Lakes TSA – Type 4 Silviculture Strategy

Modelling and Analysis Report

Version 1.1

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Project 419-24

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1 Introduction

The purpose of this Type 4 Silviculture Strategy is to clarify the status quo management approach in light of the devastating timber supply impacts from the Mountain Pine Beetle (MPB) infestation and provide direction that might improve future outcomes. Ultimately, the project will provide – through a tactical plan – general direction for investing in silviculture-related activities that address challenges for the Lakes TSA.

Underlying assumptions to this analysis are documented in the project's Data Package[1]. It identifies key assumptions as sources of significant uncertainty (e.g., shelf-life, current live/dead volumes, managed stand site productivity, MPB impacts in young stands).

1.1 Context

This document is the third of four documents that make up a Type 4 Silviculture Strategy:

- Situational Analysis – describes in general terms the situation for the unit – this could be in the form of a PowerPoint presentation with associated notes or a compendium document.
- Data Package - describes the information that is material to the analysis including the model used, data inputs and assumptions.
- **Modelling and Analysis Report** – describes modelling outputs.
- Silviculture Strategy –provides a rationale for choosing a preferred scenario and describes treatment options, associated targets, timeframes and benefits.

2 Base Case

The results presented in this section describe outcomes for three broad areas: 1) timber quantity or harvest forecast, 2) timber quality or product profile, and 3) non timber value outcomes.

2.1 Timber Quantity

The following sections discuss characteristics on the amount of timber associated with the Base Case harvest forecast for the Lakes Type 4 Silviculture Strategy (LT4).

2.1.1 Harvest Forecast

Key modelling assumptions for the LT4 Base Case harvest forecast included:

- Focus on salvaging dead pine stands until the shelf-life for the degrading pine is exhausted,
- Maximize the mid-term harvest level, and
- Set a maximum target of 350,000 m^3/yr for non-pine species for the first decade.

[1] Forsite Consultants Ltd. (2013). Lakes TSA - Type IV Silviculture Strategy, Data Package. Technical Report.

Figure 1 shows the LT4 Base Case harvest forecast (excluding non-recoverable losses) resulting from the data, assumptions and modelling approaches documented in the Data Package. The initial harvest level maintains nearly current AAC of 2 M m³/yr for just 5 years[2], drops sharply to 954,000 m³/yr for another 5 years and then drops again to a mid-term harvest level of 574,000 m³/yr. The harvest remains at this level for 20 years then begins to climb to a long-term harvest level between the 4th and 9th decades. A long-term harvest level of approximately 1,482,000 m³/yr is achieved 90 years from 2011.

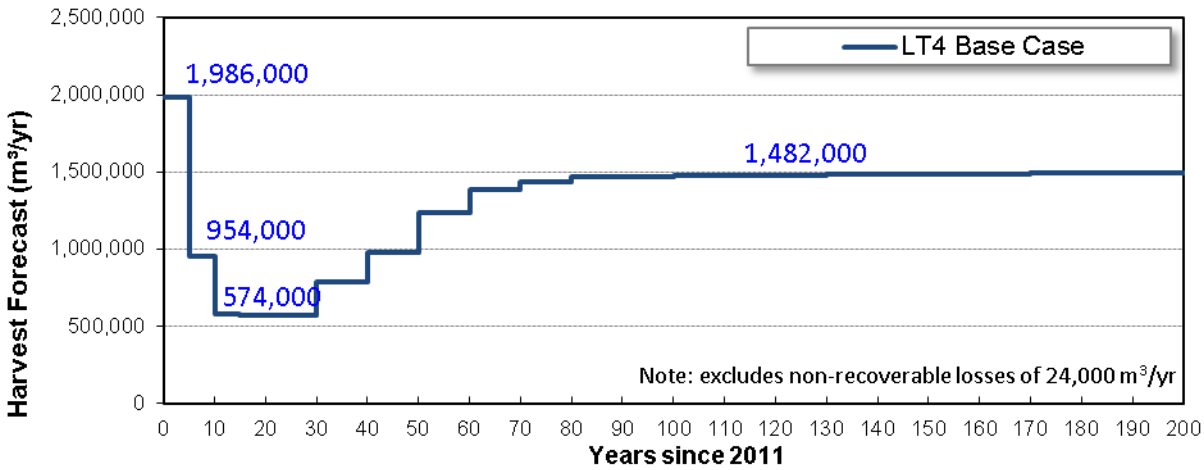


Figure 1 Harvest forecast (LT4 Base Case)

Over the first 10 years a maximum harvest volume of 350,000 m³/yr for non-pine species is in place (1.75 M m³ for each 5-year period). Figure 2 shows the model violated this target (shaded blue) slightly. Using the current AAC of 2 M m³/yr, the non-pine partition represents 17.5% of annual harvest. The achieved non-pine proportions in the base case were 22% for the first 5 years and 68% for the second 5 years). It is not possible to maintain the desired proportion of non-pine harvest once the falldown begins.

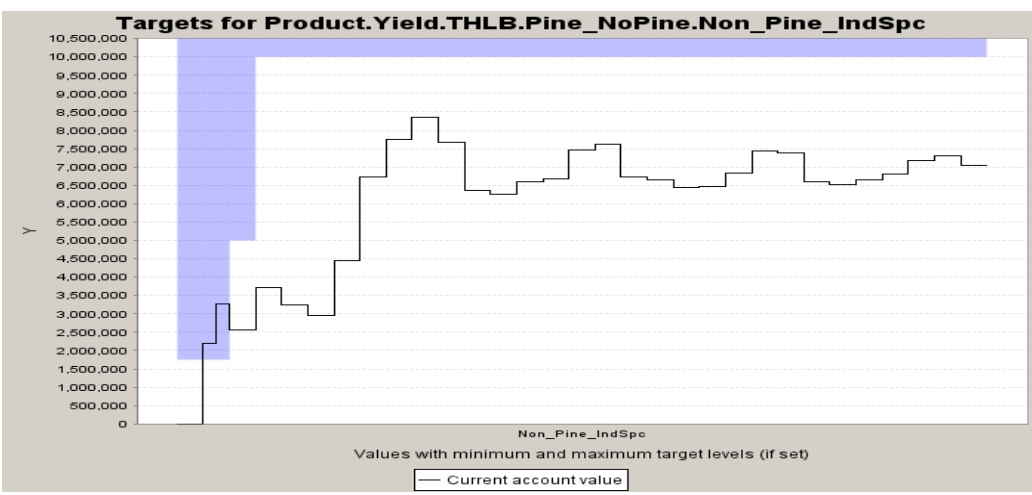


Figure 2 Target for maximum non-pine (individual species) harvest of 350,000 m3/yr in first decade

[2] Patchworks schedules harvest for each individual year but applies targets and summarizes results for each period (i.e., 5 years).

2.1.2 Harvest Forecast Details

Figure 3 shows the harvest forecast themed by individual species and condition but does not include volumes for deciduous species. Within the first 5-year period (2011-2015), 79% of the harvest volume is pine (63% dead; 16% live), with spruce and balsam comprising the rest.

The harvest of non-pine species increases to 77% throughout the mid-term, reflecting a sharp decline in merchantable pine. In the long-term, a more even harvest pattern develops of 54% pine and 46% non-pine species.

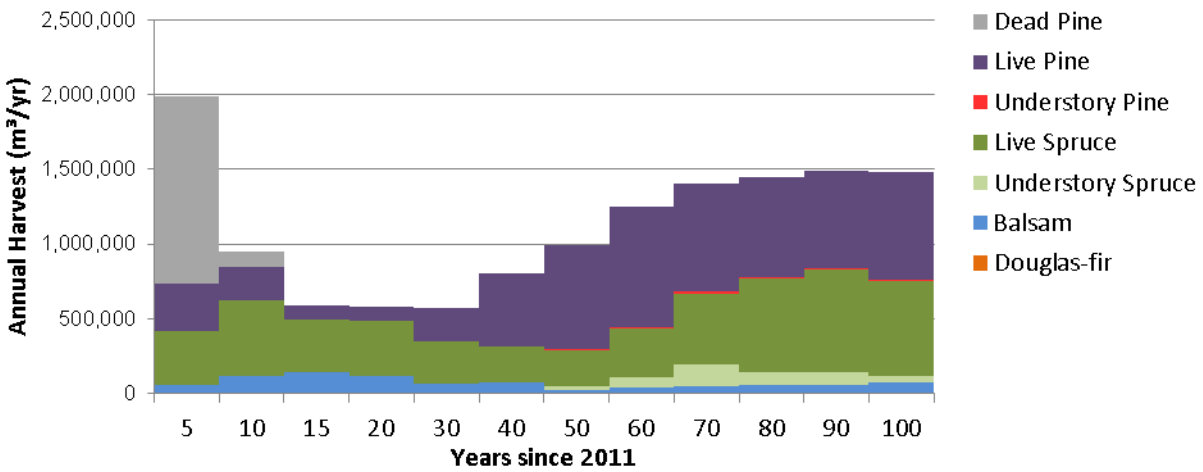


Figure 3 Harvest forecast by individual species and condition (LT4 Base Case)

The harvest contribution by natural and managed stands is shown in Figure 4. Harvesting of existing managed stands begins within the 3rd decade and by the 4th decade, the majority of the harvest comes from these stands - both future and existing. Harvesting natural stands persists over time as various constraints retain volumes longer and understory regeneration of some MPB-impacted Pl stands eventually reaches merchantable criteria.

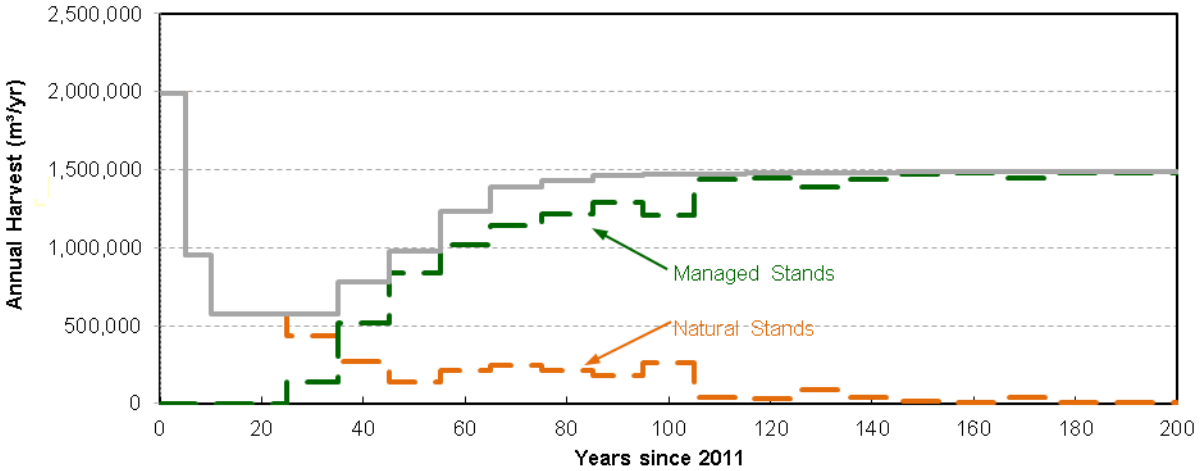


Figure 4 Harvest forecast transition of natural stands to managed stands (LT4 Base Case)

Figure 5 shows the harvest over time by region – defined according to the landscape units assigned in the Lakes North and South Sustainable Resource Management Plans (SRMP). The harvest proportion is distributed rather evenly for both regions except for the drop to and throughout the mid-term, where 74% of the harvest is scheduled from the north. In this case, harvesting economics were not considered or controlled in the model (i.e. hauling distance, product values, harvesting costs etc.).

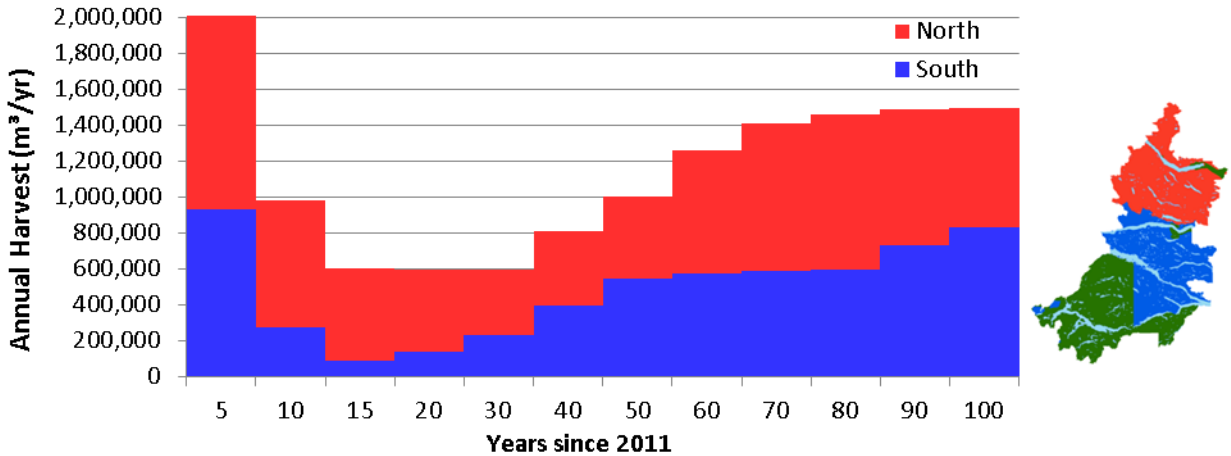


Figure 5 Harvest forecast by SRMP region (LT4 Base Case)

2.1.3 Growing Stock over Time

The total and merchantable growing stock is shown in Figure 6. The initial total growing stock is approximately 57.5 M m³ with approximately 69% (28.0 M) considered eligible for harvest in the first period (i.e., stands with merchantable volume of at least 140 m³/ha).

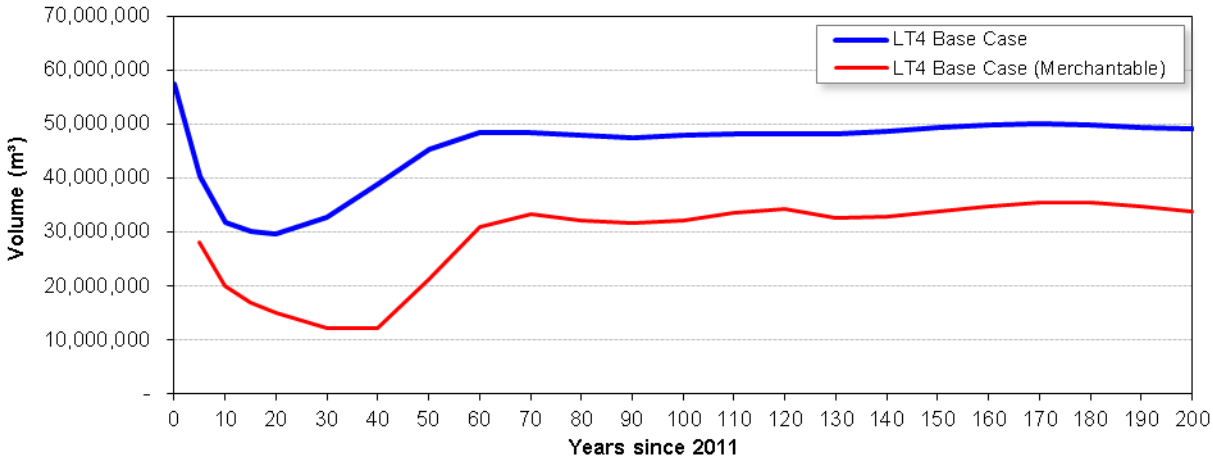
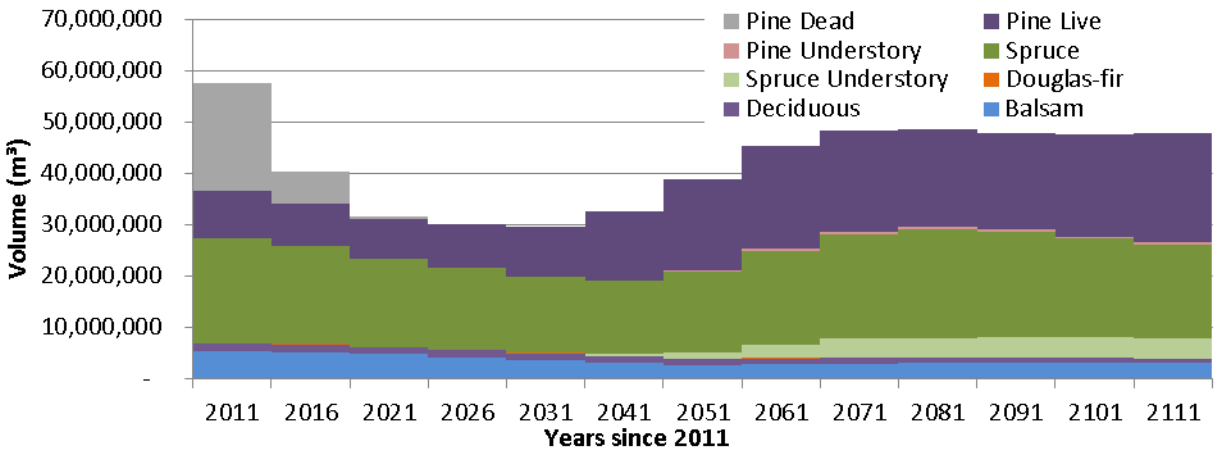


Figure 6 Volume of merchantable and total growing stock on the THLB (LT4 Base Case)

Over the first 40 years of the forecast, harvesting and mortality depletes the merchantable growing stock on the timber harvesting land base (THLB) to 12.2 M m³; the lowest level over the entire planning period. The growing stock starts to recover quickly in the 5th decade, as harvesting begins on post-MPB regenerating stands. Both the total and merchantable growing stock levels reach essentially stable levels 70 years from now.

Figure 7 shows the total growing stock themed by individual species. Initially, 21.0 M m³ (37% of total growing stock – yellow in the graph) is considered to be dead and likely merchantable. Over the first two decades of the harvest flow, virtually all of the dead pine volume is either harvested (6.8 M m³) or is assumed to deteriorate (14.2 M m³) according to the shelf-life criteria. To be eligible for harvest in the future, unsalvaged stands must first achieve minimum harvest volume criteria from the live component (mature overstory and regenerating understory).



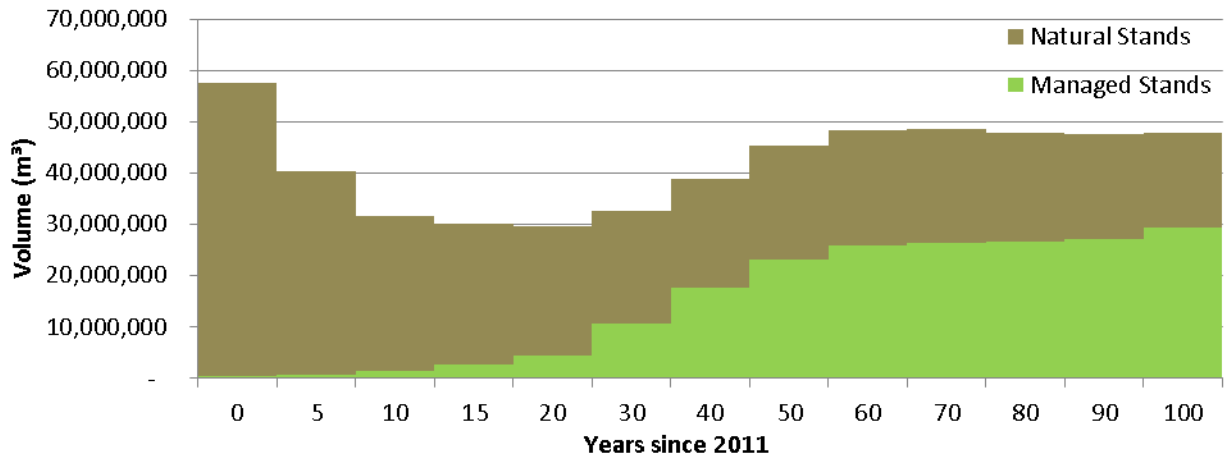
Note 1: Bars at year 0 represent the modelled inventory at 2011 while others show levels at the end of each period.

Figure 7 Volume of total growing stock on the THLB by individual species (LT4 Base Case)

Note: Bar at year 0 represents the modelled inventory at 2011 while others show levels at the end of each period.

Figure 8 shows a significant volume[3] of MPB-impacted stands remains unsalvaged throughout the entire planning horizon (i.e., Unharvested natural stands beyond the 4th decade). This live volume persists for one of two reasons (or both): adjusted stand growth assumptions for understory regeneration never recover to reach minimum harvest volumes, or the model retains these lower volume stands to satisfy forest cover constraints (e.g., visuals, wildlife habitat, and seral stage).

[3] The figure is incorrectly labled Area (ha) – it should read Volume (m³)



Note: Bar at year 0 represents the modelled inventory at 2011 while others show levels at the end of each period.

Figure 8 Volume of total growing stock on the THLB by stand type (LT4 Base Case)

2.2 Timber Quality

The following sections discuss aspects of timber quality associated with the LT4 Base Case harvest forecast.

2.2.1 Average Harvest Volume, Area and Age

The average volume, area, and age harvested over time are shown in Figure 9. As the minimum harvest age was set to the age at which stands achieve 140 m³/ha of sawlog volume, the average harvest volumes throughout the short- and mid-terms is ~190 m³/ha while the long-term volumes are ~250 m³/ha. The lowest average yield occurs during the 4th decade at the end of the mid-term as harvesting transitions to second growth (managed) stands.

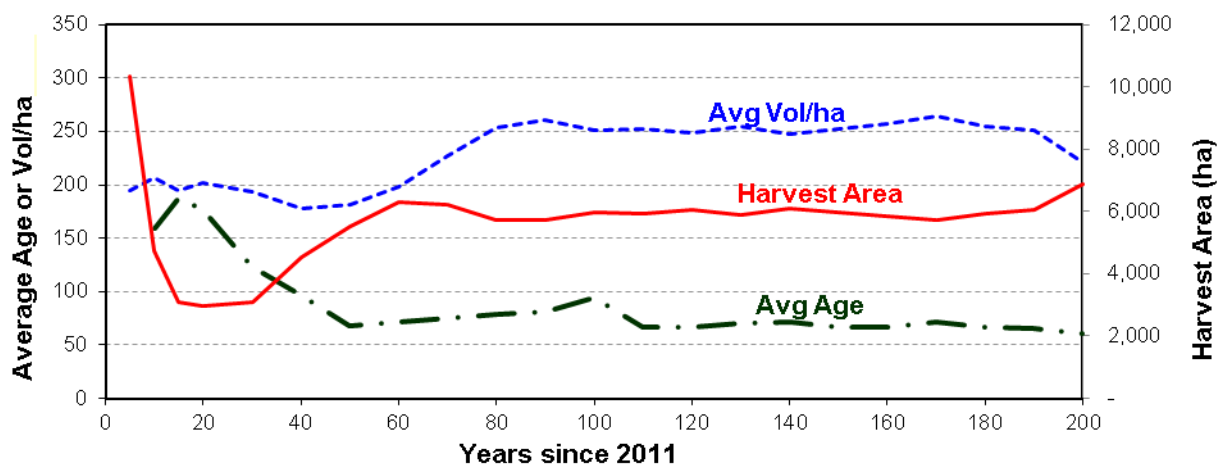
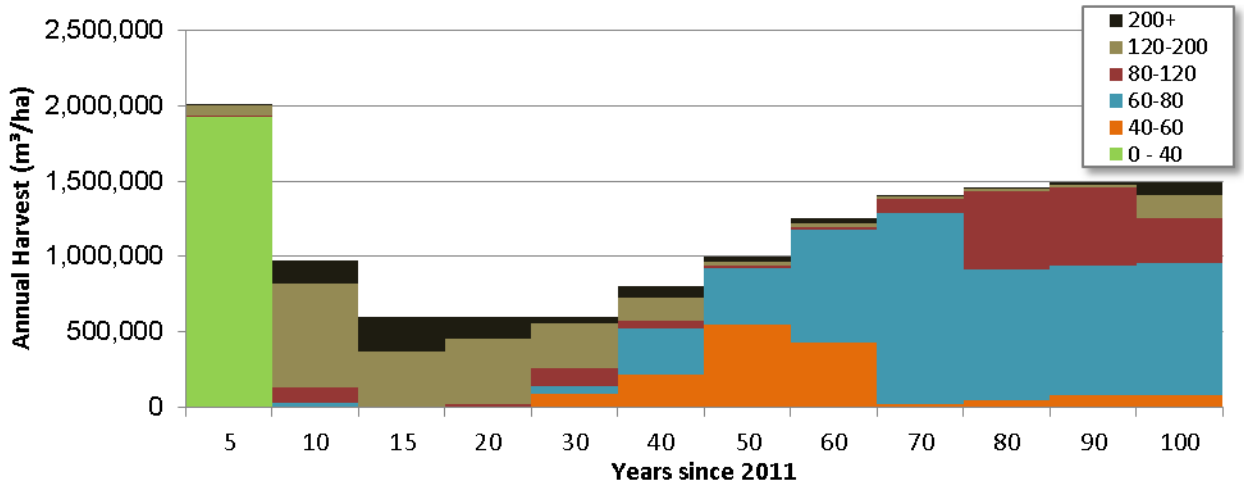


Figure 9 Average harvest volume / area / age (LT4 Base Case)

The average harvest age is artificially low at the beginning of the planning horizon as harvesting is concentrated in severely impacted stands (≥60% mortality) where ages were set to 0 at time of attack.

Average harvest age peaks 10 to 15 years from now when the harvest is largely composed of older non-pine stands. In the long-term, the average harvest age is approximately 70 years.

To provide additional insight into harvest ages, Figure 10 shows the area harvested by age range. Again, the age classes of stands harvested in first 5 years are misleading because the ages of severely impacted stands (≥60% mortality) were initially set to 0 at the assigned year of attack. In the 5th decade, over half of the harvest volume comes from stands within the 40-60 year age class but by the 6th decade, most of the harvest relies on stands within the 60-80 year age class.



Note: the volume harvested in the first term shown as 0-40 year age class represents severely impacted stands (≥60% mortality) where ages were set to 0 at time of attack.

Figure 10 Harvest volume by age class (LT4 Base Case)

2.2.2 Product Profile

Stand merchantability assumptions applied a minimum stand volume (m^3/ha) that reflected the smallest economically viable log sizes that mills are expected to require throughout the planning period. Stands become eligible for harvest in the model once they reach the age that meets this criterion.

Figure 11 shows the product profile over time derived from a report of the harvest forecast by age class and species group. Most of the short-term harvest produces dead pine sawlog/pulp logs while most of the mid-term harvest produces spruce/balsam sawlogs. In the long-term the harvest produces pine sawlogs (half) and spruce/balsam sawlogs (third). Very few higher quality logs (peelers) are produced throughout the entire planning period.

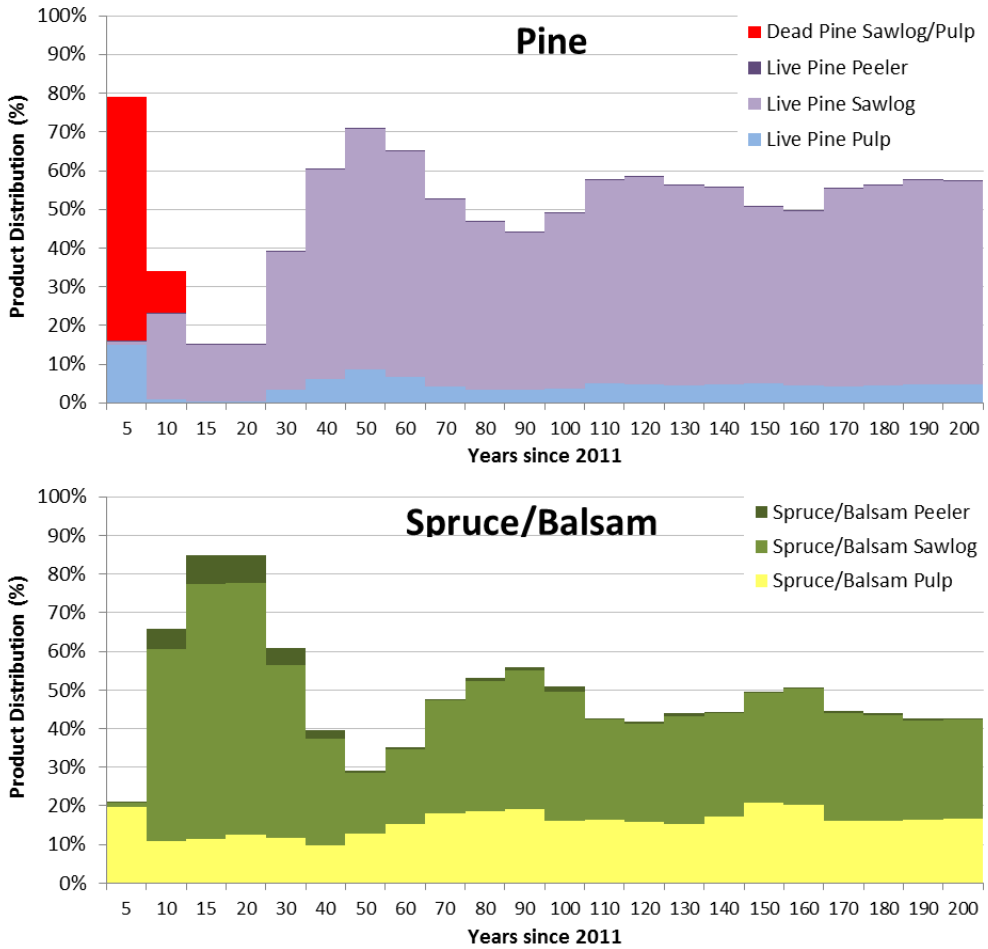


Figure 11 Product profile harvested over time (LT4 Base Case)

2.3 Non-Timber Value Outcomes

The following sections describe results of the non-timber and environmental considerations incorporated in the model. Only a few examples are provided since the full detail of these considerations is very lengthy and cumbersome to report.

A key modelling assumption was incorporated to address non-timber values, where severely impacted stands (≥60% mortality) were initially changed by setting their age to 0 at the year of death. While these revised ages are not entirely accurate, it would be inappropriate to assume that these dead pine stands provide the same ecological function as live stands. As a result, the large area impacted by MPB is now identified within the 0-10 year age class causing the initial condition of many non-timber targets to appear as significantly beyond established thresholds.

2.3.1 Age Class over Time

Figure 12 shows the age class distributions for both the THLB and NHLB at 0, 50, 100, and 200 years.

Because the ages of stands with ≥60% MPB mortality were initially set to 0 at the year of attack, a large area is currently identified in the 0-10 year age class. Fifty years into the future, however, the age

class distribution begins to concentrate within the 0-60 year age classes. By year 100, a normalized forest develops with relatively even age classes around 70 years (average harvest age).

At this time, many stands beyond the 100 year age class reflect post-MPB succession stands and assumptions for understory regeneration. Some of these stands remain throughout the planning period without being harvested again but may contribute towards addressing non-timber values.

Figure 12 Age class distribution within the THLB and NHLB at 0, 50, 100, and 200 years (LT4 Base Case)

2.3.2 Landscape Level Biodiversity

Seral stage distribution targets for the crown forested land base (CFLB) were specified for combinations of BEC, landscape unit and biodiversity emphasis option. Figure 13 shows two examples where seral stage targets and levels were applied. In the Cheslatta.ESSF.Early example (left), harvesting was limited within this unit so that by the 4th decade, it completely recovered from the MPB mortality and age adjustment. Targets for the Babine_East.ESSF.Mat_Old example (right) are never violated throughout the planning period.

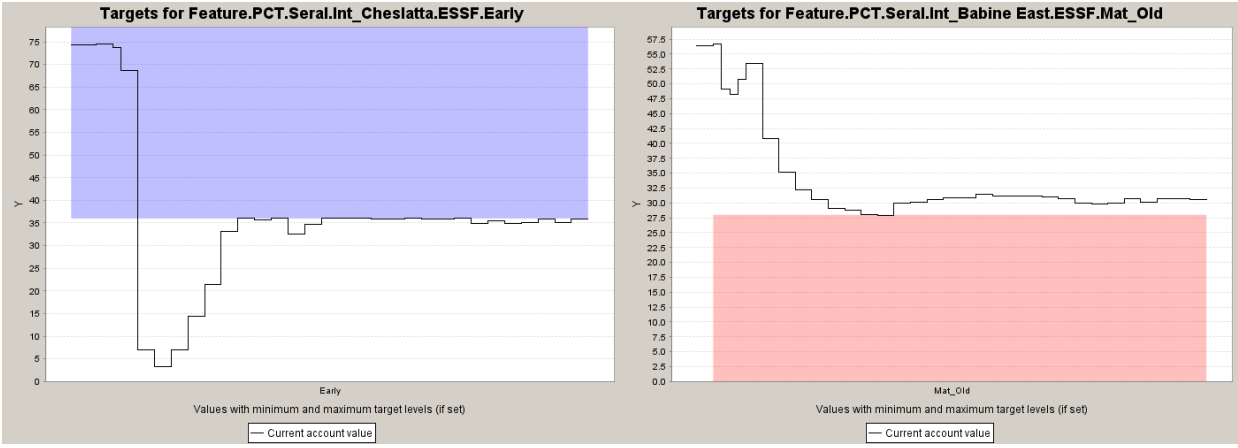


Figure 13 Examples of seral cover targets and levels (LT4 Base Case)

2.3.3 Landscape Corridors

Separate forest cover requirements were modelled for landscape corridors designated in the North and South SRMPs. Figure 14 shows examples of these landscape corridor targets and levels. For the hydro-riparian-ecosystem unit (left) harvesting was limited so that in 140 years it completely recovers from the MPB mortality and age adjustment; the SBS-all-species unit (right) recovers within 100 years.

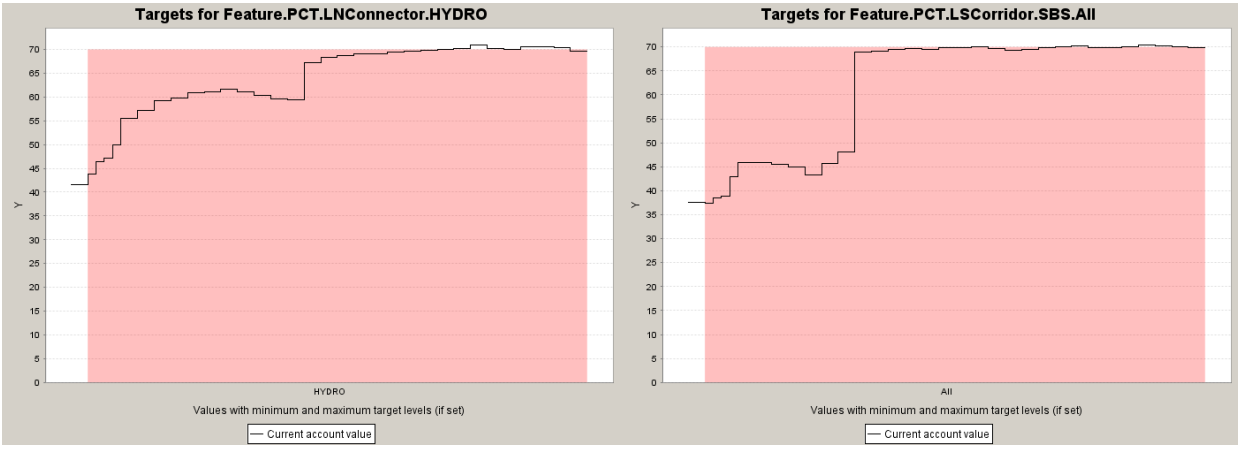


Figure 14 Examples of landscape corridor targets and levels (LT4 Base Case)

2.3.4 Visuals

This analysis used visually effective green-up (VEG) heights and a plan-to-perspective approach to model the maintenance of visual values. Figure 15 shows two examples of the visual disturbance targets and levels. In both examples, the constraints limited harvesting within these areas so that within 15 years, they substantially recovered from the MPB mortality and age adjustment.

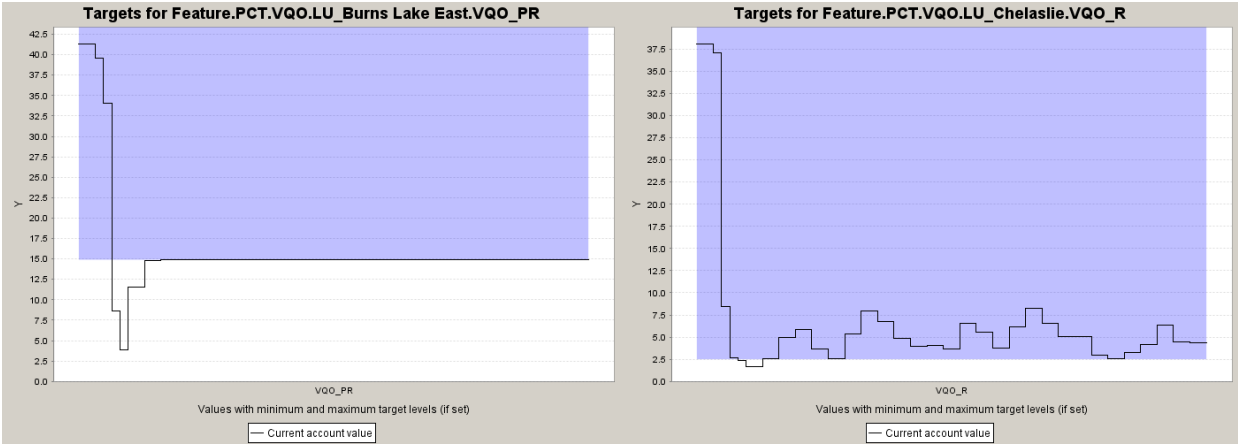


Figure 15 Examples of visual disturbance targets and levels (LT4 Base Case)

2.3.5 Wildlife Habitat

Various modelling constraints were applied to model disturbance within wildlife habitat areas designated for deer, moose, grizzly bear and caribou. Figure 16 shows six example reports for tracking targets and levels. The blue and red shades indicate maximum disturbance and minimum retention targets, respectively, tracked in percent for identified areas. As with other constraints, these require some time initially to completely recover from the MPB mortality and age adjustment. This varies for each area according to the MPB impacts experienced, size or area, stand types and analysis units, and the target level. Generally, these reports show where targets are particularly constraining and how harvest opportunities are limited in the model where levels (values) are close to the targets. Because of the weighting applied, some targets may be violated for brief periods to accommodate other modelling requirements.

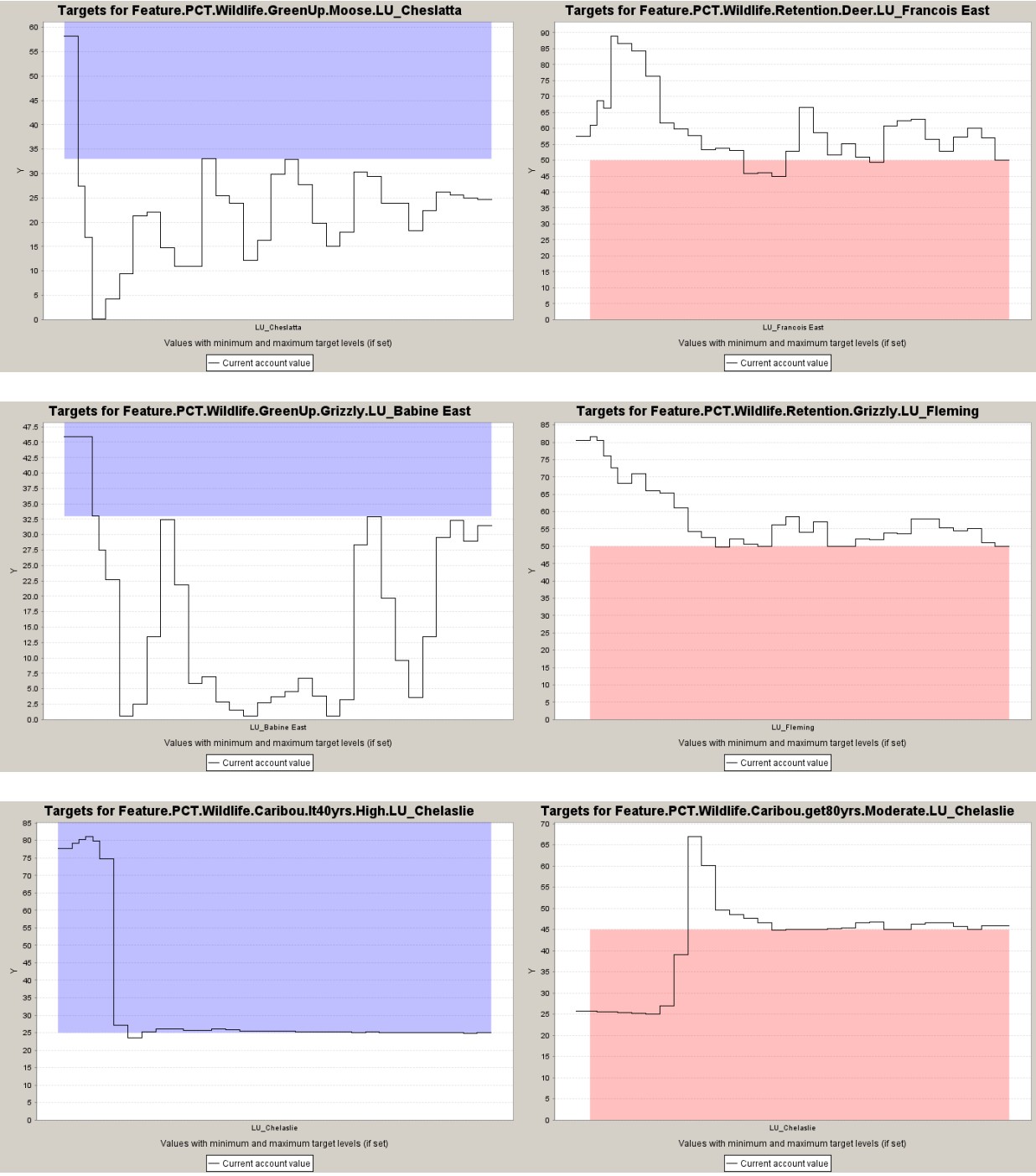


Figure 16 Examples of wildlife habitat disturbance targets and levels (LT4 Base Case)

3 Comparison to the Mid-Term Analysis

Ultimately, the LT4 Base Case is used as a benchmark to assess changes in assumptions associated with various silviculture strategies. To ensure that the LT4 Base Case is reasonable, it is often useful to compare some key outcomes against those from a previously-accepted analysis. This section discusses differences observed between the base case/reference scenarios for this LT4 Analysis and the Mid-Term Analysis[4].

Both analyses applied similar assumptions to reflect: i) existing legal and land-use decisions, ii) non-timber value constraints, and iii) a focus on harvesting pine-leading stands. The two most notable differences with the LT4 Analysis were: i) more aggressive assumptions for the dead pine shelf life and ii) significantly more complex growth and yield curves for mature stands, as they combined separate curves that reflect dead pine shelf-life, remaining live overstory and understory regeneration.

Table 1 shows that the effective THLB for the LT4 Base Case is 3.5% (17,857 ha) less than the long-term THLB used in the Mid-Term Analysis[5]. Major differences appear to involve the designation of lands not managed by the BC Forest Service (i.e., expanded area for Burns Lake Community Forest and Cheslatta Community Forest).

Table 1 Landbase – comparing LT4 Base Case and Mid-Term Analysis

Classification	LT4 Analysis (ha)	Mid-Term Analysis* (ha)	Difference (ha)
Total Area	1,121,638	1,121,609	29
Crown Forest Land Base	737,449	810,575	-73,126
Timber Harvesting Land Base	533,022	523,909	9,113
Effective Timber Harvesting Land Base	494,710	512,567	-17,857

** 2010 version*

Figure 17 compares the growing stock over time between the two analyses. The initial growing stock for this LT4 Analysis is 36% lower (32.5 M m^3) and reaches its lowest level of 29.6 M m^3 after 2 decades of harvesting and dead pine degeneration. Similarly, the Mid-Term Analysis reaches its lowest level after the 3rd decade (35.0 M m^3). By the 5th decade, the LT4 Analysis achieves a very steady growing stock of 49 M m^3 while the Mid-Term Analysis shows a more gradual increase that appears to level closer to 57 M m^3 in the 14th decade.

[4] British Columbia Ministry of Forests, Lands and Natural Resource Operations. (2012). *Mid-Term Timber Supply Project Report for the Minister and Deputy Minister Forests, Lands and Natural Resource Operations.*

[5] The Mid-Term Analysis results presented in this document and in the availale publications reflect the data compiled for 2010. More recently, the data were updated (2012) to reflect changes in tenure (not presented here).

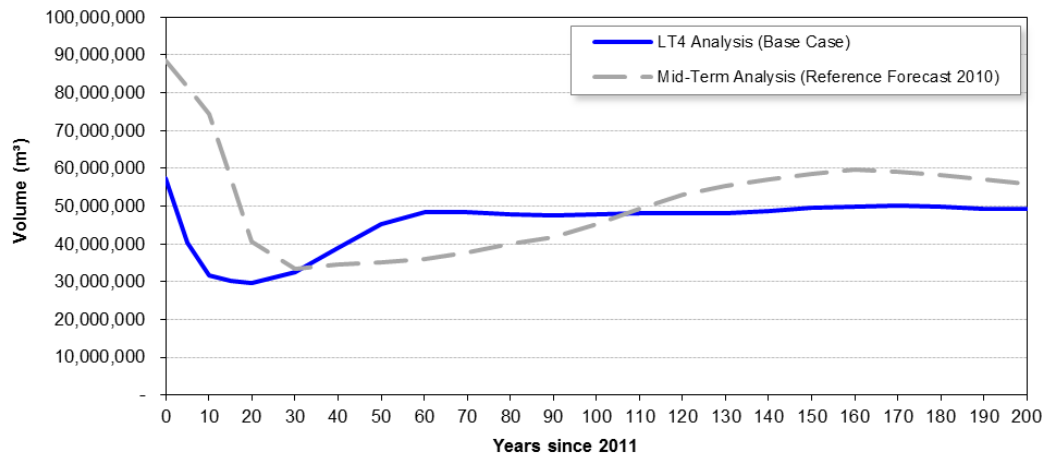


Figure 17 Growing stock – comparing LT4 Base Case and Mid-Term Analysis

The following points explain observed differences in growing stock:

- The Mid-Term Analysis assumed that dead trees remained standing and 100% of these trees were considered available for harvest until 2024, 20 years after the primary attack in 2004. For reference, the dead pine volume in the LT4 unadjusted inventory totals approximately 37.4 M m^3. Shelf-life assumptions applied in the LT4 Analysis steadily reduced the dead volume within each stand since its year of death (2004 or 2007) so that by 2011, volumes for many stands were reduced to only 52% of the dead volume (Figure 18). This explains the significant difference in short-term growing stock and the more rapid decline to the lowest level in growing stock.

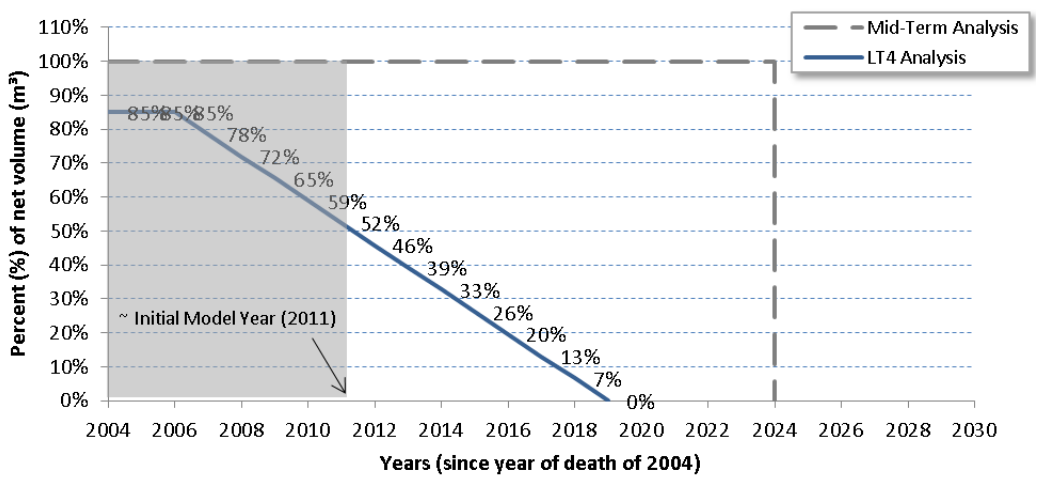


Figure 18 Shelf-life assumptions – comparing LT4 Base Case and Mid-Term Analysis

- The 2010 inventory used in the Mid-Term Analysis included a VRI Phase II ground sample adjustment that increased the VDYP7 volume by about 10% overall. Due to the uncertainty with how the MPB impacts have affected the samples, no volume adjustment was applied to the inventory used in the LT4 Analysis. This contributes to the difference in starting volumes and the rapid decline to the lowest level.

- In both analyses, estimates of MPB mortality were based on forest inventory projections from the BCMPB Model. The 2009 inventory used in the Mid-Term Analysis incorporated slightly higher levels of MPB mortality (BCMPB v.5: 80% in 2011) compared to the LT4 levels (BCMPB v.8: 76% in 2011). This slight adjustment is counter to the difference observed in growing stock (Figure 17).
- Year 0 is 2009 in the Mid-Term Analysis and 2011 in the LT4 Analysis. The 2 years of disturbance from harvesting and fire – offset somewhat by 2 years of growth from existing stands – contributes to the difference in starting volumes.
- The effective THLB is slightly larger in the Mid-Term Analysis (by 17,857 ha), which contributes to the difference in both starting and long-term volumes.
- In the Mid-Term Analysis, site productivity for managed stands was based on inventory site index while the LT4 Analysis applied provincial SIBEC estimates derived from the available PEM data. While a specific comparison between analyses was not done, the LT4 Analysis calculated area-weighted site indices for natural and managed stands as 14.5m and 17.8m, respectively. Assuming these cohorts are similar, applying the SIBEC estimates increased the average site index by 3.3m which, along with other regeneration assumptions, contributes to the growing stock differences after the 4th decade.

Figure 19 shows the LT4 Base Case harvest forecast compared with the reference forecast from the Mid-Term Analysis. Clearly, differences are observed in the short-term (0-10 years), mid-term (11-30 years), transition period (31-90 years) and the long-term (>91 years) – increasing shades of green.

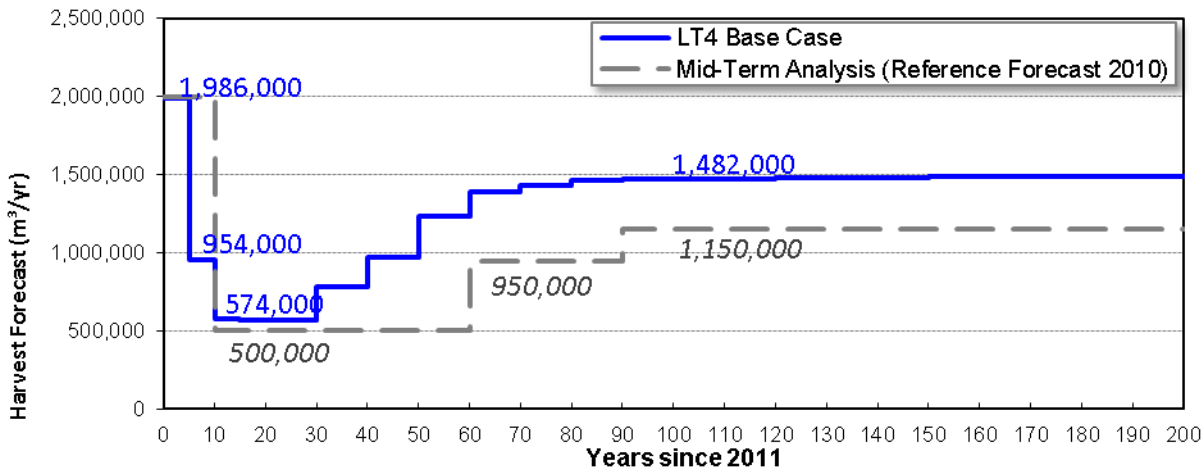


Figure 19 Harvest forecast – comparing LT4 Base Case and Mid-Term Analysis

The following discussion explains observed differences in harvest forecasts:

Difference over the short-term (first 10 years)

Over the first decade, the Mid-Term Analysis harvest forecast is higher, on average, by 530,000 m^3/yr. Because the initial growing stock used in the LT4 Analysis is significantly lower (Figure 17), it cannot maintain the current AAC (2 M m^3/yr) for 10 years. Moreover, the limited available volume in the

first period accentuates the highly constraining requirement for 350,000 m^3/yr non-pine over the first 10 years.

The difference in harvest forecast over the short-term is primarily related to differences in how MPB mortality and shelf-life assumptions were applied. While the Mid-Term Analysis assumed all dead material is available until 2019, the LT4 forecast focused on harvesting mostly sawlog material considered economically viable given the existing mill requirements. This seemed more appropriate since there are currently very few opportunities to process biomass volumes harvested from the Lakes TSA.

Difference over the mid-term (years 11 to 30)

In the LT4 Analysis, the higher harvest level (by 75,000 m^3/yr) over the two-decade mid-term is attributable to two factors: 1) the highly-constraining non-pine requirement held more green wood from being harvested in the short-term, making it available in the mid-term; and 2) higher site productivity assumptions applied to managed stands produced relatively more volume at the end of the mid-term and throughout the transition period. This allowed more volume to be spread out over the mid-term.

Difference over the transition period (years 31 to 90)

The rise from the mid-term reflects the harvesting transition from natural stands to managed stands. In most cases, the rise begins immediately following the period when merchantable stand availability is at its lowest level (4th decade in the LT4 Analysis – Figure 6).

Throughout the transition period, recently-regenerated stands (today) start becoming available for harvest so current treatments that improve growth can have a direct and positive impact on harvest levels.

Between the 4th and 9th decade, the LT4 harvest levels are higher on average, by 488,000 m^3/yr. This stark difference reflects higher volumes that become available sooner with the LT4 Analysis (Figure 17). This suggests that the LT4 Analysis used site productivity assumptions, and possibly some regeneration assumptions, that generate considerably more productive stands than those applied in the Mid-Term Analysis.

Difference over the long-term (years 91+)

The difference observed during the transition period is carried into the long-term (beyond the 9th decade) as LT4 harvest levels are higher on average, by 334,000 m^3/yr. This increase occurs in spite of a bubble of natural stands that are never harvested throughout the forecast (Note: Bar at year 0 represents the modelled inventory at 2011 while others show levels at the end of each period.

Figure 8). Again, this is attributed to the site productivity assumptions applied to managed stands.

For the LT4 Analysis, these assumptions support a long-term average mean annual increment of 3.00 m^3/ha/yr (compared to 2.24 m^3/ha/yr for the Mid-Term Analysis). Using the same operability criteria, these faster-growing stands achieve minimum harvest age sooner and take less time to cycle through each rotation. In the long-term, the LT4 Analysis can support a higher harvest level with less (at times) growing stock because its managed stands are available to harvest again much sooner.

3.1 Discussion

The LT4 Base Case applies the most current information available for forest tenures, inventories, MPB impacts, and managed stand site index estimates for the Lakes TSA. Compared to recently published forecasts, these updates, including a revised approach for addressing dead pine degeneration (shelf-life), result in a significantly lower initial growing stock. In turn, this produces a much faster drop from the current AAC but a more optimistic (higher and shorter) mid-term harvest level. Still, the impending mid-term trough persists for two decades.

The actual harvest from the Lakes TSA over the past 10 years (2003 to 2012) has averaged 1.358 M m^3/yr and only 214,575 m^3/yr was harvested over the last two years since the current AAC was set (2.0 M m^3/yr). Setting the initial harvest rate for the LT4 Base Case to the current AAC likely overestimates the actual harvest throughout the short-term. Thus, the LT4 Base Case likely underestimates the harvest potential throughout the mid-term. Ultimately, the harvest forecast for the harvest sequence sensitivity (Figure 20) may be more appropriate.

Shelf-life assumptions play a significant role in determining the timing and level for the mid-term harvest period. In this analysis, dead pine volumes steadily diminish to 0%, 15 years after the year of death assigned to the stand (grouped as either 2004 or 2007). This assumption is based on suggestions that much of the volume killed early in the infestation has already degraded too much to be economically viable to process.

The harvest forecast relies on salvaging significantly dead stands and where possible, deferring stands with higher proportions of green timber to harvest in the mid-term. The prompt salvaging and regenerating of dead pine stands also enables these stands to be harvested again throughout transition period and into the long-term.

As with most harvest forecasts, a key period occurs in 40 years when the availability of merchantable volume is at its lowest point (Figure 6) and harvesting shifts significantly from natural to managed stands (Figure 4). Ultimately, this period affects the level and duration of the mid-term harvest period.

In the model, MPB-impacted stands were set to age 0 at the year of death (at ≥60% attack). While up to 60% of these stands may still contribute to non-timber values for some time, this assumption makes several constraints appear to be immediately violated. Accordingly, harvesting activities within identified stands are deferred until the target levels are achieved.

Over 16 M m^3 (100,000 ha) of MPB-impacted stands within the THLB remain unsalvaged throughout the entire planning horizon (Figure 8). The growth and yield assumptions applied in this analysis effectively removed 20% of the THLB since these stands are either reserved to address non-timber values or they not expected to achieve the minimum harvest criteria of 140 m^3/ha. Rehabilitating available stands would increase harvest levels: a) over the long-term by increasing site productivity managed stands, and b) throughout the mid-term through incidental harvesting of green timber volumes.

4 Base Case Sensitivities

The following sections present the results of applying alternative assumptions to gauge the sensitivity of the revised harvest flow relative to the Base Case harvest flow.

4.1 Harvest Sequencing

This sensitivity examined the effect on short- and mid-term harvest levels from an immediate reduction in the current AAC uplift. This was done by first establishing the highest flat-line harvest level throughout the short- and mid-term (792,000 m³/yr) then steadily increasing the first term harvest level while accepting some loss in harvest level (~10%) throughout the mid-term. Ultimately, this sensitivity aimed to achieve the highest harvest level across both the short- and mid-terms combined, by influencing the model to balance the salvage of dead pine volume in the short term with the retention of green, by-catch volume for in the mid-term.

This alternative harvest flow (Figure 20) resulted in a lower harvest level in the first and second (by ~18% and ~28% respectively) that supported a higher mid-term harvest level by ~20% (113,000 m³/yr).

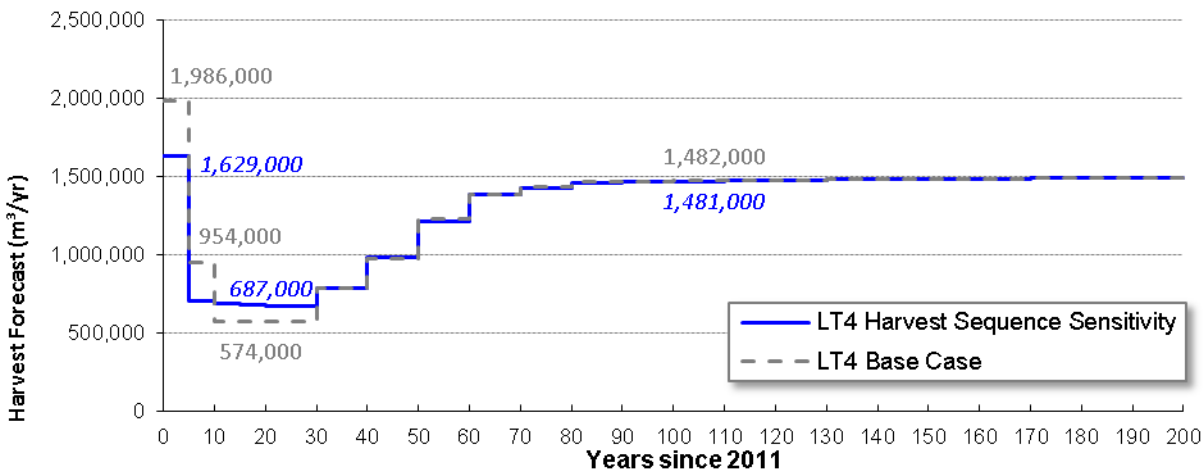


Figure 20 Harvest flow: Base Case compared to harvest sequence sensitivity

As expected, less dead pine volume was salvaged (~726,000 m³) with this sensitivity over the first decade compared to the base case, as some stands that would have been harvested with higher live volume components (by-catch), were retained for harvesting in the mid-term.

Over the past 10 years (since 2003), the actual harvest from the Lakes has averaged 1.70M m³/yr and 1.47M m³/yr since 2011. So despite the current uplift AAC of 2.0M m³/yr, it appears that the harvest sequencing harvest flow reflects the current harvest level.

4.2 Young Stand Mortality

This sensitivity was intended to explore the impact on harvest flows from reducing yields of specific stand types to account for higher estimates of mortality in young stands due to forest health agents. For this sensitivity, approximately 65,000 ha were identified for reduced yields. This was estimated to reduce the harvest forecast by approximately 20,000 m³/yr, but the impact could be more as some of these stands may contribute to the mid-term harvest. At this time, however, the young stand mortality sensitivity was not undertaken as it was identified as a lower priority within the available budget.

4.3 Cycle Times

This sensitivity examined how physical limitations with log hauling can impact the harvest flow. Effectively, this sensitivity restricted harvesting from areas designated within the maximum hauling

criteria of two or more trips per day. Areas within the cycle time zone of ≥9 hours, including barging, were not available for harvesting; reducing the THLB by 30% (161,116 ha)[6].

Figure 21 shows that the harvest level for the Cycle Time sensitivity is nearly the same as the Base Case harvest flow initially, but this falls dramatically in the second period to 299,000 m^3/yr – only 15% of the current uplift harvest level. The Cycle Time harvest level remains 40% lower than the Base Case throughout the mid-term then climbs to a long-term harvest that is still 28% lower.

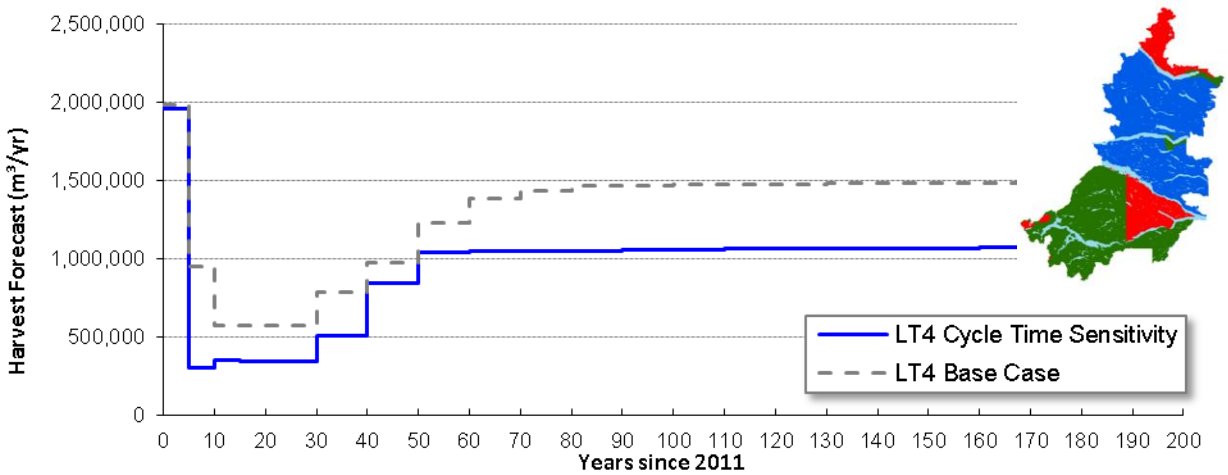


Figure 21 Harvest flow: Base Case compared to cycle time sensitivity

It is clear that reducing the available harvest area within the Lakes TSA can have a severely adverse impact on the harvest forecast. This is particularly evident between years 5 and 20 when most of the harvest in the Base Case is scheduled from the north portion of the TSA (Figure 5), where this sensitivity designates stands north of Babine Lake as unavailable.

Since the area available for harvesting was reduced compared to the Base Case, it is appropriate that the growing stock over time is also reduced (Figure 22). Over the planning horizon, the growing stock varies between 27% and 40% (36% average) of the Base Case.

[6] Not including aspatial netdowns.

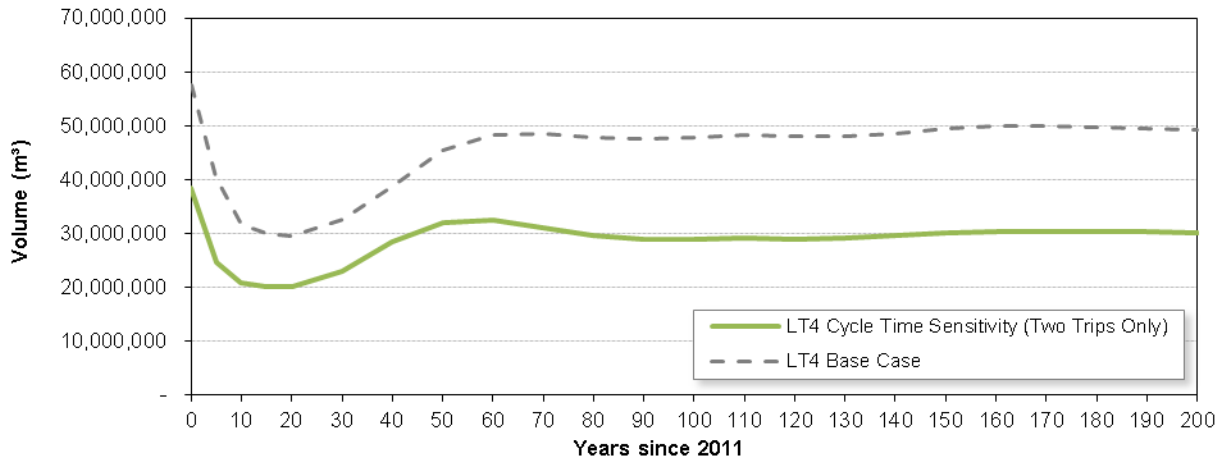


Figure 22 Total growing stock: Base Case compared to cycle time sensitivity

4.4 Hydrology

This sensitivity examined the impact of constraining harvests within proposed fisheries sensitive watersheds (FSW), a sensitivity analysis was undertaken to include Hydrologically Equivalent Disturbed Area (HEDA) thresholds currently proposed through draft orders establishing FSWs, as well as, additional riparian retention for S4, S5 and S6 streams.

For this sensitivity, the base case assumptions were adjusted by incorporating forest cover targets as described in the Data Package.

Figure 23 shows that the harvest level for the Hydrology sensitivity is nearly identical to the Base Case harvest flow. The only significant departures occur in the second period (years 6-10) and throughout the mid-term, where the harvest level for Hydrology sensitivity is 6% less than the Base Case.

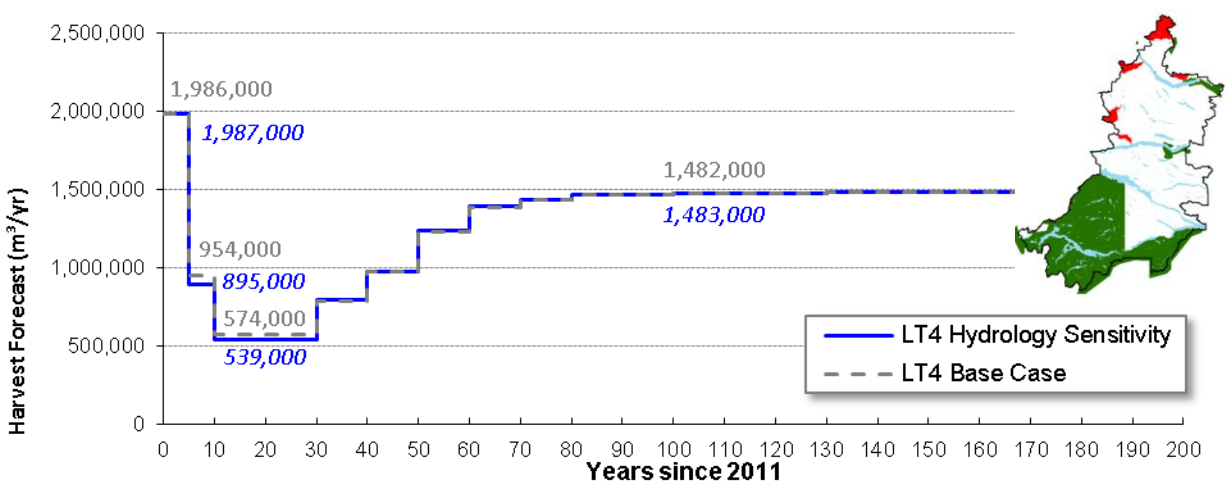


Figure 23 Harvest flow: Base Case compared to hydrology sensitivity

As expected, the growing stock for the hydrology sensitivity scenario is slightly less than the Base Case harvest flow (Figure 6), so a separate figure was not necessary.

5 Silviculture Strategies

The following sections present the results of applying alternative assumptions, as silviculture strategies, relative to the Base Case harvest flow. Each section includes a brief summary of the modelling approach documented[7], a discussion of the key forest metrics affected by the strategies and a rationale for observed differences from the Base Case. All scenarios were individually constrained within a budget of $3 M/yr.

5.1 Single Fertilization

This silvicultural strategy examined the impact to harvest flows from applying fertilizer one time throughout the rotation of pine and spruce stands. This treatment intended to increase the merchantable yield and value of stands by adding nutrients that are limited on sites that improve the growth of trees.

This strategy is expected to improve the mid-term harvest level because stands treated within the first two decades provides additional volume throughout this critical period and reduces the age that these stands become eligible for harvest (MHA). The existing volume, therefore, does not have to be metered out as long.

Eligible stands for this treatment were limited to only existing stands (natural or managed). This was intended to focus the increased volume onto stands that would most likely to support higher mid-term harvest levels. While single fertilization treatments certainly apply to future managed stands, gains from these stand types would be realized well beyond the mid-term period therefore these stands are less relevant to this analysis.

At a stand-level, a single treatment cost of $500/ha was applied but at the forest-level, the model was constrained with a maximum budget of $3 M/yr – or up to 6,000 ha/yr. No minimum budget was specified to permit the model to treat a stand only when it results in an improvement to the harvest forecast.

The stacked graph in Figure 24 shows that eligible stands to treat accumulate and dissipate from period to period as stands are: i) treated in a later period, ii) never available for harvesting and remain untreated, iii) harvested without treatment to overcome some other condition (e.g., better to harvest than wait for the retention period), or iv) retained and never treated for some non-timber value. All harvested stands that were eligible for fertilization at one time were treated.

[7] Forsite Consultants Ltd. (2013). Lakes TSA - Type IV Silviculture Strategy, Data Package. Technical Report.

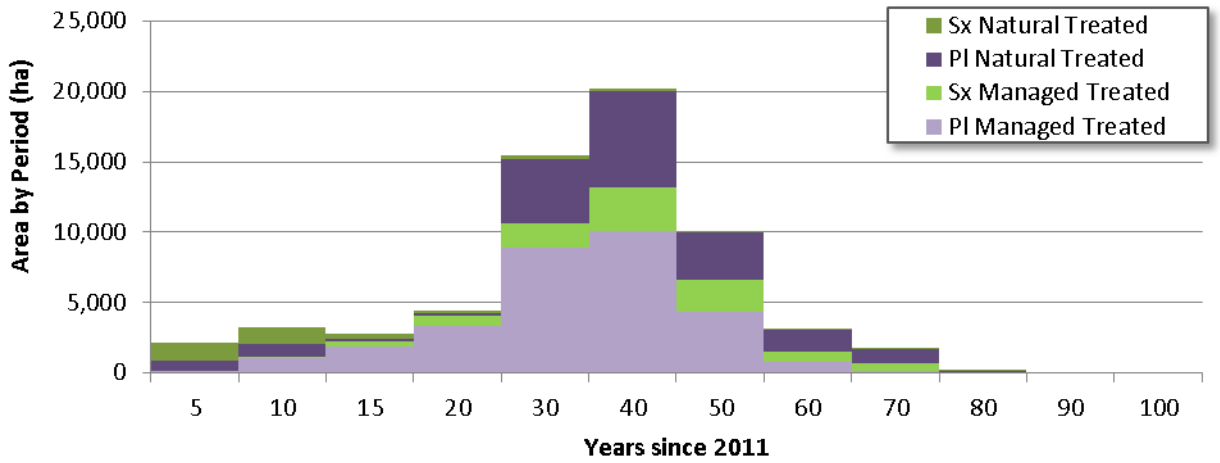


Figure 24 Area treated by stand type under the single-fertilization strategy

A total of 63,400 ha were treated under the single-fertilization strategy. Only 12,600 ha were treated within the first 20 years because the model was not configured to treat according to a fixed schedule and there was no incentive to treat available stands earlier.

Given the limited number of available stands and the model's selection of treated stands, the maximum budget was never fully utilized (Figure 25). In time though, more stands would become eligible for treatment – particularly if future managed stands were included.

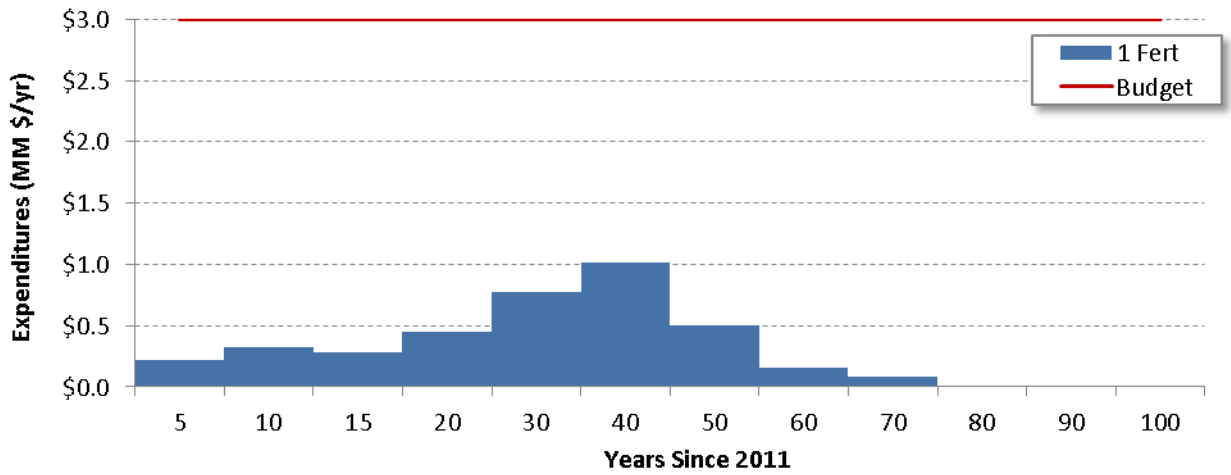


Figure 25 Expenditures over time for the single-fertilization strategy

The harvest flow resulting from the single-fertilization strategy was quite similar to the base case (Figure 26). The mid-term harvest level increased by only 6,000 m³/yr.

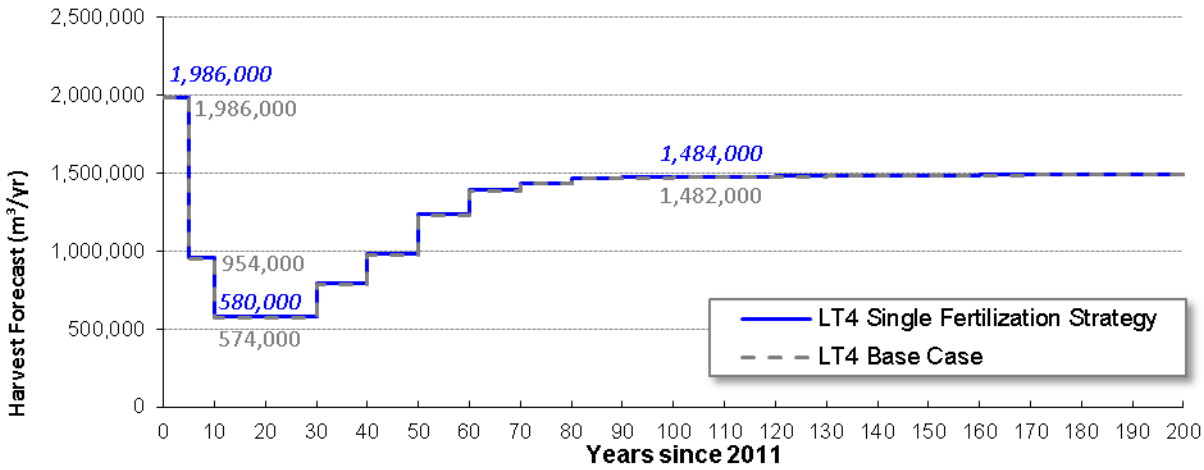


Figure 26 Harvest flow: Base Case compared to single-fertilization strategy

With only a minor amount of additional volume, the growing stock over time (Figure 27) was nearly identical to the Base Case.

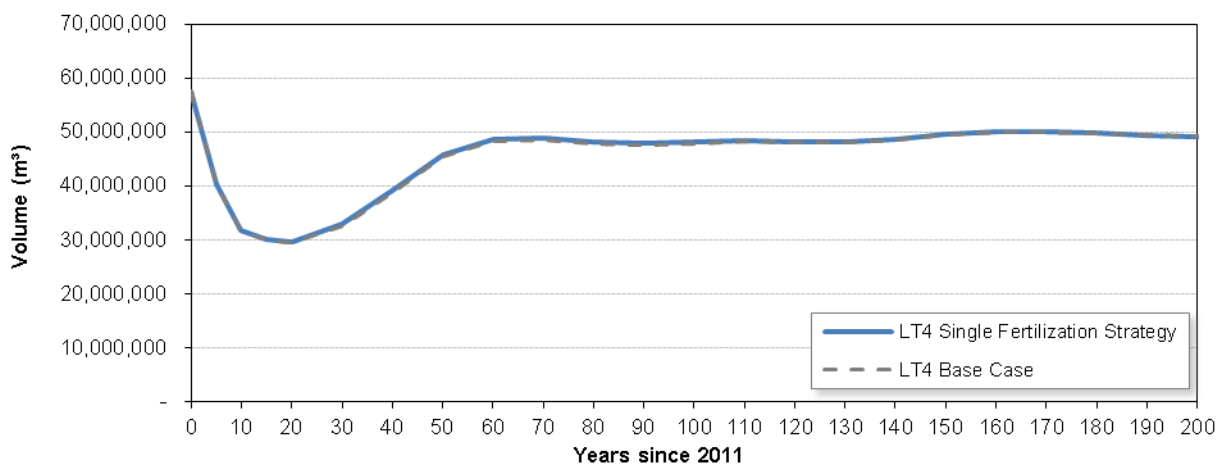


Figure 27 Total growing stock over time: Base Case compared to single-fertilization strategy

5.2 Multiple Fertilization

This silvicultural strategy examined the impact to harvest flows from applying fertilizer multiple times throughout the rotation of pine and spruce stands; every 10 and 5 years, respectively. Several treatment frequency regimes were developed for each species that reflected a fixed number of applications (up to 4 for Pl and 6 for Sx) and their corresponding response and cost. Eligible stands could only be assigned one treatment frequency regime.

Like the single fertilization scenario, eligible stands for this treatment were limited to only existing stands (natural or managed). Again, stand-level treatment costs of $500/ha were applied but at the forest-level, the model was constrained with a maximum budget of $3 M/yr – or up to 6,000 ha/yr. No minimum budget was specified to permit the model to treat a stand only when it results in an improvement to the harvest forecast.

The stacked graph in Figure 28 shows that eligible stands to treat accumulate and dissipate from period to period as stands are: i) treated in a later period, ii) never available for harvesting and remain untreated, iii) harvested without treatment to overcome some other condition (e.g., better to harvest than wait for the retention period), or iv) retained and never treated for some non-timber value. Again, all harvested stands that were eligible for fertilization at one time were treated.

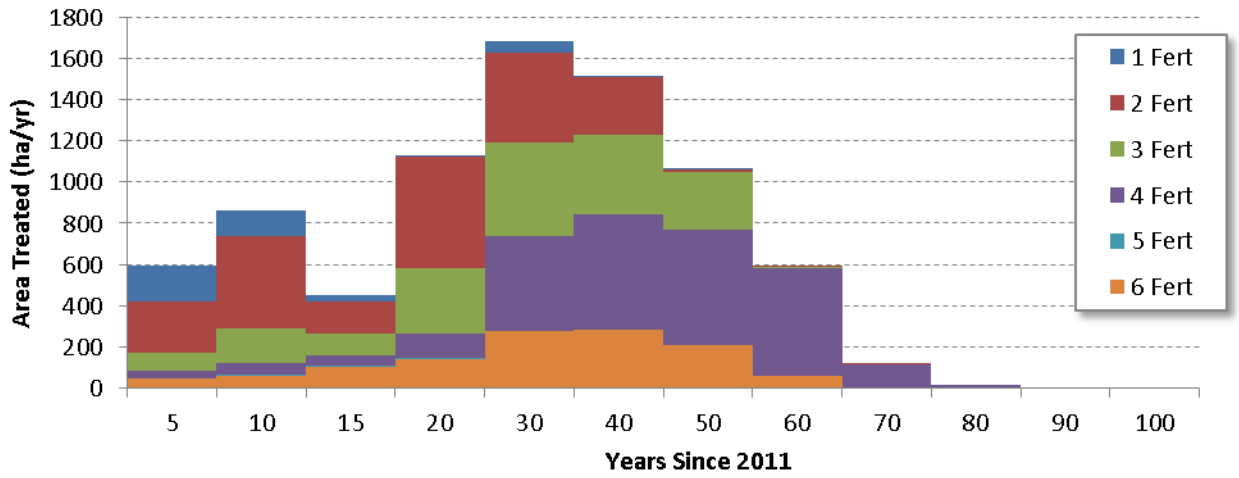


Figure 28 Area treated by stand type under the multiple-fertilization strategy

Including the repeated treatments, over 230,000 ha were treated under the multiple-fertilization strategy. Only 41,800 ha were being treated within the first 20 years because the model was not configured to treat according to a fixed schedule and there was no incentive to treat available stands earlier.

Figure 29 shows that as more stands become eligible, the budget for the multiple-fertilization strategy steadily increases until the 3rd decade when nearly the entire budget is utilized. This declines afterwards as fewer existing stands are left to treat.

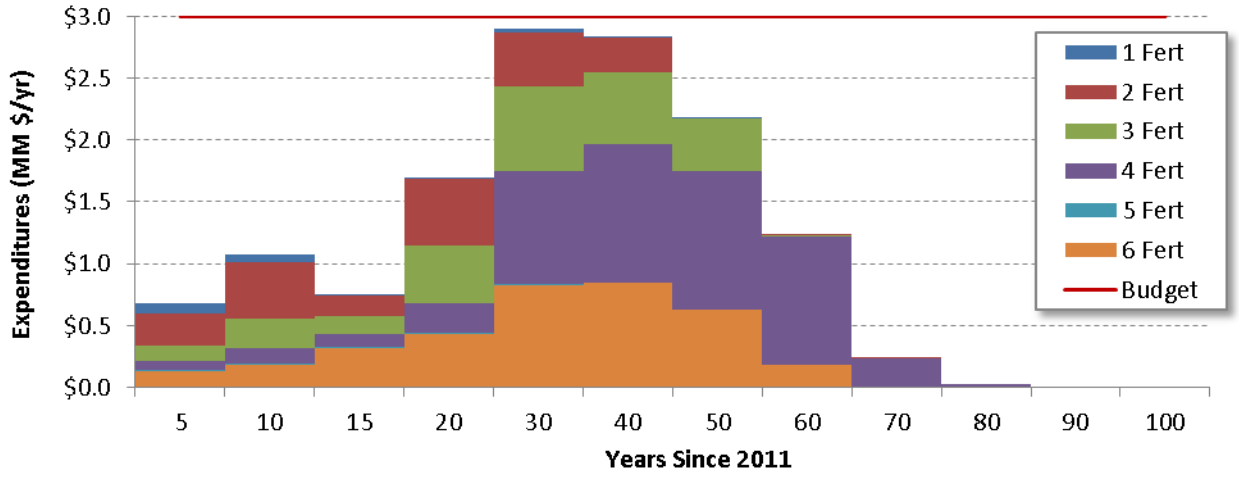


Figure 29 Expenditures over time for the multiple-fertilization strategy

Figure 30 shows a very slight improvement to the harvest flow with multiple-fertilization. The harvest level increased by 17,000 m³/yr in the mid-term, 53,000 m³/yr in the rise to the long-term and 28,000 m³/yr in the long-term.

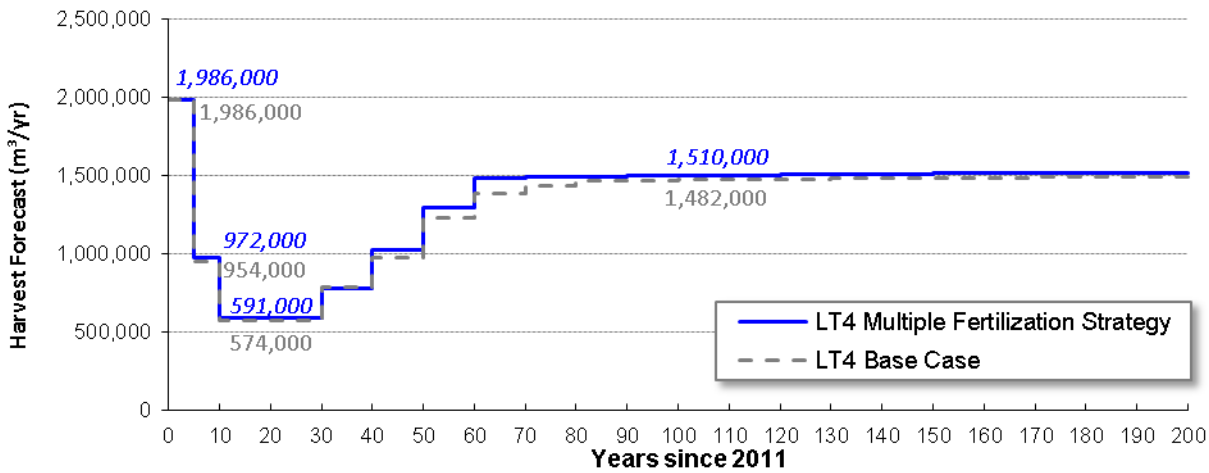


Figure 30 Harvest flow: Base Case compared to multiple-fertilization strategy

Most of the incremental volume from fertilization was harvested after the mid-term trough (Figure 31) because most of the short- and mid-term harvest comes from natural stands. Only some natural stands that were eligible for treatment contributed in the mid-term. The gradual rise from to the long-term that maximizes the harvest flow on existing managed stands between the 4th and 9th decades (Figure 4) also dampens any allowable cut effect (ACE[8]) that one might expect to improve the mid-term.

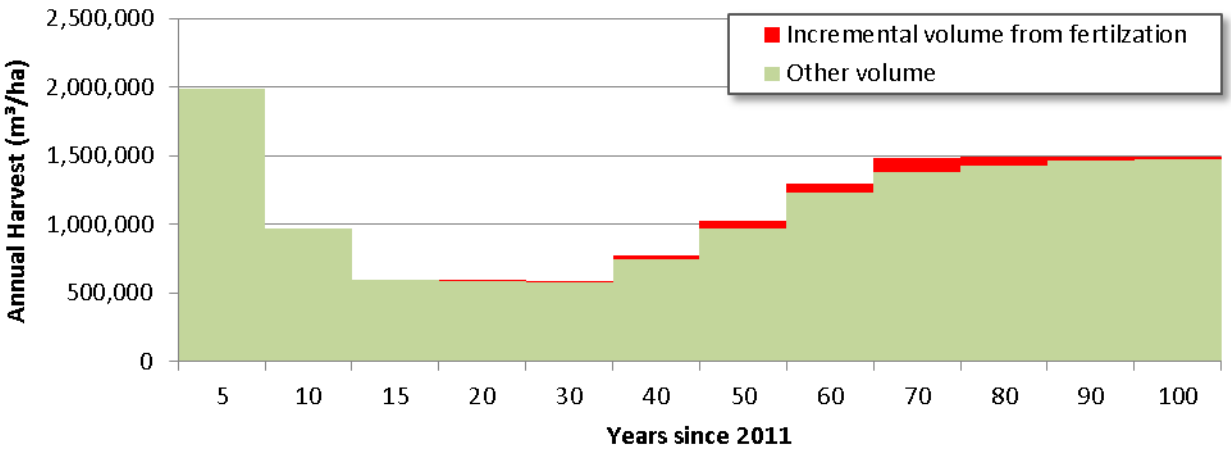


Figure 31 Harvest flow: Incremental volume harvested in the multiple-fertilization strategy

[8] An immediate increase in timber supply resulting from expected future gains. This occurs because incremental volume in the future takes the place of existing stand volume that would otherwise be needed at that time. This effectively allows existing stand volumes to be harvested at a faster rate over the intervening time period.

5.3 Pre-Commercial Thinning and Fertilization

The pre-commercial thinning (PCT) and fertilization strategy examined the impact on harvest flow from reducing the density of over-stocked stands (typically 5,000-20,000 sph) to increase opportunities for subsequent fertilization treatment(s). The intent was to improve stand quality/health/resilience through leave tree selection, increase stand volumes through fertilization and advance operability in these stands.

Only existing stands were considered for this strategy to focus the increased volume onto stands that would most likely to support higher mid-term harvest levels and because post-harvest regeneration assumptions in the Base Case reflect suitable stand density conditions. Treatment options included PCT only and PCT plus fertilization.

The stacked graph in Figure 32 shows that eligible stands to treat accumulate and dissipate from period to period as stands are: i) treated in a later period, ii) never available for harvesting and remain untreated, iii) harvested without treatment to overcome some other condition (e.g., better to harvest than wait for the retention period), or iv) retained and never treated for some non-timber value. Again, all harvested stands that were eligible for fertilization at one time were treated.

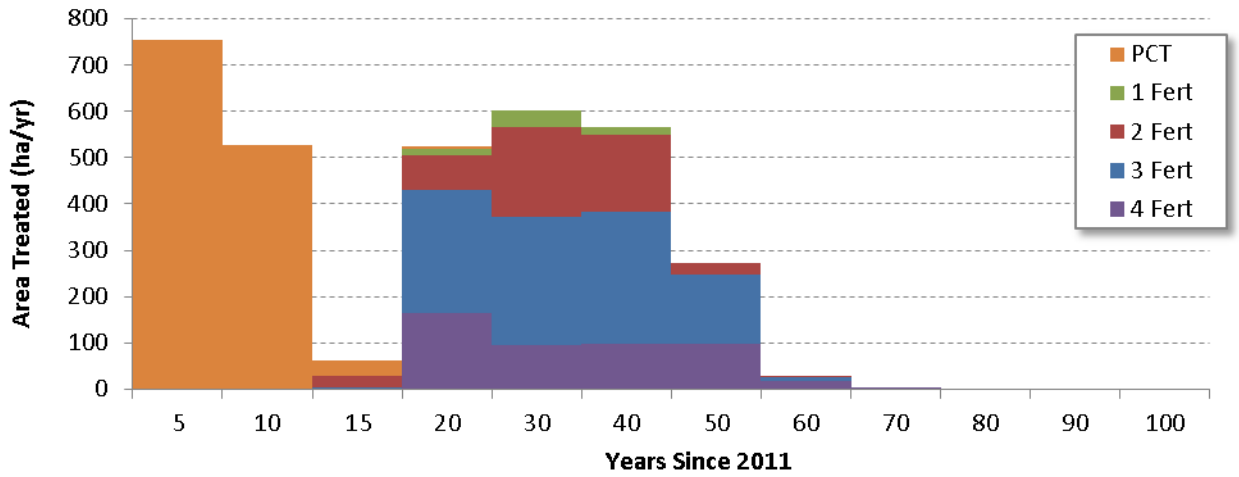


Figure 32 Area treated by treatment type under the pre-commercial thin and fertilization strategy

The model thinned over 6,600 ha and fertilized over 17,000 ha - including repeated fertilization treatments. All of the PCT and 2,700 ha of fertilization was done within the first 20 years.

Figure 33 shows that stands that are eligible are treated with PCT within the first decade and are later treated under the multiple-fertilization strategy. Eventually, all the PCT-treated stands are fertilized.

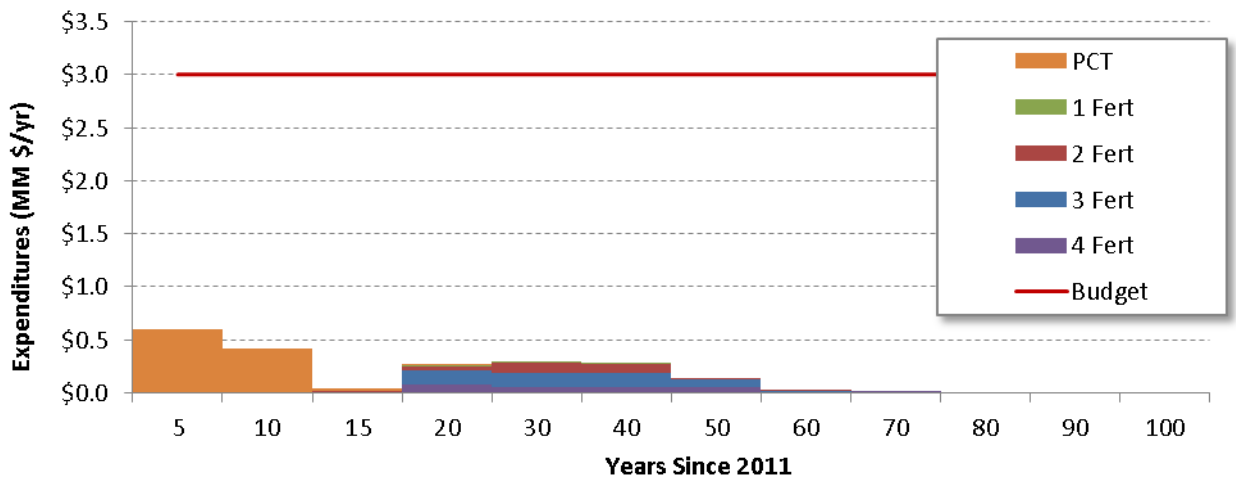


Figure 33 Expenditures over time for the multiple-fertilization strategy

Figure 34 shows a slightly improved harvest flow with the PCT and fertilization treatment. The limited opportunities (~20,000 ha) combined with marginal volume gains suggest that this treatment is a poor choice if harvest volume is the only metric considered; and particularly poor if return on investment is considered. In practice however, this treatment may be regarded as a cleaning treatment that prepares stands for other treatments, including fertilization (i.e., volume gains over fewer stems).

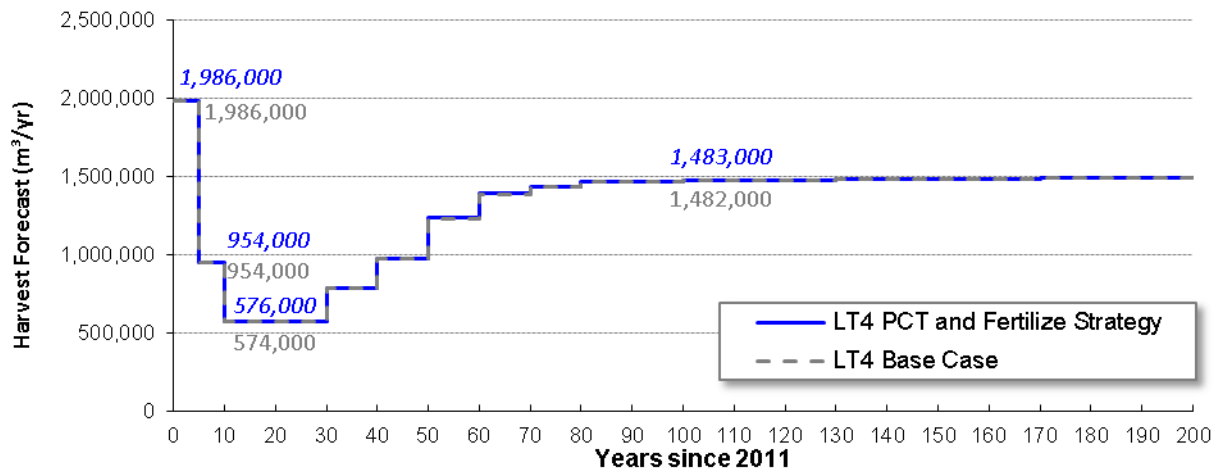


Figure 34 Harvest flow: Base Case compared to pre-commercial thin and fertilize strategy

5.4 Rehabilitating MPB-Impacted Stands

Approximately 53,000 ha were never harvested in the Base Case scenario because they do not meet the minimum harvest criteria of 140 m³/ha where the MPB impact on young or marginal stands plus the available understory regeneration does not achieve this minimum merchantability requirement. This effectively reduces the landbase that contributes to the harvest flow.

This silvicultural strategy examined the impact to harvest flows from rehabilitating MPB impacted stands with little or no salvage opportunity. Rehabilitation provides extra merchantable (green) volume at the time of treatment (that would not have otherwise entered the marketplace) and increases the long-term harvest level as managed stand performance is significantly improved.

The model salvaged most of the high percent pine stands so many of the post-MPB stands selected under this rehabilitation strategy are low volume mixed stands. Figure 35 shows that initially, rehabilitation is distributed fairly evenly among the three merchantability classes. Throughout the mid-term, however, a much higher proportion of stands with live volumes less than 80 m³/ha (very low merchantability) are treated. A total of 69,000 ha were treated over the first 3 decades with expenditures of $85.8 M.

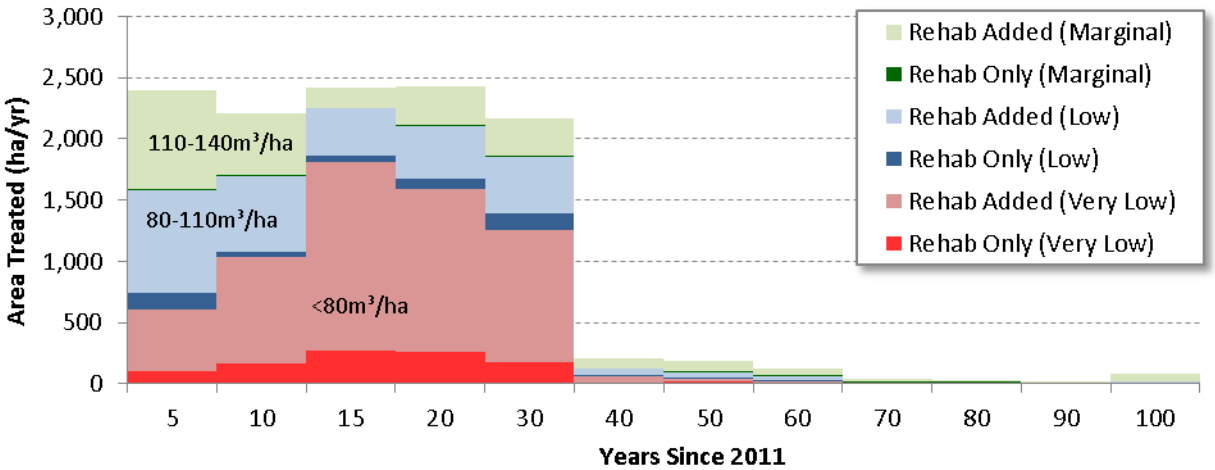


Figure 35 Area treated by merchantability class under the rehabilitation strategy

MPB-impacted stands identified for "rehabilitation only" had already deteriorated below the 140 m³/ha volume threshold in the first period and never recovered to become available for harvesting. Otherwise, some stands were available for salvage or clearcut at some point but then fell below the minimum volume criteria and were "added" as eligible for rehabilitation.

Figure 36 shows that nearly all of the available funds are expended for the first three decades then, as the mid-term timber shortage is alleviated, the remaining stands identified for rehabilitation are treated incidentally throughout the planning horizon.

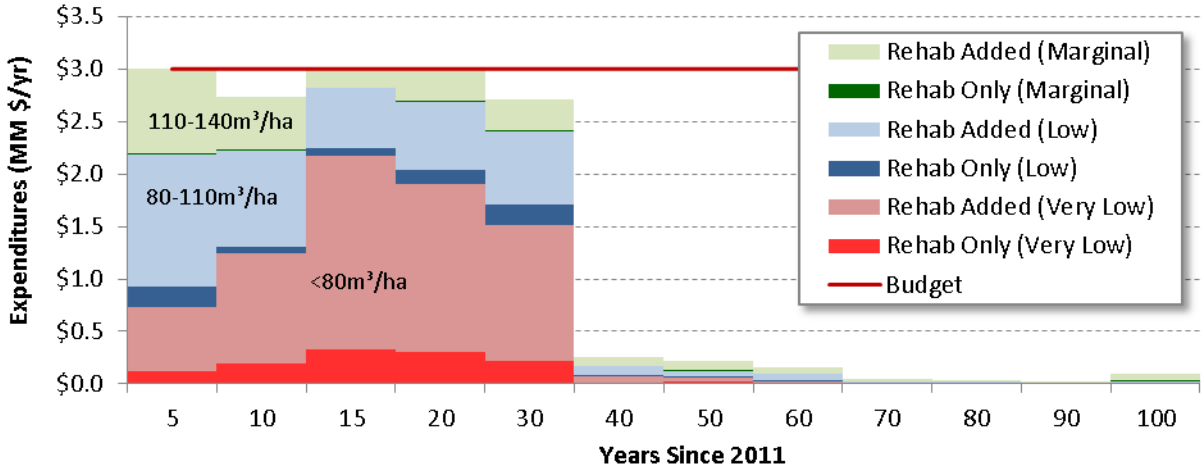


Figure 36 Expenditures over time for the rehabilitation strategy

Figure 37 shows a significantly improved harvest flow with the rehabilitation strategy – particularly throughout the mid-term that increases by 22% compared to the Base Case. This is attributed to the remaining live volume being harvested from rehabilitate stands. In reality, however, only a portion of this green volume will likely be harvested. The increased harvest levels following the mid-term (4-6%) reflects the landbase reintroduced as available for harvest.

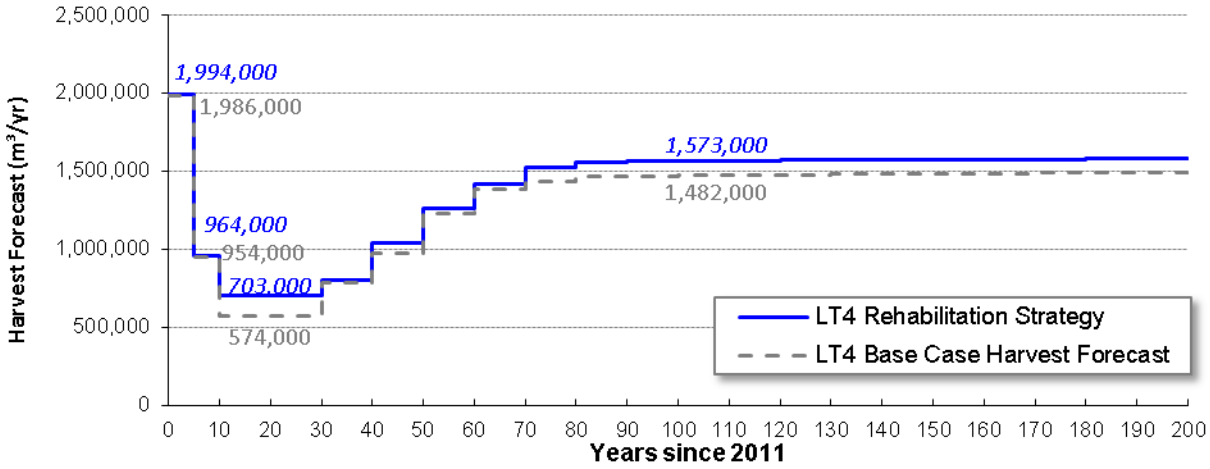


Figure 37 Harvest Flow: Base Case compared to rehabilitation strategy

Rehabilitation treatments were available through the planning horizon, where eligible stands had deteriorated below the minimum harvest volume criteria. In practice, the focus should initially be on treating younger or burned stands and those with lower merchantability while deferring stands with live volumes that can rehabilitated in the mid-term. Of course, access and market conditions also play a key role in prioritizing stands for rehabilitation.

5.5 Enhanced Basic Reforestation

This silvicultural strategy was intended to examine the impact to harvest flows by enhancing basic reforestation practices where current performance is not optimal (e.g., achieving minimum well-spaced trees/ha versus target well-spaced trees/ha). However, the current regeneration assumptions provide near-optimum yields for future managed stands and growth data for Fd and Lw within the TSA (facilitated adaptation to climate change) are not well-supported. Consequently, the enhanced basic reforestation strategy was not pursued further as it was not identified as a priority strategy within the available budget.

5.6 Composite Mix of Strategies – Budget of $3 M/year

For this scenario, the model was configured to include assumptions for all of the strategies presented above so that the model can select the timing and range of treatments that produces the most appropriate outcome. A budget constraint of $3 M/year was applied in this scenario to reflect realistic funding levels for these activities.

The area of silviculture treatments selected under this scenario (Figure 38) is dominated by rehabilitation in the first 3 decades (92 K ha overall) and fertilization afterwards (118 K ha). This suggests that, given a limited budget, the model favours the extra green volume harvested with the rehabilitation

treatments over the smaller and delayed gains in volume from fertilization. Similarly, very few stands were selected for the PCT and fertilization strategy.

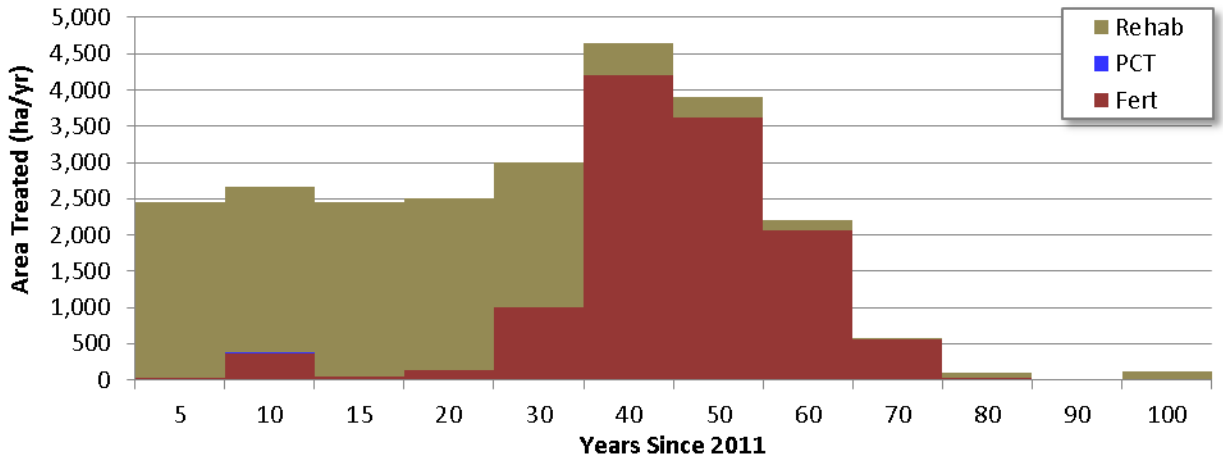


Figure 38 Area treated by silviculture treatment under the composite strategy at $3 M/yr

The $3M/yr budget assigned to the composite scenario is maximized throughout the short- and mid-term then declines as the area of eligible stands for fertilization decreases.

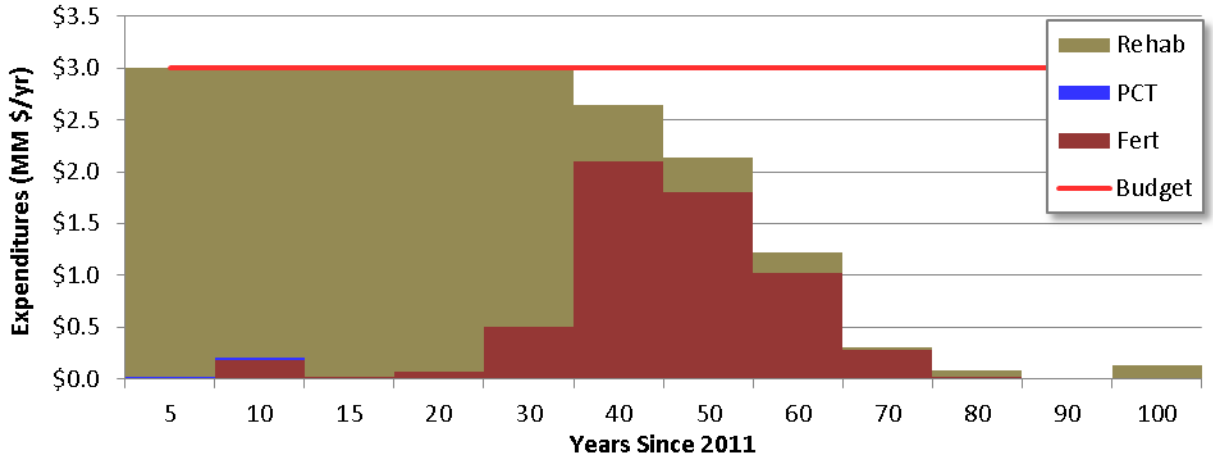


Figure 39 Expenditures over time by silviculture treatment for the composite strategy at $3 M/yr

Combining the silviculture strategies significantly improves the harvest flow compared to the base case (Figure 40), particularly throughout the mid-term (+22% or 160,000 m^3/yr) where additional green volume becomes available through the rehabilitation treatments. The rise out of the mid-term is also improved (+10%) by gains from fertilization and early rehabilitation of natural stands converted to high-producing managed stands. The increased long-term harvest level (+6%) reflects the additional volume from rehabilitated stands that were otherwise unharvested (i.e., did not meet the minimum harvest criteria in the Base Case).

When investment dollars are limited, the initial focus is on rehabilitation treatments. Ideally stands with little to no merchantable volume would be addressed while the salvage uplift is in place (volume not needed; avoid rehabilitating stands that may be salvaged), and then shift to stand that provide

merchantable volume during the mid-term period. Fertilization is delayed because managed stands do not contribute to the harvest in a significant way until over 30 years in the future and because fertilization provides weaker financial returns than rehabilitation.

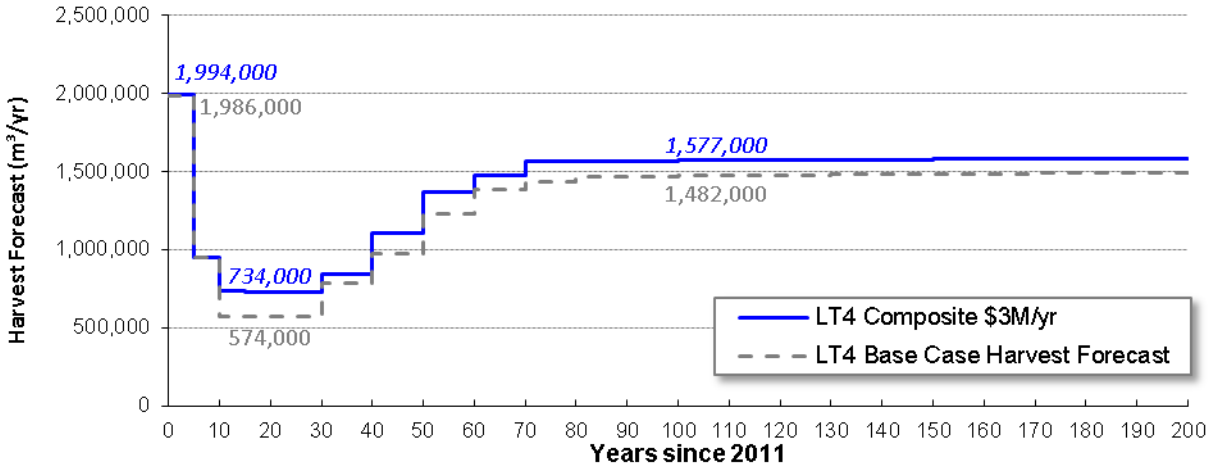


Figure 40 Harvest flow: Base Case compared to composite strategy at $3 M/yr

5.7 Composite Mix of Strategies – Budget of $7 M/year

Similar to the previous scenario all of the above-mentioned strategies were available to the model. In this case, however, the budget was increased to a favourable level of $7 M/yr. The increased funding provides the model with more flexibility to select treatments that are less responsive than the rehabilitation treatments. Figure 41 shows that while rehabilitation is still preferred (84 K ha), while PCT (4 K ha) and fertilization treatments (176 K ha) are applied earlier and in higher proportions.

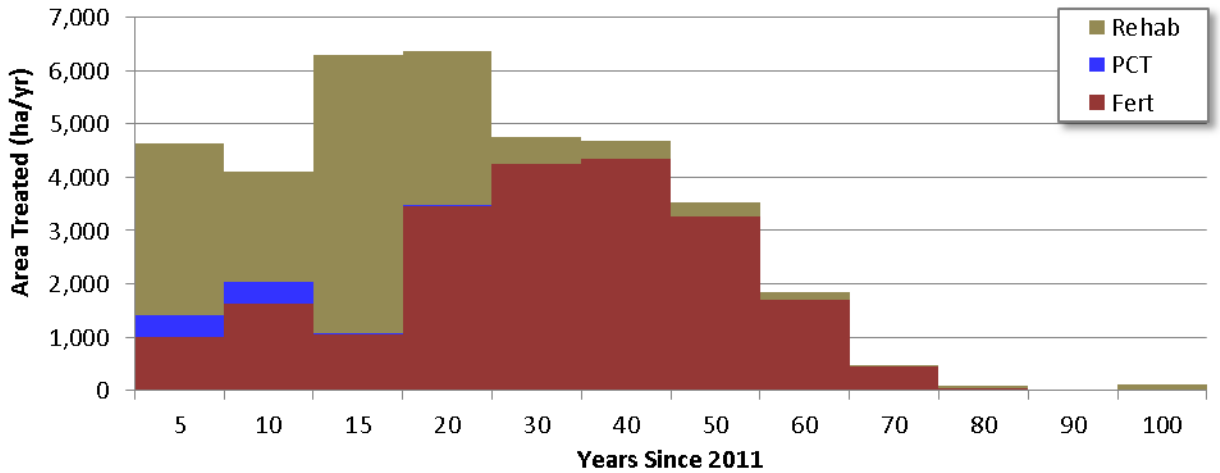


Figure 41 Area treated by silviculture treatment under the composite strategy at $7 M/yr

The $7 M/yr budget assigned for this composite scenario is only maximized once throughout the planning period (Figure 42). Expenditures for the first 20 years average $5.25 M/yr and then decline as the area of eligible stands for rehabilitation and fertilization decreases.

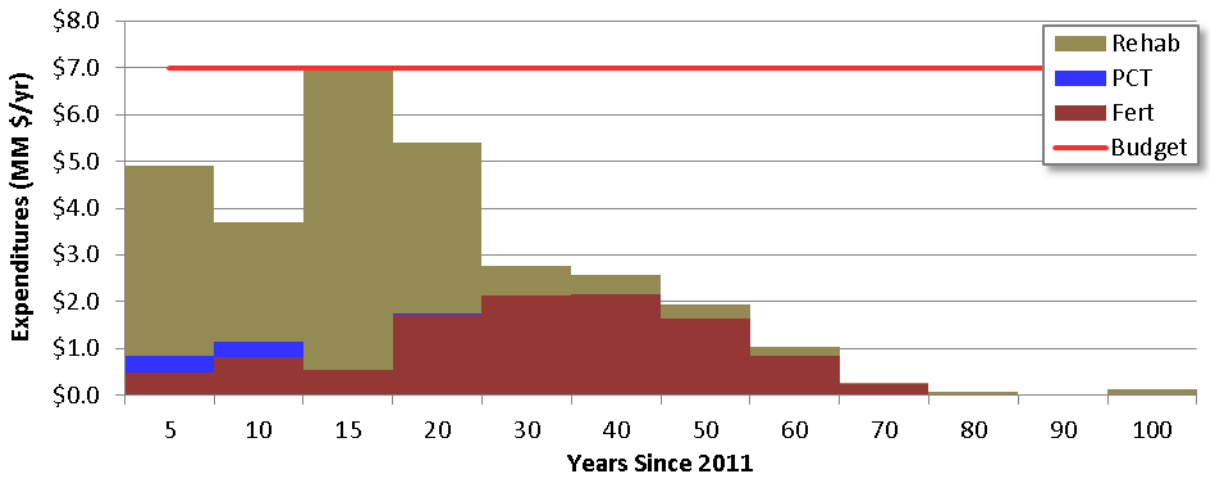


Figure 42 Expenditures over time by silviculture treatment for the composite strategy at $7 M/yr

Again, Figure 43 shows that combining silviculture strategies significantly improves the harvest flow compared to the Base Case. The mid-term harvest level increases by 29% (166,000 m³/yr) over the Base Case while the rise and long-term harvest levels increase by 12% and 7%, respectively. Since funding is almost unlimited in this scenario, there is only a slight improvement over the same scenario under constrained funding (Figure 40). This occurs because less efficient investments are being applied to improve harvest flow. Fertilization and PCT and fertilization occur earlier and in larger amounts, plus additional rehabilitation occurs but at a higher cost/ha. It appears that at this budget level, investment opportunities are exhausted which result in a less efficient use of dollars than the $3 M/yr budget scenario which focuses on the best opportunities. This is discussed more under in section 6 below.

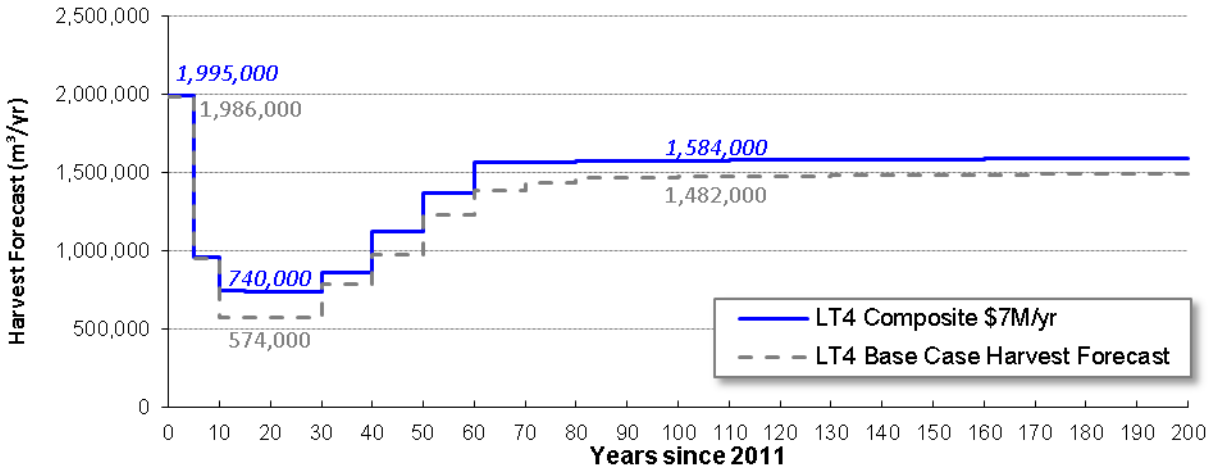


Figure 43 Harvest flow: Base Case compared to composite strategy at $7 M/yr

6 Economic Considerations

The following section evaluates silviculture strategies using both stand- and forest-level economic criteria by providing relative comparisons of different strategies. The investment efficiency of alternative silviculture treatments were assessed using net present value (NPV) calculations (i.e. the present day

value of a series of costs and revenue(s) that occur over time). This is one way to compare alternative investments that can be used at the forest level by valuing the incremental timber supply as it occurs against the investments made to deliver these gains. This often can look more attractive than stand-level assessments because investments made today can produce harvest volume increases quickly through an allowable cut effect (i.e., that solve pinch points).

6.1 Stand-level

The following assumptions were applied to calculate stand-level NPVs:

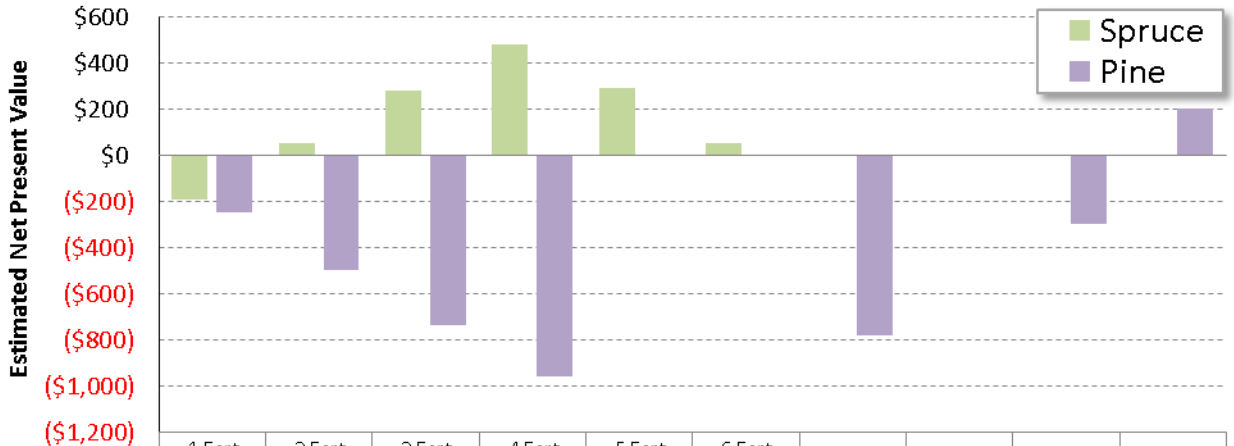
- 2% discount rate and a net economic benefit to the crown of $25/m^3 on the additional volume realized.[9] The economic benefit to the licensee would be additional but is not included here as the investor (crown) would not realize this benefit directly. The $25/m^3 value provides a basis for relative comparisons between treatments – site specific values should be used to evaluate actual investment opportunities.
- **Multiple Fertilizations** (including Single Fertilization)
  - 10-year harvest delay from time of last fertilization application
  - Pl: Treatment cost of $500/ha; revenues of $300/ha, $600/ha, $900/ha, $1100/ha ($25/m³ times 12m^3/ha) for 1, 2, 3, and 4 applications, respectively; realized 20, 30, and 40 years from first treatment
  - Sx: Treatment cost of $500/ha applied in 5-year intervals; revenues of $375/ha, $1125/ha, $2225/ha, $3300/ha, $3875/ha, $4400/ha ($25/m³ times 75m³/ha, 49m³/ha, 89m³/ha, 132m³/ha, 155m³/ha, 176m³/ha) for 1, 2, 3, 4, 5 and 6 applications, respectively; realized 10, 15, 20, 25, and 30 years from first treatment
- **PCT Plus Fertilization** - 10-year harvest delay from time of application
  - Treatment cost of $800/ha for PCT and $500/ha for fertilization; revenue of $660/ha ($25/m³ plus incremental value of $30/m³ times 12m^3/ha) realized 55 years from treatment
- **Rehabilitation**
  - For very low, low and marginal sawlog recovery classes (respectively): net treatment costs (after utilizing any merchantable timber) of $1200/ha, $1500/ha and $1000/ha plus additional distance costs for cycle time zones (<5 hrs @ $0/ha, ≥5 & <7 hrs @ $50/ha, ≥7 hrs @ $250/ha); revenue generated at $5000/ha ($25/m³ times 200m³/ha) realized 70 years from treatment

Using these assumptions, favourable stand-level NPVs were calculated for multiple-fertilization of spruce stands and low-cost rehabilitation of MPB-killed stands (Figure 44). PCT plus fertilization and

[9] $25/m³ was used as a generic value for all situations for this exercise and is meant to reflect the economic benefit to the crown (the investor) through stumpage, taxes and fees collected as the cubic meter moves thorugh the economy.

Source - (Unpublished report prepared for the Forest Sector Climate Action Steering Committee, Forest Carbon Subcommittee c/o BC Ministry of Forests, Lands and Natural Resource Operaionts, Forest Practices and Investment Branch): Forsite Consultants Ltd., EcoRessources Carbone Inc., ESSA Technologies Ltd. and Thrower, J. Implementing Forest Carbon Offset Projects at the Management Unit Level in British Columbia – Results and Recommendations from Testing on Pilot Areas in BC's Interior and Coastal Regions. June 13, 2011. 123pp.

fertilization of pine stands resulted in negative NPVs, due to small volume response and long intervals between investment and return.



	1 Fert 10 years prior to harvest	2 Fert 10 years prior to harvest	3 Fert 10 years prior to harvest	4 Fert 10 years prior to harvest	5 Fert 10 years prior to harvest	6 Fert 10 years prior to harvest	PCT Plus Fert	Rehab @ $1200/ha (Very Low)	Rehab @ $1500/ha (Low)	Rehab @ $1000/ha (Marginal)
Spruce	($190)	$50	$280	$480	$290	$50				
Pine	($250)	($500)	($735)	($960)			($780)	$0	($300)	$200

Figure 44 Stand-level net present values for silviculture activities using a 2% discount rate.

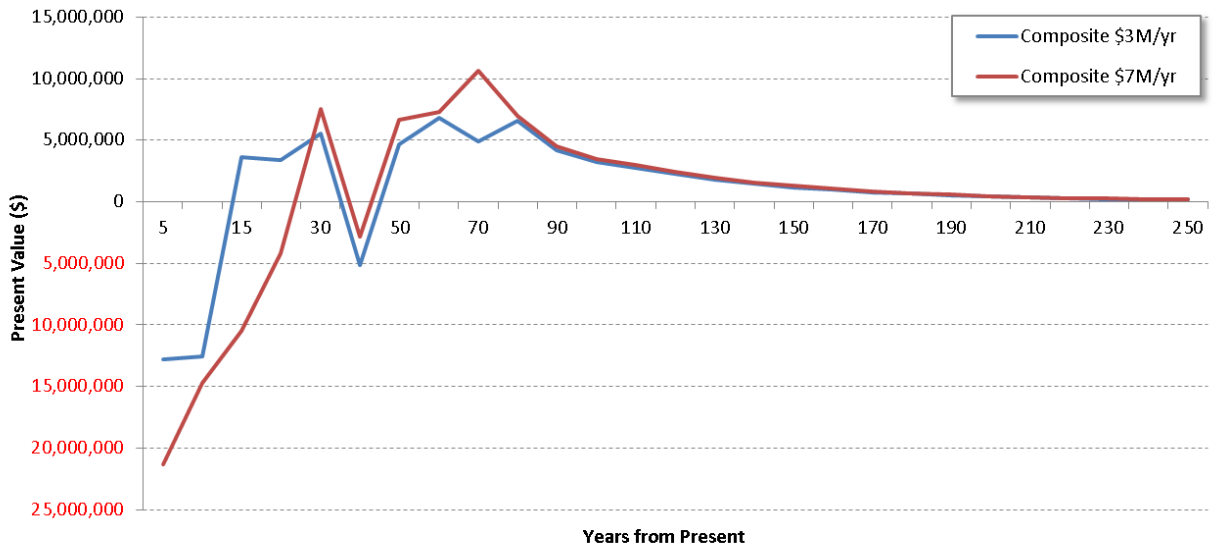
All treatments look less attractive when discount rates are increased but those with the longest timeframes between investment and return (e.g., rehabilitation) are the most sensitive. For example, an increase in the discount rate to 4% results in negative NPVs for rehabilitation across all sawlog recovery classes.

6.2 Forest-level

To assess investment efficiency at a forest level, NPVs were calculated for several scenarios by examining the series of silviculture investments and incremental revenue generated from improved harvest levels. This presents a conservative view of the scenarios because some investment costs made near the end of the period were included but the returns generated were not.

Timber supply dynamics make NPVs look considerably different at a forest-level compared to the stand-level. Figure 45 shows the NPVs calculated for the composite (optimized) silviculture treatments strategies at both the $3 M/yr and $7 M/yr budget levels. Both strategies begin with a negative NPV as costs are incurred and no revenue is realized (harvest remains at current AAC - 2.0 M m^3/yr). The incremental volume realized throughout the mid-term / long term contributes to positive NPVs except in the 4th decade when a lower level of incremental harvest volume is scheduled yet costs remain the same.

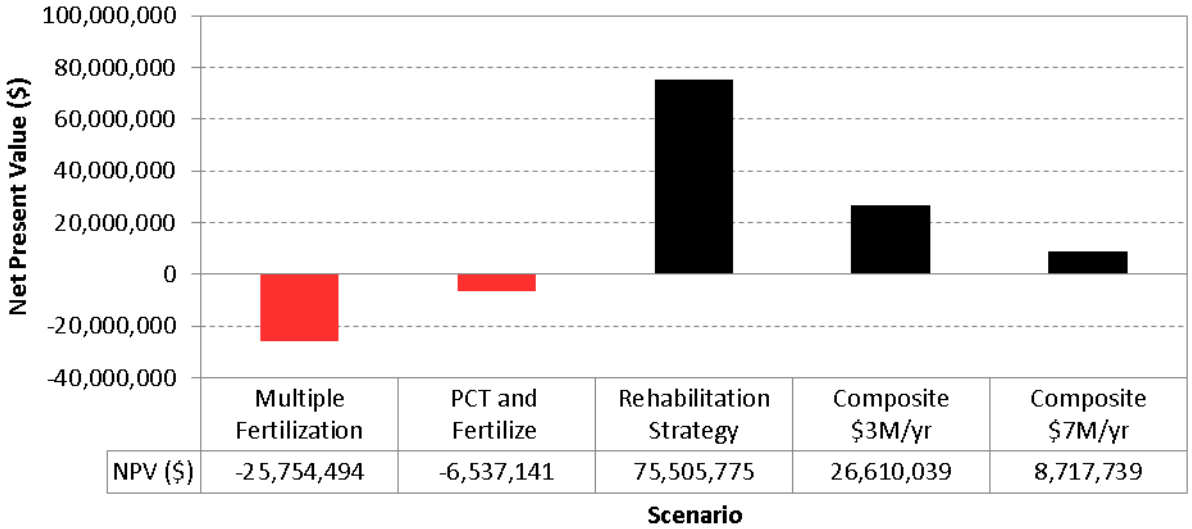
Over the entire planning period, the total NPV for the $3 M/yr and $7 M/yr budget levels were $26.6 M and $8.7 M, respectively. As discussed earlier, the $3 M/yr scenario is financially more attractive because it leverages the most cost effective investments to achieve most of the potential harvest gains at a reduced annual budget. The $7 M/yr budget in not constraining and effectively exhausts the opportunities by employing less efficient silviculture treatments.



Note: Assumes a 2% discount rate and a $25/m³ value for volumes incremental to the Base Case

Figure 45 Present values for the composite strategies

A comparison of NPVs for all of the silviculture strategies explored (Figure 46) shows that at a 2% discount rate, $3 M/yr and $7 M/yr composite silviculture programs will produce a positive NPV – or an internal rate of return (IRR) greater than 2%. This reinforces the conclusion that the rehabilitation strategy is the most economically efficient.



	Multiple Fertilization	PCT and Fertilize	Rehabilitation Strategy	Composite $3M/yr	Composite $7M/yr
NPV ($)	-25,754,494	-6,537,141	75,505,775	26,610,039	8,717,739

Figure 46 Net present values for silviculture strategies relative to the Base Case

As these silviculture strategies focused on opportunities for the mid-term, they were only applied to existing managed stands. Including future managed stands under these strategies would likely present even higher NPVs at a forest level.

7 Discussion

Table 2 summarizes the harvest flow changes, relative to the Base Case, resulting from the sensitivities and silviculture scenarios modelled. The strategy that best alleviates the mid-term trough was the composite mix of silviculture strategies that allows the model to select from the full suite of treatments using an annual budget of $7 M/yr.

Table 2 Summary of harvest flow differences for silviculture strategies relative to the Base Case

		Change relative to Base Case (m^3/yr) *							
Type	**Scenario**	**Short-Term**		**Mid-Term**		**Rise to Long-Term**		**Long-Term**	
Base Case Sensitivities	Harvest Sequencing	(304,000)	-21%	106,000	18%	(2,000)	0%	(1,000)	0%
	Cycle Times	(340,000)	-23%	(227,000)	-40%	(263,000)	-23%	(415,000)	-28%
	Hydrology	(29,000)	-2%	(35,000)	-6%	5,000	0%	1,000	0%
Silviculture Scenarios	Single Fertilization	2,000	0%	6,000	1%	6,000	1%	2,000	0%
	Multiple Fertilization	9,000	1%	17,000	3%	53,000	5%	28,000	2%
	Pre-Commercial Thin and Fertilization	-	0%	2,000	0%	4,000	0%	1,000	0%
	Rehabilitation	9,000	1%	128,000	22%	48,000	4%	91,000	6%
	Combined Silviculture ($3 M/yr)	2,000	0%	160,000	28%	112,000	10%	95,000	6%
	Combined Silviculture ($7 M/yr)	6,000	0%	166,000	29%	137,000	12%	102,000	7%

** Short-term = years 0-10; Mid-term = years 11-30; Rise to Long-term = years 31-90; Long-term = years >90*

This modeling and analysis work explored opportunities to improve timber quantity, timber quality and non-timber values. The following points summarize some of the key points learned from this exercise:

- The Lakes TSA will begin to experience a severe shortage of available volume in 20 years (12.2 M m^3; ~31% of current) lasting 2 decades.
- The approach applied in this analysis was to first develop a base case scenario that reflects a realistic harvest forecast. We learned that the harvest flow is very sensitive to assumptions involving salvage effort, shelf-life, and minimum harvest criteria.
- The vast majority of the mid-term harvest is from existing natural stands metred out until existing managed stands become merchantable to contribute to the harvest. Because minimum harvest criteria are less than the biological maximum, filling the mid-term typically involves robbing from potential long-term harvest levels.
- While not identified as a specific strategy, it is essential the natural stands that support the mid-term harvest are monitored and managed to ensure that these stands are available throughout this critical period.
- Aiming to maximize the mid-term harvest level also maximizes the harvest flow during the rise to the long-term. Ultimately, this affects which stands are available for specific treatment and dampens any ACE that one might otherwise expect to improve the mid-term. In fact, nearly all of the harvest throughout the short- and mid-term comes from natural stands. So, while there are many opportunities to improve forest conditions in the long-term, there are few silviculture treatments that can increase the mid-term harvest level.
- Reducing salvage immediately leaves more green timber on the landbase that can be harvested throughout the mid-term. However, this benefit comes at the cost of increased loss of dead Pl (less salvage) and the economic loss of a reduced short-term harvest level.
- Waiting longer to harvest managed stands (i.e., applying minimum harvest ages based on culmination of MAI versus the minimum stand volume criteria of ≥140 m^3/ha) significantly

lowers and prolongs the projected mid-term but improves the long-term harvest level, product profile, and harvest costs (also reduces hectares harvested per year and improves age classes distribution).

- Reducing the uplift salvage immediately (to reflect the current harvest level) leaves more green timber on the landbase that can be harvested throughout the mid-term. However, this approach comes at a cost from the deteriorating dead pine volumes, as well as, the economic loss from the reduced short-term harvest level.
- Despite the number of times stands can be fertilized, there are limited opportunities for fertilization in the short-term (next 20 years). This is due, in part, to the current lack of stands in suitable age classes (25-80 year old stands). Fertilization opportunities increase 15 years from now.
- Single-fertilization treatments are best carried out closer to harvest to maximize the NPV and minimize risk. While more opportunities for multiple-fertilization treatments are available sooner, risk of investment loss are increased as costs are carried longer.
- Cumulative gains from multiple-fertilization of spruce stands make this treatment the most favourable treatment at a stand level. Still, fertilization of pine stands should not be overlooked given the relative abundance of these stands.
- Fertilization is an important strategy but not as time-sensitive as others. There are several decades before any of the managed stands will be harvested so there's plenty of time to treat them. First, the model selected treatments that offer more immediate and/or larger gains; then fertilization increased as treatment windows closed.
- Rehabilitation offers the largest opportunity and warrants significant investment. It buys wood in the short-term from stands that are not otherwise eligible, plus adds to the long-term harvest by putting these stands into production. Since it is unlikely that all of the available green volume will actually be harvested, revenues assumed to offset treatment costs may be less than assumed in this analysis.
- The area eligible for rehabilitation is largely dependent on access, market prices for fibre and innovative funding mechanisms to promote rehabilitation. This treatment should initially focus on treating younger or burned stands and those with lower merchantability while deferring stands with live volumes that can rehabilitated in the mid-term.
- Given some uncertainty with regenerated stand densities, there are limited opportunities for pre-commercial thinning in the short-term (next 20 years). While this treatment alone provides little direct benefit to timber supply, it can contribute by improving timber quality and preparing suitable stands for other treatments such as fertilization.

This analysis utilized an inventory that is largely un-verified given the recent MPB impacts. Uncertainty around existing volume estimates leads to uncertainty with mid-term harvest levels. If the current inventory overestimates growing stock, then the mid-term harvest levels presented in this analysis will be substantially lower. While the current forest inventory is disconcerting, it should not detract from the results and learning from this analysis. Instead, our focus should be on the relative differences between the Base Case and modeled strategies rather than absolute harvest flow values.

This analysis does not attempt to provide a comprehensive assessment of the full range of treatments available to mitigate mid-term timber supply shortages. The silviculture treatments investigated in this analysis were selected based on expectations that they might: a) increase the

productivity of the landbase, b) increase volumes at final harvest, or c) enhance the quality of harvested products to maximize economic contributions from this fibre. While assumptions were made to reflect the cause and effect relationships expected, existing knowledge gaps and the possibility of unforeseen circumstances (i.e., wildfires, outbreaks of forest insect and disease) must also be considered.

It is clear that no single treatment will solve the forecasted mid-term timber supply shortage. Rather, a diverse suite of scheduled strategies is required that consider the costs, benefits, risks and temporal aspect of forest dynamics.