (decades 16 to 25). Note that there is no commercial thinning in the base case.

Changes in the Silvicultural State of the Base Case

Figure 3-7
Stable inventory measures indicates sustainable LTHL

Figure 3-7 plots the total and operable growing stock over the planning horizon. The total growing stock rises from its initial level, before leveling out. The operable growing stock declines through the transition to managed stands and remains relatively constant in the long term (decades 16-25). The stability of these inventory measures indicates that the long-term harvest level (LTHL) is likely to be sustainable.

Figure 3-4. Composition by grade of forecast harvest of managed stands, silviculture base case (S01b).

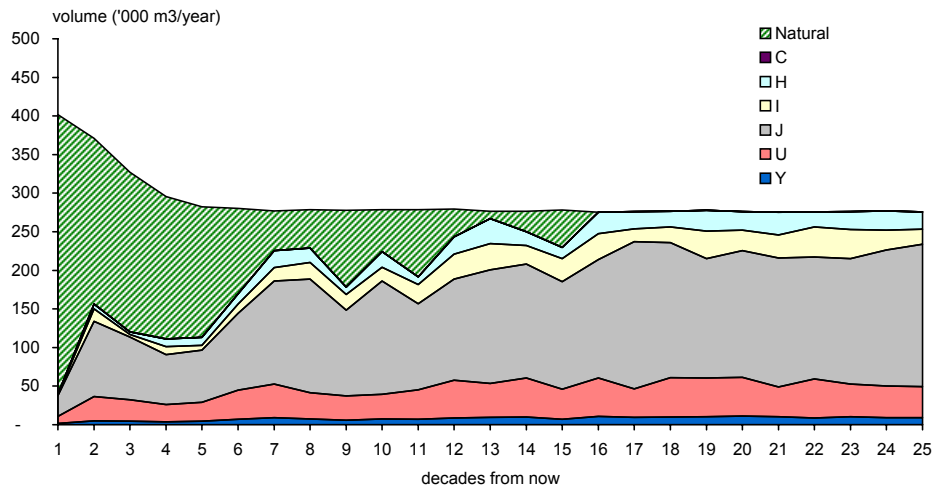


Figure 3-5. Composition by dimension of forecast harvest of managed stands, silviculture base case (S01b).

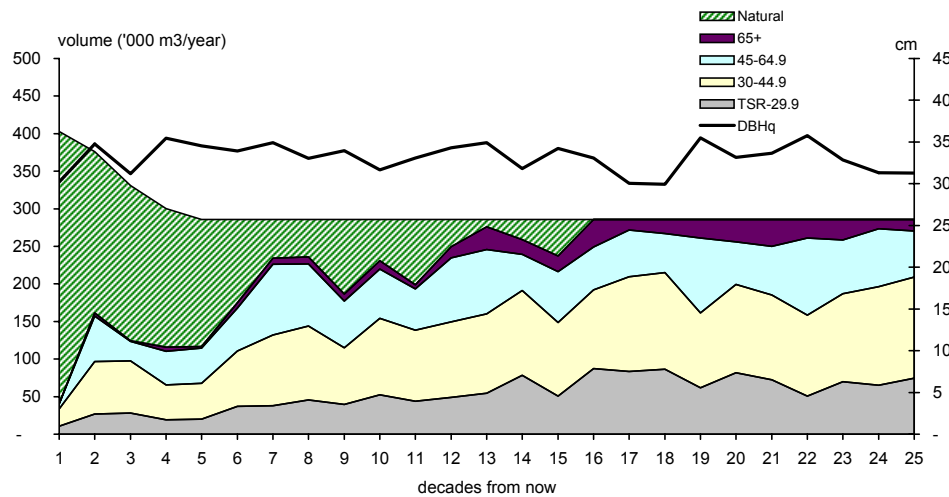


Figure 3-6. Total area and volume per unit area of the forecast harvest, silviculture base case (S01b).

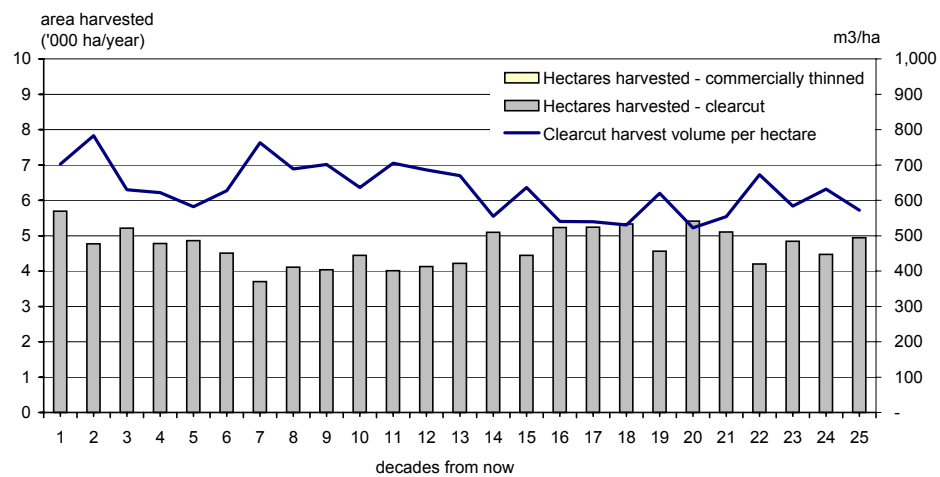


Figure 3-7. Total and operable growing stock forecast, silviculture base case (S01b).

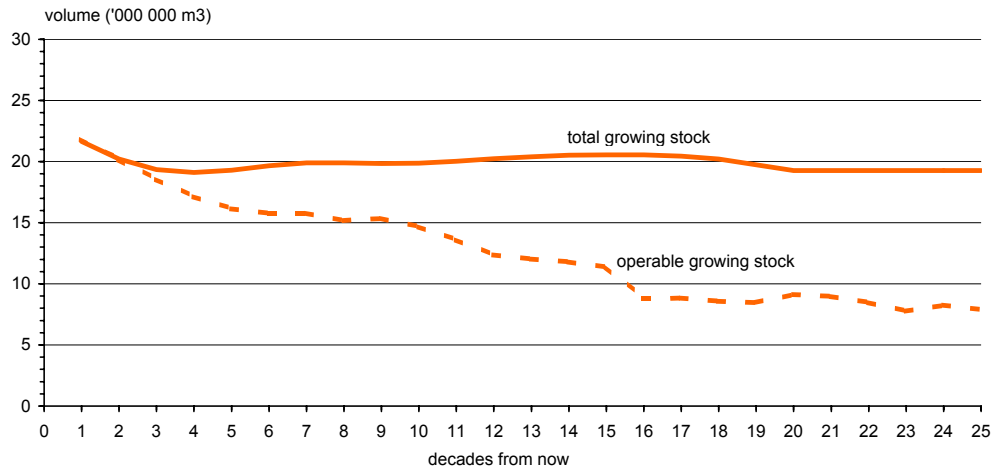


Figure 3-8. Percent disturbed (not greened-up) by constraining management zones, silviculture base case (S01b).

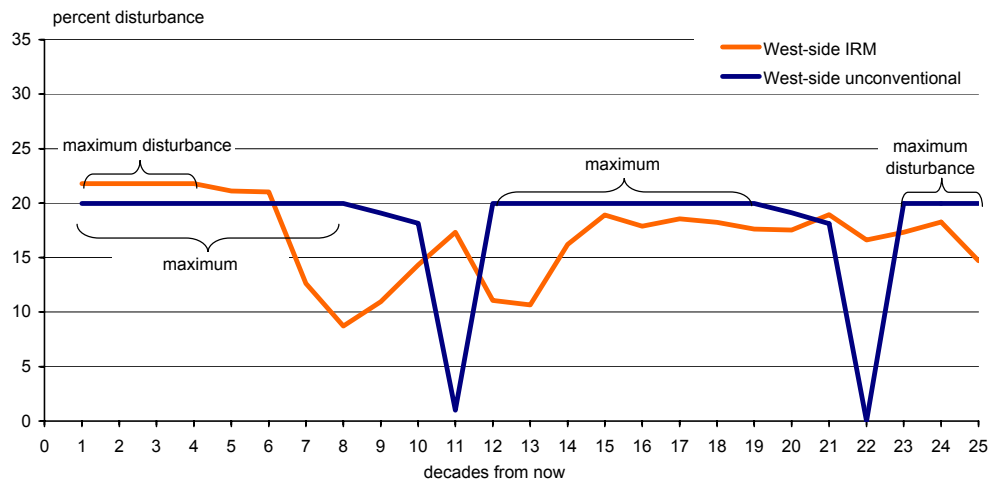
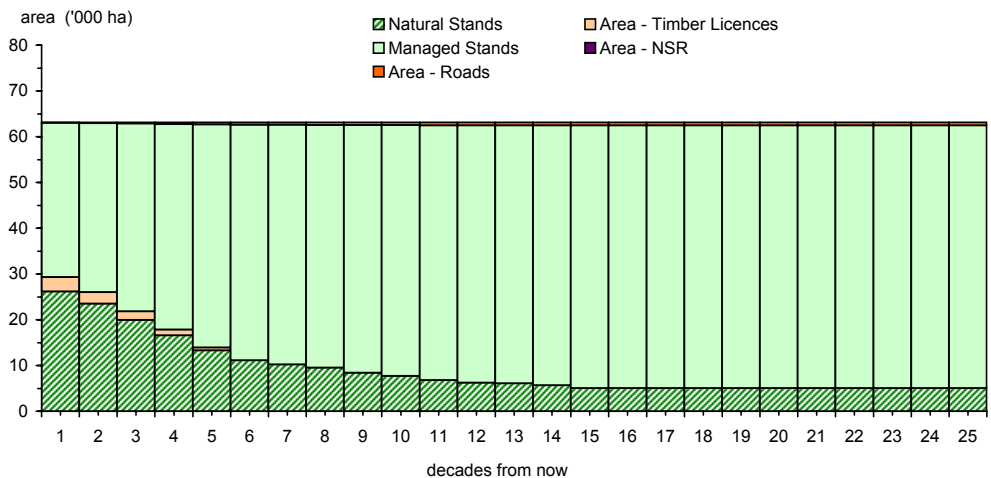


Figure 3-9. Aggregate silviculture state area forecast, silviculture base case (S01b).





Arrowsmith TSA Silviculture Strategy Analysis

Section 3 — Analysis Results

Figure 3-8
All east-side
disturbance constraints
are tight

All of the green-up constraints are tight (constraining) across the planning horizon except for two zones. Figure 3-8 tracks the disturbance (percent not greened-up) for the two management zones that are not always constraining. Green-up requirements in the west-side IRM zone are tight only in decades 1-4. The west-side unconventional zone is within its disturbance limit in decades 8-11 and decades 20-22.

Figure 3-9
Some poor site cedar
and hemlock balsam is
not harvested

Figure 3-9 tracks the change in silvicultural state of the THLB over the planning horizon. At the end of the first decade, the THLB is composed of approximately 33 000 ha natural existing stands, 26 000 ha of existing and future (created by the model) managed stands, and about 4 200 Timber Licences. The Timber Licences are harvested and regenerated as managed stands by the end of decade 5, and the areas of natural stands and existing managed stands are steadily reduced as the harvesting and regeneration convert them to future managed stands. Note that at the end of decade 25 there remains approximately 5 000 ha of natural stands that have not been harvested. These natural stands are predominantly poor site cedar and poor site hemlock/balsam.

The model considers
the objectives over the
entire planning horizon

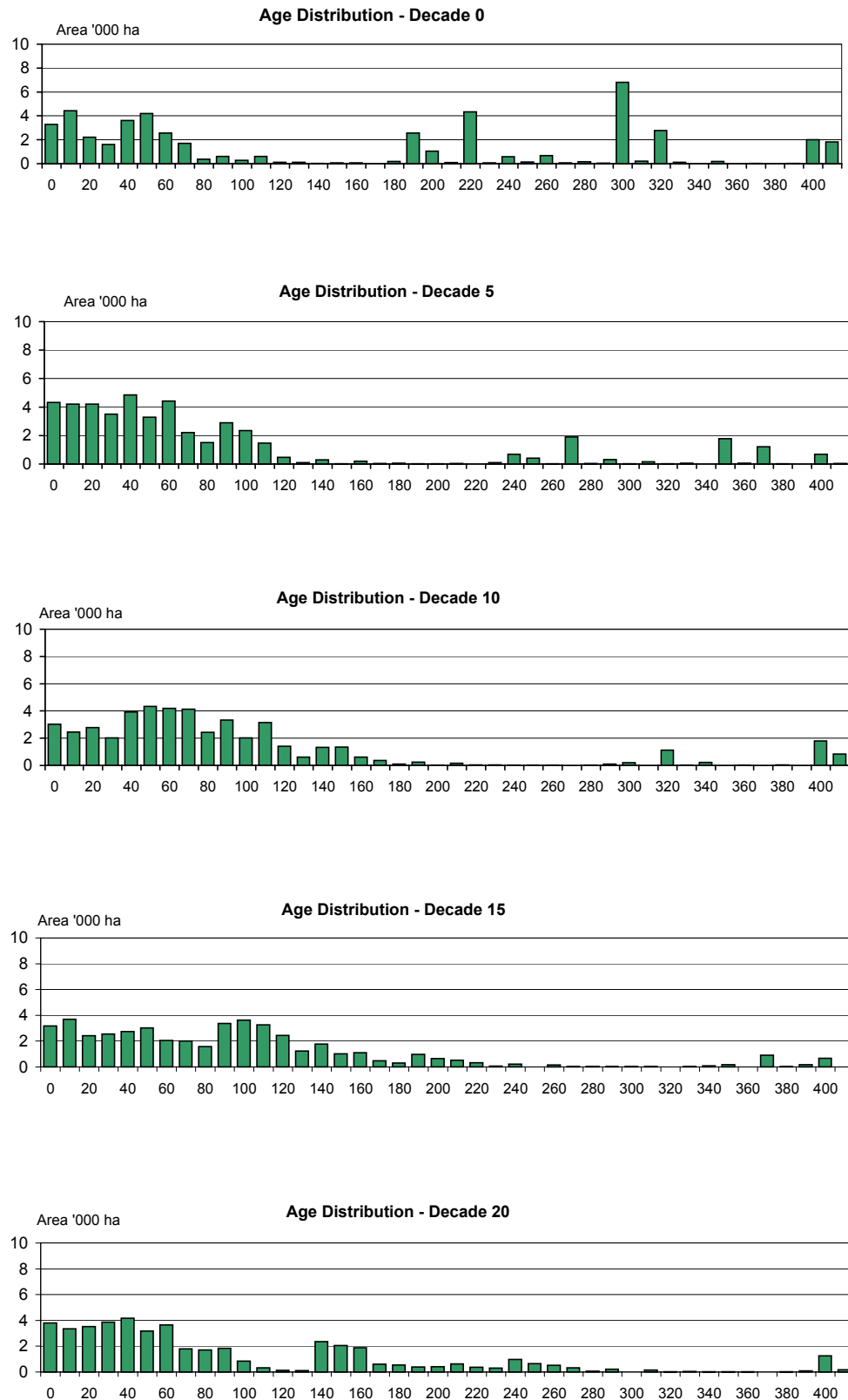
The reason why the model leaves the low productivity stands is logical. The model selects stands for harvesting that optimize its timber supply objectives across the entire planning horizon, namely to maximize short, medium and long-term timber supply (in that order). It has calculated that harvesting the low site stands will return a small yield and that the stand will not attain operable volume (400 m³/ha) again for a long time (approximately 145 years for cedar and 165 years for the hemlock balsam). The stand may not be accessible again within the planning horizon. Focusing harvesting on higher site stands with shorter rotations increases the productivity of the THLB and increases timber supply over the planning horizon.

Simulation models, such as FSSIM, use a simple harvest selection rule, such as oldest first, and cannot consider the future implications of harvesting a stand. This is a significant difference between simulation and LP models and underlines the importance of having a clear objective when forecasting timber supply.

Figure 3-10

Table 3-10 shows the progression of the age class distribution of operable timber on the TSA over the planning horizon. Age class 400 includes all stands 400 years or older, although the model tracks stands for 700 years before converting them to the regenerating state. By decade 25, almost all of the stands age class 230 or older, are poor site cedar or poor site hemlock

Figure 3-10. Forecast distribution of operable area for total inventory, silviculture base case (S01b).





3.2 Management for Timber Quantity

This section presents the results of incorporating the district-supplied management regimes into the silviculture planning model, and explores the implications of alternative levels of expenditure on incremental silviculture.

Incorporating the district-supplied management regimes requires three types of changes to the model. First, the set of allowable silviculture activities is expanded from the base case (harvesting and planting) to include the incremental silviculture activities of planting, spacing and fertilization. Second, harvesting is expanded to include commercial thinning.

Select Stock, Commercial Thinning and Intensive Silviculture Scenarios

Figure 3-11

Figure 3-11 shows the incremental benefits from planting select stock (S02), commercial thinning (S03) and spacing and fertilization (S04). These scenarios were implemented with the management objective of maximizing the quantity of timber harvested, and assumed an unlimited silviculture budget.

S02 Select stock

The volume benefits from planting select stock are first apparent in decade 7, as future managed stands planted with select stock become available for harvesting, and provide a 13% increment over the base case (S01b). A small increment (3%) is available as early as decade 2, due to the effect of releasing for harvest in decade 2, current mature stands that were rationed for later harvest under S01b, but this increment is difficult to discern on Figure 3-11.

S03 Commercial thinning

Commercial thinning regimes, including the juvenile spacing activities intrinsic to those regimes, increase the harvest substantially in decades 2-8 (by as much as 10% in decade 6) and less so in the long term (4%).¹

In accordance with the model's schedule of priorities, commercial thinning is used to bring harvest forward to fill the mid-term trough. In the long term, the increment from commercial thinning may be due to loosening up the harvest queue and allowing stands to be harvested closer to their culmination ages.

S04 Spacing and fertilization

Implementing spacing and fertilization regimes, in addition to select stock and commercial thinning regimes, returns an increment of 11% starting in decade 8 and this level is sustainable through the long term. The total increment above the base case from the intensification of management (plant select stock, space and fertilize, commercially thin) is 30%, beginning in decade 8. Smaller increments (7%-17%) are realized over decades 2-7.

Figure 3-12
Growing stock

Figure 3-12 plots the total and operable growing stock level for each of the scenarios. The criterion for sustainability (of timber supply) noted in the discussion of the base case, that total and operable growing stock should be non-declining in the long term, is met.

¹ Unless otherwise described, all increment percentages in this report are calculated with reference to the silviculture base case harvest level (S01b).

Figure 3-11. Impact of planting select stock, commercial thinning, spacing and fertilization on the forecast harvest.

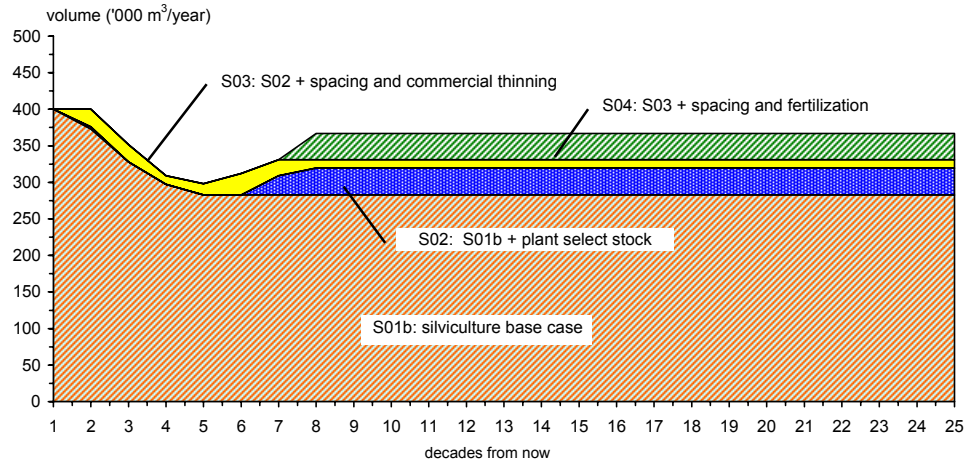


Figure 3-12. Total and operable growing stock forecasts with intensification of management.

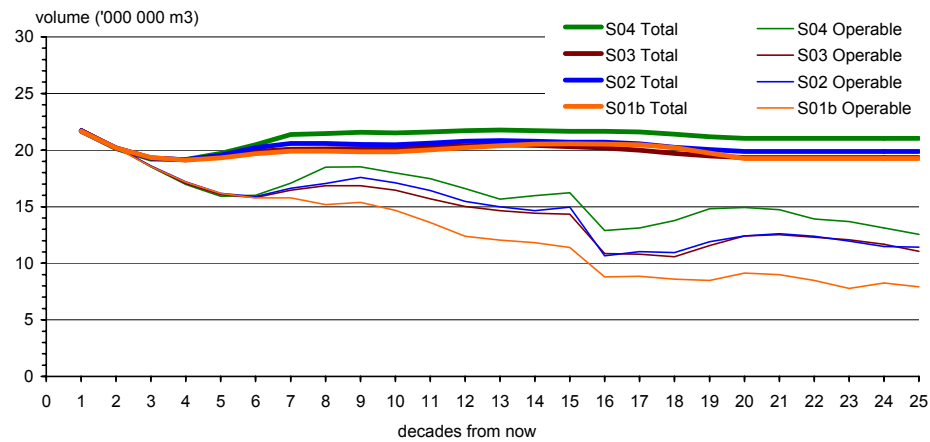
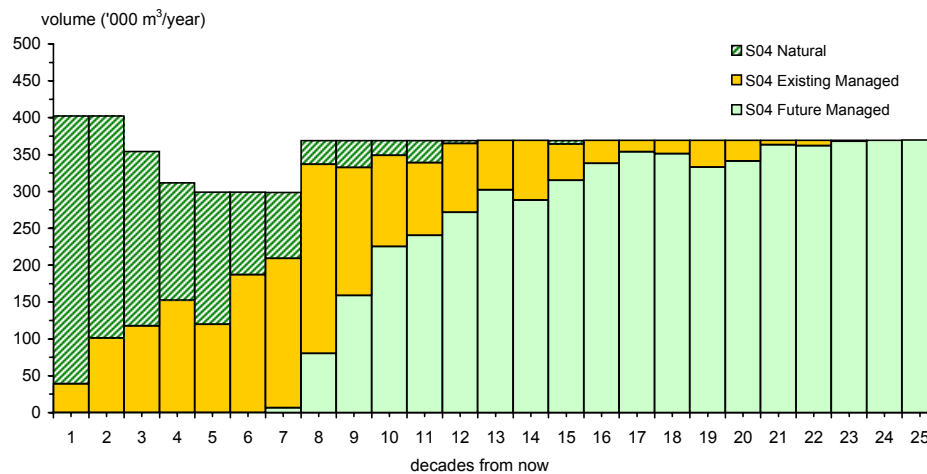


Figure 3-13. Composition of forecast harvest by existing natural and managed stands, maximum intensive management scenario (S04).





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Both total and operable growing stock increase with intensification of management – inventory levels for the select stock scenario are higher than the base case and the scenarios that include spacing and fertilization regimes lift inventory levels higher. Commercial thinning has little effect on growing stock, except to reduce operable growing stock in decades 9-15. This reduction is due to the model employing commercial thinning to “borrow from the future”, i.e., drawing down inventory via commercial thinning and clearcutting the residual stand at a later date.

Figure 3-13
Transition to
managed stands

Figure 3-13 shows the transition in the timber supply from natural stands to managed stands. Comparing this figure with the base case transition plotted in Figure 3-3, with the intensification of management, the transition is completed sooner (decade 11 versus decade 15). Also, continued management (especially repeat fertilization) of existing managed stands has increased the yield from these stands, allowing the initial harvest of future managed stands to be delayed from decade 6 to decade 8.

Figure 3-14
Clearcut vs
commercial thinning

Figure 3-14 compares the area harvested by clearcutting versus commercial thinning. In decade 1 the area commercially thinned is constrained to be less than the recent levels of 200 ha per year, but the model schedules only 130 ha per year. However, in decade 2 the area scheduled for commercial thinning increases to 250 ha, allowing the decade 1 harvest level to be increased (see Figure 3-11). Commercial thinning then drops off due to scarcity of operable stands in decade 3-6 before returning to higher levels in decade 7-9. These higher levels of commercial thinning allow the model to increase the harvest level in decades 7-9, before the end of the transition to dependence on managed stands.

Figure 3-15
Composition of
harvest by diameter
limit.

Figure 3-15 shows the composition by diameter limit of the harvest from managed stands. Comparing this figure with the equivalent base case Figure 3-5, it is apparent that the largest increment is in smallest diameter category, i.e., stems with dbh exceeding 17.5 cm (the TSR lower limit) and less than 30 cm.

Figure 3-16
Composition of
harvest by grade.

Figure 3-16 shows the composition by grade of the harvest from managed stands. Comparing this figure with the equivalent base case Figure 3-4, there is no discernable shift in grade for the regimes implemented by the model. This result is not unexpected, given that the objective of this scenario was to maximize harvest volume.

The portion of the harvest labeled “not graded” is due to missing or incomplete TASS managed stand yield tables. Among other problems with the yield tables, “C” grade volume yields were not supplied to this study.

Figure 3-14. Total area and volume per unit area of the forecast harvest, maximum intensive management scenario (S04).

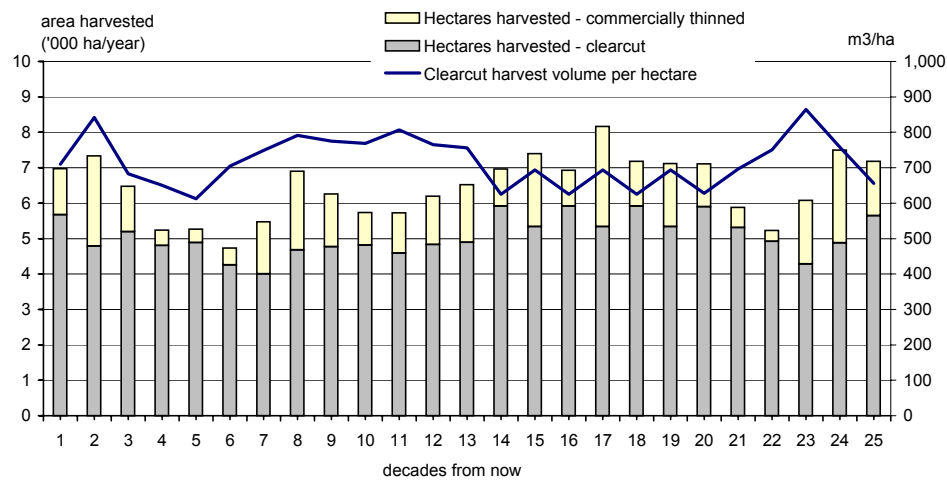


Figure 3-15. Composition by dimension of forecast harvest of managed stands, maximum intensive management scenario (S04).

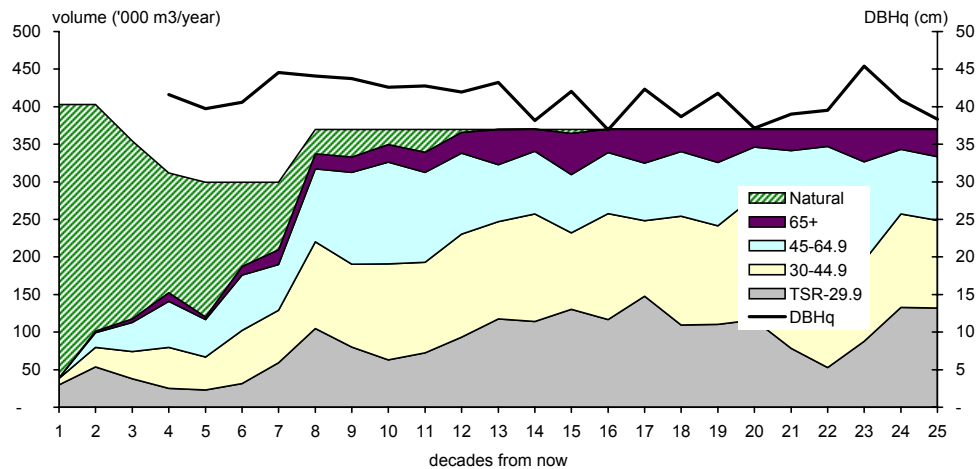
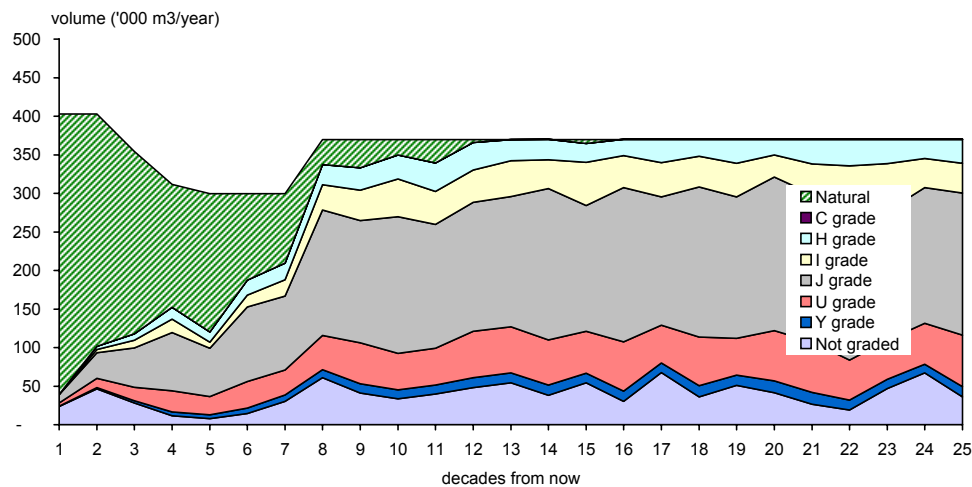


Figure 3-16. Composition by grade of forecast harvest of managed stands, maximum intensive management scenario (S04).





Optimal Management for Maximizing Harvest Quantity

Figures 3-17, 3-18, and 3-19 plot the area by treatment, treatment costs, and direct silviculture employment benefits, respectively, for the harvest maximization scenario.

Figure 3-17
Treatment area

Figure 3-17 shows that the fertilization program more than doubles in size from 360 ha per year in decade 1 to an average of 770 ha per year in decades 7-25. The area juvenile spaced per year grows from 180 ha in decade 1 to an average of 337 ha per year in decades 7-25.

Figure 3-18
Treatment cost

The cost of spacing and fertilization (Figures 3-18) and the silviculture employment outputs of these programs (Figures 3-19) follow a similar pattern. The average cost of spacing and fertilization over the planning horizon is \$583 000 per year.

Figure 3-19
Employment

The regimes implemented to achieve the quantity benefits described in this section will be discussed in Section 4.

Management Intensity and Levels of Funding

S05 Levels of
funding

The timber supply benefits and management information described above and plotted on Figures 3-11 through 3-19 are the results of a scenario that maximizes harvest quantity (volume) without limiting annual expenditure (S04). In scenario S05, the annual expenditure is constrained to percentages (10%, 20%, 30%, 50%, and 75%) of the maximum average expenditure (\$427 000 per year).

Figure 3-20
Volume increments
vs annual expenditure

Figure 3-20 shows how the increment of harvest (above the base case) that is attributable to spacing and fertilization changes with increasing annual expenditure. The harvest increment is plotted as separate lines for each of three time intervals: decade 2, decade 3-7 (early transition) and 8-25 (late transition and long term). Note that it is assumed that the level of expenditure along the horizontal axis is maintained over the planning horizon.

The increment of harvest volume in decade 2 attributable to spacing and fertilization rises sharply to 27 000 m³ per year as the annual expenditure rises to \$43 000 per year. Additional funds will not increase the harvest in decade 2 because the harvest is restricted to be less than or equal to the decade 1 harvest (current AAC) by the TSR harvest flow rules.

In decades 3-7, the increment of harvest volume attributable to spacing and fertilization also rises sharply, to 32 000 m³ per year at a funding level of \$43 000 per year, and then continues to rise more gradually to 41 000 m³ at \$213 000 per year. Increasing the level of expenditure beyond \$213 000 per year causes the incremental volume to decrease gradually back down to 39 000 m³ per year at the maximum expenditure (\$427 000 per year) determined by the model.

Increasing expenditure
causes the volume
benefit to decrease
(decades 3-7)

The model puts a higher priority on maximizing harvest levels in the mid term (decades 3-15) then in the long term (decades 16-25), but is indifferent as to when in the mid term the harvest is taken, as long as the harvest flow constraints are met. Therefore, as annual silviculture expenditures increased, the model may have found it advantageous (with respect to the objective of maximizing total harvest) to reduce the incremental harvest in the early mid term (decades 3-7) and increase it in the late mid term (decades 8-15).

Figure 3-17. Treatment area forecast, maximum intensive management scenario (S04).

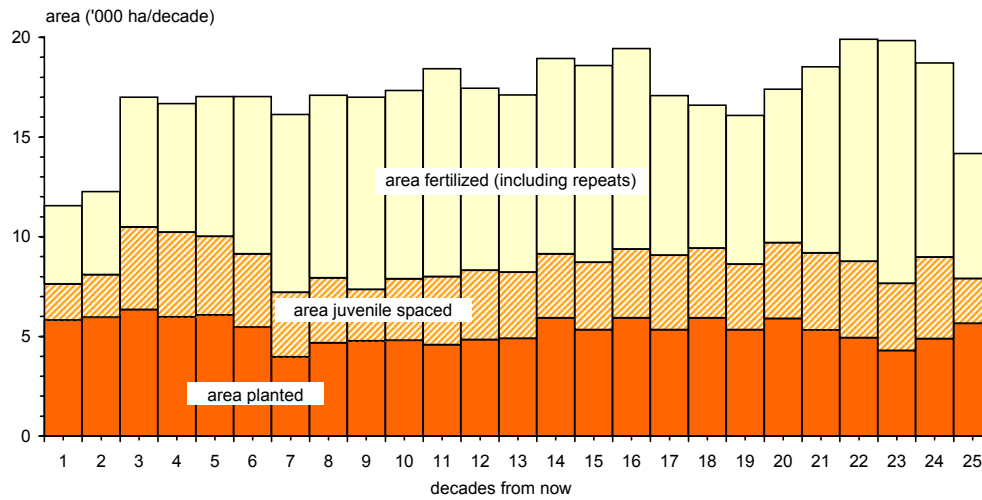


Figure 3-18. Treatment cost forecast, maximum intensive management scenario (S04).

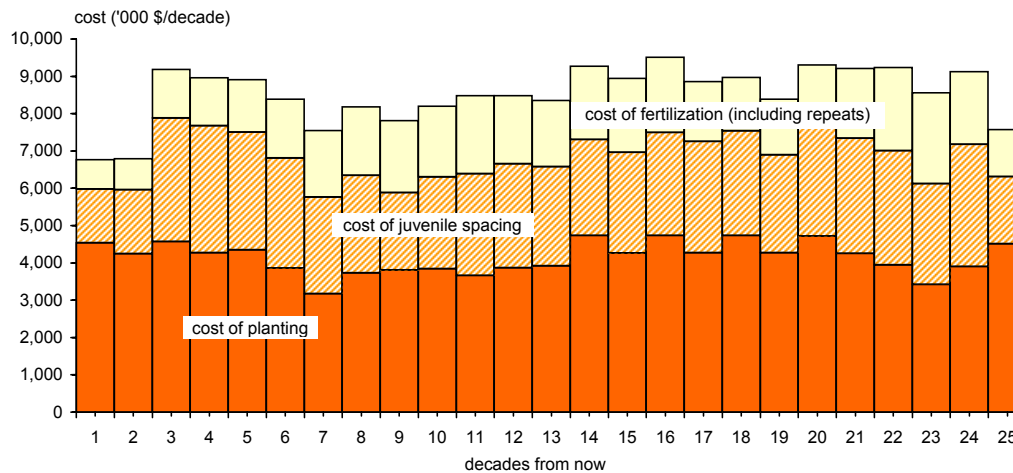


Figure 3-19. Silviculture direct employment forecast, maximum intensive management scenario (S04).

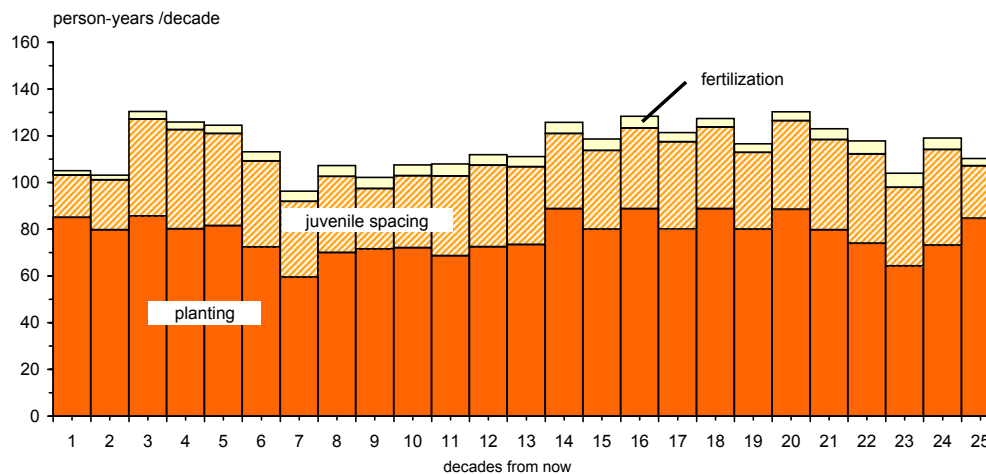


Figure 3-20. Incremental harvest volume from annual expenditures on spacing and fertilization, levels of funding scenario (S05).

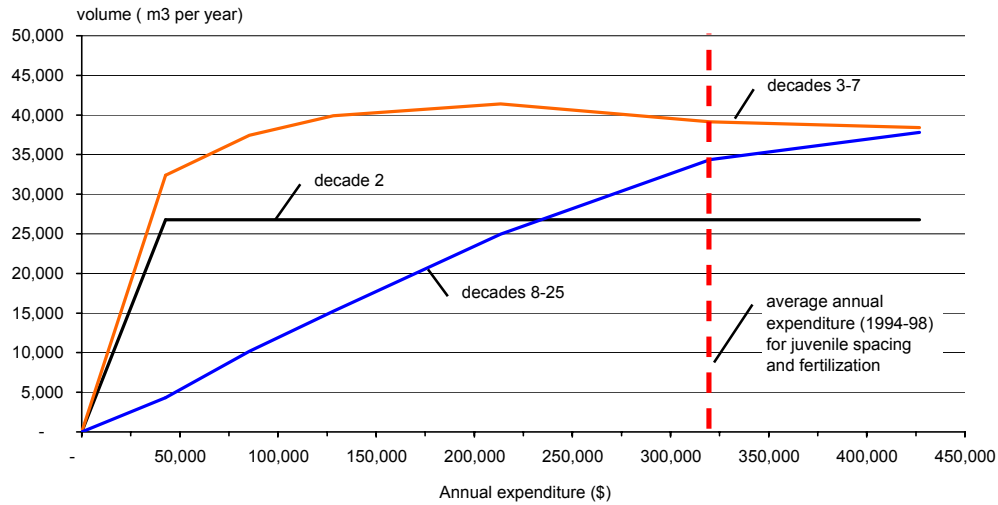


Figure 3-21. Area juvenile spaced at increasing levels of annual expenditure, levels of funding scenario (S05).

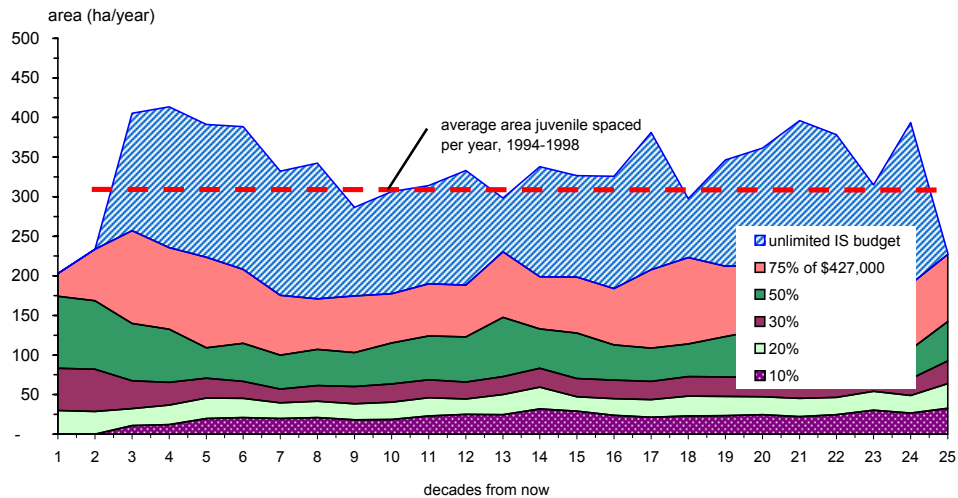
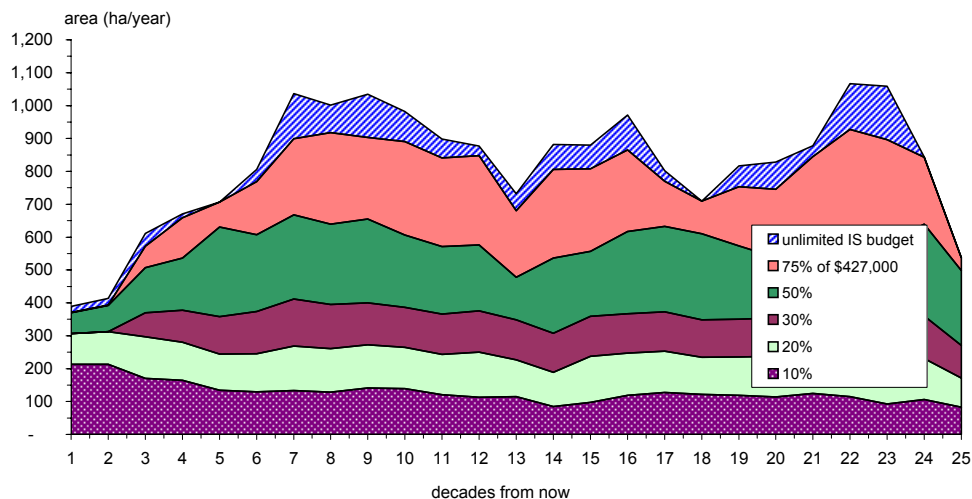


Figure 3-22. Area fertilized at increasing levels of annual expenditure, levels of funding scenario (S05).





Classic declining returns to scale in the late mid and long term

In the late mid term and long term (decades 8-25), the response of incremental harvest volume to increasing annual expenditure demonstrates the classic pattern of declining returns to scale– the rate of increase of the volume benefit declines as the annual expenditure rises, and is nearly flat between \$320 000 and \$427 000 per year. Note that recent annual expenditure for spacing and silviculture, calculated as the average annual expenditure over 1994-1998, is \$320 000 per year.

Figure 3-21
Spacing vs annual expenditure

Figure 3-21 and 3-22 plot the area of juvenile spacing and fertilization, respectively, undertaken annually for increasing levels of expenditure.

Figure 3-22
Fertilization vs annual expenditure

The relative width and variation of the plotted bands corresponding to activity levels are determined by the silviculture opportunities encountered by the model, and by variations in treatment costs. The model allocates funds to two cost categories of spacing — east side (\$1700 per hectare) and west side (\$800 per hectare), and fertilization (\$200 per hectare).

3.3 Management for Timber Quality

This section presents the results of two scenarios that implement silviculture treatments in order to achieve timber quality objectives. The objectives are to maximize the yield of solid clear wood (scenario S09) and the yield of large logs (scenario S06). Both scenarios maximize the quality objective in the long term and assume that sufficient silviculture can be undertaken in the short and medium term to establish a sustainable long-term output.

S09:
Max solid-clear wood

The harvest of solid-clear wood was not maximized directly by the model. The volume of wood from pruned stands in the long term (decades 16-25) was maximized and the average expenditure on pruning was noted (\$166 915). The model was re-solved five times with the same objective but annual pruning expenditures were constrained to be less than \$86,129, \$90,103, \$107,909, \$137,609, and \$166,915. Note that the harvest schedule was constrained to be equal to the maximum harvest schedule forecast in scenario S04.

Figure 3-23
Volume of solid-clear wood vs expenditure

Figure 3-23 shows the relationship between the incremental volume of solid-clear wood and annual expenditure on pruning. The straight-line relationship infers that the investment in today's dollars for a cubic metre of solid clear wood in decade 11 is \$4.50. Assuming a discount rate of 4% the future value of this investment in 110 years is \$337 per cubic metre.

Figure 3-24
Schedule of solid-clear wood by expenditure

Figure 3-24 shows the schedule of increments of solid-clear wood harvested with increasing levels of average annual expenditure on pruning. The average annual expenditure is an upper limit on pruning activity– the model may choose to prune less than its budget allows. These increments are calculated only for existing managed and future managed stands, and cannot be calculated for natural stands. The increment of solid clear available with no further investment (labeled \$0) is the product of historical pruning activity, i.e., existing pruned stands.

Figure 3-23. Incremental harvest volume (long term) of solid-clear wood with increasing expenditure on pruning (\$09).

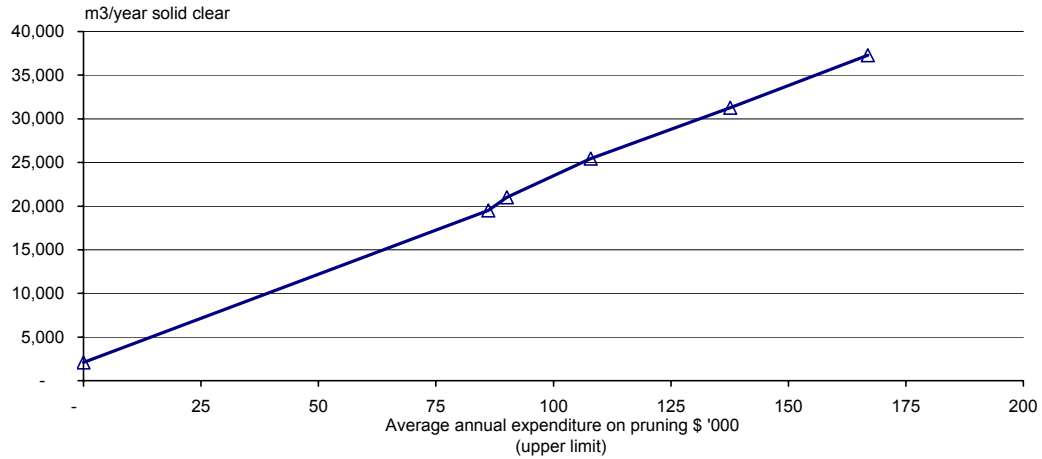


Figure 3-24. Forecast harvest of solid-clear wood with increasing levels of annual expenditure on pruning (\$09).

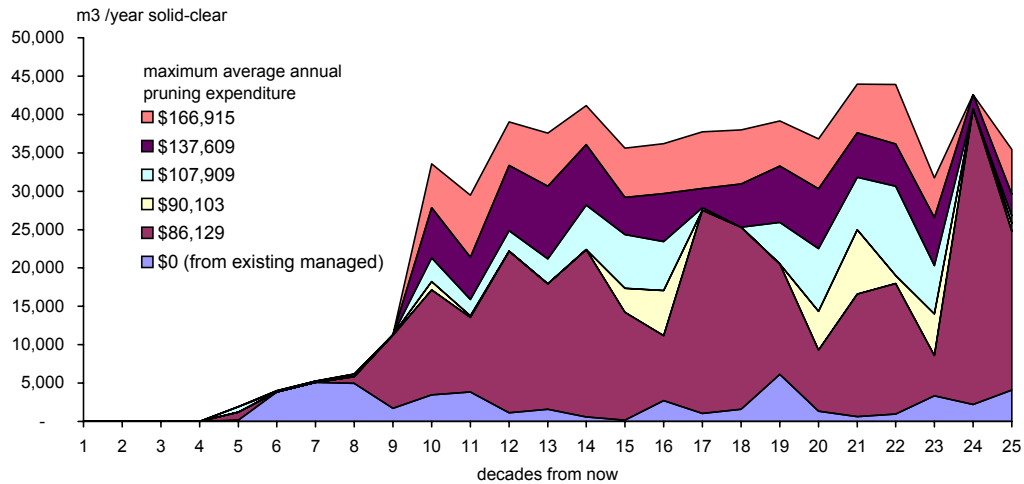
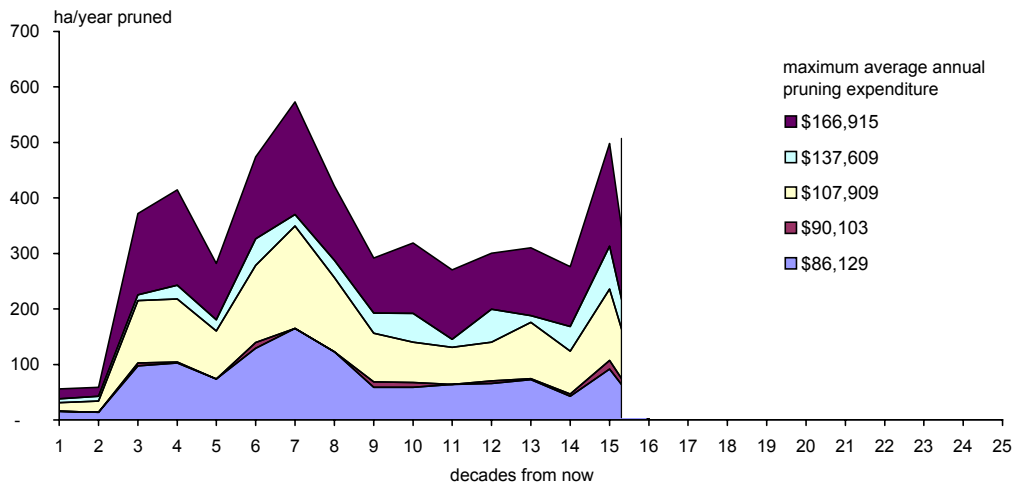


Figure 3-25. Area pruned at increasing levels of annual expenditure (\$09).





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Figure 3-25
Schedule of area
pruned by expenditure

Figure 3-25 shows the schedule of area pruned at increasing levels of annual expenditure. Only pruning activity in the short and mid term is plotted because the model's objective is to maximize the production of clear wood in the long term. Since pruning activity undertaken in the long term will result in few harvestable stands within the planning horizon, modeled pruning activity in the long term is erratic.

Appendix E describes the results of the pruning scenario (S09) in more detail.

S06:
Max large logs

This scenario was implemented by maximizing the harvest of stems of DBH ≥ 65 cm, i.e., the model maximized the volume produced from a yield table that was compiled with utilization limits of 65+ cm DBH. A major difference between this scenario and S09 (clear wood) is that the harvest schedule was constrained to be greater than or equal to the base case harvest schedule. The rationale for this relaxation of volume production requirements is that the harvest of 65+ cm volume showed very little increase unless the harvest flow constraint was relaxed; however, it is unlikely that a trade-off of volume for piece size would be acceptable if it reduced the harvest schedule below the current base case.

Volume is traded-off
for piece size

Figure 3-26

Figure 3-26 shows the composition of the harvest by dimension. The harvest schedule maintains the initial cut for two decades and then declines to 301 000 m³. The schedule maintains this harvest level out to the planning horizon.

S06 Increases
harvest of 65+cm
stems by 33 000 m³
per year

Comparing Figure 3-26 to Figure 3-15 – the composition of the harvest by dimension for scenario S04 (maximize volume production)--the annual harvest volume of 65+ cm stems has almost doubled from 35 000 m³ (S06) to 68 000 m³ (S04) while the harvest of 45– 64.9 cm stems has remained relatively constant – 90 000 m³ (S06) versus 93 000 m³ (S04).

Opportunity cost is
18% of long-term cut

Note that this doubling of harvest of stems with DBH > 65 cm was achieved at the cost of lowering the long-term annual harvest level from 367 000 m³ to 301 000 m³.

Figure 3-28,3-29
Age at harvest
increases

The reason why long-term harvest volume is reduced under S06 is apparent from Figure 3-28. The age-class distribution of the harvested stands has shifted to older age classes. Figure 3-29 compares the long-term average age-class distribution of the harvested stands when the management objective changes from maximizing volume harvest to maximizing piece size.

Figure 3-27,3-30
Shift to higher
grades

Figures 3-27 and 3-30 show that a similar shift has occurred in the distribution of grades in the harvested stands in the long term, with a shift out of J grade and into the H and I grades.

Figure 3-26. Composition by dimension of forecast harvest of managed stands, maximum dimension scenario (S06).

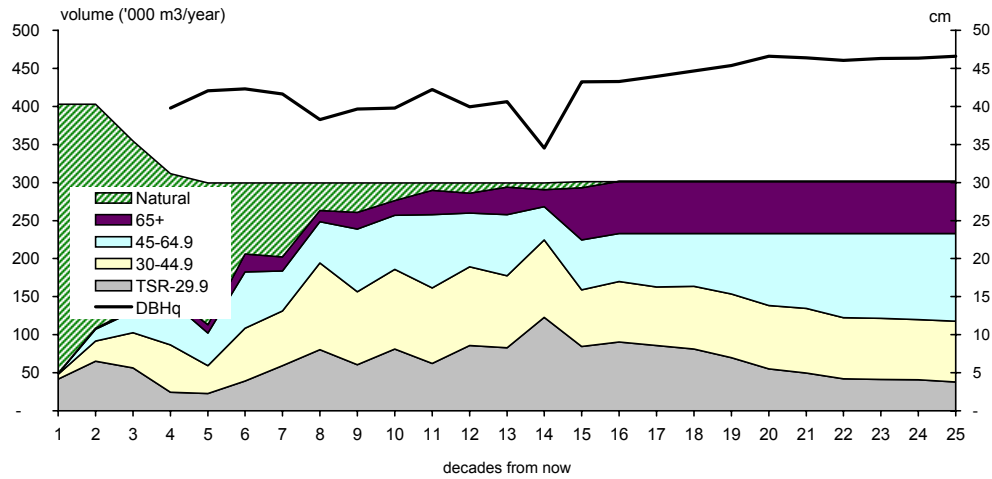


Figure 3-27. Composition by grade of forecast harvest of managed stands, maximum dimension scenario (S06).

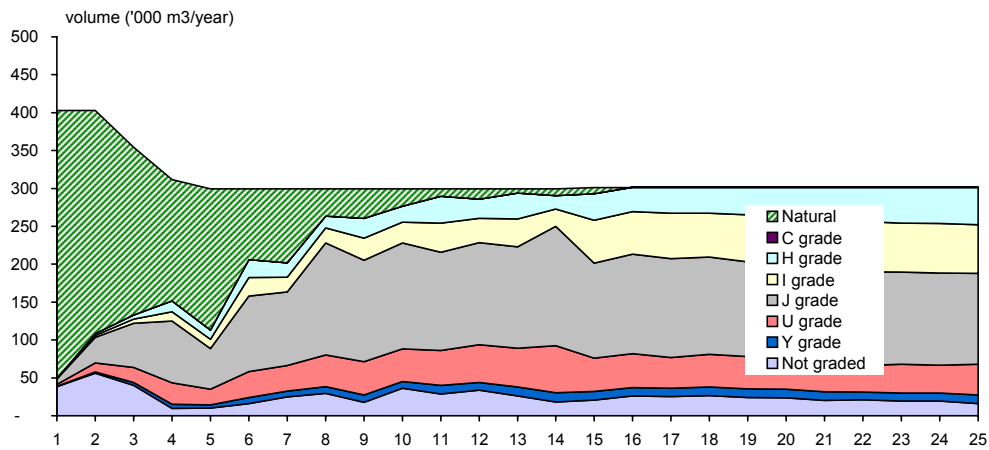


Figure 3-28. Composition by stand age of forecast harvest of managed stands, maximum dimension scenario (S06).

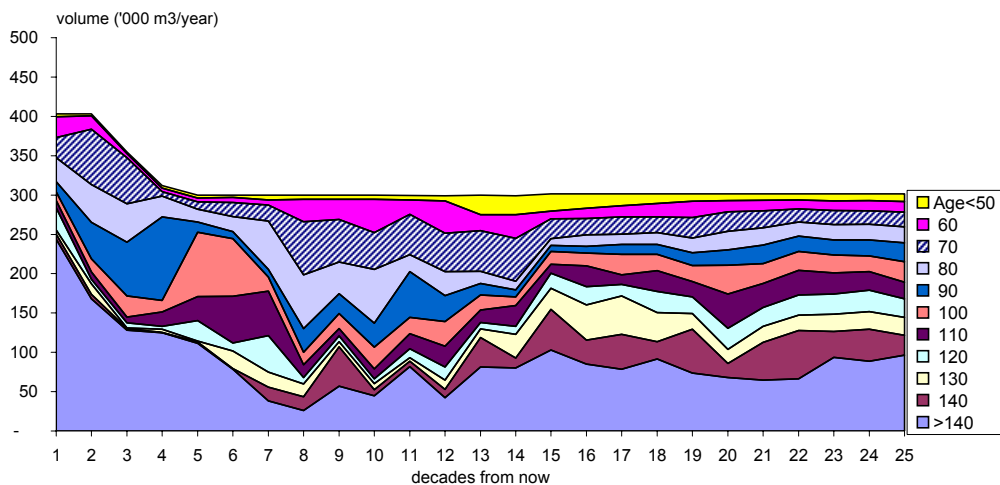


Figure 3-29. Age class distribution of stands harvested in the long term, maximum dimension scenario (S06).

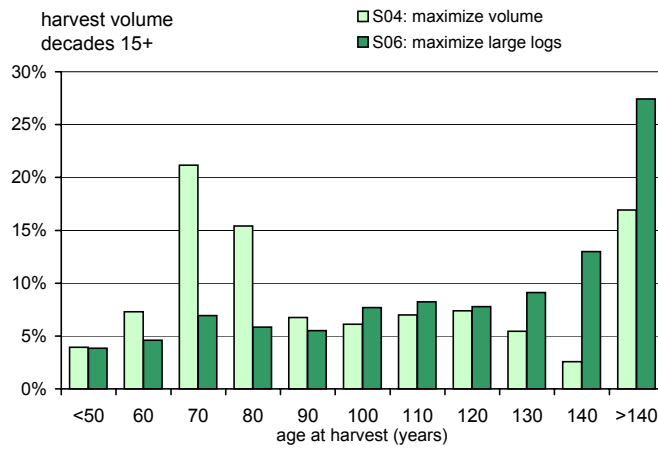
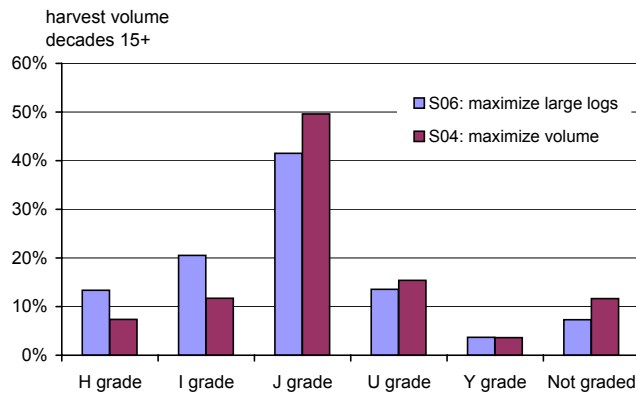


Figure 3-30. Grade distribution of stands harvested in the long term, maximum dimension scenario (S06).





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4.0 Recommendations for Management

The previous section (3.0) reported (described) the potential productive capacity of the Arrowsmith TSA under three management objectives, and also described the impact of intensified management on indicators of the state of the forest. This section (4.0) identifies the specific regimes selected by the model to achieve the management objectives in the long term. The description of the regimes that achieve the forest-level management objectives constitutes the long-term silviculture strategy. A short-term program (1st decade) that identifies the opportunities to implement these regimes in the first decade plan is also included.

4.1 Long-Term Silvicultural Strategy

Table 4-1
Silvicultural regimes vs.
management objectives

The long-term silvicultural strategy determined for the Arrowsmith TSA is summarized in Table 4-1 for each silvicultural analysis unit and management objective. This table reports the percent of the total area of each silvicultural analysis unit that is managed by each regime. Note that the management objectives are represented in the tables by the scenario that implemented each objective in section 3.0 of this report, i.e.,

S04-- maximize harvest volume complied to TSR utilization standards

S06-- maximize piece size (harvest volume complied at 65+ cm)

S09-- maximize harvest of volume solid-clear wood

SAU01 Fd SI=35

For both S04 (maximize harvest volume) and S09 (maximize harvest of volume solid-clear wood) the regime most often implemented (59% in both cases) is:

- Plt Fd 1200 sph, JS to 600 sph, CT, clearcut.

However, when the objective is to maximize piece size (S06), the percentage of the area managed by this regime drops to 37% and 41% of the area is managed under the regime:

- Plt Fd 1200 sph, JS to 500 sph, clearcut.

SAU02 Fd SI=28

With the management objective of maximizing harvest volume (S04), the regime most often implemented (93%) is

- Plt Fd75Cw25 1600 sph, JS to 800 sph, CT, clearcut.

When the management objective changes to maximize piece size (S06), the area managed by this regime drops to 76% and 24% of the area is managed under the regime:

- Plt Fd 1200 sph, JS to 600 sph, CT, clearcut



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SAU03 Fd SI=20

As specified by the district, after planting to 1200 sph, 50% of the stands will develop to free growing at that density and the remainder will undergo ingress of an additional 1800 stems.

The model addresses all three management objectives with the same regimes. The portion of the managed area that is at 1200 sph at free growing is simply held for clearcut, i.e.,

- Plt Fd 1200 sph, clearcut.

The portion that ingresses to 3000 sph is spaced and repeat fertilized (RF) until it is clearcut:

- Plt Fd 1200 sph, ingress +1800 sph, JS to 800 sph, RF, clearcut.

SAU04 Other conif,
SI=22

The only development options provided for this analysis unit are alternative planting densities. The model addresses all three management objectives with the same regimes. The model most often (76%-78%) selected 1200 sph as the optimum planting density, with the remainder distributed between 600 sph and 1600 sph.

SAU05: Hw leading,
SI=22

The regime diagram developed with the district specifies that after planting to 1200 sph, 50% of the stands will develop to free growing at that density and the remainder will undergo ingress of an additional 4800 stems.

Under all three management objectives, most of the area (>94%) is planted to 1200 sph. With the objective of maximizing harvest volume (S04) or maximizing the harvest of solid-clear wood (S09), the regimes implemented by the model were identical:

- Plt Hw7Cw2Ba1 1200 sph, JS to 800 sph, CT, clearcut
- Plt Hw7Cw2Ba1 1200 sph, ingress +4800, JS to 800 sph, CT, clearcut.

These regimes are also implemented for 74% of the analysis unit where the management objective was to maximize piece size (S06). However the model spaced to a lower density and eliminated commercial thinning on 26% of the analysis unit.

SAU06: Hw leading,
SI=14

All of this analysis unit is planted to 1200 sph, regardless of the management objective. The 50% of the stands that ingress to 6000 sph are spaced:

- Plt Hw7Cw2Ba1 1200 sph, clearcut
- Plt Hw7Cw2Ba1 1200 sph, ingress +4800, JS to 1000 sph, clearcut.

SAU07: Cw leading,
SI=23

Under the management objective of maximizing volume (S04), 92% of the area was planted to 1200 sph. Stands that ingressed to 6000 sph were spaced to 1000 sph and subsequently clearcut (38%) or commercially thinned and clearcut (9%):



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- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut
- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, commercial thin, clearcut.

Stands that were 1200 sph at free growing were spaced to 700 sph and either held for clearcut (36%) or commercially thinned and subsequently clearcut (9%):

- Plt Cw7Hw2Ba1 1200 sph, JS to 700 sph, clearcut
- Plt Cw7Hw2Ba1 1200 sph, JS to 700 sph, commercial thin, clearcut

Some of the area (8%) was planted to 600 sph and held for clearcutting.

- Plt Cw7Hw2Ba1 600 sph, clearcut

With the management objective of maximizing piece size, the regime of planting to 600 sph was eliminated and commercial thinning reduced to a low level-- 4% of the managed area. Otherwise the management regime was unchanged from S04.

Under the management objective of maximizing solid-clear wood, 27% of the stands that developed to 1200 sph and spaced to 700 sph were subsequently pruned and 7% not pruned. A further 10% of the 1200 sph stands were pruned without spacing:

- Plt Cw7Hw2Ba1 1200 sph, JS to 700 sph, Pr, clearcut
- Plt Cw7Hw2Ba1 1200 sph, Pr, clearcut

Of the stands that ingressed to 6000 sph and were subsequently spaced to 1000 sph, 27% were held for clearcutting, 17% were pruned and clearcut, and 6% were pruned, commercially thinned and clearcut:

- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut
- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, CT, clearcut
- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, Pr, CT, clearcut

SAU08: Cw leading,
SI=14

Both the S04 (maximize harvest volume) and S09 (maximize solid-clear volume) scenarios plant 6% of the area of SAU08 to 600 sph and hold it for clearcutting.

- Plt Cw7Hw2Ba1 600 sph, clearcut

The remainder is planted to 1200 sph, 50% of which ingresses to 6000 sph and is subsequently spaced back to 1200 sph.

- Plt Cw7Hw2Ba1 1200 sph, clearcut
- Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1200 sph, clearcut

The S06 scenario (maximize piece size) plants only 1200 sph and follows the ingress pattern and management regimes specified above.



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SAU09: Ba leading,
SI=22

Similar to SAU08, both the S04 (maximize harvest volume) and S09 (maximize solid-clear volume) scenarios plant 4% of the area of SAU09 to 600 sph and hold it for clearcutting.

- Plt Ba6Hw2Cw2 600 sph, clearcut

The remainder is planted to 1200 sph, 50% of which ingresses to 6000 sph and is subsequently spaced back to 1200 sph.

- Plt Ba6Hw2Cw2 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut

A portion of the analysis unit that is planted to 1200 sph and does not undergo ingress is commercially thinned—9% for S04 and 7% for S09.

The S06 scenario (maximize piece size) plants only 1200 sph and follows the pattern of ingress and management regimes specified above.

Table 4-2
Source of harvest by
silvicultural state.

Table 4-2 identifies the percent of the total harvest volume obtained from each regime utilized by the model (regime S04), in the short-, medium-, and long-term. Note that 42% of the mid-term harvest and 40% of the long-term harvest come from 7 regimes applied to 3 SAUs.

SAU01 Plt Fd 1200 sph, JS to 600 sph, clearcut
Plt Fd 1200 sph, JS to 600 sph, CT, clearcut

SAU02 Plt Fd 1200 sph, RF, clearcut
Plt Fd 1200 sph, RF, CT, clearcut
Plt Fd 1600 sph, JS to 800 sph RF, clearcut
Plt Fd 1600 sph, JS to 800 sph RF, CT, clearcut

SAU07 Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut

Strategy - Summary

Under the S04 scenario, the model puts the highest priority on maximizing harvest levels in decade 2, then in the mid term (decades 3-15), and finally in the long term (decades 16-25). Therefore the model implements commercial thinning to bring timber forward in the harvest queue in order to reduce falldown in decade 2 and fill the mid-term trough. Fertilization and genetic gain produce timber quantity benefits in the late mid term and early long term which are conveyed forward in the harvest queue by commercial thinning.

Under the S06 scenario the objective of maximizing piece size is met in the main by increasing age at harvest. Lengthening the rotation age past culmination age reduces the productivity of the TSA, a fact reflected by the 19% drop in the long-term harvest level obtained for scenario S06. In addition to longer rotations, there is a shift in some analysis units (SAU01, SSU02, SAU05, and SAU07) to spacing to lower densities.

Managing for solid-clear harvest volume (S09) is achieved by implementing pruning options of regimes already selected in S04 (maximize volume) in analysis units SAU01, SAU02, and SAU07.



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Table 4-1. Silvicultural regimes implemented under different management objectives.

Silvicultural Regime	S04 % area	S06 % area	S09 % area
SAU01: Fd leading, SI=35			
Plt Fd 600 sph, clearcut	2	0	2
Plt Fd 1200 sph, JS to 500 sph, clearcut	18	41	2
Plt Fd 1200 sph, JS to 500 sph, Pr, clearcut			5
Plt Fd 1200 sph, JS to 600 sph, CT, clearcut	59	37	59
Plt Fd 1200 sph, JS to 600 sph, Pr, CT, clearcut			9
Plt Fd75Cw25 1600 sph, JS to 800 sph, CT, clearcut	20	22	23
	100	100	100
SAU02: Fd leading, SI=28			
Plt Fd 600 sph, clearcut	3		3
Plt Fd 1200 sph, JS to 600 sph, CT, clearcut	4	24	2
Plt Fd 1200 sph, JS to 600 sph, Pr, CT, clearcut			1
Plt Fd75Cw25 1600 sph, JS to 800 sph, CT, clearcut	93	76	19
Plt Fd75Cw25 1600 sph, JS to 800 sph, Pr, CT, clearcut			75
	100	100	100
SAU03: Fd leading, SI=20			
Plt Fd 600 sph, clearcut	8		6
Plt Fd 1200 sph, clearcut	46	50	47
Plt Fd 1200 sph, ingress +1800 sph, JS to 800 sph		5	
Plt Fd 1200 sph, ingress +1800 sph, JS to 800 sph, RF, clearcut	46	45	47
	100	100	100
SAU04: Other conif, SI=22			
Plt Cw5Bg3Hw2 600 sph, clearcut	9		11
Plt Cw5Bg3Hw2 1200 sph, clearcut	78	78	76
Plt Cw5Bg3Hw2 1600 sph, clearcut	13	22	13
	100	100	100
SAU05: Hw leading, SI=22			
Plt Hw7Cw2Ba1 600 sph, clearcut	5		6
Plt Hw7Cw2Ba1 1200 sph, JS to 600 sph, clearcut	3	26	2
Plt Hw7Cw2Ba1 1200 sph, JS to 800 sph, CT, clearcut	46	37	46
Plt Hw7Cw2Ba1 1200 sph, ingress +4800, JS to 800 sph, CT, clearcut	46	37	46
	100	100	100

continued on next page



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Table 4-1. Silvicultural regimes implemented under different management objectives *(continued)*.

Silvicultural Regime	S04 % area	S06 % area	S09 % area
SAU06: Hw leading, SI=14			
Plt Hw7Cw2Ba1 1200 sph, clearcut	50	50	50
Plt Hw7Cw2Ba1 1200 sph, ingress +4800, JS to 1000 sph, clearcut	50	50	50
	100	100	100
SAU07: Cw leading, SI=23			
Plt Cw7Hw2Ba1 600 sph, clearcut	8		
Plt Cw7Hw2Ba1 1200 sph, CT, clearcut	9	2	6
Plt Cw7Hw2Ba1 1200 sph, JS to 700 sph, clearcut	36	48	7
Plt Cw7Hw2Ba1 1200 sph, JS to 700 sph, Pr, clearcut			27
Plt Cw7Hw2Ba1 1200 sph, Pr, clearcut			10
Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut	38	48	27
Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, Pr, CT, clearcut	9	2	6
Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1000 sph, Pr, clearcut			17
	100	100	100
SAU08: Cw leading, SI=14			
Plt Cw7Hw2Ba1 600 sph, clearcut	6		6
Plt Cw7Hw2Ba1 1200 sph, clearcut	47	50	47
Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 1200 sph, clearcut	47	50	47
	100	100	100
SAU09: Ba leading, SI=22			
Plt Ba6Hw2Cw2 600 sph, clearcut	4		4
Plt Ba6Hw2Cw2 1200 sph, clearcut	39	45	41
Plt Ba6Hw2Cw2 1200 sph, CT, clearcut	9	5	7
Plt Ba6Hw2Cw2 1200 sph, ingress +4800 sph, JS to 1000 sph, clearcut	48	50	48
	100	100	100

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Table 4-2. Contribution of harvest from silvicultural states to timber supply objectives

Source of Harvest:			Contribution:		
SAU	Silviculture State	Silviculture Code Description	Timber Supply - % Total Volume		
			Short 1-2	Mid 3-14	Long 15-25
1	N	Natural existing	18.2	6.2	-
2	N	Natural existing	9.6	0.1	-
3	N	Natural existing	2.6	1.0	-
4	N	Natural existing	1.4	0.4	-
5	N	Natural existing	12.1	0.1	-
6	N	Natural existing	7.8	0.4	-
7	N	Natural existing	21.3	1.0	-
8	N	Natural existing	4.2	9.6	0.1
9	N	Natural existing	1.8	0.2	-
10	N	Natural existing	3.6	2.7	-
1	12-S05	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 500 sph	-	1.4	7.5
1	* 12-S06	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph	0.5	5.0	6.6
1	* 12-S06-T	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph, commercially thinned	-	5.4	5.2
1	16-S08	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph	1.0	2.1	1.9
1	16-S08P	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, pruned	-	0.2	0.0
1	16-S08PT	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, pruned, commercially thinned	-	0.4	0.1
1	16-S08-T	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, commercially thinned	-	0.8	1.6
1	CT	Volume from commercial thinning	1.6	1.7	1.8
2	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.2	0.0
2	* 12---F	Plant 1200 sph, density after ingrowth 1200 sph, fertilized	3.8	5.2	-
2	12---T	Plant 1200 sph, density after ingrowth 1200 sph, commercially thinned	-	0.0	-
2	* 12---TF	Plant 1200 sph, density after ingrowth 1200 sph, commercially thinned, fertilized	-	6.0	0.1
2	12-S06	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph	1.4	0.4	0.2
2	12-S06P	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph, pruned	-	0.2	0.0
2	12-S06PT	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph, pruned, commercially thinned	-	0.1	0.1
2	12-S06-T	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 600 sph, commercially thinned	-	0.4	0.6
2	16-S08	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph	2.5	0.3	0.3
2	* 16-S08--F	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, fertilized	-	9.7	9.6
2	* 16-S08-TF	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, commercially thinned, fertilized	-	6.3	13.2
2	16-S08-T	Plant 1600 sph, density after ingrowth 1600 sph, juvenile spaced to 800 sph, commercially thinned	-	0.1	0.5
2	CT	Volume from commercial thinning	6.7	4.9	5.6
3	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.6	2.2
3	1218	Plant 1200 sph, density after ingrowth 1800 sph	-	0.1	0.1
3	1218---F	Plant 1200 sph, density after ingrowth 1800 sph, fertilized	-	0.5	-
3	1218S08	Plant 1200 sph, density after ingrowth 1800 sph, juvenile spaced to 800 sph	-	0.4	-
3	1218S08--F	Plant 1200 sph, density after ingrowth 1800 sph, juvenile spaced to 800 sph, fertilized	-	1.7	3.1
4	12	Plant 1200 sph, density after ingrowth 1200 sph	-	1.5	1.7
4	16	Plant 1600 sph, density after ingrowth 1600 sph	-	-	0.2
5	12	Plant 1200 sph, density after ingrowth 1200 sph	-	1.4	2.8
5	1248	Plant 1200 sph, density after ingrowth 4800 sph	-	-	0.0
5	12---T	Plant 1200 sph, density after ingrowth 1200 sph, commercially thinned	-	0.4	0.9
5	12-S08	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 800 sph	0.0	1.3	-
5	12-S08-T	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 800 sph, commercially thinned	-	0.8	-
5	1248S08	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 800 sph	-	1.7	3.4
5	1248S08-T	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 800 sph, commercially thinned	-	-	0.5
5	CT	Volume from commercial thinning	0.0	0.4	0.4
6	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.2	1.0
6	1248S10	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph	-	1.2	0.6
7	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.9	3.1
7	12---T	Plant 1200 sph, density after ingrowth 1200 sph, commercially thinned	-	1.2	1.2
7	12-S07	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 700 sph	-	3.1	2.4
7	12-S07P	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 700 sph, pruned	-	0.0	-
7	12-S07PT	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 700 sph, pruned, commercially thinned	-	0.0	-
7	12-S07-T	Plant 1200 sph, density after ingrowth 1200 sph, juvenile spaced to 700 sph, commercially thinned	-	0.1	-
7	* 1248S10	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph	-	4.5	5.8
7	1248S10P	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph, pruned	-	0.0	-
7	1248S10PT	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph, pruned, commercially thinned	-	0.0	-
7	1248S10-T	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph, commercially thinned	-	1.3	1.3
7	CT	Volume from commercial thinning	-	0.7	0.7
8	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.3	5.0
8	1248	Plant 1200 sph, density after ingrowth 4800 sph	-	-	0.4
8	1248S12	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1200 sph	-	0.8	4.4
9	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.2	0.6
9	1248	Plant 1200 sph, density after ingrowth 4800 sph	-	0.5	0.5
9	12---T	Plant 1200 sph, density after ingrowth 1200 sph, commercially thinned	-	0.1	0.1
9	1248S10	Plant 1200 sph, density after ingrowth 4800 sph, juvenile spaced to 1000 sph	-	0.3	0.2
9	CT	Volume from commercial thinning	0.0	0.1	0.1
10	12	Plant 1200 sph, density after ingrowth 1200 sph	-	0.9	2.3
Total volume harvested:			8,059,989	41,559,895	40,702,467
Total % Volume Harvested from Managed Stands:			17	78	100



4.2 Short-Term Silvicultural Program

The previous section (4.1) described the regimes selected by the model to address three management objectives, to be applied over the 25 decade planning horizon. This section focuses on the silvicultural activities of the first decade, assuming the management objective of maximizing volume production (scenario S04).

Table 4-3
1st decade treatments

Table 4-3 lists the analysis units to be treated in decade 1, their assumed silvicultural state, the silvicultural treatment, and the area treated. While the activities and areas treated are selected based on the forest-level management objective, the opportunities areas that are feasible for treatment are limited in the first decade by the current silvicultural state of the TSA, which in turn is determined by harvesting and silvicultural history.

Shadow prices of
silvicultural opportunities

The table also lists shadow prices for each activity with respect to five timber supply objectives: the priority-structured timber supply objective, timber supply in the short, mid and long term, and supply compiled to >65cm.

Shadow prices are calculated specific to a schedule of harvesting and silvicultural treatment; in Table 4-3 they are determined for the optimum harvest and silviculture schedule determined for the S04 scenario (maximize harvest volume).

The shadow prices are calculated assuming that the optimal schedule of silviculture developed in the S04 scenario will be applied in decades 2-25, but no spacing, fertilization or commercial thinning is allowed in decade 1. The shadow prices are interpreted as the change in the objective if this constraint is relaxed and one hectare is treated. For example, juvenile spacing to 1000 sph of one additional hectare of SAU06 would increase mid-term supply by 75 m3 and long-term supply by 454 m3.

Only scarce silviculture
opportunities have
shadow prices

Shadow prices quantify the value of scarce resources to the forest-level management objectives. This implies that SAU06 in a state feasible for spacing to 1000 sph is scarce, i.e., fully consumed by the JS activity at the optimum schedule determined for the S04 scenario. Conversely, at the optimum S04 schedule, SAU03 spacing opportunity (to 800 sph) has a shadow price of 0 and is not scarce—there is a surplus of this opportunity and the model has consumed the optimum amount, and does not want to treat additional hectares of SAU03.

All of the shadow prices associated with the short-term (ST) timber supply objective are zero, implying that no silvicultural activities implemented in decade 1 will have an impact on supply in decade 2.

Shadow prices associated with the objective of maximizing supply compiled to >65cm (large piece size) are also all zero, consistent with the observation earlier in this section that this objective was achieved by lengthening rotation ages rather than through silvicultural actions. Shadow prices calculated at the optimal activity levels for decade 1, rather than at zero (not shown), show negative values for commercial thinning — increasing the level of commercial thinning will negatively impact the objective of maximizing large piece size.

Note that there are no shadow prices associated with re-fertilization as the structure of the model precluded calculation of these values. When the model



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	<p>implements an initial fertilization action, it is required to maintain the schedule of re-fertilization until harvest.</p>
<p>Some treatments are desirable but cannot be implemented</p>	<p>In two cases, spacing of SAU09 and initial fertilization of SAU02, there are large positive shadow prices but the area actually treated in decade 1 is zero. The interpretation is that these activities would strongly support the management objectives but there was no opportunity to implement these activities in decade 1, i.e., no stands were operable with respect to the spacing and fertilization activities.²</p> <p>Two activities, spacing in SAU01 and commercial thinning in SAU07 have shadow prices of zero, and no area is treated in decade 1. The interpretation of this combination is that implementing these activities in decade 1 would have no positive effect on the management objectives.</p>
<p>Shadow prices rank silviculture opportunities</p>	<p>The shadow prices are used to rank the importance of silvicultural treatments to forest-level management objectives in Table 4-3. The shadow prices are assigned ranks in ascending order, and are specific to the management objective. The ranks cannot be compared between management objectives.</p>
<p>Commercial thinning and fertilization are highest priority</p>	<p>Across the three management objectives with useful shadow prices (priority-structured timber supply, and timber supply in the mid and long term), commercial thinning and initial fertilization activities rank the highest. Although ranks are not available for re-fertilization activities, the high rankings of the initial fertilization activities infer that re-fertilization should also be a high priority.</p>
<p>Juvenile spacing is a lower priority</p>	<p>In decade 1, spacing of SAU07 and SAU08 receive medium ranks, while other spacing opportunities are ranked lower. Spacing is intrinsic to most commercial thinning and fertilization regimes so the relatively low rankings of spacing activities infers that the model does not find that stands spaced in decade 1 are limiting CT and fertilization opportunities in subsequent decades.</p>
<p>SAU09 (Ba, SI=22) spacing doubles mid-term harvest opportunity</p>	<p>The rank for spacing of SAU09 is the highest ranking activity with respect to maximizing mid-term harvest, but is ranked 10th for long-term harvest. A possible explanation of this is that spacing reduces the minimum harvest age of dense (6000 sph) balsam- leading stands from 80 to 50 years. The reduced minimum harvest age would allow stands spaced in decade 1 to be harvested twice within the mid-term period (decades 3-14). If the same stand was not spaced in decade 1, it would not be available for harvest until decade 8, and could not be harvested again until decade 16.</p> <p>In determining an operational short-term silviculture program, apparent opportunities such as spacing of dense SAU09 should be examined to determine if they are anomalies of the modelling process or reflect useful information about the structure and productivity of the TSA.</p>

² The interpretation that fertilization of S02 would strongly support the management objectives is plausible; however, the impact of spacing of S09 seems less likely and should be investigated further.

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Table 4.3 Prescribed silvicultural treatment, activity levels, and impacts on management objectives (S04 scenario).

SAU	LS	SI	Current silvicultural state (history)	Prescribed Treatment	Activity ¹ (ha)	Shadow Price (m3/ha treated) ²					Rank by Management Objective ⁷				
						TS ³	ST ⁴	MT ⁴	LT ⁴	>65 cm ⁵	TS	ST	MT	LT	>65 cm
SAU01	Fd	35	Plt Fd 1200 sph	JS to 600-800 sph	0	0	0	0	0	0	14	1	14	14	1
SAU02	Fd	28	Plt Fd 1200 sph	JS to 600 sph	15	690	0	7	21	0	13	1	13	13	1
SAU03	Fd	20	Plt Fd 1200, ingress +1800 sph	JS to 800 sph	312	3,107	0	28	301	0	12	1	12	6	1
SAU05	HW	22	Plt Hw7Cw2Ba1 1200 sph, 50% ingress +4800	JS to 600-800 sph	0	0	0	0	0	0	14	1	14	14	1
SAU06	Hw	14	Plt Hw7Cw2Ba1 1200 sph, ingress +4800 sph	JS to 1000 sph	182	7,938	0	75	454	0	11	1	11	3	1
SAU07	Cw	23	Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph	JS to 1000 sph	574	16,857	0	166	234	0	7	1	8	8	1
SAU07	Cw	23	Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph	JS to 700 sph	257	16,857	0	166	234	0	7	1	8	8	1
SAU08	Cw	14	Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph	JS to 1200 sph	464	11,978	0	114	599	0	10	1	10	2	1
SAU09	Ba	22	Plt Ba6Hw2Cw2 1200 sph, ingress +4800 sph	JS to 1000 sph	0	25,537	0	273	199	0	1	1	1	11	1
SAU02	Fd	28	Plt Fd 1200 sph; Plt Fd 1200-1600 sph, JS to 600-800 sph	initial fertilization	0	20,301	0	194	869	0	5	1	6	1	1
SAU03	Fd	20	Plt Fd 1200, ingress +1800 sph	initial fertilization	312	15,595	0	273	199	0	9	1	1	11	1
SAU02	Fd	28	Plt Fd 1200 sph, F	re-fertilize	396	ng ⁶	ng	ng	ng	ng	ng	ng	ng	ng	ng
SAU02	Fd	28	Plt Fd 1200 sph, JS to 800 sph, F	re-fertilize	276	ng	ng	ng	ng	ng	ng	ng	ng	ng	ng
SAU03	Fd	20	Plt Fd 1200 sph, F	re-fertilize	1,975	ng	ng	ng	ng	ng	ng	ng	ng	ng	ng
SAU03	Fd	20	Plt Fd 1200 sph, JS to 800 sph, F	re-fertilize	974	ng	ng	ng	ng	ng	ng	ng	ng	ng	ng
SAU01	Fd	35	Plt Fd 1200-1600 sph, JS to 600-800	CT	656	21,641	0	212	435	0	2	1	4	4	1
SAU02	Fd	28	Plt Fd 1200-1600 sph, JS to 600-800	CT	627	21,641		212	435		2	1	4	4	1
SAU05	Hw	22	Plt Hw7Cw2Ba1 1200 sph, ingress +4800, JS to 800 sph	CT	10	21,560	0	213	293	0	4	1	3	7	1
SAU07	Cw	23	Plt Cw7Hw2Ba1 1200 sph, ingress +4800 sph, JS to 700-1000 sph	CT	0	0	0	0	0	0	14	1	14	14	1
SAU09	Ba	22	Plt 1200	CT	1	18,545	0	188	217	0	6	1	7	10	1

Notes:

¹ Activity is the area treated as scheduled by the S04 scenario at its optima.

² The shadow price can be interpreted as the increase in the management objective for an additional hectare treated. These shadow prices were calculated at the S04 optimum activity levels, constrained in 1st decade to zero.

³ TS is the timber supply objective used to optimize S04. This objective establishes priorities for scheduling the harvest: first, short term harvest is maximized, then mid-term, and last, long term.

⁴ ST, MT and LT are the short-, mid- and long-term components of the timber supply.

⁵ >65 cm is the volume harvested complied to >65 cm.

⁶ ng means "no guidance". The computer model could not supply the information required to rank repeat fertilizations.

⁷ Ranks are only meaningful within objectives.



5.0 Limitations of the Study

This study is a descriptive analysis. It quantifies the changes in productive capacity of the Arrowsmith TSA that result from modifying:

- management objective
- level of expenditure
- intensity of management

This study is not prescriptive: it makes no recommendations concerning the appropriate management objectives and does not specify a desirable level of expenditure and intensity of management.

Prescriptive studies should follow confirmation of the descriptive model

The critical components of the physical production model (yield tables, silviculture history, and regime diagrams) should be confirmed before addressing the question of the appropriate level of silviculture investment.

1. Accuracy of the Yield Tables

All of the biology in the modelling process is contained in the yield curves. The remainder of the model is an accounting system that selects yield tables and moves hectares through feasible sequences (regimes) of activities. Therefore the accuracy of the forest-level yield forecasts of the model is largely associated with the accuracy of the yield tables, specifically the managed-stand yield tables developed with TASS.

TASS-TIPSY issues

In the execution of this project, it became apparent that a top-height adjustment was required in the development of the TASS tables to make them consistent with TIPSY managed stand yield tables. The inclusion of this adjustment necessitated the development of “work-around” procedures to simulate the application of juvenile spacing, pruning and commercial thinning to fertilized stands and stands grown from select stock (incorporating genetic gain). The yield tables developed for this study (Appendix E) – and in particular, the “work-arounds” devised to deal with the TIPSY-TASS differences – should be reviewed for plausibility, and, subsequently, the forest-level productivity forecasts reported in this document should be considered in light of this review.

TASS is central to silviculture strategies

The accuracy and scope of TASS is central to the development of meaningful silviculture strategies and forest-level plans. The strengthening of TASS should be encouraged and its proper application in studies such as this should be clarified and documented.

2. Representation of Silvicultural History

The accurate assignment of existing managed stands to silvicultural states is essential if the model is to develop a plausible schedule of management actions in the initial decades. The assignment of the existing managed stands to the



inventory data set used in this study (Appendix A) was accomplished with an *ad hoc* procedure that is unlikely to be accurate. The representation of silviculture history in the model should be reviewed in conjunction with consideration of the short-term silviculture program (section 4.2).

Ultimately the silvicultural history records should be spatially integrated with the inventory database.

3. Modelling of Regimes

Just as the biology in the modelling process is contained in the yield curves, the alternative development pathways that a stand may take as the result of management actions are embodied in the regime diagrams. The diagrams must be accurate with respect to the transitions that occur when a stand is treated, and must be of appropriate scope—i.e., include sufficient management actions and development pathways to account for the current and future management of the stands.

Operability issues

Of special concern are limitations on management actions that are related to operability factors not included in the silvicultural state of the model. For example, according to a regime diagram, a stand may be operable for commercial thinning if certain target volume and residual tree requirements are met. However, the silviculturalists may know that only 30% of the terrain is appropriate for commercial thinning, regardless of whether the stand meets the target volume and residual tree criteria. These operability constraints must be implemented in the model in order to obtain reasonable results.



Appendix A– The Current Silvicultural State

Assignment of existing managed

The accurate assignment of existing managed stands to silvicultural states is essential if the model is to develop a plausible schedule of management actions in the initial decades.

The silviculture state of a stand records the information that the manager needs in order to determine what silviculture activities are immediately feasible (not including operational considerations such as harvesting restrictions, accessibility, terrain, or markets). For example, the species mix, age, density, basal area, crown closure may be the variables that the silviculturalist considers when deciding the treatment of a stand. These state variables change over time with the development of the stand (growth, competition, mortality) and with silviculture actions (e.g., juvenile spacing).

Describing the silviculture state at this level of detail is appropriate for tactical, program-level planning, but is too detailed for strategic planning with a forest-level model. For the purposes of this project, the silviculture state of (aggregations of) forest stands will be described by the list of treatments already applied. The possible silviculture states for the Arrowsmith TSA are listed in Table B-1 (Appendix B).

Method

The assignment of the existing managed stands to the inventory data set used in this study was accomplished with an *ad hoc* procedure. From ISIS, a table was constructed that listed for each analysis unit and age class combination the total area recorded as planted, juvenile spaced, pruned and fertilized.

Each of these records (analysis unit x age class) was subdivided into additional records according to a set of rules based on logical silviculture practices:

1. The priority for areas to be fertilized will be, first, areas pruned, second, areas spaced but not pruned, and third, areas planted but not subsequently spaced or pruned.
2. The priority for areas to be pruned will be, first, areas spaced, and second, areas planted but not subsequently spaced.
3. The priority for areas to be spaced will be areas that have been previously planted.
4. If the area fertilized or pruned or spaced exceeds the area planted, then it is assumed that the treatments were applied to natural stands, and the same hierarchy of treatment priorities applies.

While it is unlikely that applying these rules to the ISIS data has resulted in the exact silviculture state of the TSA, the procedure is unambiguous and results in a unique set of silviculture states for each age class of each analysis unit. Table A-1 summarizes the relevant silvicultural history for the Arrowsmith TSA as obtained from ISIS. In Table 2 this history is allocated across the inventory as existing managed stands.

Arrowsmith TSA Silviculture Strategy Analysis

Appendix A - Silvicultural State

Table A-1. Silviculture history of the Arrowsmith TSA (Source ISIS).

Year	Juvenile Spacing (ha)	Pruning (ha)	Fertilization (ha)
1971	32		
1977	137		
1978	712		563
1979	1,537		585
1980	1,479		2,713
1981	1,052		2,300
1982	956		
1983	329		
1984	556		
1985	224		
1986	194		856
1987	491		588
1988	560		2,113
1989	361		276
1990	262		1,082
1991	289	4	856
1992	634		619
1993	386	22	353
1994	246	103	160
1995	518	415	
1996	133	161	102
1997	458	242	
1998	316	210	
1999	43	14	
2000			2
	11,904	1,171	13,168
Average 1994-98	334	226	52

Arrowsmith TSA Silviculture Strategy Analysis
Appendix A - Silvicultural State

Table A-2. Initial silvicultural state of the Arrowsmith TSA.

State Code	Silvicultural State	Fd			other conif	HwBa		Cw West		Ba/Ss		Total
		SAU01	SAU02	SAU03		SAU05	SAU06	SAU07	SAU08	SAU09	Heli west all	
N	Natural	5,494	1,309	2,700	1,099	1,140	1,384	2,797	12,888	250	2,218	31,278
TL	Natural - timber lease	9	2	50	-	1,246	809	938	77	15	-	3,146
NSR	NSR	-	-	19	1	-	47	85	5	7	-	162
12	Plt to 1200 sph	378	421	644	519	298	269	1,480	1,461	157		5,627
1218	Plt to 1200 sph, Ing +1800 sph			741								741
1248	Plt to 1200 sph, Ing +4800 sph						269	1,480	1,461	157		3,367
1218--F	Plt to 1200 sph, Ing +1800 sph, Fe			1,087								1,087
1218S08	Plt to 1200 sph, Ing +1800 sph, Js to 800 sph			931								931
1218S08-F	Plt to 1200 sph, Ing +1800 sph, Js to 800 sph, Fe			757								757
1248S10	Plt to 1200 sph, Ing +4800 sph, Js to 1000 sph						534	131		69		733
1248S10P	Plt to 1200 sph, Ing +4800 sph, Js to 1000 sph, Pr							3				3
1248S12	Plt to 1200 sph, Ing +4800 sph, Js to 1200								207			207
12---F	Plt to 1200 sph, Fe		5,414									5,414
12-S06	Plt to 1200 sph, Js to 600 sph	1,018	1,296									2,314
12-S06P	Plt to 1200 sph, Js to 600 sph, Pr		381									381
12-S07	Plt to 1200 sph, Js to 700 sph							131				131
12-S07P	Plt to 1200 sph, Js to 700 sph, Pr							2				2
12-S08	Plt to 1200 sph, Js to 800 sph					1,574						1,574
16-S08	Plt to 1600 sph, Js to 800 sph											2,314
16-S08--F	Plt to 1600 sph, Js to 800 sph, Fe	1,018	1,296									2,669
16-S08P	Plt to 1600 sph, Js to 800 sph, Pr	328	2,669									328
Grand Total	Total	8,244	12,790	6,928	1,619	4,257	3,312	7,045	16,098	655	2,218	63,166

Codes:

Plt - Planted
Ing - Ingressed
Fe - Fertilized
Js - Juvenile spaced
Pr - Pruned



Arrowsmith TSA Silviculture Strategy Analysis



Appendix B– Regimes Diagrams

Regime diagrams are the “blueprint” for the construction of the silviculture modules of the forest-level model.

The silviculture regime specifies a sequence of management actions that may be applied to the stands of the silviculture analysis unit for which the regime was designed. Each of these actions causes the stand to change silviculture state, and so alternative regimes result in alternative development pathways that a silviculture analysis unit may follow.

A series of alternative regimes was specified for each the 10 silviculture analysis units defined for the Arrowsmith TSA by district staff, and the alternative development pathways were plotted (Figures B-1 to B-14). These arcs of these diagrams correspond to silviculture actions and the nodes represent the silviculture state of the stand. Tables B-1 and B-2 explain the codes used in these diagrams and Table B-3 lists the treatment specification for each feasible regime. Note that clearcut harvesting (clc_m) may occur from any treatment state (including planting and ingress only), but the activity arcs that would lead back to regenerating (R) are not shown in the regime diagrams in order to maintain legibility. Also, forest stands are not required to progress along a pathway – a stand may remain in any state indefinitely.

Table B-1. State codes

Code	Treatment state
N	Natural
N---T	Natural, commercially thinned
R	Regenerating post-harvest
06	Plant to 600 sph, ingrowth to 600 sph
12	Plant to 1200 sph, ingrowth to 1200 sph
1218	Plant to 1200 sph, ingrowth to 1800 sph
1218---F	Plant to 1200 sph, ingrowth to 1800 sph, fertilized
1218S08	Plant to 1200 sph, ingrowth to 1800 sph, PCT to 800 sph
1218S08--F	Plant to 1200 sph, ingrowth to 1800 sph, PCT to 800 sph, fertilized
1248	Plant to 1200 sph, ingrowth to 4800 sph
1248-P	Plant to 1200 sph, ingrowth to 4800 sph, pruned
1248S06	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 600 sph
1248S06P	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 600 sph, pruned
1248S07P	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 700 sph, pruned
1248S08	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 800 sph
1248S08P	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 800 sph, pruned
1248S08PT	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 800 sph, pruned, commercially thinned
1248S08-T	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 800 sph, commercially thinned
1248S10	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 1000 sph



Arrowsmith TSA Silviculture Strategy Analysis

Appendix B—Regimes Diagrams

Table B-1. State codes *(continued)*

Code	Treatment state
1248S10P	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 1000 sph, pruned
1248S10PT	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 1000 sph, pruned, commercially thinned
1248S10-T	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 1000 sph, commercially thinned
1248S12	Plant to 1200 sph, ingrowth to 4800 sph, PCT to 1200 sph
12---F	Plant to 1200 sph, ingrowth to 1200 sph, fertilized
12--P	Plant to 1200 sph, ingrowth to 1200 sph, pruned
12--PT	Plant to 1200 sph, ingrowth to 1200 sph, pruned, commercially thinned
12-S05	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 500 sph
12-S05P	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 500 sph, pruned
12-S06	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph
12-S06--F	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, fertilized
12-S06P	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, pruned
12-S06P-F	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, pruned, fertilized
12-S06PT	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, pruned, commercially thinned
12-S06PTF	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, pruned, commercially thinned, fertilized
12-S06-T	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, commercially thinned
12-S06-TF	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 600 sph, commercially thinned, fertilized
12-S07	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 700 sph
12-S07P	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 700 sph, pruned
12-S07PT	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 700 sph, pruned, commercially thinned
12-S07-T	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 700 sph, commercially thinned
12-S08	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 800 sph
12-S08P	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 800 sph, pruned
12-S08PT	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 800 sph, pruned, commercially thinned
12-S08-T	Plant to 1200 sph, ingrowth to 1200 sph, PCT to 800 sph, commercially thinned
12---T	Plant to 1200 sph, ingrowth to 1200 sph, commercially thinned
12---T	Plant to 1200 sph, ingrowth to 1200 sph, commercially thinned
12---TF	Plant to 1200 sph, ingrowth to 1200 sph, commercially thinned, fertilized
12---TF	Plant to 1200 sph, ingrowth to 1200 sph, commercially thinned, fertilized
16	Plant to 1600 sph, ingrowth to 1600 sph
16	Plant to 1600 sph, ingrowth to 1600 sph
16-S08	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph
16-S08--F	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, fertilized
16-S08P	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, pruned
16-S08P-F	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, pruned, fertilized
16-S08PT	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, pruned, commercially thinned
16-S08PTF	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, pruned, commercially thinned, fertilized
16-S08-T	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, commercially thinned
16-S08-TF	Plant to 1600 sph, ingrowth to 1600 sph, PCT to 800 sph, commercially thinned, fertilized



Arrowsmith TSA Silviculture Strategy Analysis

Appendix B—Regimes Diagrams

Table B-2. Activity codes.

Code	Activity Description
clc_exist	Clearcut of existing unmanaged stands
clc_managed	Clearcut of existing managed and future managed stands
cThin	Commercial thinning
rehabNSR	Rehabilitation of NSR
revertTL	Reversion of timber licenses
plntWS600	Plant non-genetic wild stock to 600 sph
plntWS1200	Plant non-genetic wild stock to 1200 sph
plntWS1600	Plant non-genetic wild stock to 1600 sph
plntWSTSR1	Plant non-genetic wild stock to TSR1 assumption
plntSS600	Plant genetic select stock to 600 sph
plntSS1200	Plant genetic select stock to 1200 sph
plntSS1600	Plant genetic select stock to 1600 sph
plntSSTSR1	Plant genetic select stock to TSR1 assumption
space500	Juvenile spacing to 500 sph
space600	Juvenile spacing to 600 sph
space700	Juvenile spacing to 700 sph
space800	Juvenile spacing to 800 sph
space1000	Juvenile spacing to 1000 sph
space1200	Juvenile spacing to 1200 sph
space500Prune	Juvenile spacing to 500 sph, prune
space600Prune	Juvenile spacing to 600 sph, prune
space700Prune	Juvenile spacing to 700 sph, prune
space800Prune	Juvenile spacing to 800 sph, prune
space1000Prune	Juvenile spacing to 1000 sph, prune
pruneOnly	Prune only non spaced stands
space600Fert	Juvenile spacing to 600 sph, fertilize
space800Fert	Juvenile spacing to 800 sph, fertilize
space600PruneFert	Juvenile spacing to 600 sph, prune, fertilize
space600PruneFert	Juvenile spacing to 600 sph, prune, fertilize



Arrowsmith TSA Silviculture Strategy Analysis

Appendix B—Regimes Diagrams

Table B-3. Specifications for TASS runs to create volume tables for regenerated development types, Arrowsmith TSA

1. Utilization levels

- min dbh: 17.5 cm
- max stump: 30 cm
- min top diameter: 10 cm

2. OAFs

OAF1 = 15%, OAF2 = 5%

3. Juvenile Spacing

- leave well-spaced trees, favouring tallest

4. Pruning

- use predominant height -- has been converted to age
- retain 30% live crown on first lift
- retain 40% live crown on second lift
- prune all trees that meet the crown ratio condition, OR the largest trees (ordered by diameter) that meet the CR condition up to the max number specified in the spreadsheet. For example, the "best 300"

5. Commercial Thinning

- CT at the operability limits listed in the spreadsheet, otherwise leave for clearcut harvest
- CT at a quadratic mean diameter of 30 cm (see specs in spreadsheet) and when the prime 250 trees have live crown $\geq 40\%$, <-- converted to age
- thin from below: removing shortest, and leaving well-spaced trees, favouring fattest
- CT stems leave takes precedence over volume remove, leave the specified number of trees.

6. Fertilization

- in general, repeat fertilization where indicated on a 10-year cycle.
- time fertilizations to occur 1 year after pruning and 1 year after commercial thinning

Figure B-1. Alternate Development Pathways for Managed Stands

Arrowsmith TSA
SAU01 Good site Fd leading

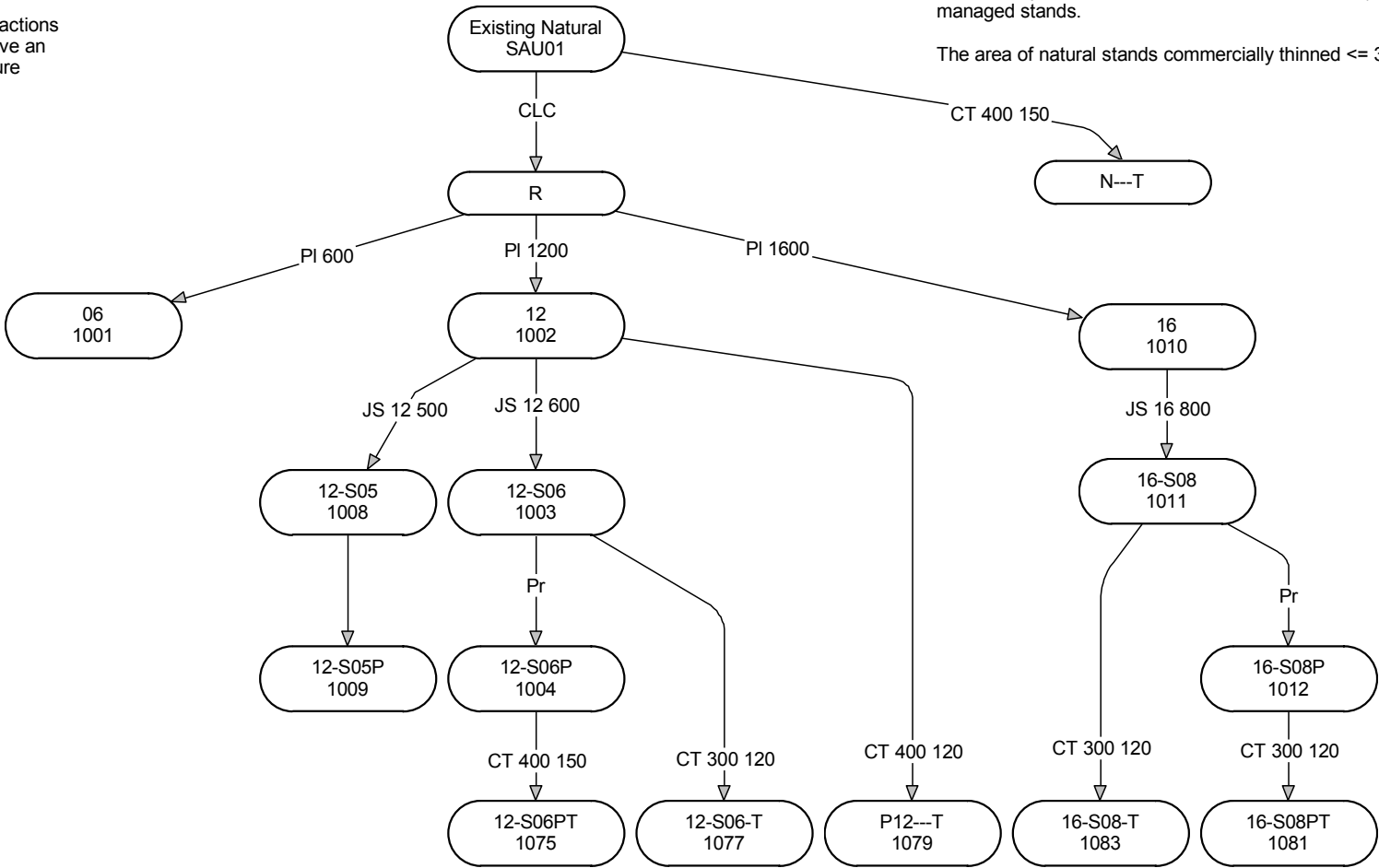
Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states

Existing Natural and Future Managed Stands

Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

The area of natural stands commercially thinned <= 300 ha.



CT Opportunity

12
12-S06
12-S06P
16-S08
16-S08P
N

CTstates

12---T
12-S06-T
12-S06PT
16-S08T
16-S08PT
N---T

Figure B-2. Alternate Development Pathways for Managed Stands

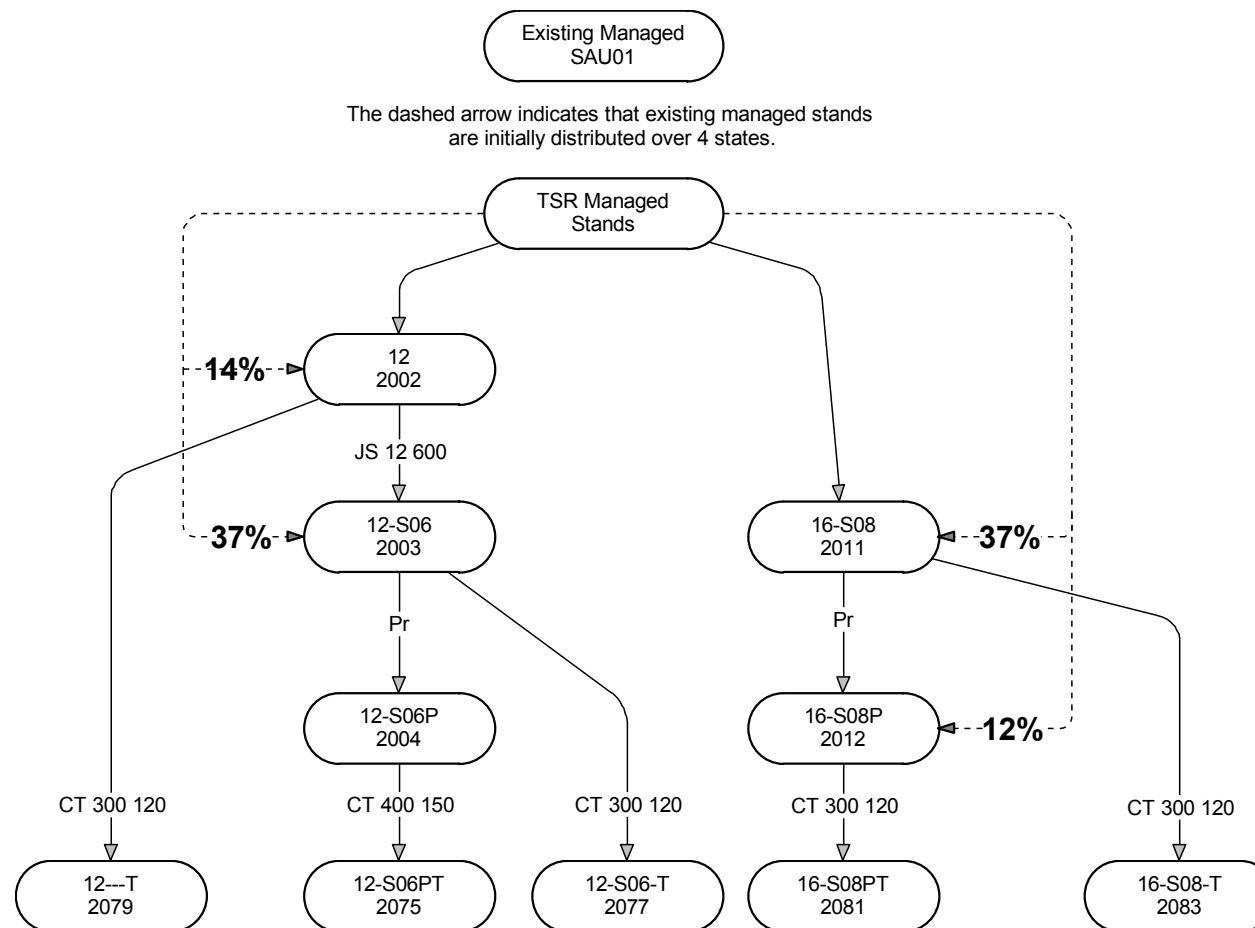
Arrowsmith TSA SAU01 Good site Fd leading

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states

Existing Managed Stands

Commercially thinned stands will be modelled as:
residual ≥ 300 sph
removed = 150 m3, dbh ≥ 22.5

The development of these stands will be modelled (e.g., TIPSYS) as planted managed stands.



CT Opportunity

12
12-S06
12-S06P
16-S08
16-S08P

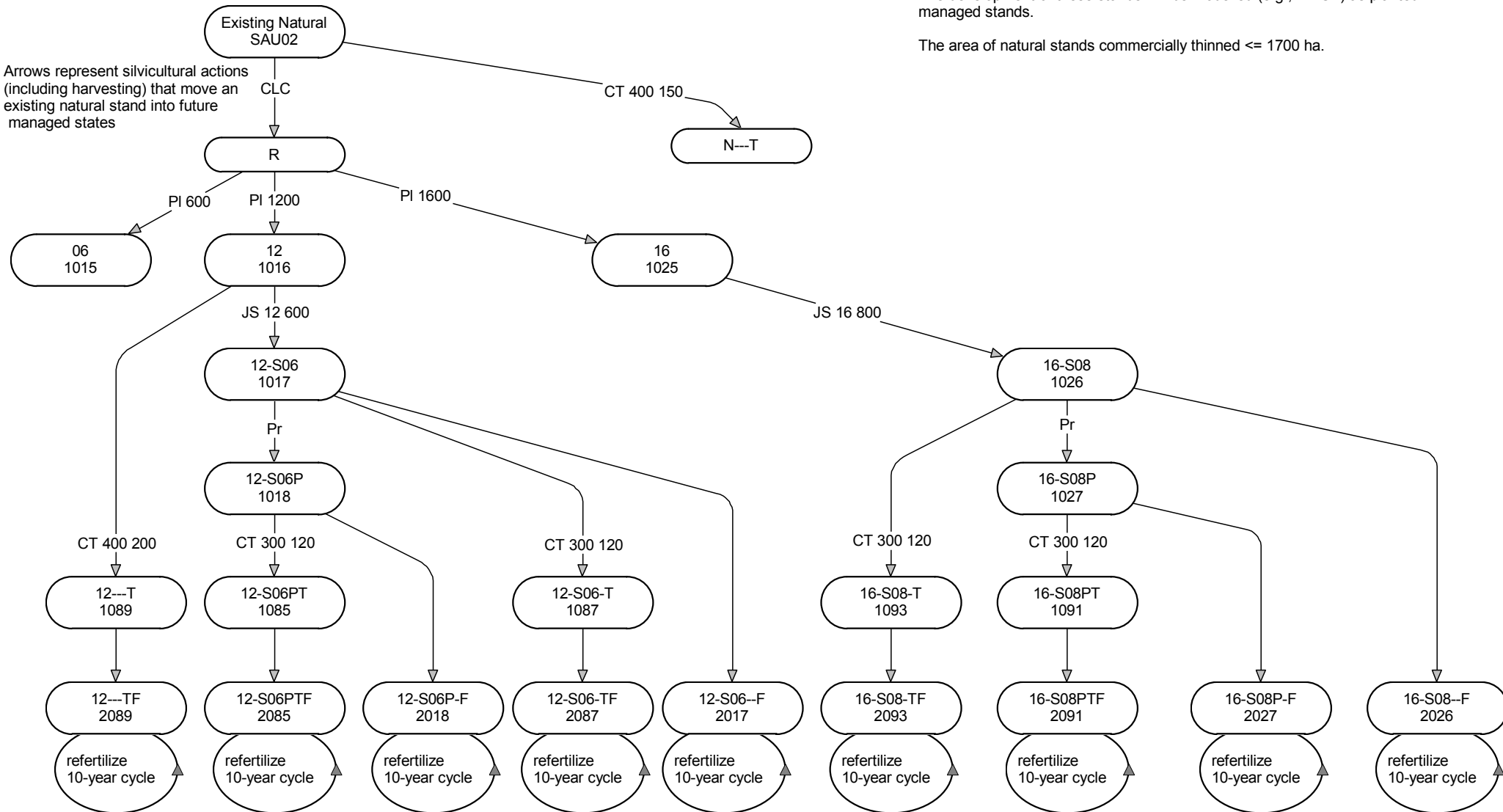
CTstates

12---T
12-S06-T
12-S06PT
16-S08T
16-S08PT

Arrowsmith TSA
SAU02 Medium site Fd leading

Commercial thinning will only be undertaken if
residual sph $\geq$ 300 sph
removed $\geq$ 100 m³ at dbh $\geq$ 22.5 cm

The area of natural stands commercially thinned ≤ 1700 ha.



12
12-S06
12-S06P
16-S08
16-S08P
N

12---T
12-S06-T
12-S06PT
16-S08T
16-S08PT
N---T

Figure B-4. Alternate Development Pathways for Existing Managed Stands

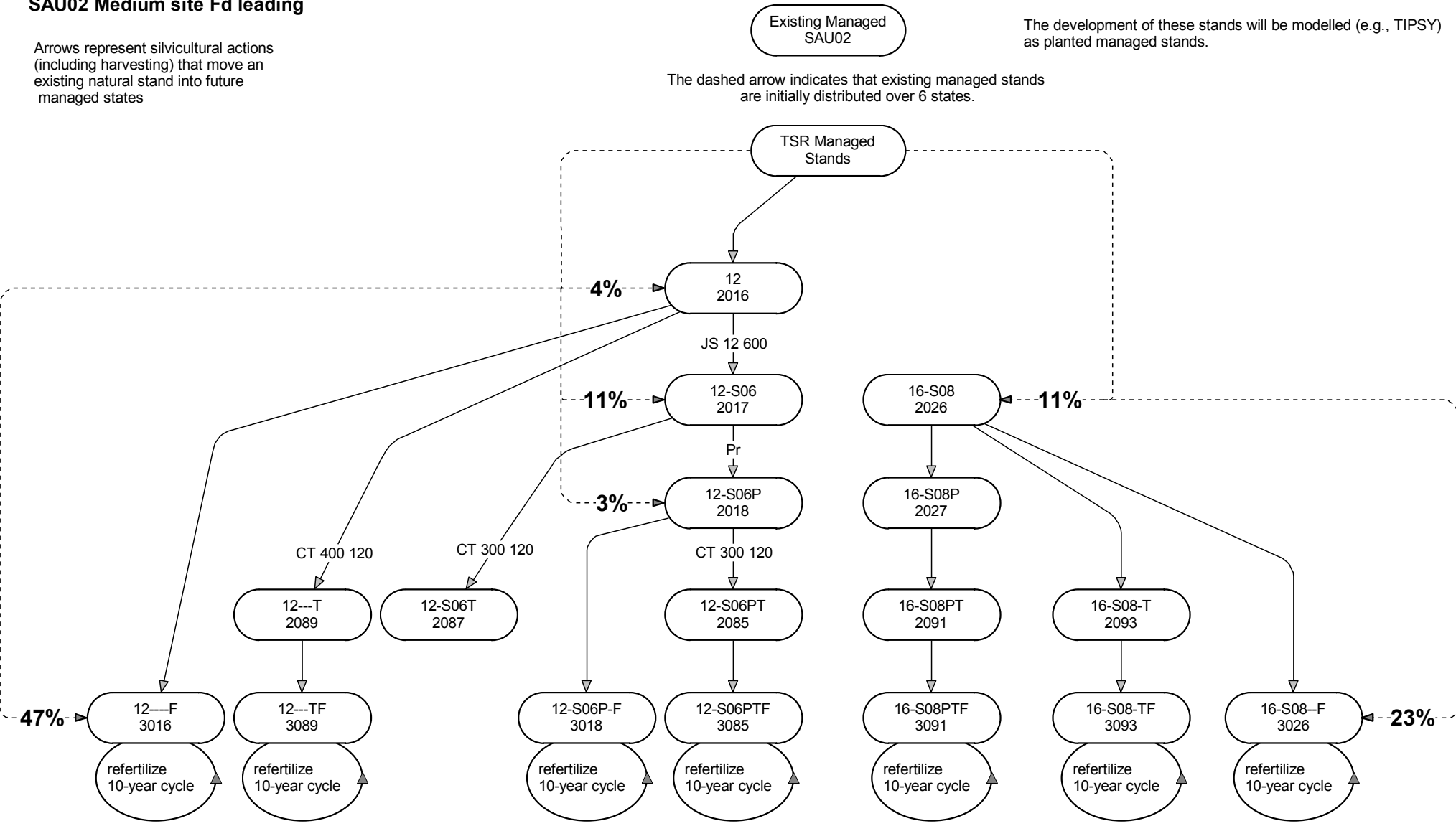
Arrowsmith TSA
SAU02 Medium site Fd leading

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states

Existing Managed Stands

Commercially thinned stands will be modelled as:
residual >= 300 sph
removed = 150 m3, dbh >= 22.5

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

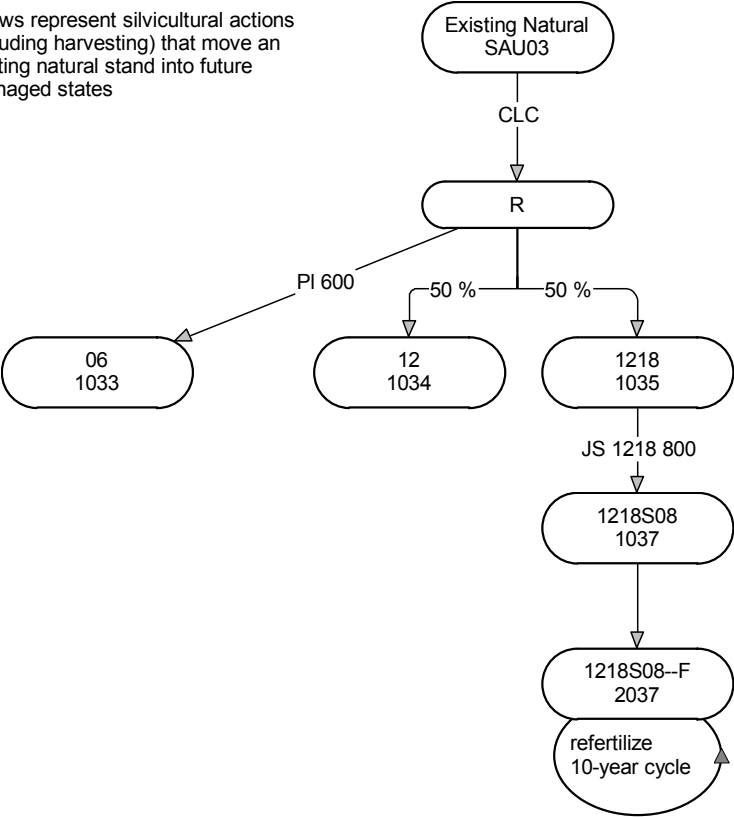


CT Opportunity	CTstates
12	12---T
12-S06	12-S06-T
12-S06P	12-S06PT
16-S08	16-S08T
16-S08P	16-S08PT

Figure B-5. Alternate Development Pathways for Managed Stands

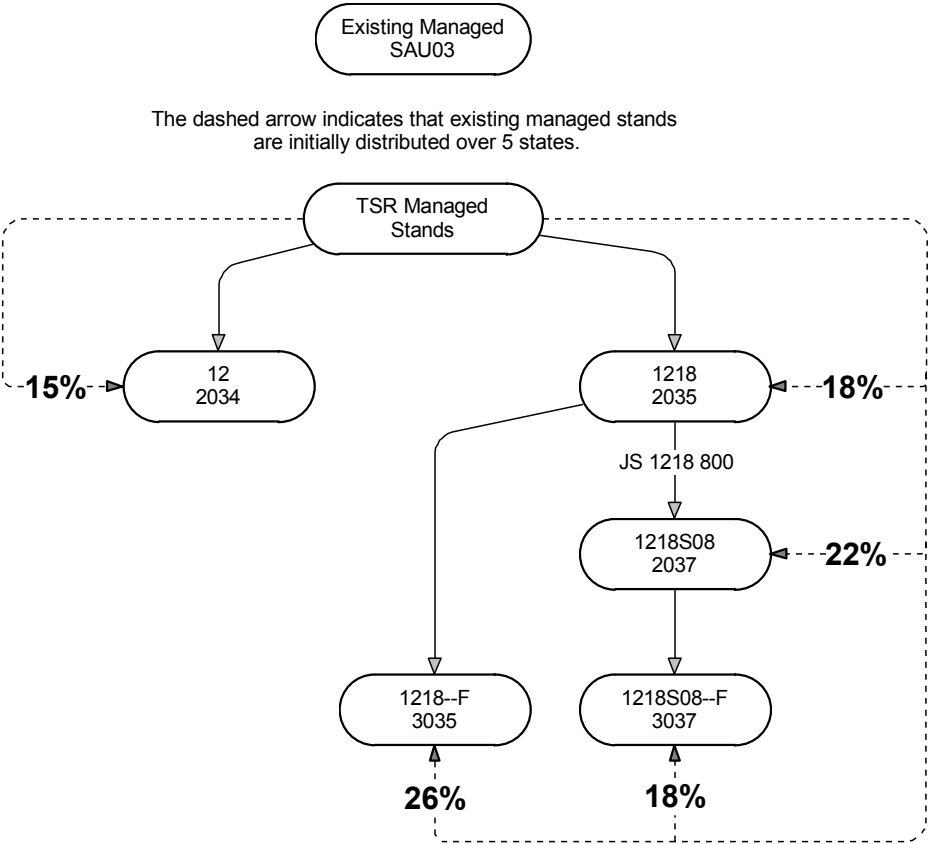
Arrowsmith TSA
SAU03 Poor site Fd leading

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.



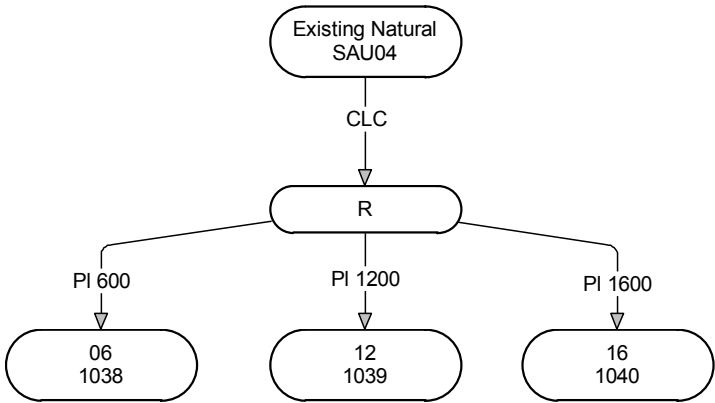
Existing Managed Stands

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

Figure B-6. Alternate Development Pathways for Managed Stands

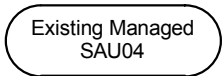
Arrowsmith TSA
SAU04 Good, medium and poor sites, other conifers

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.



100% of existing managed stands are initially distributed over 1 state.

Existing Managed Stands

Existing managed stands are assumed to have been established at 1200.

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

Figure B-7. Alternate Development Pathways for Managed Stands

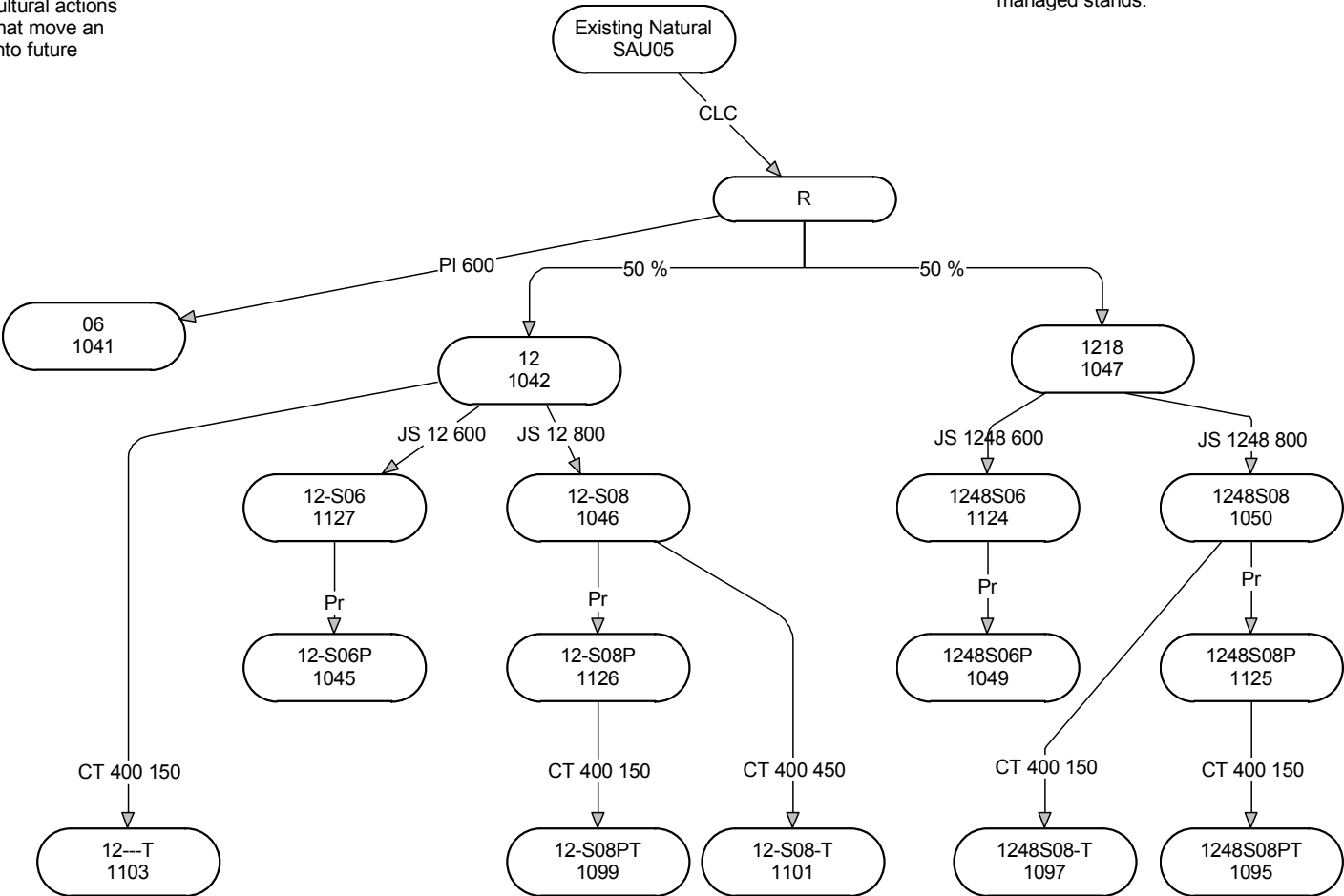
Arrowsmith TSA
SAU05 Good, medium sites, Hw leading, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states

Existing Natural and Future Managed Stands

Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSY) as planted managed stands.



CT Opportunity

12
12-S08
12-S08P
1248S08
1248S08P

CTstates

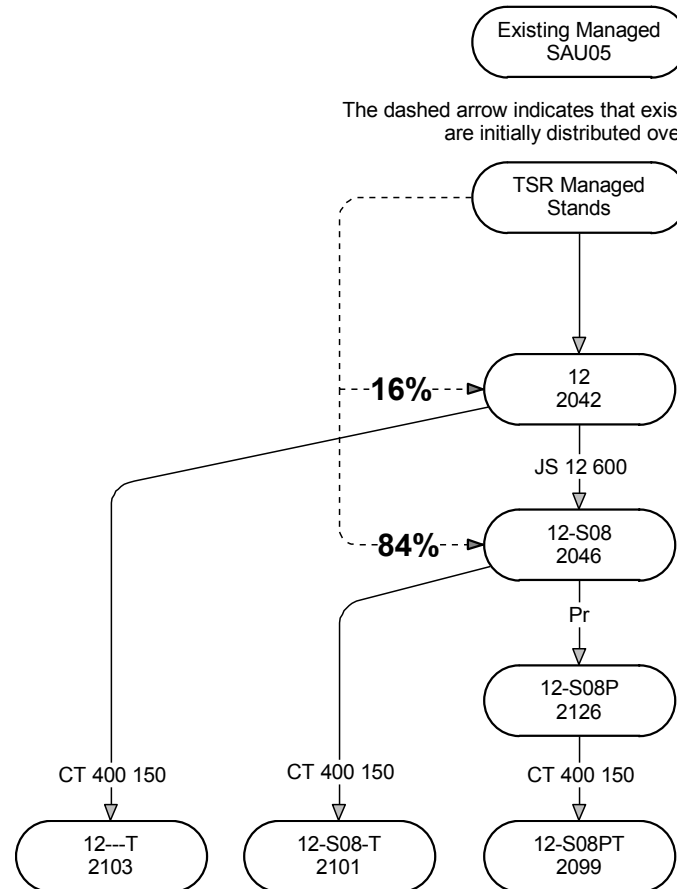
12---T
12-S08-T
12-S08PT
1248S08-T
1248S08PT

Figure B-8. Alternate Development Pathways for Managed Stands

Arrowsmith TSA

SAU05 Good, medium sites, Hw leading, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



CT Opportunity

12
12-S08
12-S08P

CTstates

12---T
12-S08-T
12-S08PT

Existing Managed Stands

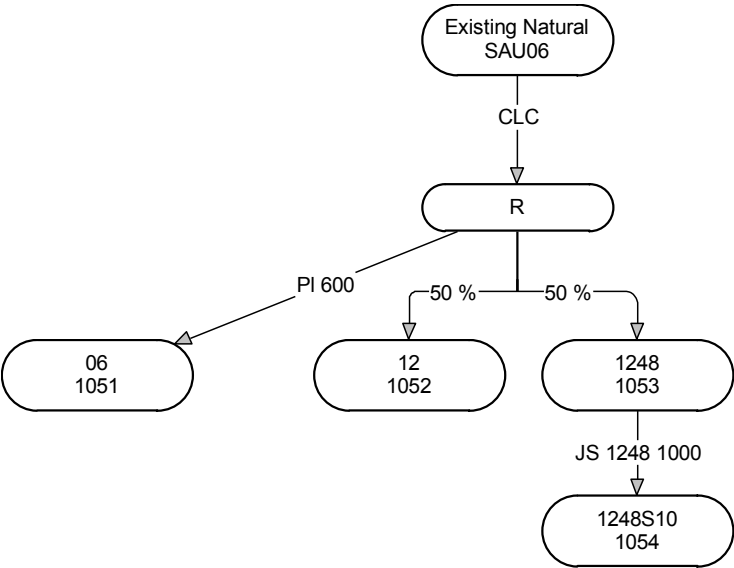
Commercial thinning will only be undertaken if
residual sph ≥ 300 sph
removed ≥ 100 m3 at dbh ≥ 22.5 cm

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

Figure B-9. Alternate Development Pathways for Managed Stands

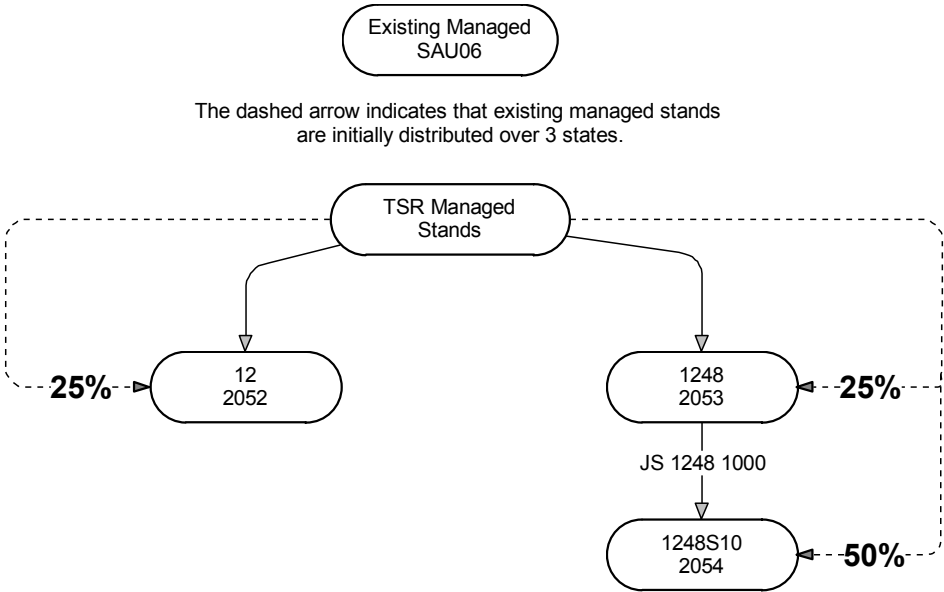
Arrowsmith TSA
SAU06 Poor sites, Hw leading, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.



Existing Managed Stands

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.

Figure B-10. Alternate Development Pathways for Managed Stands

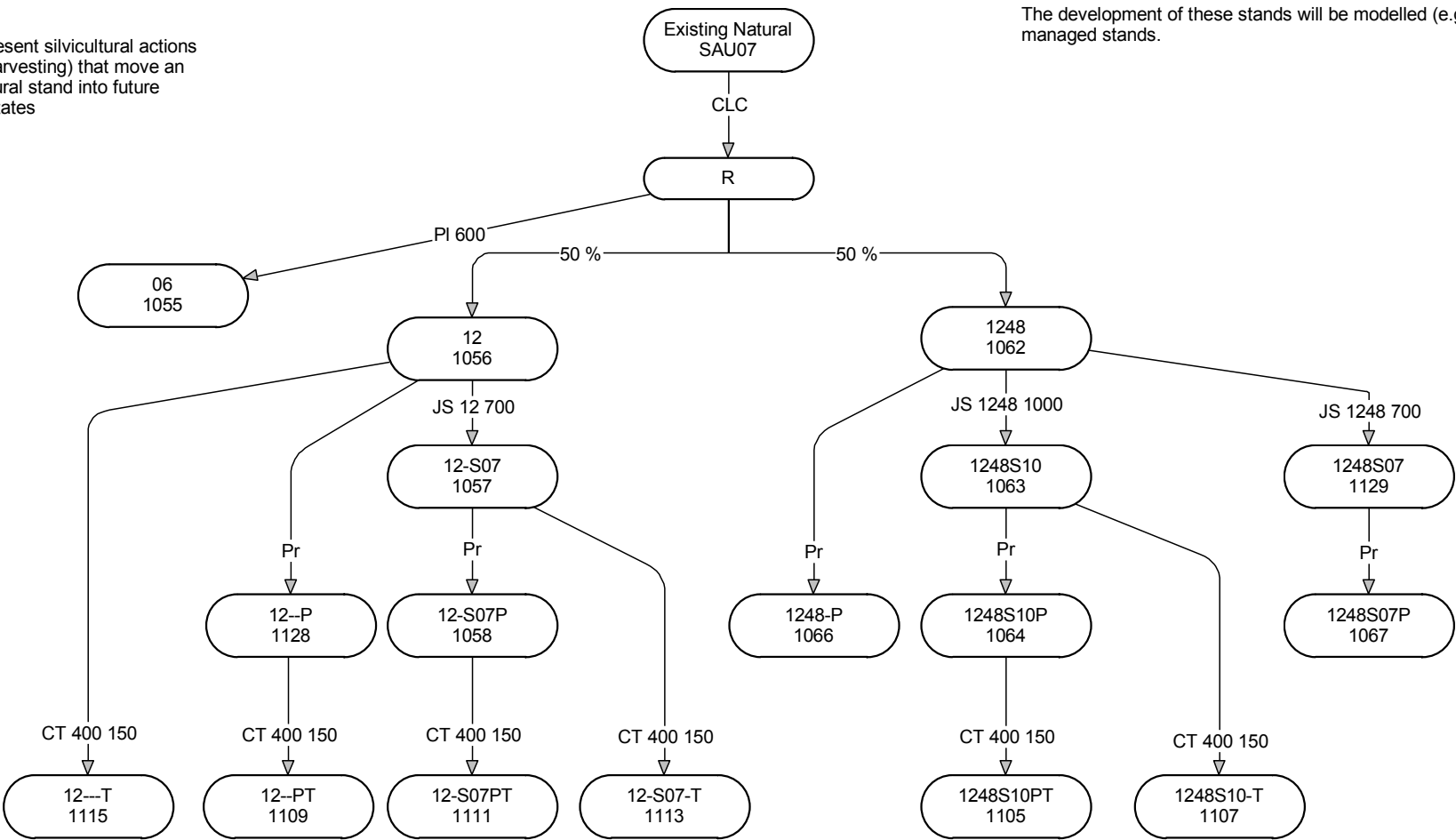
Arrowsmith TSA
SAU07 Good, medium sites, Cw leading, west side

Arrows represent silvicultural actions
(including harvesting) that move an
existing natural stand into future
managed states

Existing Natural and Future Managed Stands

Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSy) as planted
managed stands.



CT Opportunity

12
12--P
12-S07
12-S07P
1248S10
1248S10P

CTstates

12---T
12--PT
12-S07-T
12-S07PT
1248S10-T
1248S10PT

Figure B-11. Alternate Development Pathways for Managed Stands

Arrowsmith TSA

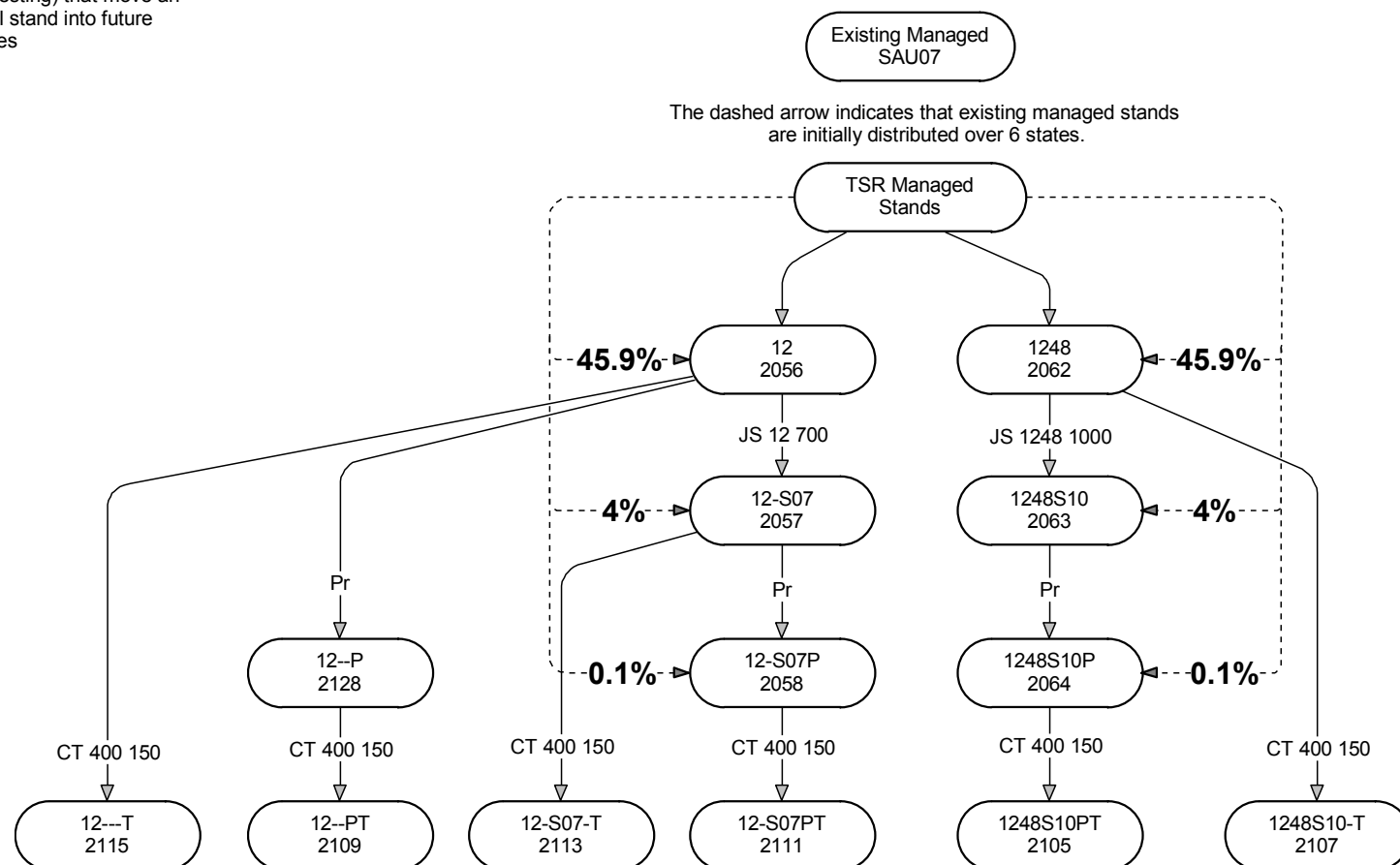
SAU07 Good, medium sites, Cw leading, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states

Existing Managed Stands

Commercial thinning will only be undertaken if
residual sph ≥ 300 sph
removed ≥ 100 m3 at dbh ≥ 22.5 cm

The development of these stands will be modelled (e.g., TIPSy) as planted managed stands.



CT Opportunity

12
12--P
12-S07
12-S07P
1248S10
1248S10P

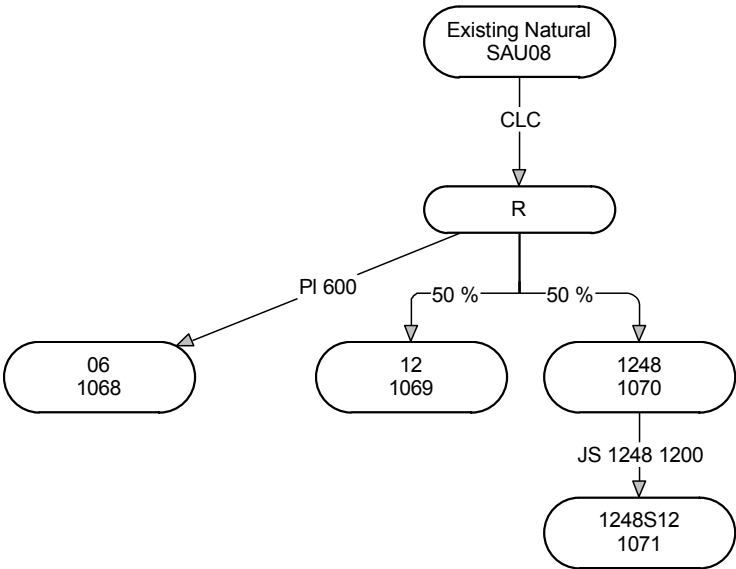
CTstates

12---T
12--PT
12-S07-T
12-S07PT
1248S10-T
1248S10PT

Figure B-12. Alternate Development Pathways for Managed Stands

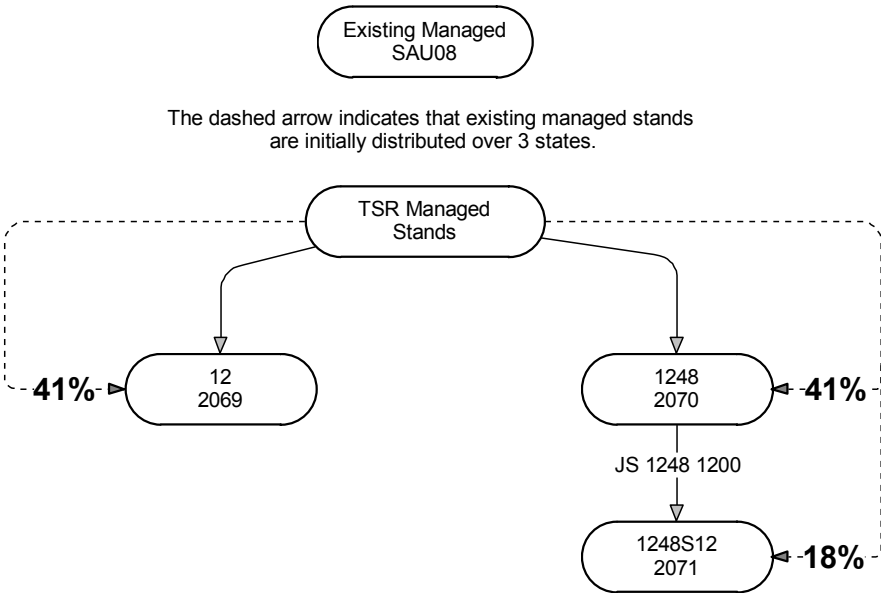
Arrowsmith TSA
SAU08 Poor sites, Cw leading, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

The development of these stands will be modelled (e.g., TIPSY) as planted managed stands.



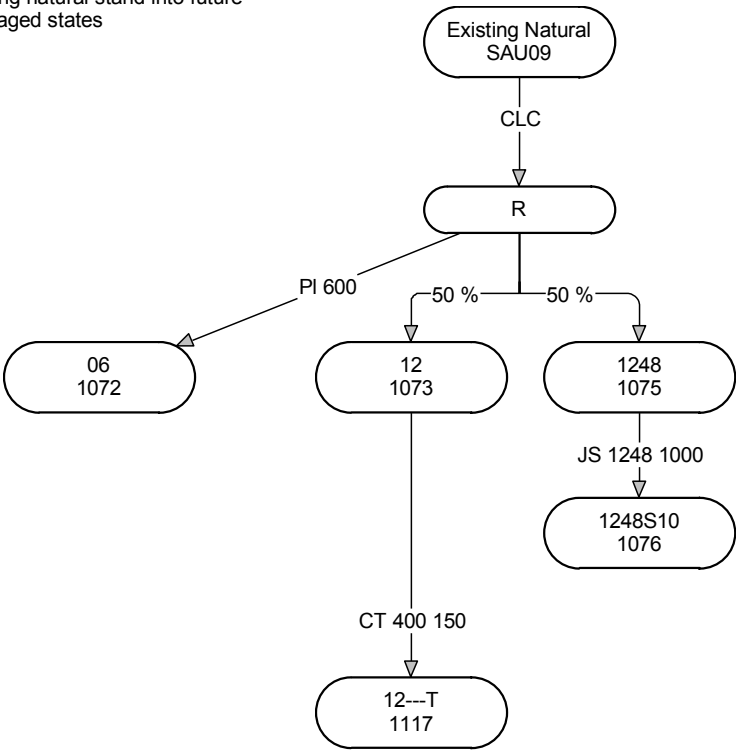
Existing Managed Stands

The development of these stands will be modelled (e.g., TIPSY) as planted managed stands.

Figure B-13. Alternate Development Pathways for Managed Stands

Arrowsmith TSA
SAU09 Other sites, other species

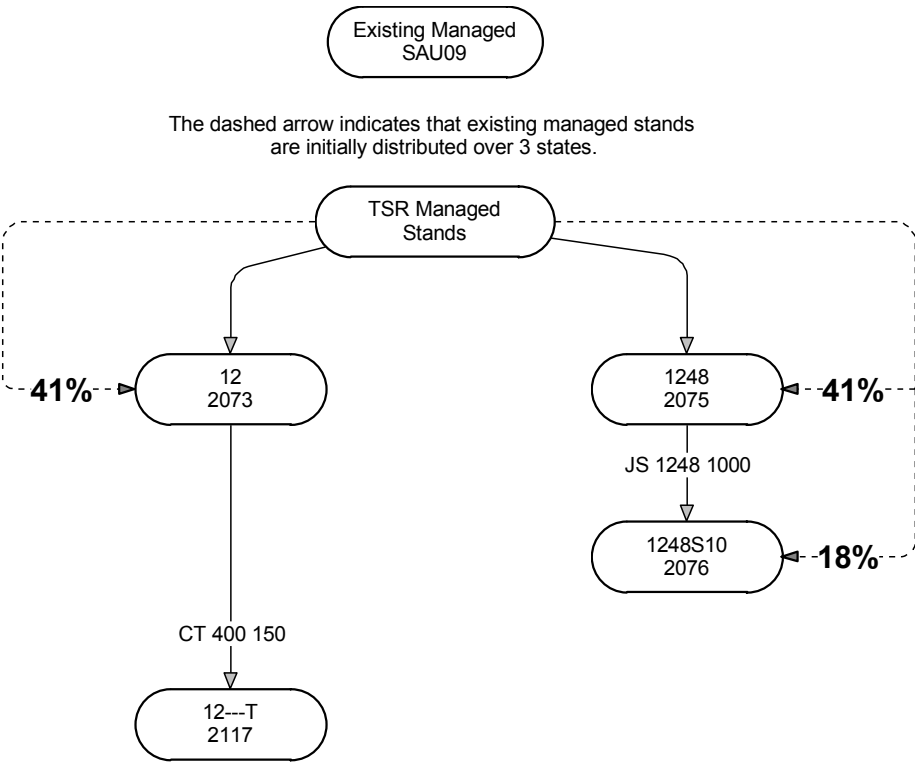
Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSYS) as planted managed stands.



Existing Managed Stands

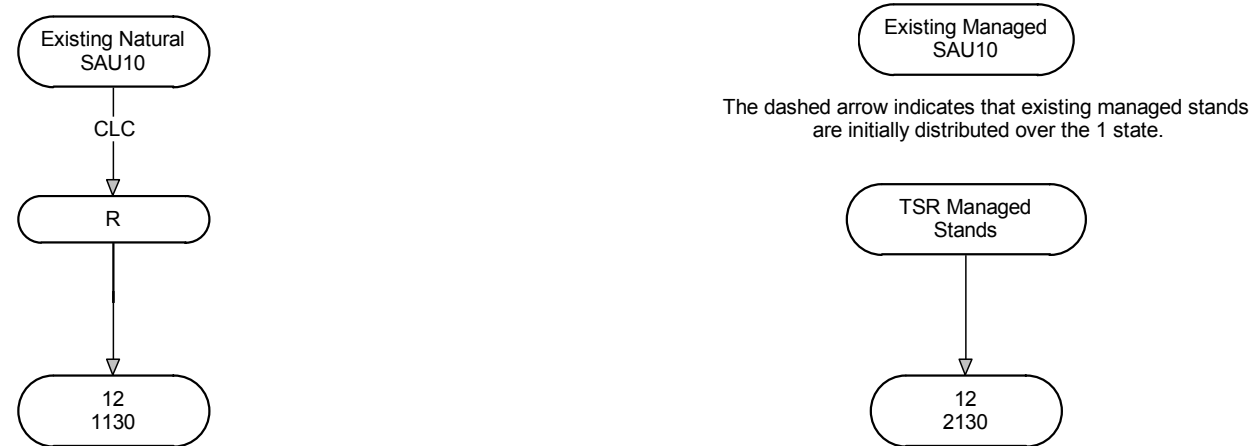
Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSYS) as planted managed stands.

Figure B-14. Alternate Development Pathways for Managed Stands

Arrowsmith TSA
SAU10 All sites, all species, unconventional, west side

Arrows represent silvicultural actions (including harvesting) that move an existing natural stand into future managed states



Existing Natural and Future Managed Stands

Commercial thinning will only be undertaken if
residual sph >= 300 sph
removed >= 100 m3 at dbh >= 22.5 cm

The development of these stands will be modelled (e.g., TIPSY) as planted managed stands.

Existing Managed Stands

The development of these stands will be modelled (e.g., TIPSY) as planted managed stands.



Appendix C — Genetic Gain

The seed zones and elevation breaks (Table C-1) and the forecast gain in volume from improved seed (Table C-2) for the Arrowsmith TSA were obtained from the Forest Genetics Council. The gain forecast for 2007–2008 was assumed to be applicable out to the planning horizon of this study (25 decades) and was prorated over the planting mixes identified by the district and the proportion of the TSA in each elevation zone (Table C-3).

Table C-1. Class "A" Seed Zones related to each TSA by species, Arrowsmith TSA.

Class "A" Seed Zones by species

Fd	Hw	Cw	Ba	Yc	SxSs	Ss
M	M	M	M	M	M	M

100 % of the Arrowsmith TSA = M

22.5 % of the Arrowsmith > 700m

77.5 % of the Arrowsmith TSA < 700m

Source: FGC, Ron Planden

Table C-2. Forecast gain in volume from improved seed, Arrowsmith TSA.

Species & Seed Zone	Elevation (m)	Gain from Improved Seed (%)		
		99-00	04-05	07-08
Fd M Low	<700	8.0	12.2	14.0
Fd M High	>700	2.0	5.0	5.0
Hw M Low	<700	15.0	15.0	15.0
Hw M High	>700	2.0	2.0	2.0
Cw M Low	<700	2.5	11.6	11.6
Cw M High	>700	no genetic gain information available		
Bg M Low	<700	2.0	2.0	2.0
Ss M Low	<700	3.0	4.0	4.9
SxSs SM/NST	all	2.0	2.0	2.0
Yc M	400-1200	5.1	10.5	20

Source: FGC



Arrowsmith TSA Silviculture Strategy Analysis Appendix C — Genetic Gain

Table C-3. Calculation of area-weighted genetic gain, Arrowsmith TSA.

Species Planting Mix (%)	Species	Percent Species	Seed Zones	Elevation % of Landbase	Elelevation	Gain from Improved Seed	Area Weighted Genetic Gain
Fd 100	Fd	100	M	22.5	> 700 m	22.5% * 5	9.1
				77.5	< 700 m	77.5% * 14	1.4
							10.5
Fd 75 Cw 25	Fd	75	M	22.5	> 700 m	22.5% * 5	1.1
	Fd	75	M	77.5	< 700 m	77.5% * 14	10.9
							12.0
	Fd	75				75% * 12	9.0
	Cw	25	M	100	< 700 m	25% * (100% * 11.6)	2.9
							11.9
Cw 50 Bg 30 Hw 20	Hw	20	M	22.5	> 700 m	22.5% * 2	0.5
				77.5	< 700 m	77.5% * 15	11.6
							12.1
	Hw	20				20% * 12.1	2.4
	Cw	50	M	100	< 700 m	50% * (100% * 11.6)	5.8
	Bg	30	M	100	< 700 m	30% * (100% * 2.0)	0.6
							8.8
Hw 70 Cw 20 Ba 10	Hw	70	M	22.5	> 700 m	22.5% * 2	0.5
				77.5	< 700 m	77.5% * 15	11.6
							12.1
	Hw	70				70% * 12.1	8.5
	Cw	20	M	100	< 700 m	20% * (100% * 11.6)	2.3
	Ba	10	M	100	< 700 m	10% * (100% * 2.0)	0.2
							11.0
Cw 70 Hw 20 Ba 10	Hw	20	M	22.5	> 700 m	22.5% * 2	0.5
				77.5	< 700 m	77.5% * 15	11.6
							12.1
	Hw	20				20% * 12.1	2.4
	Cw	70	M	100	< 700 m	70% * (100% * 11.6)	8.1
	Ba	10	M	100	< 700 m	10% * (100% * 2.0)	0.2
							10.7
Ba 60 Hw 20 Cw 20	Hw	20	M	22.5	> 700 m	22.5% * 2	0.5
				77.5	< 700 m	77.5% * 15	11.6
							12.1
	Hw	20				20% * 12.1	2.4
	Cw	20	M	100	< 700 m	20% * (100% * 11.6)	2.3
	Ba	60	M	100	< 700 m	60% * (100% * 2.0)	1.2
						5.9	



Appendix D – Analysis Method

The key component of the analysis method the development a silvicultural planning model that is consistent with the TSR model and base case for the Arrowsmith TSA, and also fully represents the additional forest-level objectives and silvicultural activities required for silvicultural planning in a multiple resource planning context. The model will then emulate the TSR base case if incremental silviculture activities are turned off (i.e., the silviculture budget is constrained to \$0). As the budget is increased, the model will select silviculture activities that maximize its objectives. In essence, the model devises a silvicultural strategy that is consistent with the analyst's objectives for the TSA from the silviculture treatments specified for each SAU.

The silviculture model is constructed with Woodstock/LP

3.1 Develop a LP Model of the TSR Base Case

One of the major differences between this analysis and the TSR is the choice of the forest estate model. While the TSR uses FSSIM, a forest-level simulator, this analysis casts the silviculture planning problem as an linear model, solvable by linear programming (LP). Woodstock™ (Remsoft, 1997) was used to create the LP model and two optimization codes (C-Whiz™ and XA™) were used to solve it.¹

The first step in the analysis is to develop an LP model formulation of the TSR base case. An LP model represents the forest and its management as a series of linear equations, which can be arranged in a matrix. One equation, the objective function, expresses the forest-level objective (e.g., maximize volume production). Other equations represent the forest management rules such as limits on harvest fluctuation and forest cover constraints. The LP solution software finds the set of management activities (e.g., harvesting) that best meet the objective.

Regime diagrams are the “blueprint” for the model

3.2 Implement Silviculture Activities in the Forest-Level Model

The regime diagrams (Appendix B) are implemented in the silviculture planning model as activities, transitions, inputs and outputs.

Actions are defined in the model to represent each silvicultural activity listed or implied in the regime diagram for each SAU. Transitions map the flow of land between states. For example, a spacing action moves land from a regenerated state to a spaced state and a pruning action moves spaced land to a post-first-lift state.

¹ C-WHIZ Linear Programming Optimizer, Ketron Management Science, July 1994
XA/LP, Sunset Software Technology, San Marino, CA



Costs are incurred and outputs generated with each transition initiated by an action. Costs are summed by regime, by strategy, and in total, and are constrained by budget. Other outputs, such as employment, volume harvested, quality and value measures, are summed to the appropriate objective functions in the model.

Multiple objectives
guide the analysis

3.3 Implement Forest Level Objectives

Each forest-level objective must be implemented in the silviculture planning. The current version of the ASPM has six objectives implemented:

- maximize short-term timber harvest (decades 1-2)
- maximize mid-term timber harvest (decades 3-14)
- maximize long term timber supply (decades 15-20)
- maximize a priority-structured timber supply
- maximize volume harvested with dbh $\geq$ 65cm
- maximize volume harvested from pruned stands

The priority-structured objective maximizes the harvest over the entire 25-year planning horizon but puts the highest priority on maximizing harvest levels in decade 2, the second priority in the mid term (decades 3-14), and the lowest priority in the long term (decades 15-25).

Only one of the forest-level objectives can be active at a time and the other rows are described as non-constraining. These non-constraining rows calculate the contribution of harvesting and silvicultural activities to each forest level objective and are referred to as objective tracking rows.

Forest cover
constraints

Harvest-flow
guidelines

3.4 Implement Management Rules as LP Constraints

Forest cover constraints, as specified in TSR1, are represented explicitly in the LP model of the base case.

TSR harvest forecasts are shaped in part by harvest-flow guidelines. When using a simulation model such as FSSIM, harvest-flow guidelines are implemented by the modeller during the search for the best harvest schedule. However, with an LP model, the harvest flow guidelines must be implemented explicitly in the model as constraints.

To model the TSR1 base case, the following constraints were added to the model.

- decade 1: annual harvest = the current AAC (1996) of 393 073 m³
- decade 2: annual harvest $\leq$ annual harvest decade 1
- decade 3-5: annual harvest $\geq$ 88% of annual harvest previous decade



decade 6 –25: annual harvest $\geq$ annual harvest of previous decade

Disturbance constraints	Constraints on the area disturbed (not “greened up”) are specified for each of the eight management zones recognized in the TSR.
Sustainable target forest	Other forest management rules may be added as constraints. In order to ensure that the long-term harvest is sustainable in decades 26 and beyond, the growing stock (total inventory volume) in decade 25 is constrained equal or exceed 17,288,000 m ³ . This growing stock level was identified through experimentation with the base case model.
Harvest profile	The first-decade harvest profile (Section 2.4) for clear cutting and commercial thinning are implemented in the LP model as constraints.

3.5 Analyze Scenarios

The silvicultural planning problem expands the timber supply problem by adding silvicultural activities, constraints on silviculture expenditures, and the objective function rows required to calculate contributions to forest-level objectives.

Silviculture scenarios are constructed in a manner that the benefits from specific silvicultural practices can be identified in terms of the models objectives, e.g., the impact (benefit) of fertilization on mid-term timber supply.

The LP solver finds both the harvest area and the level of silvicultural activity for each of the time periods represented in the model. Silvicultural expenditures are constrained and shadow prices (sensitivity coefficients) associated with each constraint are calculated as part of the solution process.

The scenarios developed for this analysis are:

- S01. TSR1 Base Case – This scenario reproduces the TSR2 base case in order to validate the data and model. The management objective is to maximize priority-structured timber supply.
- S02. TSR1 Base Case plus Planting Select Stock – This scenario assumes that select stock will be planted for species for which it is available, with genetic gains as described in Appendix C. The management objective is to maximize priority-structured timber supply.
- S03. TSR1 Base Case plus Commercial Thinning and Select Stock – This scenario demonstrates the changes in the harvest forecast attributable to commercial thinning. The management objective is to maximize priority-structured timber supply.
- S04. Optimal Management Scenario– This scenario demonstrates the combined effects of all of the silviculture activities implied by the regimes defined for the TSA. It assumes an unlimited silviculture budget.



The management objective is to maximize priority-structured timber supply.

- S05. Optimal Management Scenario at Various Budget Levels– This scenario demonstrates the effects on harvest levels of setting the incremental silviculture budget to various levels between 0% and 100% of the total silviculture expenditure of the unlimited optima (S04). The management objective is to maximize priority-structured timber supply.
- S06. Optimal Management Scenario (Quality/Dimension) – This scenario is identical to S04 except that the objective is to maximize the harvest volume compiled at a utilization level of 65 cm dbh. The harvest flow (compiled at TSR2 utilization levels) is constrained such that it cannot drop below the minimum level (mid-term trough) experienced in S04.
- S07. Optimal Management Scenario at Recent Historical Levels – This scenario is identical to S04 except that the incremental silviculture activities in the first decade are constrained to recent historical levels. The management objective is to maximize priority-structured timber supply. The purpose of this scenario is to calculate the shadow prices of the incremental silviculture activities constrained in the first decade.
- S08. Not used in this analysis.
- S09. Optimal Management Scenario (Quality/Clear) – This scenario is identical to S04 except that the objective is to maximize volume harvested from pruned stands. The harvest flow (compiled at TSR2 utilization levels) is constrained to the harvest flow achieved in S04 so loss of timber supply is avoided. The annual expenditure on pruning is constrained at five different levels.



Appendix E – Pruning Scenarios

This appendix records additional information obtained from the analysis of pruning scenarios that was too detailed to include in the main body of the report, or was developed subsequent to the documenting of the scenario analysis.

Scenario 9 (S09): Production of Solid-Clear Wood and Pruning Expenditure

Scenario 9 (S09) was analysed to determine the volume of solid-clear wood that could be produced at various levels of pruning expenditure. It is discussed more fully in section 3.3 (Management for Timber Quality) of this report.

The harvest of solid-clear wood was not maximized directly by the model. Analysis of the scenario was accomplished by solving (via linear programming) the following problem:

Find the schedule of harvests and silviculture activities (including pruning) that

- maximizes the harvest of pruned stands in decades 15-25
- maintains the harvest levels achieved in scenario 4 (S04 – maximize harvest levels)
- restricts the average annual pruning cost in decades 1-14 to be less than or equal to \$166,915

Table E-1
S09 Pruning Report

The results are summarized in Table E-1. The model attempts to maximize the harvest of pruned in decades 15-25, which in turns drives pruning activity in decades 1-14.

Note that the model may not choose to prune if the stands are not available for harvest in the target time periods (decades 15-25). The low level of pruning in decades 1 and 2 (250 ha and 297 ha, respectively) may be the result of this mechanism— stands that are managed in decades 1 and 2 may be scheduled for harvest prior to decade 15 in order to maintain the required levels of harvest.

Arrowsmith TSA Silviculture Strategy Analysis

Appendix E - Pruning Scenarios

Table E-1. Pruning Report - Arrowmith TSA

Scenario S09. Objective: maximize the harvest of pruned stands in decades 15-25 without (1) reducing timber supply in decades 1-25 and (2) exceeding an average pruning costs per year of \$166,915.

Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Area (ha) of Pruned Stands																									
SAU01	328	328	328	329	382	588	593	590	841	1,269	1,823	2,053	2,074	2,154	2,213	1,568	1,958	1,919	1,867	1,580	1,218	1,074	404	404	137
SAU02	381	381	1,010	1,807	2,564	3,865	5,811	7,372	7,839	7,724	7,493	6,955	6,533	6,073	6,798	7,948	7,063	6,050	6,496	6,659	6,618	5,852	5,779	5,113	4,021
SAU03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05	-	-	-	-	-	-	-	-	-	-	-	51	51	51	51	51	51	51	51	51	51	51	51	51	95
SAU06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU07	255	552	1,488	2,654	2,956	3,206	3,394	3,360	3,379	2,512	2,026	1,799	1,894	1,840	2,658	2,897	3,361	3,381	3,444	3,308	3,012	1,935	1,502	528	359
SAU08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total area (ha) of pruned stands	964	1,261	2,825	4,790	5,902	7,659	9,799	11,322	12,059	11,505	11,343	10,858	10,552	10,119	11,720	12,465	12,432	11,401	11,857	11,598	10,899	8,913	7,736	6,096	4,613
Pruning Activity (ha/decade)																									
SAU01	-	-	0	2	92	236	75	57	270	430	565	305	86	131	456	11	390	23	82	0	0	-	-	-	-
SAU02	-	0	628	797	820	1,425	1,972	1,569	1,034	702	601	881	858	868	1,463	1,503	738	329	1,624	1,310	1,294	0	-	-	-
SAU03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05	-	-	-	-	-	-	-	-	-	-	-	51	-	-	0	0	-	0	-	-	-	-	-	-	44
SAU06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU07	250	297	938	1,166	302	294	191	27	50	656	228	367	396	524	700	746	445	299	926	56	0	0	-	-	0
SAU08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total pruning activity (ha/decade)	250	297	1,567	1,964	1,214	1,955	2,239	1,653	1,354	1,788	1,394	1,604	1,340	1,524	2,618	2,260	1,573	651	2,632	1,366	1,294	0	-	-	44
Cost ('000 \$/decade)	275	327	1,723	2,161	1,335	2,151	2,462	1,818	1,489	1,967	1,534	1,765	1,474	1,676	2,880	2,486	1,730	716	2,895	1,503	1,423	0	-	-	49
Employment (p-days/decade)	1,499	1,783	9,400	11,787	7,283	11,731	13,431	9,916	8,121	10,729	8,366	9,626	8,041	9,142	15,710	13,560	9,436	3,907	15,790	8,197	7,762	0	-	-	265
Harvest ('000 /decade)																									
Total stands (pruned and not pruned)	4,030	4,030	3,846	3,385	3,255	3,255	3,255	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569	3,569
SAU01 12-S05P	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2	-	71	83	358	217	185	549	0	0
SAU01 12-S06P	-	-	-	-	-	-	-	-	-	-	-	81	0	-	3	578	-	7	63	-	123	-	12	-	0
SAU01 12-S06PT	-	-	-	-	-	-	-	-	-	-	-	0	51	51	356	44	-	0	11	-	76	-	149	0	265
SAU01 16-S08P	-	-	-	-	33	25	63	55	22	2	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU01 16-S08PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 12-S06P	-	-	-	-	27	56	13	4	-	20	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 12-S06P-F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 12-S06PTF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 12-S06PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 16-S08P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU02 16-S08P-F	-	-	-	-	-	-	-	-	-	245	149	255	661	503	456	86	575	383	427	418	433	193	87	338	550
SAU02 16-S08PTF	-	-	-	-	-	-	-	-	295	256	334	570	222	379	169	176	719	560	383	333	381	265	-	148	257
SAU02 16-S08PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 12-S06P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 12-S08P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 12-S08PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 1248S06P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 1248S08P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SAU05 1248S08PT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-</					



Scenario 10 (S10): Maximizing Production of Solid-Clear Wood with Reduced Harvest Levels

Scenario 10 (S10) was analysed to determine the volume of solid-clear wood that could be produced if harvest flow constraints were relaxed.

Analysis of the scenario was accomplished by solving (via linear programming) the following problem:

Find the schedule of harvests and silviculture activities (including pruning) that

- maximizes the harvest of pruned stands (and, hence, solid-clear wood) in decades 1-25
- allows the harvest levels to fall but not to go below the mid and long-term “floor” of the base case (283 thousand m³ per year).
- pruning costs are not constrained

Table E-2
S10 Pruning Report

The results are summarized in Table E-2. The model attempts to maximize the harvest of pruned in decades 1-25, which in turns drives pruning activity.

Figure E-1
Impact of total harvest

Figure E-1 shows the impact on the forecast harvest of maximizing the harvest of pruned timber and allowing the harvest levels to decline from their maximum (S04) levels. The harvest is reduced in the short and mid term but recovers to the S04 level in the long term.

Figure E-2
Solid-clear wood harvest

The solid-clear wood component of the harvest from pruned stands (Figure E-2) is double the production of solid clear achieved without relaxing timber harvest levels (80 thousand versus 37 thousand m³ per year, on average over decades 10-25.)

Figure E-3
Area pruned

Figure E-3 shows the pruning activity required to achieve the production of solid-clear wood plotted in Figure E-2. Average pruning costs in decades 1-15 are \$310 thousand per year for this scenario, versus \$167,000 for S09 (harvest constrained to maximum S04 levels).

Areas pruned in decades 16-25 are represented with white columns to signify that they may be atypical of the program level required to obtain the production levels plotted in Figure E-2. Stands pruned in these decades may not be harvested before the end of planning horizon, and so may not contribute to the objective of maximizing the harvest of solid-clear wood. Hence the model will prune fewer stands as it approaches decade 25.

Scenario S10 demonstrates that benefits from pruning will be increased substantially by reducing harvest levels in the short and mid term, allowing pruned stands harvested during the transition to maximize their production of solid-clear wood.

Arrowsmith TSA Silviculture Strategy Analysis

Appendix E - Pruning Scenarios

Table E-2. Pruning Report - Arrowsmith TSA

Scenario S10. Objective: maximize the harvest of solid-clear wood in decades 1-25 without reducing timber supply below 2,856,533 m3/decade

Decade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Area (ha) of Pruned Stands																										
SAU01	328	329	1,895	3,498	4,023	4,343	4,974	4,975	4,643	4,201	4,697	5,410	6,919	6,492	6,727	6,736	6,734	6,735	4,731	5,093	6,279	5,897	3,588	3,236	1,576	
SAU02	445	730	1,824	2,628	5,577	6,843	9,195	9,540	9,759	8,888	8,453	7,562	6,032	6,346	7,707	8,721	8,664	7,978	8,191	8,498	7,848	5,802	7,037	6,748	3,953	
SAU03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU05	-	0	431	870	1,493	1,980	2,014	2,259	3,225	4,047	4,030	3,842	3,644	3,453	3,056	2,855	3,123	3,275	3,230	2,800	2,788	2,780	2,551	689	354	
SAU06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU07	1,146	2,435	3,469	4,594	4,852	5,069	5,629	5,353	4,620	4,849	5,150	4,823	5,227	5,895	5,379	4,839	5,107	5,012	5,097	4,335	2,990	2,949	3,204	1,829	1,278	
SAU08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Total area (ha) of pruned stands	1,919	3,494	7,620	11,590	15,945	18,235	21,811	22,127	22,247	21,984	22,329	21,638	21,821	22,186	22,869	23,151	23,628	23,000	21,249	20,726	19,904	17,428	16,381	12,501	7,161	
Pruning Activity (ha/decade)																										
SAU01	-	1	1,569	1,607	528	382	696	176	654	470	1,700	1,077	1,930	408	423	836	188	825	186	816	2,044	95	27	25	20	
SAU02	63	286	1,094	890	3,066	1,380	2,504	416	396	107	229	981	664	1,873	2,194	1,558	832	542	886	1,224	665	886	1,279	25	18	
SAU03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU05	-	0	431	439	623	487	34	247	979	844	24	26	42	213	238	401	632	599	361	315	22	17	13	10	66	
SAU06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU07	1,141	1,289	1,057	1,185	272	259	653	233	143	752	891	557	525	850	123	155	630	699	326	817	120	123	1,432	17	153	
SAU08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
SAU09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Total pruning activity (ha/decade)	1,205	1,576	4,150	4,121	4,489	2,508	3,887	1,073	2,172	2,172	2,844	2,641	3,162	3,345	2,977	2,949	2,281	2,665	1,758	3,172	2,852	1,121	2,751	77	257	
Total pruning opportunity (ha/decade)	1,214	2,209	4,171	4,159	4,525	2,544	3,925	1,110	2,211	2,211	2,883	2,682	3,203	3,386	3,020	3,005	2,332	2,720	1,807	3,358	3,453	3,418	3,722	3,585	2,901	
Cost ('000 \$/decade)																										
Cost ('000 \$/decade)	1,325	1,734	4,565	4,533	4,938	2,759	4,276	1,180	2,389	2,389	3,128	2,905	3,478	3,679	3,275	3,244	2,510	2,931	1,934	3,489	3,137	1,233	3,026	85	283	
Employment (p-days/decade)	7,228	9,458	24,901	24,728	26,932	15,047	23,324	6,435	13,033	13,030	17,062	15,848	18,972	20,069	17,864	17,692	13,689	15,988	10,549	19,031	17,111	6,724	16,507	462	1,542	
Harvest ('000 /decade)																										
Total stands (pruned and not pruned)	4,030	3,546	3,121	2,857	2,857	2,857	2,857	2,857	2,858	2,862	3,319	3,647	3,664	3,664	3,664	3,665	3,665	3,665	3,665	3,665	3,665	3,665	3,665	3,665	3,665	
SAU01 12-S05P	-	-	-	-	-	0	1	2	4	8	21	197	170	77	47	13	13	15	187	341	917	250	1,011	162	87	
SAU01 12-S06P	-	-	-	-	-	0	1	37	704	59	911	119	201	486	67	605	78	22	766	120	115	205	1,083	73	47	
SAU01 12-S06PT	-	-	-	-	-	-	0	2	127	694	253	69	77	301	59	38	69	672	1,258	42	12	48	259	119	525	
SAU01 16-S08P	-	0	1	3	2	55	51	114	53	55	16	11	11	11	13	18	12	11	14	14	13	17	29	13	490	
SAU01 16-S08PT	-	-	-	-	-	-	0	1	2	3	4	6	7	8	7	7	7	9	11	7	6	8	10	9	13	
SAU02 12-S06P	-	-	-	29	40	42	64	31	10	94	15	47	1	1	2	2	2	2	2	2	2	2	2	2	2	
SAU02 12-S06P-F	-	-	-	-	-	0	1	1	2	3	4	5	7	7	7	7	7	7	7	7	8	12	6	7	8	
SAU02 12-S06PTF	-	-	-	-	-	-	0	0	1	2	3	4	5	6	6	6	7	7	6	5	7	10	4	6	7	
SAU02 12-S06PT	-	-	-	-	-	-	-	0	0	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	
SAU02 16-S08P	-	-	-	-	-	-	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	
SAU02 16-S08P-F	-	-	-	-	-	0	2	11	127	751	546	1,751	2,257	1,516	979	573	1,043	1,104	561	765	1,197	2,634	13	90	649	
SAU02 16-S08PTF	-	-	-	-	-	-	-	0	2	4	6	8	12	12	11	11	14	16	13	8	15	41	4	117	890	
SAU02 16-S08PT	-	-	-	-	-	-	-	-	0	0	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	
SAU05 12-S06P	-	-	-	-	-	-	-	-	0	1	2	2	3	3	3	3	3	3	3	4	3	3	4	6	4	
SAU05 12-S08P	-	-	-	-	-	-	-	-	-	3	5	15	141	11	155	114	192	183	64	60	192	7	4	80	392	73
SAU05 12-S08PT	-	-	-	-	-	-	-	-	-	-	2	2	3	6	125	57	23	57	10	86	2	1	2	85	32	
SAU05 1248S06P	-	-	-	-	-	-	-	0	1	1	2	2	3	4	4	4	4	5	5	7	3	3	5	7	4	
SAU05 1248S08P	-	-	-	-	-	-	-	0	1	3	4	11	192	183	284	218	37	229	278	353	5	4	96	635	68	
SAU05 1248S08PT	-	-	-	-	-	-	-	-	-	0	1	1	1	2	2	2	2	2	2	3	1	1	2	3	9	
SAU07 12--P	-	-	-	-	-	-	-	0	1	3	4	5	5	6	9	12	11	17	11	21	21	11	13	48	171	
SAU07 12-S07P	-	-	-	-	-	3	19	237	345	106	234	301	31	67	267	226	71	366	58	443	492	16	50	321	86	
SAU07 12-S07PT	-	-	-	-	-	-	-	-	0	0	1	3	6	9	90	13	34	18	9	85	64	13	18	41	8	
SAU07 1248S10P	-	-	-	-	-	3	8	75	246	281	197	461	64	71	59	50	25	171	26	463	386	17	203	346	242	
SAU07 1248S10PT	-	-	-	-	-	-	-	-	0	0	1	2	3	7	137	14	54	79	12	62	130	24	195	131	29	
Total harvest pruned ('000 m3)	-	0	1	32	42	104	147	514	1,628	2,074	2,244	3,151	3,076	2,940	2,295	2,075	1,705	2,881	3,306	3,033	3,415	3,331	3,091	2,618	3,452	
Solid Clear ('000 m3)																										
Solid Clear ('000 m3)	-	0	0	14	18	36	51	140	448	586	615	893	894	834	615	694	512	831	881	821	944	1,008	831	759	1,049	
Solid Clear/ total pruned					0.44	0.35	0.34	0.27	0.28	0.28	0.27	0.28	0.29	0.28	0.27	0.33	0.30	0.29	0.27	0.27	0.28	0.30	0.27	0.29	0.30	
Solid Clear/ total stands					0.01	0.01	0.02	0.05	0.16	0.20	0.19	0.24	0.24	0.23	0.17	0.19	0.14	0.23	0.24	0.22	0.26	0.28	0.23	0.21	0.29	

Figure E-1. Impact on forecast harvest of maximizing the volume of solid-clear wood produced by pruning (S10).

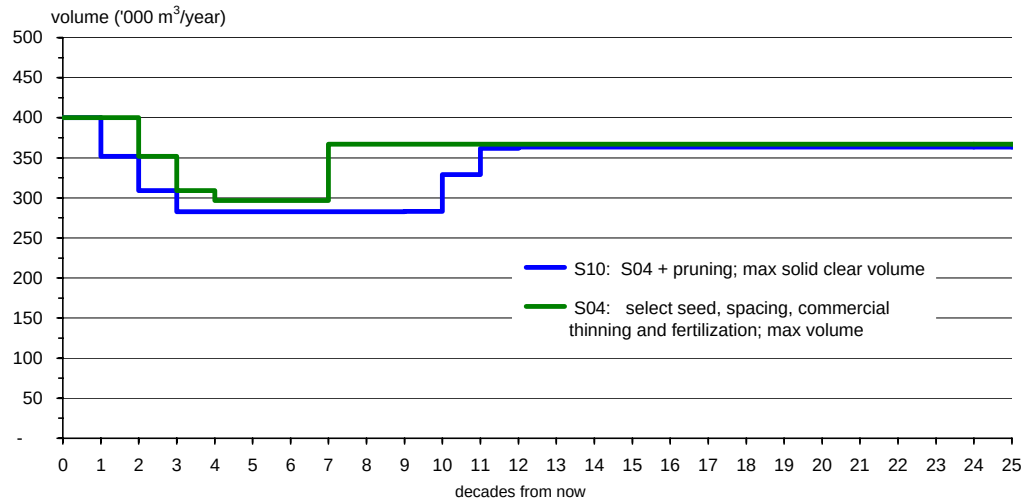


Figure E-2. Forecast harvest of solid-clear wood with reduction in short and mid-term harvest (S10).

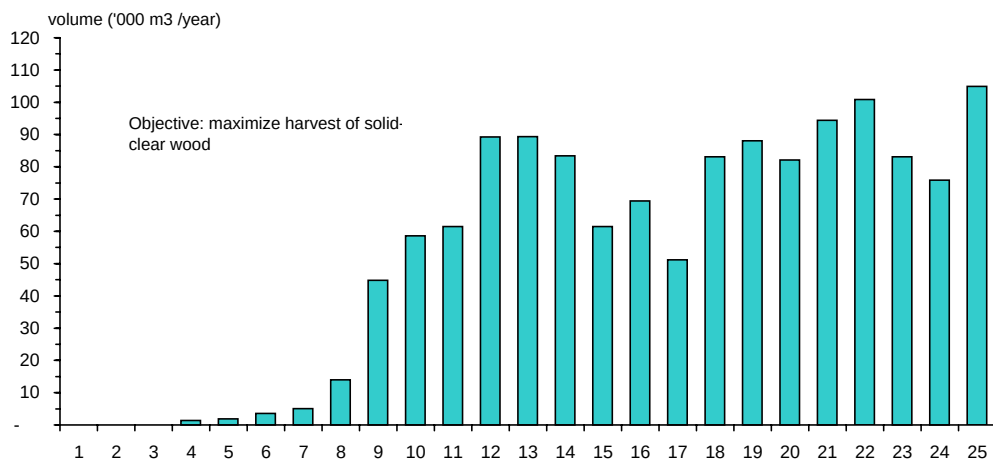
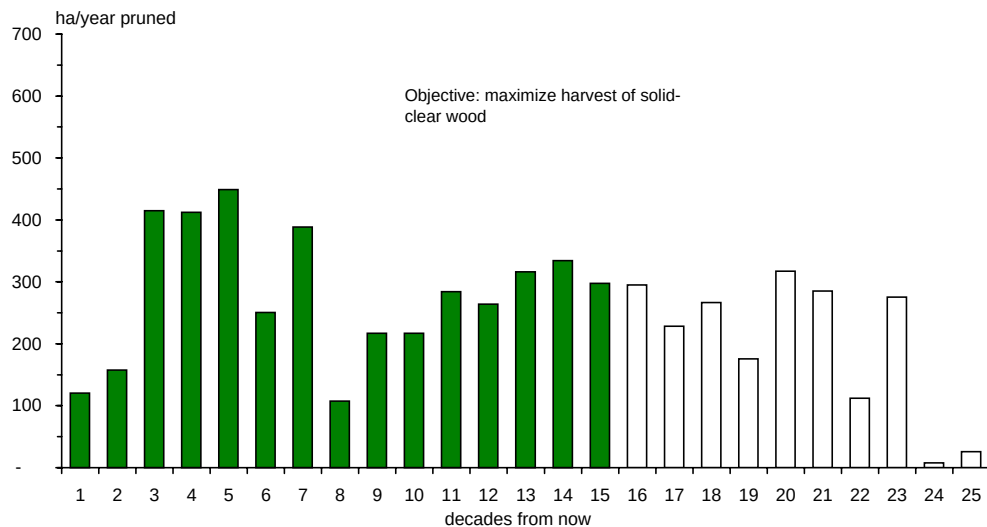


Figure E-3. Area pruned at increasing levels of annual expenditure (S10).





Arrowsmith TSA Silviculture Strategy Analysis