Forest Estate Analysis
of the Impacts of Silviculture Expenditures
on Short- and Long-Term Timber Supply
and Harvest Level Projections
for the
Vanderhoof Forest District

Prepared for
Forest Practices Branch
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Executive Summary

This document reports the results of a forest estate analysis of intensive silviculture opportunities in the Vanderhoof Forest District. With an objective of maximizing current and future timber supplies, alternative budget levels were tested for allocation to silviculture investment opportunities. The Woodstock (Remsoft 1997) modelling system was used to find optimal combinations and timing of silviculture investments over a 100-year planning horizon.

The Vanderhoof Forest District currently has 183 million m^3 of standing inventory volume, and the harvest rate is approximately 1.8 million m^3/yr. The merchantable forest is mainly lodgepole pine, with some spruce, Douglas-fir and balsam fir stands.

The analysis indicates that post-harvest stand establishment is the most critical silviculture activity. Post-harvest natural regeneration is sporadic and patchy in most areas of the Vanderhoof Forest District, and at least 90% of harvested sites are manually planted. A scenario was tested to inspect the consequences of greater reliance on natural regeneration. With a 10-year regeneration delay and harvest flow constraints, total volumes harvested over the 100-year planning horizon are reduced 12–16% if the planting program is replaced with natural regeneration. An additional benefit of planting is an ability to use the genetically selected stock that will be available over the next 5-10 years.

Juvenile spacing is found to be the most cost-effective post-establishment silviculture treatment. Expenditures of $1 million/yr on a juvenile spacing program enable increases of over 250 000 m^3/yr in current harvest rates. This additional harvest volume is achieved at an average cost of under $4/$m^3$. Further expenditures on juvenile spacing yield diminishing returns. Expenditures on juvenile spacing above $2.5 million/yr provide small additional short-term gains in current harvest levels.

Commercial thinning (CT) provides an opportunity to remove standing volume before stands reach culmination age and a final clear felling. Timber value from the CT is assumed to pay for the activity. However, the regimes provided for this analysis include a fertilization treatment following the CT activity. This does impact the fertilization budget. The model postpones CT activity until later in the planning horizon, when existing mature stands become scarce and constrained by other resource requirements. CT was most often undertaken in stands that had been previously juvenile spaced.

Expenditures on pruning activity have minimal positive impacts on current or future harvest levels. Pruning was only undertaken by the model at budget levels above $2.5 million/yr, in periods when there is a lack of other intensive silviculture activities on which to spend the budget.

Acknowledgements

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The cooperation and support of many individuals made this project possible. Thanks are directed to Dave Sommerville, silviculture officer in the Vanderhoof Forest District, Jennifer Pollard, IRM technician in the Prince George Forest Region and Ken Polsson, stand modelling analyst at Research Branch, Ministry of Forests, for support in the preparation of data and assumptions.

Ralph Winter, stand management officer at Forest Practices Branch, Ministry of Forests, oversaw the project with patience, interest and encouragement. Lorne Bedford and Pat Martin both added significant support from Forest Practices Branch. Mark Messmer, formerly with Forest Practices Branch, provided early advice in the use of Woodstock at the forest district scale of modelling. Andrew Cogswell, working with Remsoft Inc. in New Brunswick, provided technical advice on many modelling issues.

The author extends thanks to these and all other people who contributed to a successful completion of this project.

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Forest Estate Analysis of the Impacts of Silviculture Expenditures on Short- and Long-Term Timber Supply and Harvest Level Projections for the Vanderhoof Forest District

1 Introduction

This report presents the results of an investigation of intensive silviculture opportunities in the Vanderhoof Forest District. Establishment of a free-growing regenerated stand is a requirement of harvest, and this report investigates intensive treatments above and beyond the basic silviculture obligation. Treatments considered in the report include juvenile spacing, pruning, commercial thinning, and fertilization. Scenarios that consider the use of genetically selected stock, natural regeneration, and control/salvage of bark beetle attack are also included.

Silviculture opportunities are assessed for their impact on current and future potential harvest yields, mainly in terms of increasing sustainable harvest rates. Treatment costs are compared with volume responses, and recommendations are made for appropriate levels and types of intensive silviculture.

The Woodstock (Remsoft 1997) modelling language was used in the analysis. Woodstock facilitates formation of forest management scenarios as linear programming problems, and the solution to a model is the optimum feasible solution for the given inputs and management rules. Working with the model, scenarios with different inputs and rules are defined, and optimal solutions are found for each scenario. The solutions are then compared to understand the relative merits of different scenarios.

1.1 The Vanderhoof Forest District

The Vanderhoof Forest Districe (VFD) is located in the geographic centre of British Columbia, on the north-west portion of the Interior Plateau (Figure 1). The VFD, one of three forest districts in the Prince George Timber Supply Area, covers approximately 1.4 million ha, of which approximately 0.9 million ha is considered available and suitable for timber harvesting.

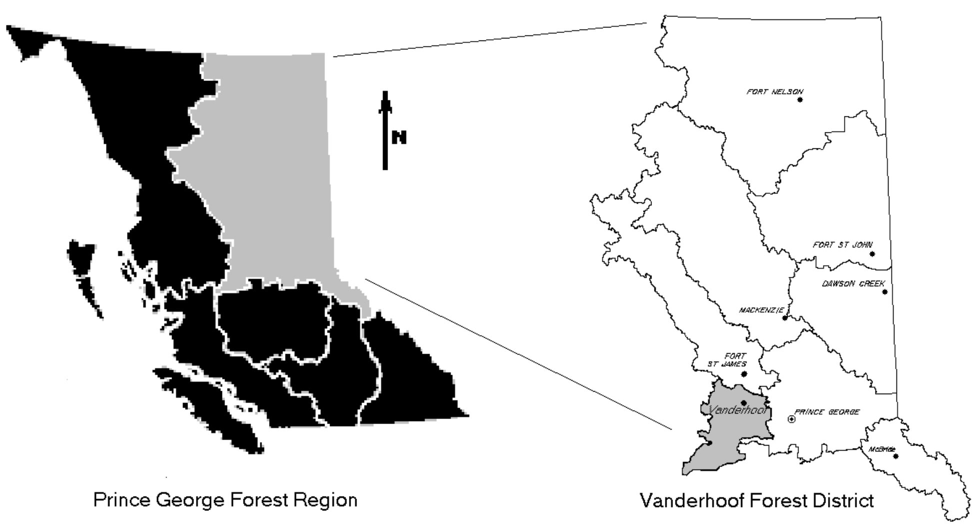

FIGURE 1. Location of the Vanderhoof Forest District.

Forests in the VFD are predominantly lodgepole pine (87%), with some spruce-, Douglas-fir-, and balsam-leading stands. The terrain is fairly flat and rolling, with gentle slopes. The climate is continental. Most of the timber harvesting land base is in the Sub-Boreal Spruce biogeoclimatic ecosystem classification zone, with some area to the south and west of the district at higher elevations in the Engelmann Spruce–Subalpine Fir zone.

The boundaries of the Vanderhoof Land and Resource Management Plan (LRMP) coincide with those of the VFD. The LRMP now has approval in principle, and is approaching the order in council stage of full implementation. Five large wood processing facilities are located in the VFD. The current allowable annual cut is 1.8 million m^3/yr.

2 Information Preparation

Three types of information are required to undertake a timber supply analysis: a description of the land base, estimates of timber growth and yield, and land management concerns. This section summarizes the three types of inputs used in this analysis.

2.1 Land Base

Prince George Forest Region staff provided a database file for the Vanderhoof Forest District (VFD) in Microsoft Access format. The database is over 500 Mb in size, and a zipped copy is included on the data CD (Appendix 2). Information about the district includes the state of the timber inventory and a depletion update and is current to January 1998. The database identifies the net harvestable area using the netdown logic from the 1995 Timber Supply Review. Net area information included on the file was used for this analysis.

The total net harvestable area in the VFD (the timber harvesting land base, or THLB) is 903 025 ha, an increase of 80 000 ha (9%) since the last TSR analysis in 1995. In the THLB, 590 000 ha are presently stocked with harvest-aged timber, with a total standing merchantable volume of approximately 183 million m^3. Figure 2 illustrates the present area distribution within the THLB by 5-year age class.

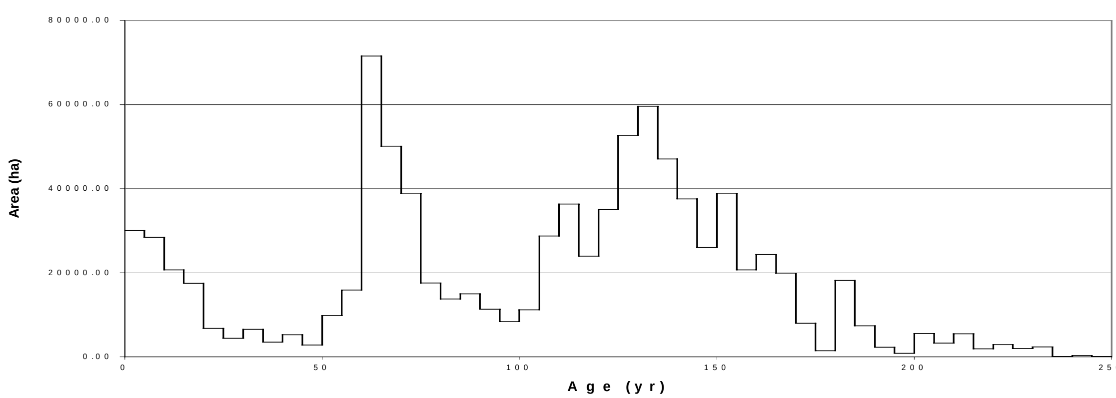

FIGURE 2. Existing age-class distribution on the THLB in the Vanderhoof Forest District.

Figure 2 illustrates the significant area now occupied by mature forest stands. In the analysis that follows, even with rates of harvest significantly higher than now, this area supports 50 to 60 years of future harvest without requiring any harvesting in currently immature stands.

Figure 3 illustrates the distribution of area among the four species groups and three site classes, which form the 12 analysis units in the analysis. Lodgepole pine is the dominant tree species in the VFD. The average site index for existing stands is approximately 16 metres at breast height age 50 (mbha50), and is projected to be 19 mbha50 for regenerated stands.

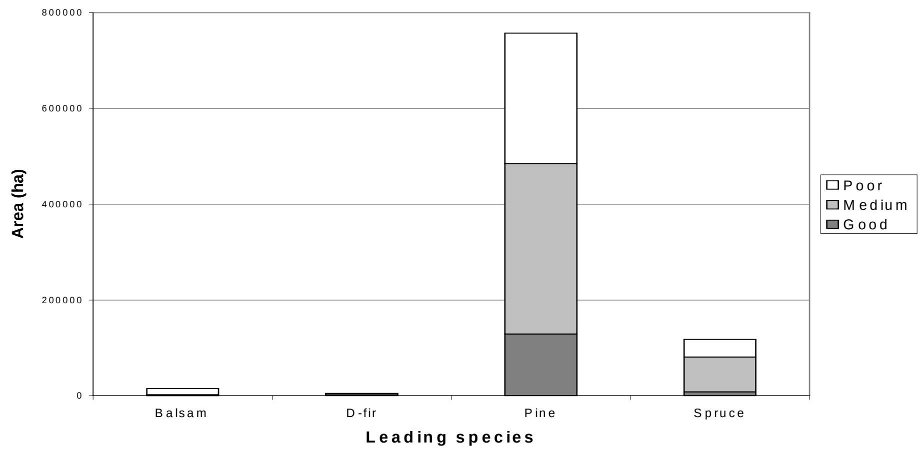

FIGURE 3. Distribution of area by species and growing site quality.

2.2 Timber Growth and Yield

The analysis projects forest development and harvesting in the VFD to 100 years into the future. By that time, most present forested stands will have been harvested, and in some areas stands regenerated after current harvesting will be harvested again. To make such projections the rates of growth and types of stands that will develop in response to alternative regeneration and stand tending assumptions must be estimated.

Existing stands older than 60 years of age are assumed to be stands of natural origin, not planted or managed, and will grow to harvestable age without further tending. These stands are assigned volume yield estimates using the Variable Density Yield Projection (VDYP) volume estimates published in the 1995 TSR report (B.C. Ministry of Forests 1995, Table A-21b). Existing stands younger than 60 years are grown on regenerated stand yield curves, and may be allocated by the model to intensive silviculture treatments that occur at an age greater than the current stand age.

Young and regenerated stands are inspected for a number of alternative treatments in the analysis, depending on stand location, leading species, and growing site quality. The silviculture officer in the VFD provided guidance to which treatments would be considered, and where they might be applied (see Appendix XX). This information was provided to the Forest Productivity and Decision Support (FPDS) section of Research Branch, Ministry of Forests. FPDS maintains and continues to develop the Tree and Stand Simulator (TASS) computer modelling program, which simulates growth of forest stands by modelling a complete hectare of individual trees, tracking data for individual stem and branch development, and inter-tree competition. TASS was used to estimate growth response to the alternative treatment regimes for this analysis.

Yield estimates from TASS for this project consist of five components: volumes from 12.5 to 15 cm dbh, volumes from 15 to 25 cm dbh, volumes greater than 25 cm dbh, clear volumes resulting from pruning treatments, and volumes from commercial thinning, where applicable. Total yields reported in the analysis consist of the sum of all volume types, although some scenarios focus on individual volume components. Existing stand (VDYP) estimates provide only total merchantable volume estimates, without a breakdown by diameter or log quality class.

The site index assigned for existing stands older than 60 years is the site index included in the inventory planning database. For stands younger than 60 years, and regenerated stands, the old-growth site index was adjusted. This change resulted in an upward lift of approximately 3 m at 50 years breast height age, compared with the site index for regenerated stands in the 1995 TSR analysis.

2.3 Management Practices

Forest management practices are modelled in a manner similar to those described for the VFD in the 1995 TSR analysis of the Prince George TSA. There are four levels of visual quality management, an integrated resource management zone, a 10-year harvest delay in the Entiako and Blackwater LRUP areas, and special old-age requirements in the Chedakuz Riparian Management Area. Table 1 summarizes forest age-class requirements for these management zones.

TABLE 1. Summary of forest cover requirements

Management zone	Green-up height	Green-up age	Maximum % non-green
VQO - P	5	23	0
VQO - R	5	22	5.3
VQO – PR	5	23	15.9
VQO - M	5	23	26.5
IRM	2.5	by AU*	25
10-yr delay	2.5	15	25
Chedakuz**	2.5	15	25

*Years to the required height depend on species and growing site.
**Also requires at least 15% of the area to be greater than 150 years old.

Figure 4 illustrates the proportions of the THLB in the visual and IRM management zones. The dominant zone in the analysis is integrated resource management, with four-pass harvesting and green-up ages of approximately 15 years. The IRM forest cover requirements are required to be met independently within each analysis unit.

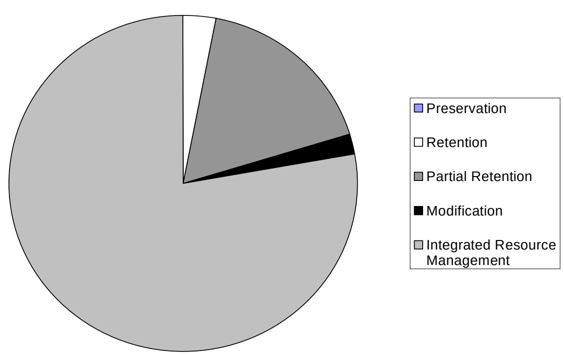

FIGURE 4. Distribution of area in the THLB by different green-up requirements.

The analysis inspects the economic advisability and consequences of alternative silviculture treatments. Some treatments are contemplated for many areas in the district, while other treatments, such as commercial thinning and pruning, would only occur relatively near manufacturing facilities. Appendix 1 categorizes treatments according to where they might occur, and Figure 5 illustrates the relative proportions of the THLB in each candidate treatment area. *[Dave, do you have names for these 5 areas?]*

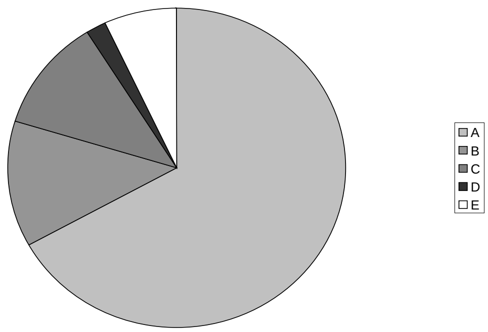

FIGURE 5. Distribution of area by silviculture treatment zone.

Currently the VFD has 9082 ha of permanent roads. Future road construction is modelled by removing 7% of the area harvested from existing mature stands to non-productive status. Subsequent harvests in regenerated stands are assumed to use the same road network established during the harvest of existing stands.

3 Analysis Methods

This analysis examines potential benefits that may accrue at the forest level from investments in intensive silviculture activities. Benefits are measured in terms of the ability to increase short- and long-term harvest levels above levels indicated in a no-investment scenario. Investment options include juvenile spacing, pruning, and fertilization. The analysis results are intended to support district silviculture planning for stands that are free-growing.

Use of a forest estate model enables consideration of harvesting potentials across the entire land base. Some treatments that enhance the growth of an individual stand may be poor investments at the forest level, if alternative sources of timber harvest are plentiful when the benefits of the treatment are realized. Alternatively, marginally beneficial stand treatments may fill a supply shortfall in a particular future period, and be wise investments at the forest level.

The Woodstock (Remsoft 1997) modelling system was used to complete this project. Woodstock is a modelling language, rather than a structured model such as FSSIM (Forest Service Simulator). The Woodstock language is used to express a model structure specific to the problem statement. The language consists of a syntax to express yields, actions, changes to, and outputs from a forest estate. The only mandatory assumption in a Woodstock model is that time increments forward; otherwise, the model is completely written by the user.

The Woodstock model developed for this project, and several variants thereof, are included on the data CD. Stand management alternatives are expressed as regimes, which are specific sequences of management events that may be considered feasible on a piece of land. (An alternative to regimes would be to express silviculture activities as independent events.) Regimes may be conceptualized as pipes, through which area flows over time. Along the pipe, certain costs are encountered, and each pipe has an associated level of timber quality and quantity yield.

For example, a planted lodgepole pine stand on a good growing site has a choice of five treatment regimes. It may be (1) not treated, (2) juvenile spaced and left, (3) juvenile spaced to low density, pruned twice and fertilized, (4) juvenile spaced, commercially thinned, and fertilized, or (5) commercially thinned and fertilized. Each alternative regime represents different timing and quantity of costs, and different timing and amount of timber harvest. Table 2 summarizes the costs of the individual silviculture treatments that make up the regimes, and Appendix 1 lists the timing of the cost components.

TABLE 2. Costs of the intensive silviculture treatments

Treatment	Cost ($/ha)
Juvenile space	475–525
Prune, first lift	1200–1300
Prune, second lift	1000
Commercial thin	0
Fertilize	400

The Woodstock interpreter builds a linear programming (LP) matrix from the present inventory, and the alternative regimes to which the inventory may be subject over time. All possible alternatives, across the entire land base, are represented simultaneously in the LP matrix. This matrix is passed to a mathematical programming solver (CWhiz, by Ketron Management Science, was used for this project) that finds an optimal solution to the matrix, where optimality is the maximization of a single output. A solution file is generated (where a feasible solution is found) and then Woodstock runs a simulation of the mathematical solution, and reports in terms of forestry variables.

Typical solution times for the three-step (build matrix, solve matrix, and simulate solution) model run on the VFD are two hours for a 100-year planning horizon, and eight hours for a 150-year planning horizon on a P350 computer. Run times increase dramatically as the planning horizon lengthens into multiple rotations. Changes to some constraints, such as growing stock requirements, may double or halve solution times.

Continuing the pipeline analogy, the LP decides which pipeline to send each stand down after harvest. Each pipeline has a minimum length, or time to earliest stand maturity, after which the stand may be harvested in any period as it continues down that pipe. At harvest, it may repeat in the same pipe, or transition to any other candidate pipe, based on its location and growth type (analysis unit). The LP solution selects the best mix of area and pipes, subject to limits on available budgets and the production objective. All areas have a no-treatment option available to use when budgets are set to nil.

The analysis method is not as simple as setting up the complete range of options, and solving the model matrix once. Analysis is a feeling-out process, where small changes are made to inputs, and the output is inspected to determine the next incremental change to the inputs. For example, harvest flows have many different patterns (flat-line, accelerated front end, non-declining yield, an initial period of stability, and varying levels of between-period requirements for stability). Different flow patters were tested. Budgets were tested from $0 to $6 million, and a number of different product objectives were tested.

4 Results

A base case harvest projection was made with an intensive silviculture budget of zero. This harvest level is used to calibrate harvest level gains at higher budget levels. Figure 6 illustrates alternative feasible harvest flows for the base case.

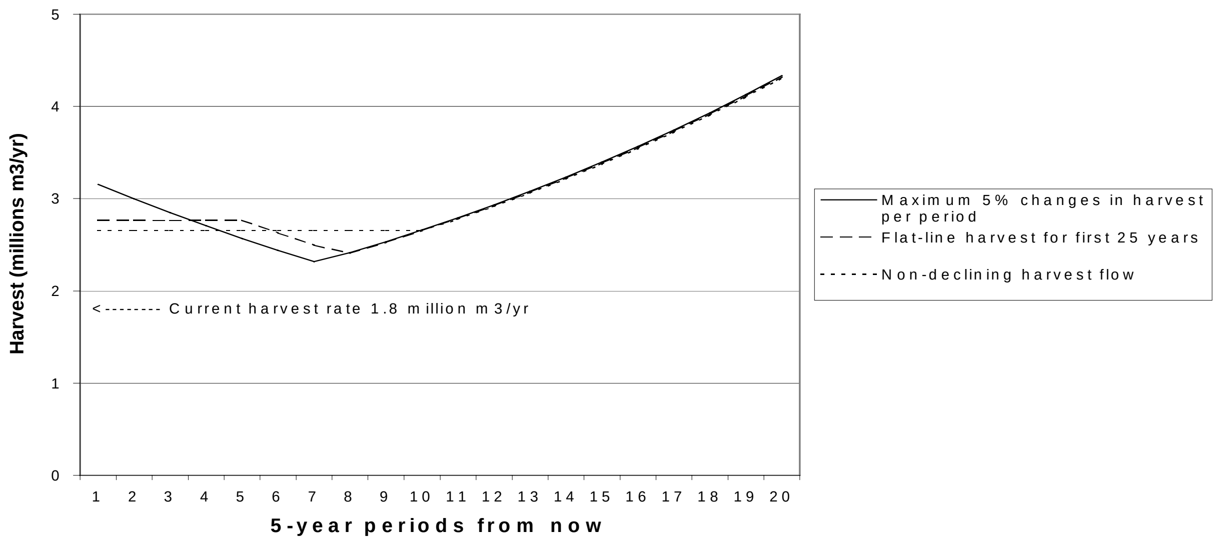

FIGURE 6. Alternative harvest flows for the base case.

The present harvest rate in the VFD of1.8 million m³/yr is based on historic harvest rates, the 1995 TSR analysis, and socio-economic considerations. The present harvest rate in the VFD is lower than any harvest flow illustrated in Figure 6. There are several factors that contribute to the higher indicated harvest levels in the present analysis:

1. The THLB in this analysis is 894 000 ha (Jan 1998 file); the TSR analysis models a land base of 817 000 ha.
2. The new site index values for regenerated stands (old-growth site index adjustment) have increased estimated yields for young existing and regenerated stands by 20–40%. This makes larger second-growth volumes available sooner, and permits earlier harvest of existing old forest.
3. This analysis does not subtract unsalvaged losses for windthrow, fire, and bark beetles (a 1% reduction in harvest levels in the TSR).
4. This analysis uses an optimization model, while the TSR used a simulation model. A simulation model does not necessarily find the maximum possible solution.

The harvest flows in Figure 6 incorporate a constraint of maximum 5% change in harvest rates per 5-year period, and require an ending growing stock level of 140 million m³. All harvest projections show a rising harvest rate in the latter half of the 100-year planning horizon.

The middle harvest flow was selected for assessing benefits of intensive silviculture activities. The harvest rate is constrained to be a stable, flat line for the first 25 years of the planning horizon, and may change by up to 5% per 5-year period after that.

Figure 7 illustrates growing stock levels in the VFD for the base case harvest projection. Existing older stands are mostly harvested over the planning horizon, with some stands reserved from harvest by visual quality considerations, and the old-age requirement in the Chedakuz Riparian Management Area. Standing volumes in regenerated stands increase steadily over the planning horizon, until the final four periods.

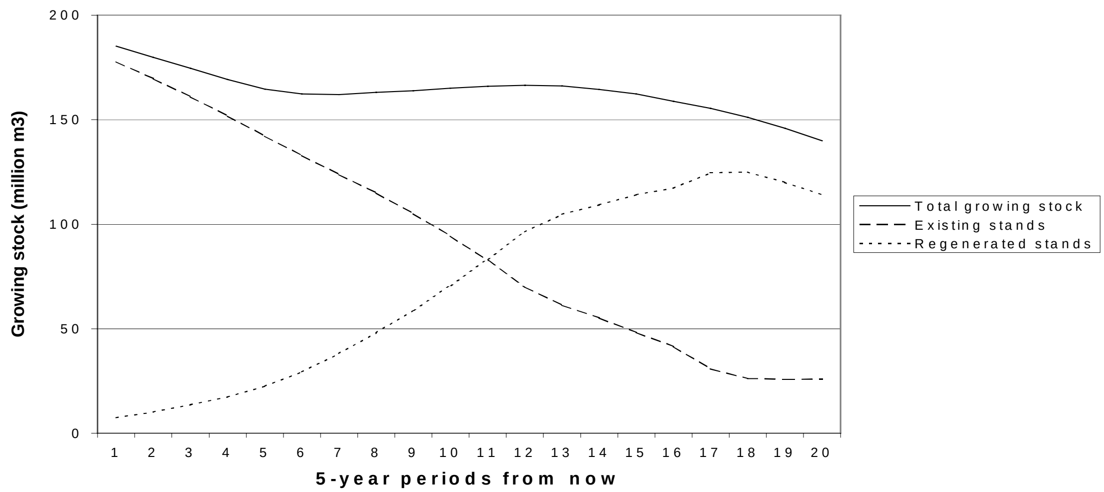

FIGURE 7. Growing stock inventory levels for the base case harvest projection.

The LP model solves the objective of harvest maximization by maintaining high levels of growing stock, which are drawn down toward the end of the planning horizon. This enables the high harvest rate toward the end of the planning horizon for the projections in Figure 6.

If growing stock levels are required to be stable for the final 25 years of the planning horizon, long-term harvest levels top out at approximately 3.4 million m³/yr, and the growing stock stabilizes at 149.4 million m³. Figure 8 illustrates the projected harvest flow compared with the base case. Lower future harvest rates permit a 2.6% increase in short-term harvest levels, although the total yield over the planning horizon declines by 1.2%.

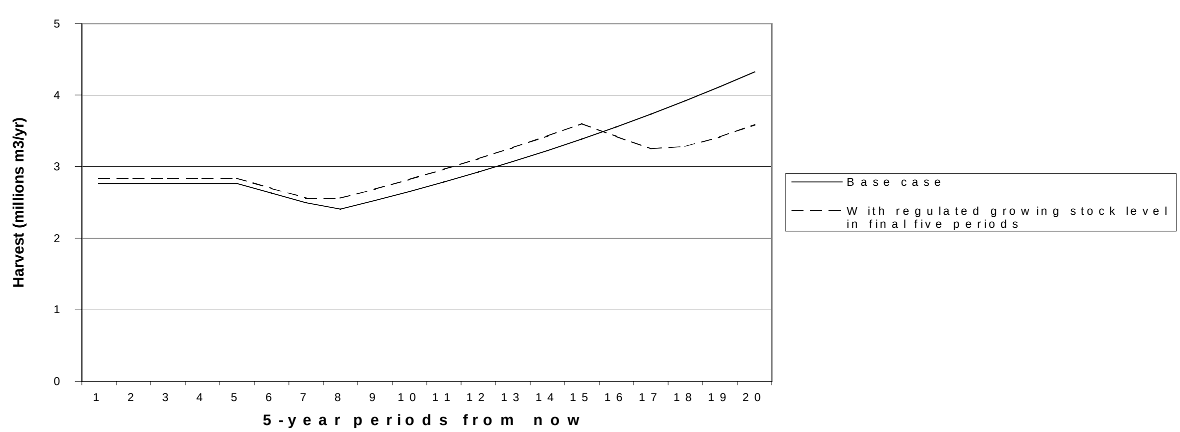

FIGURE 8. Harvest levels with stable ending growing stock requirement.

Figure 9 illustrates the distribution of area by seral stage in the future forest under the base case harvest flow. Age breaks for the seral stages are: early (0–40), mid (45–80), mature (85–140), and old (145+). Compared with now, the future forest will have more area in younger age classes. At year 100, 19% of the forest area is in mature and old seral stages, compared with 60% in those stages now.

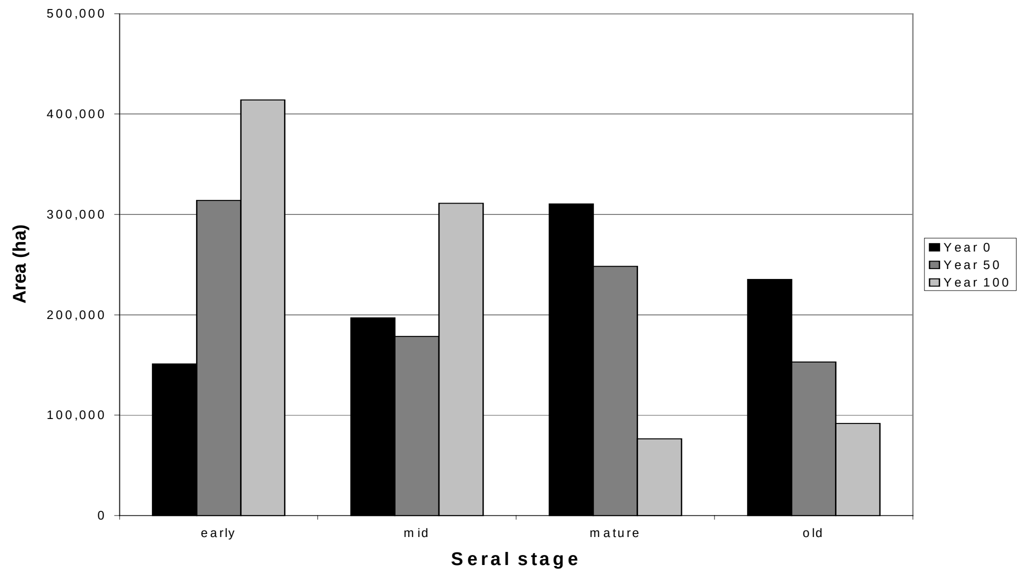

FIGURE 9. Present and future distributions of area by seral stage for the base case.

4.1 Budget Levels

The base case harvest flow does not include an intensive silviculture budget, and therefore does not include juvenile spacing, pruning, or fertilization activities. Figure 10 illustrates the impact on harvest flows if different levels of silviculture budget are added to the model. The model allocates the budget to treatments that will be most cost-effective in increasing the harvest rate across the planning horizon. All harvest projections in Figure 10 use the same assumptions and flow constraints as the base case.

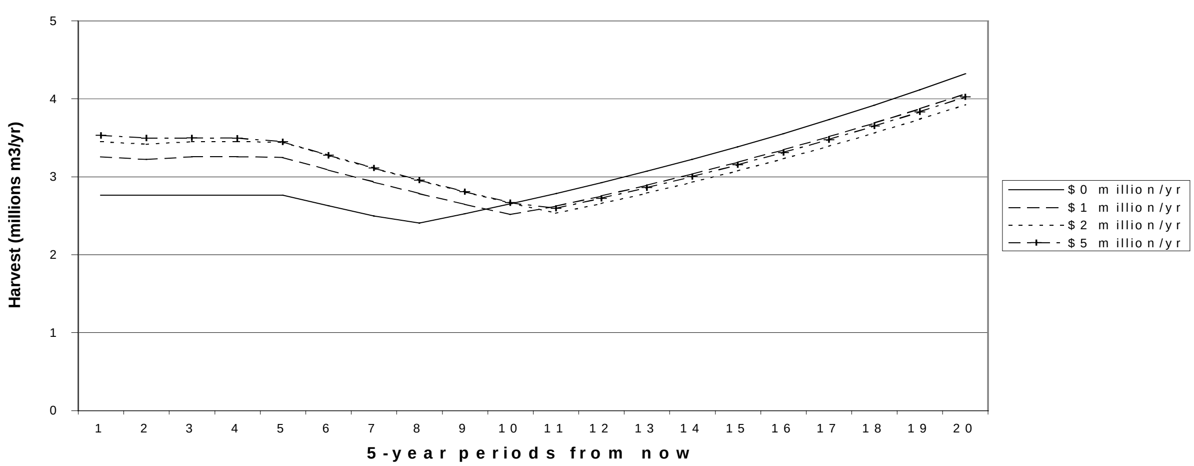

FIGURE 10. Harvest levels with alternative silviculture budgets.

The investment in intensive silviculture permits a transfer of harvest volume from future periods into current periods. Juvenile spacing, in particular, permits regenerated stands to be harvested at ages 5–20 years younger than untreated stands. However, there may be a sacrifice of longer-term harvesting opportunity, with the lower volumes per hectare achieved in a shorter-rotation forest. Table 3 lists the total volumes harvested over the planning horizon. Total volume increases with increased budgets, but at a lesser rate than the increase in the short-term harvest level.

TABLE 3. Short-term harvest levels, and total volumes harvested over the 100-year planning horizon

Silviculture budget ($ millions)	Short-term harvest level (million m³/yr)	Volume harvested (millions m³)
0	2.766	308
1	3.256	316
2	3.450	319
3	3.524	321
4	3.518	324
5	3.531	325
6	3.524	325

Dollars spent on intensive silviculture produce diminishing returns. The first $1 million provides a significant short-term increase in harvest levels, and each subsequent $1 million provides a smaller increase in the harvest level. To inspect the relationship, the model was run with budget increments of $0.25 million, from $0 to $6 million. Results are presented in Figure 11. For reference, the present intensive silviculture budget in the VFD is approximately $2.5 million/yr.

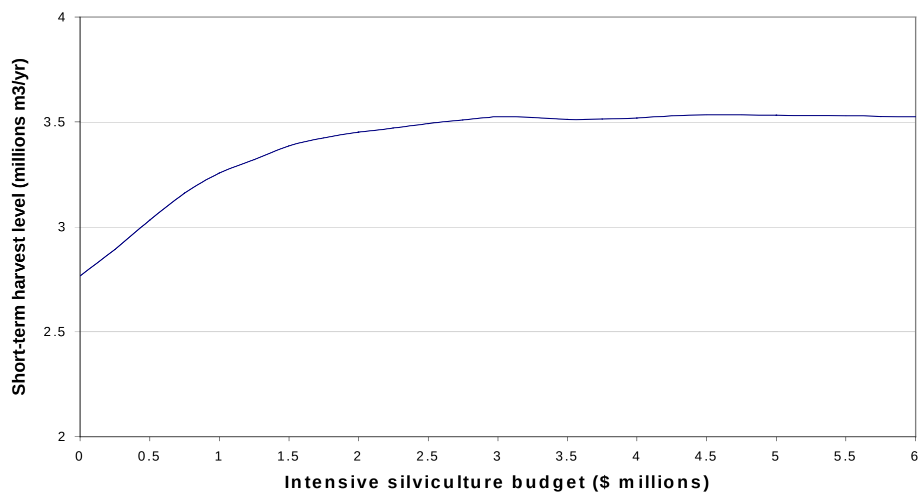

FIGURE 11. Short-term harvest levels achievable with alternative silviculture budgets

In Figure 11, short-term benefits from the intensive silviculture program show a declining rate of increase after about $1–$1.5 million/yr. There are no benefits in terms of short-term harvest gains with an investment of over $3 million/yr. Table 4 lists the incremental cost (per m³ harvested) of increasing current harvest rates through intensive silviculture treatments. On the VFD timber harvesting land base a natural rate of growth supports harvesting at the base case levels. Intensive silviculture changes the rate and harvest timing of that growth, and results in incremental harvest level gains, up to a point. Eventually, the possibility for improvement declines as tree growth rates are maximized on the fixed land base.

TABLE 4. Short-term harvest gains, and cost per yield increment

Intensive silviculture budget ($ millions)	Added harvest volume per dollar spent (m^3/$)	Cost of increased short-term harvest level ($/$m^3$)
0.00	0.00	0.00
0.25	0.51	1.97
0.50	0.56	1.79
0.75	0.51	1.95
1.00	0.38	2.60
1.25	0.25	3.93
1.50	0.26	3.82
1.75	0.16	6.44
2.00	0.11	9.47
2.25	0.08	12.63
2.50	0.09	11.47
2.75	0.07	14.04
3.00	0.06	17.86

The appropriate investment threshold would be determined based on funds available and need for incremental current harvest yields. At a threshold of $5/$m^3$ the intensive silviculture budget would be set at $1.6 million annually, whereas with a threshold of $15/$m^3$ the budget would be $2.8 million/yr. The higher budget levels permit treatment of more marginal stands.

4.2 Budget Allocation

The discussion to this point presents model results for the aggregate VFD land base. However, it is also interesting to know which candidate intensive treatments are preferred (most cost effective) in the model, and to which stands those treatments are applied. Appendix 1 lists the complete set of treatment regimes used in the model.

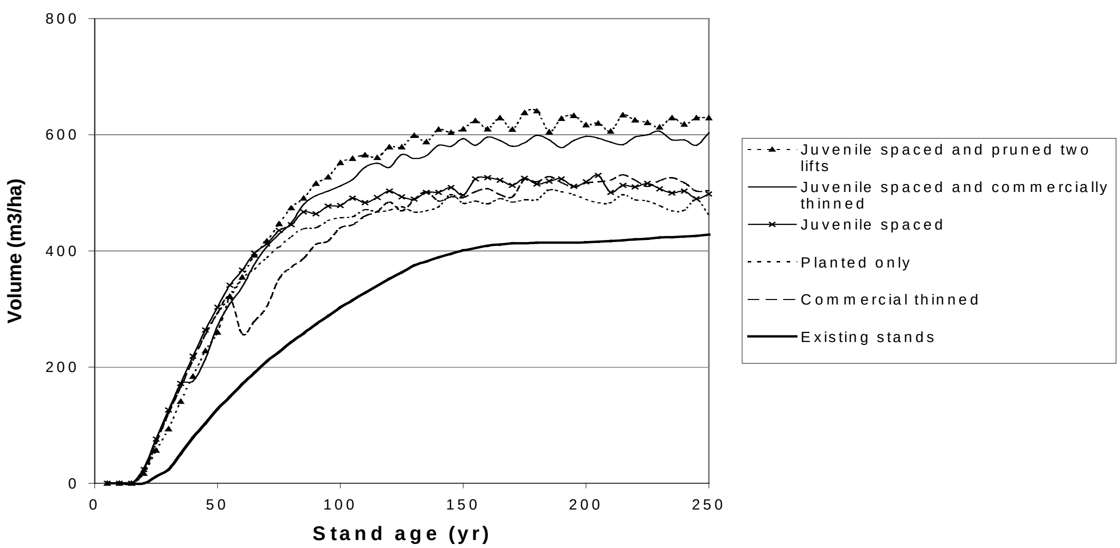

FIGURE 12. Yield curves for the pine, good site, planted analysis unit.

Figure 12 illustrates the expected yield response to treatment regimes for lodgepole pine on good growing sites. This analysis unit is a candidate for the complete range of treatment regimes. The existing stand yield curve is from VDYP, and all other curves are from TASS. Yield tables for these and all other analysis units are included on the data CD. Clearly, all regenerated stands will produce yields significantly higher than existing stands. Also, the stands that are treated twice, either spaced and twice pruned, or spaced and later commercially thinned, produce significantly higher volumes in the long term than stands that are simply regenerated and left, or treated once. However, the yield responses to treatment do not become apparent until 80 years after regeneration, which is late in the planning horizon of this analysis.

Figure 13 illustrates the proportions of the budget allocated to intensive silviculture treatments over the 100-year planning horizon. Treatments are divided between juvenile spacing and fertilization, with essentially no pruning activity. At higher budget levels, a portion of the budget remains unallocated in some early planning periods.

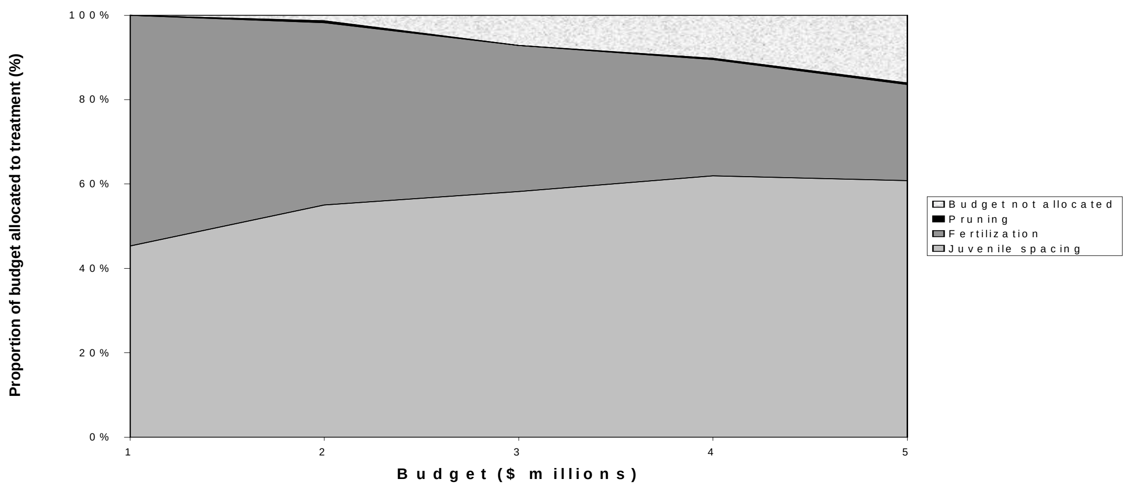

FIGURE 13. Average budget allocation between intensive silviculture treatments over the 100-year planning horizon.

Figure 13 provides the average allocation over the entire planning horizon, by budget level, and illustrates that with increased budgets, relatively more money is allocated to juvenile spacing than to fertilization treatments. A portion of the budget remains unallocated, usually in the second planning period, but also in the first, eighth, and ninth periods at higher budget levels, due to a shortage of candidate stands to treat.

Figure 14 illustrates budget allocation to treatments over time, for a fixed budget of $2 million/yr. Juvenile spacing is the most important treatment in the short term, while new stands are being established, and fertilization will increase in importance over time, as the new stands are nearing maturity. Juvenile spacing activity declines because the LP is seeking to maximize return on investment within a fixed-length planning horizon, rather than for an ongoing sustained forest management plan.

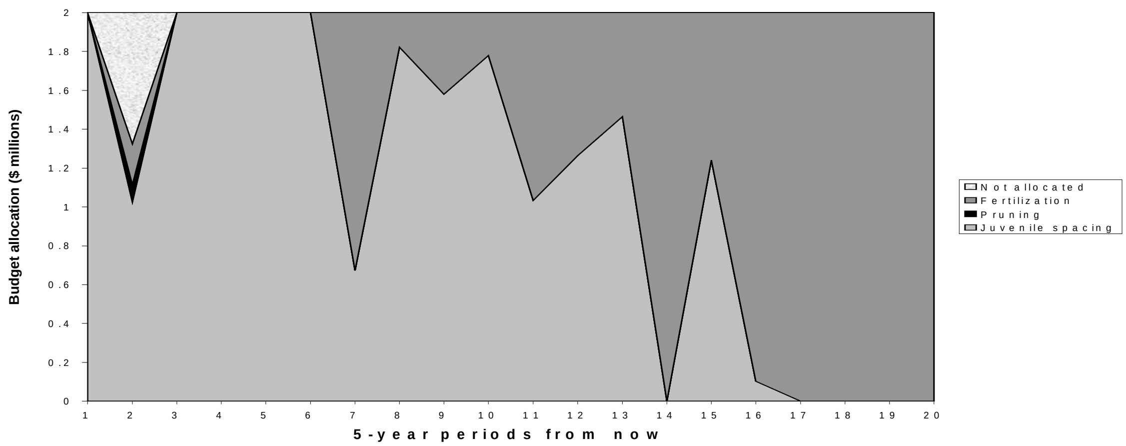

FIGURE 14. Allocation of a $2 million budget between treatments over the 100-year planning horizon

4.3 Juvenile Spacing

To recap results to this point, a cost-effective intensive silviculture program for the VFD would spend from $1.6 to $2.8 million/yr, and in the short-term would focus on juvenile spacing treatments.

The model output was inspected to determine which analysis units receive juvenile spacing treatment. At the smallest budget level of $0.25 million/yr, the entire budget in the early years is allocated to juvenile spacing 500 ha/yr in the pine, medium, planted analysis unit (AU). Treatments in the pine, good, planted AU begin in the fourth 5-year period at this budget level.

Figure 15 illustrates the distribution of budget between the juvenile spacing-only regime, and the juvenile spacing followed by commercial thinning regime. At a budget level of $2 million the pine, medium AU is again the preferred investment area. More area is transferred into the juvenile spacing followed by commercial thinning regime than is assigned to the juvenile spacing-only treatment regime. Not shown in the graph, some area is also transferred to the pine, poor site and spruce and Douglas-fir good and medium site AUs by the 5th planning period. The large transfer in the first planning period represents allocation of existing young stands to the juvenile spacing treatment regimes.

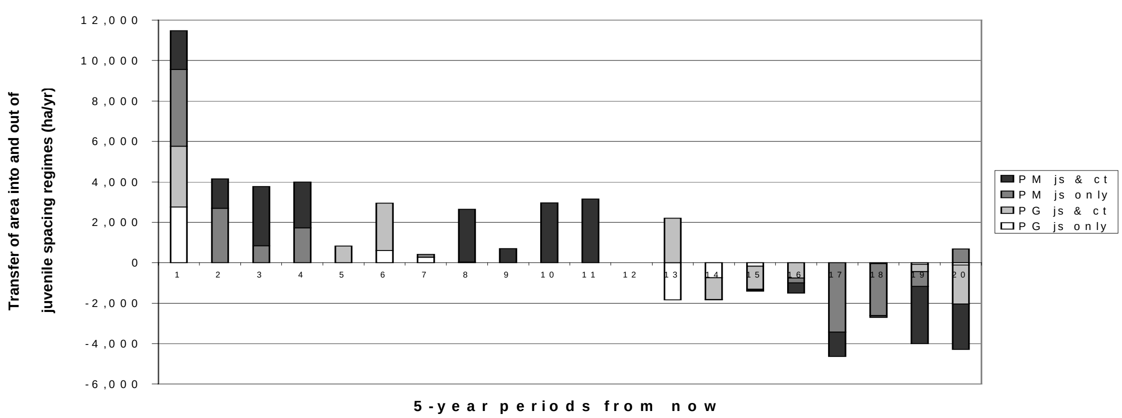

FIGURE 15. Area transferred by the model into, and later harvested from, the primary juvenile spacing regimes at a budget level of $2 million/yr. (PG = pine, good site; PM = pine, medium site; js = juvenile space; ct = commercial thin.)

In addition to increased volume production, a benefit of stand density control (spacing and thinning) is the development of larger tree diameters at an earlier age. Figures 16 and 17 illustrate the distribution of log sizes in the future harvest for different budget levels. Volume estimates for existing stands were not divided into diameter classes.

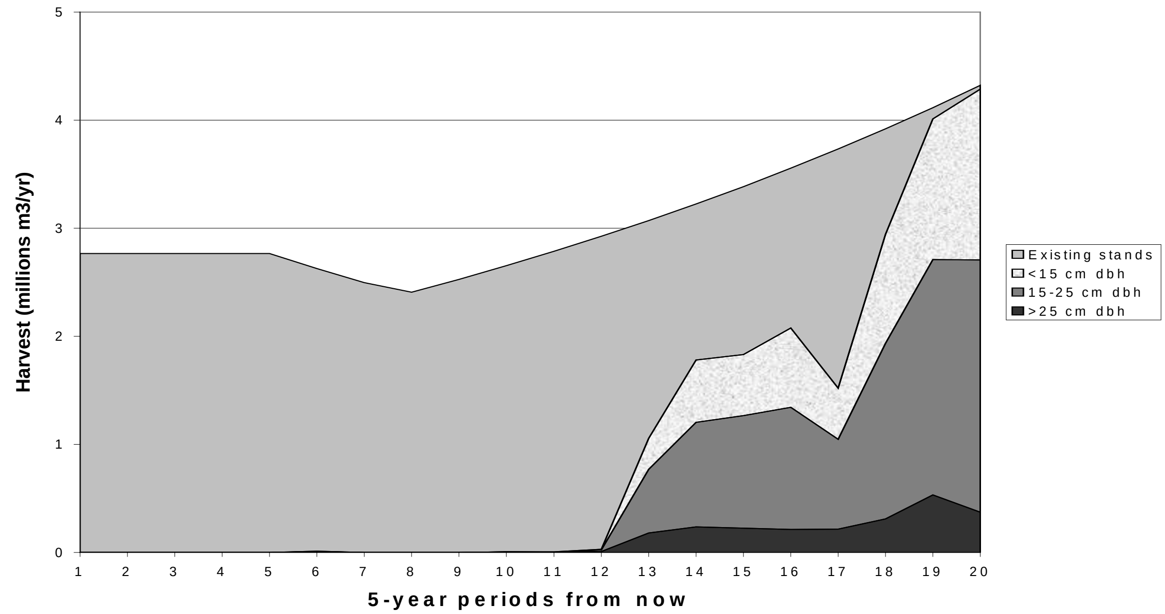

FIGURE 16. Distribution of diameter classes in the future harvest at a zero intensive silviculture budget level

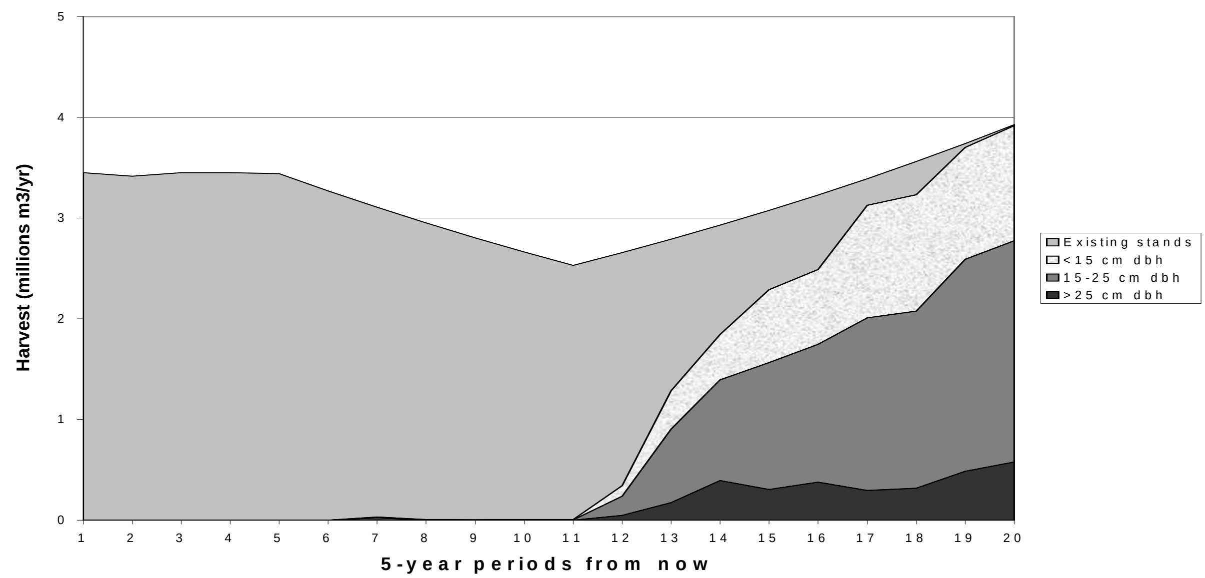

FIGURE 17. Distribution of diameter classes in the future harvest at a budget level of $2 million/yr

4.4 Fertilization

Fertilization is included as a follow-up treatment for all regimes that include pruning and/or commercial thinning. The cost of a fertilization treatment is $400, and the benefit is assumed to be a volume increase of 20 m^3/ha, which is added to the yield estimates output from TASS, 10 years after the treatment. The yield gain persists for the remaining development of the stand. Stands that are fertilized are assumed to receive a single application. Fertilization gains are included in the yield curves illustrated in Figure 12.

Because fertilization is "hard-wired" into particular regimes that include other treatments, little can be said about the advisability of fertilization per se. The allocation of budget to fertilization in the model generally reflects area being commercially thinned.

4.5 Pruning

In Figures 13 and 14, the only pruning activity—a very small amount—is in the second 5-year period, when there are an inadequate number of stands to spend the budget on other treatments. In fact that period has a budget surplus. Pruning is by far the most expensive treatment. The pruning regimes cost $2600–$2700/ha.

The model is run to maximize harvest yield over the planning horizon, subject to a limited budget. Figure 12 illustrated that the pruning regime has the highest volume production of all regimes, in the long term. However, the juvenile spacing plus commercial thinning regime is a close second, and has a total cost of $900/ha. The model allocates area to this more cost-effective treatment. The model prefers to carry a budget surplus in some periods rather than prune, because the pruning regime includes the later fertilization cost, incurred when more productive investments might be made.

Figure 18 illustrates the potential production of clear wood volume due to pruning treatments, with model priority set to maximize the clear volume component, and a budget of $2 million/yr. Some of the budget is used for other treatments, because the pruning regimes are only applicable to pine and Douglas-fir, good site analysis units. A total of 10.9 million m^3 of clear wood is produced toward the end of the planning horizon, but the total volume harvested over the planning horizon declines by 8 million m^3 relative to the volume-maximizing use of a $2 million budget.

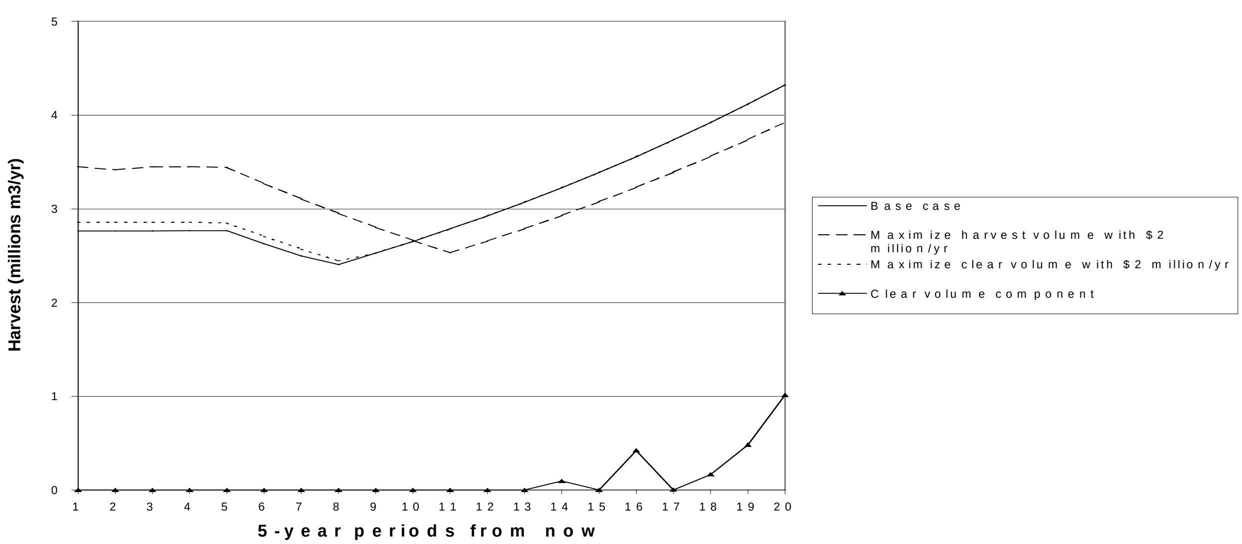

FIGURE 18. Harvest flow with priority on clear wood production versus volume maximization

4.6 Commercial thinning

Commercial thinning (CT) is included in regimes for pine and Douglas-fir, good and medium site quality analysis units. The CT regimes are summarized in Table 5.

TABLE 5. Summary of commercial thinning regimes

Analysis unit	Juvenile space	CT age (yr)	CT volume (m^3/ha)
Pine, good	yes	40	43
Pine, good	no	60	94
Pine, medium	yes	50	41
Pine, medium	no	70	89
Fir, good	yes	50	59
Fir, medium	yes	60	53

Commercial thinning is assumed to pay its own way, and does not have a direct cost as an intensive silviculture treatment. However, all CT activities are followed by one fertilization treatment, which costs $400/ha; therefore, to undertake CT the model must use a portion of the available budget.

Figure 19 illustrates expected harvest levels for alternative budget levels when CT yields are added to the clearcut harvested yields shown in Figure 10. The model objective is set to maximize the combination of clearcut harvested plus CT yields. With a budget of $2 million/yr, total CT yields over the planning horizon are 18.7 million m^3. The CT yield, coming mainly in the latter half of the planning horizon, raises long-term harvest levels toward the base case long-term level, and thereby facilitates the accelerated short-term level.

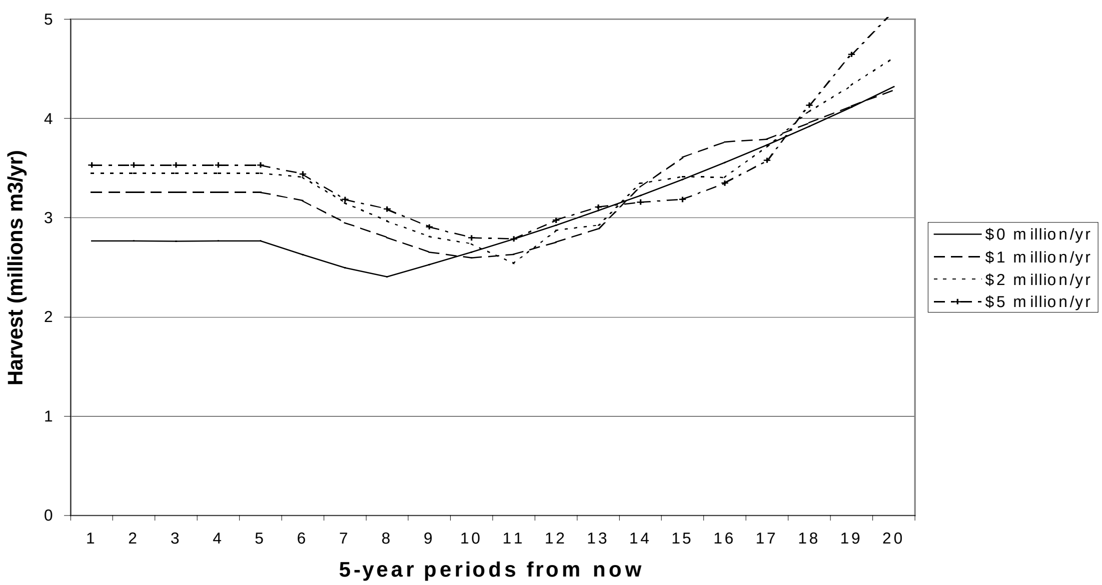

FIGURE 19. Harvest flows with the addition of commercial thinning yields.

Further details about basic model results are available in digital format on the data CD. The silviculture forester in the VFD has been provided a copy of the Woodstock model used for the analysis, and a tutorial in its use.

5 Scenarios

In addition to the basic analysis, several scenarios of interest to the district silviculture program were inspected. The scenarios include the impact to timber supply of reducing the current planting program to save budget expense; the impact of using genetically selected trees, which grow faster than natural stock; and the consequences of an impending lodgepole pine bark beetle infestation which is approaching the district from the south.

5.1 Natural regeneration

In the VFD 90% of harvested areas are regenerated by planting. The planting activity is expensive, but it ensures prompt reforestation, and facilitates use of genetically improved stock, where available. However, if natural regeneration were feasible, it would save considerable budget expense that might be used for other activities.

A scenario was developed to investigate the benefits of the planting activity. With rougher harvesting practices (site disturbance to expose mineral soil, and to crack cones open), it might be possible to stimulate natural regeneration, although stocking would be patchy and require some time to fill in. The assumed impact across the THLB would be an average ten-year regeneration delay. Figure 20 illustrates the impact at the forest level of this potential change in management practices.

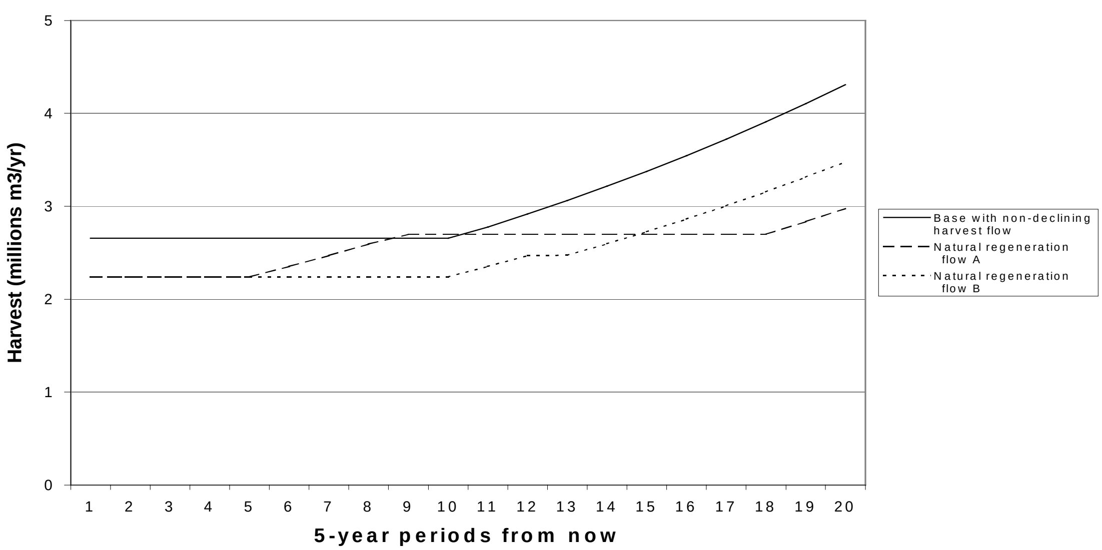

FIGURE 20. Alternative non-declining harvest flows with natural regeneration.

With non-declining harvest flows, the short-term impact is a 15% drop in harvest levels relative to non-declining harvest flows with the present planting program. The long-term impact is a drop on the order of 20% or more.. The availability for harvest of regenerating stands is delayed ten years, so volumes harvested from existing stands must drawn out for 10 years longer than in the base case.

Interestingly, using the base case harvest flow constraints, the LP model, which is seeking to maximize harvest volume over the planning horizon, actually raised short-term harvest levels above the base case level for this scenario (Flow C in Figure 21). The higher short-term harvest is then followed by a prolonged decline in harvest rates, to a low point in period 13. Harvest flows A and B in Figure 20 represent a 20% reduction in total harvested volume over the planning horizon, relative to the base case. Harvest flow C in Figure 21 makes an 11.6% reduction in total harvested volume over the planning horizon.

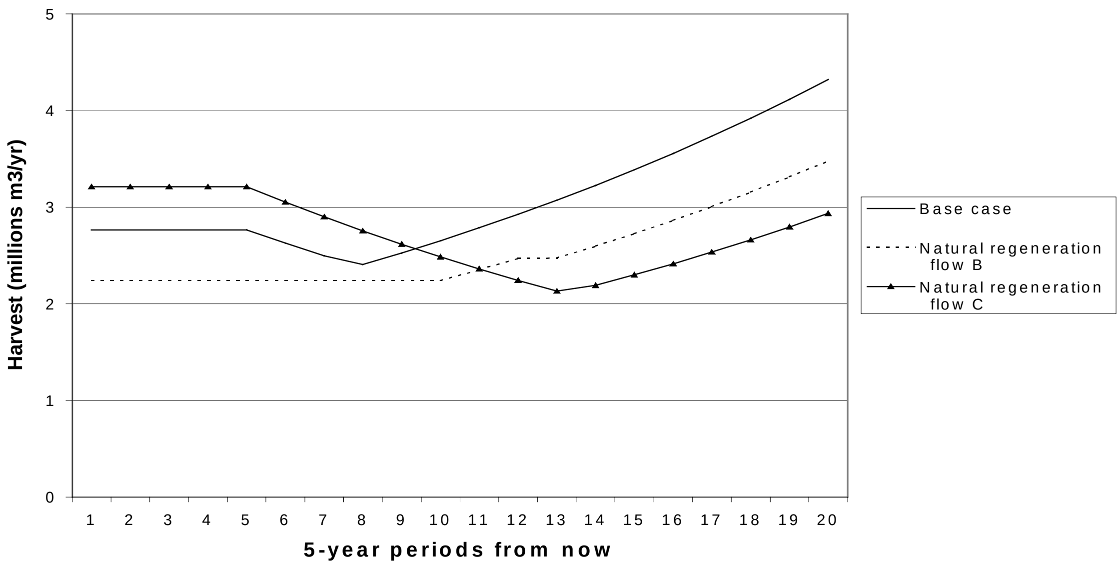

FIGURE 21. Natural regeneration solution illustrating optimal solution (flow C) for maximizing volume production over the planning horizon

5.2 Genetic gain

Genetically selected seed suitable for planting in the VFD is now being produced in moderate quantities, and the supply is expected to be adequate for the complete planting program within 5–10 years. Current estimates for growth rate increases are 15% for lodgepole pine stands and 10% for spruce stands in the VFD area. These estimates are based on trials of the performance of trees from the Willow-Bowron, Vernon and Bulkley Valley seed orchards. Height increments are measured at 6, 10 and 15 years of age, and compared with the development of managed stands from wild seed. First-generation orchards are producing seed from 40–60 selected parents.

The assumptions of a 15% volume increase for regenerated lodgepole pine stands, and 10% volume increase for regenerated spruce stands, is applied to all regimes. Thus the benefits of the juvenile spacing treatments are also magnified by that percentage. The cost of using genetically selected seed is small ($35/ha) compared with any other silvicultural treatment ($500–$1200/ha). In the base case, approximately 8 600 ha are harvested and regenerated annually, so the cost of genetically improved seed to plant 100% of the district would be $300 000/yr, less the cost of wild seed.

Harvest flows under the genetic improvement scenario are compared with the zero-budget base case in Figure 22. The magnitude of the gains are scalable to other budget responses reported earlier in the Results section.

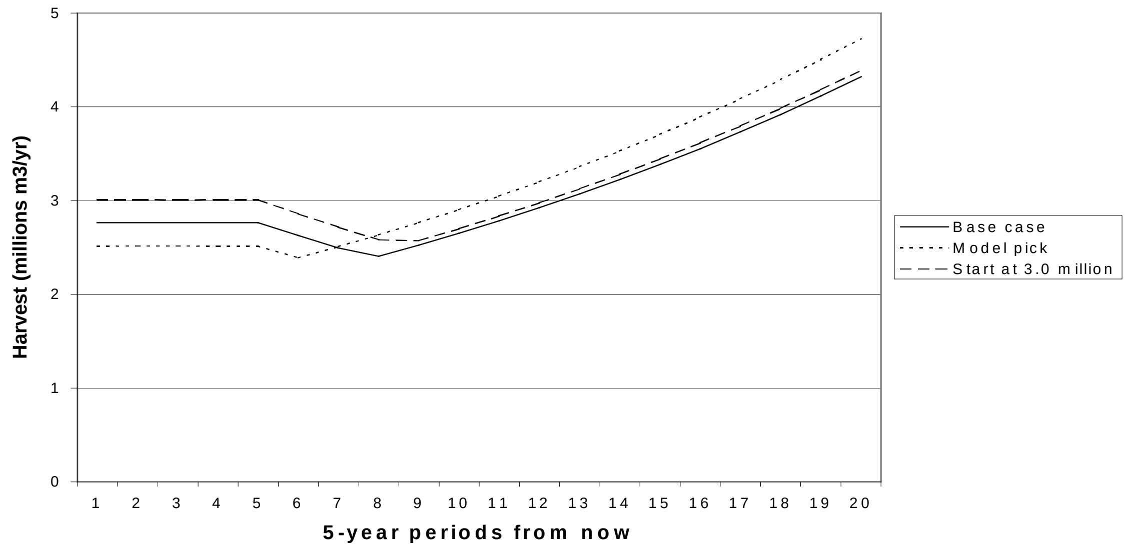

FIGURE 22. Alternative harvest flows with genetic gain assumptions.

With base case harvest flows, the LP model reduces the short-term harvest level by 250 000 m³/yr, and the total harvest over the planning horizon rises by 4.2%. An alternative harvest flow, starting at 3.0 million m³/yr, captures the expected gain early in the planning horizon. This alternative flow is slightly sub-optimal, resulting in a 3.8% gain in total harvested volume over the planning horizon.

5.3 Bark beetles

There is presently a serious outbreak of mountain pine beetle (*dendroctonus ponderosae*) moving into the southern portions of the VFD. Over 80% of the commercial forest in the VFD consists of leading lodgepole pine stands, and there is concern that without a large and immediate control program, the forestry economic base of the district could be damaged. The present outbreak is attacking all ages of pine stands; stands as young as 40 years are being seriously damaged.

Present methods of controlling the beetle include pheromone trapping, sanitation fell and burn, and cutting and removal of infested timber. There are enormous quantities of dead, salvageable timber left as the infestation proceeds, which must be cut within one season to reduce economic losses due to stain and checking.

This scenario inspects the consequences for timber supplies in the VFD if the mountain pine beetle infestation continues to spread. The assumption is that salvage of beetle-killed timber will necessitate a short-term increase in district harvest rates, and that operations will move from a dispersed pattern into a focussed salvage in the southern portion of the district. Forest cover requirements for the IRM zone are relaxed to require a maximum 33% less than green-up age (compared with 25% less than green-up in the base case), and the short-term harvest rate is set to 5.0 million m³/yr.

Figure 23 illustrates the impact of different budget levels on ameliorating the mid-term impact of a short-term accelerated harvest. After 15 years at 5.0 million m³/yr, the harvest is permitted to adjust to a lower sustainable level, after which changes in harvest rate are limited to 5% per 5-year period.

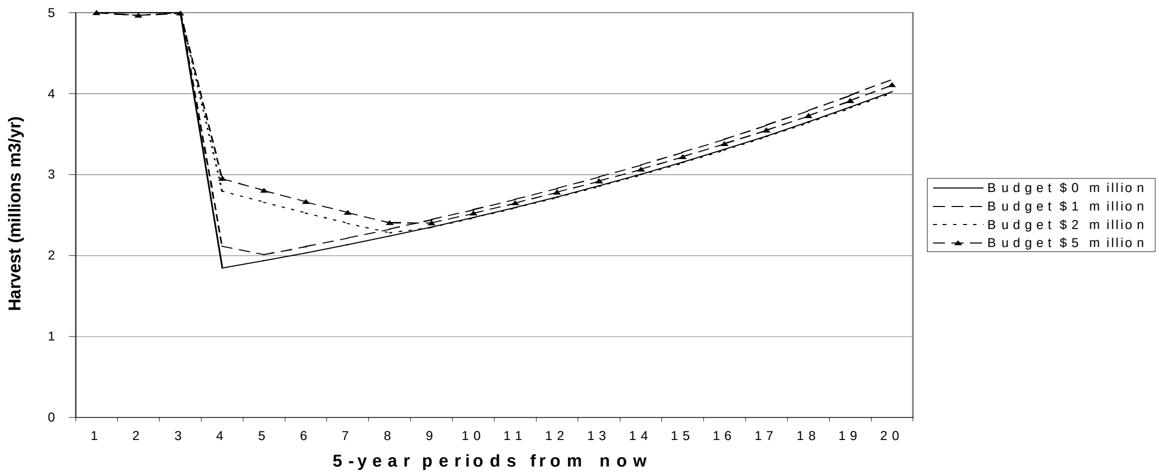

FIGURE 23. Budget impact on harvest level recovery after beetle salvage.

In Figure 23 there is a significant difference in future harvest sustainability between the $1 and $2 million budget levels. Those budget levels are applied from the first period in the planning horizon. Budgets are allocated by the model to juvenile spacing treatments, which bring second-growth stands online sooner, an especially important consideration following the accelerated beetle salvage harvests.

An alternative statement of the recovery option is to set a future harvest rate that would be achievable under the base case, and study the ability of the silviculture budget to fill a potential supply shortfall that may be caused by the accelerated harvesting to control the mountain pine beetle. In Figure 24, the same short-term harvest of 5 million m³/yr for 15 years is followed by a flat line harvest level for 40 years, which is followed by another flat line set to 3.2 million m³/yr for the remainder of the planning horizon.

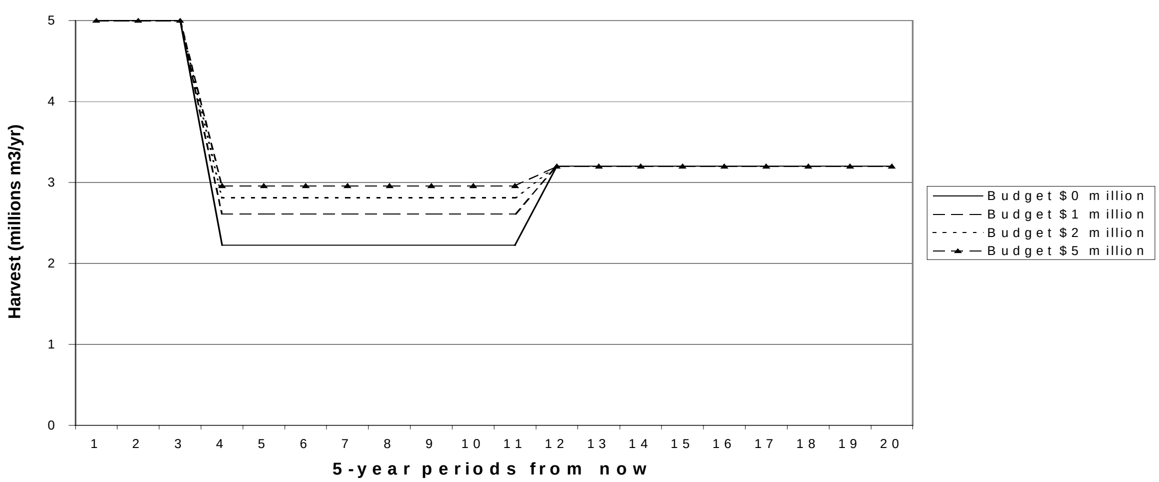

FIGURE 24. Using intensive silviculture to fill the mid-term dip in harvest levels caused by an accelerated short-term harvest rate

More model runs were made for this scenario, and the other (genetic gain and natural regeneration) scenarios than are reported here. The model variants and more detailed output reports for each scenario are contained on the data CD, and have been reviewed with the silviculture officer in the VFD.

6 Recommendations

This analysis of intensive silviculture opportunities in the Vanderhoof Forest District finds that a budget level of at least $1.6 million/yr could be well-spent in enhancing present and future harvest rates. Higher budget levels, up to $2.8 million/yr, will provide marginal additional benefits, and budgets higher than $2.8 million/yr do not significantly benefit the harvest rate.

The budget would be best spent on juvenile spacing young stands in the short-term. This will prepare the stands for later commercial thinning, and establish improved patterns of growth. The recommended budget levels are adequate to juvenile space 800–1400 ha/yr. The spacing treatments would focus on medium site quality pine stands, with second priority on good site pine.

While fertilization is an attractive treatment for increasing volume yields, with a limited intensive silviculture budget fertilization should be postponed until later planning periods. There is presently a large stock of mature timber in the VFD, and the incremental growth response to fertilization is not required at this time. It is currently more important to establish growth pattern, by juvenile spacing in young stands. These stands will then be in better condition for a subsequent commercial thinning, and fertilization treatment.

Pruning is not a recommended treatment to achieve increased volume yields. Spending budget on pruning treatments depresses future yields, by reducing the amount of other types of intensive silviculture within a limited budget.

Using the cost and yield information provided as inputs to the analysis, the recommended budget level would enable an increase of 6% relative to current harvest levels across the entire planning horizon. Depending on harvest flow requirements, short-term harvest levels could increase by two to three times that amount.

This project has resulted in a working model of intensive silviculture opportunities in the VFD. The model may be used in an ongoing basis, to further refine results as specific questions arise, and to test new scenarios.

The project has demonstrated some benefits of assessing intensive silviculture opportunities at the forest estate level. Remote conditions influence local stand treatment decisions. For example, although commercial thinning and fertilization are attractive activities from a yield perspective, they are not advised at the present time because the whole forest estate will achieve greater benefit if the investment is instead placed in juvenile spacing activities. Pruning regimes, with the highest stand yields in Figure 12, were found to be the least desirable because of high treatment costs.

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