Morice & Lakes IFPA

Morice & Lakes Innovative Forest Practices Agreement

Benchmarking the Tesera Scheduling Model (TSM) with the Forest Service Simulator (FSSIM)

Prepared for:

Hubert Burger
BC Ministry of Sustainable Resource Management

Prepared by:

Tesera Systems Inc.
Prince George, BC

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Executive Summary

The **Morice & Lakes Innovative Forest Practices Agreement** (IFPA) will be using the **Tesera Scheduling Model** (TSM) to assist in delivering the **IFPA Forestry Plan** and its associated timber supply analysis. In order to use a model other than the British Columbia Forest Service's timber supply model – **Forest Service Simulator** (FSSIM) – for that purpose, the province's Chief Forester requires that such a model be benchmarked with FSSIM so that Forest Service staff gain a better understanding of how the model functions, and can ensure that timber supply effects are a result of innovative practices and not just model differences.

In order to satisfy this requirement, Tesera Systems Inc. completed a benchmarking analysis between TSM and FSSIM using the Lakes Timber Supply Area (TSA) TSR2 data inputs and assumptions. TSM has the capability to provide solutions to forest management problems using a number of modelling approaches including aspatial and spatial simulation as well as aspatial and spatial simulated annealing. Each of these approaches were demonstrated in this benchmarking analysis and the results were compared to the results obtained with FSSIM using an aspatial simulation approach that utilized aspatial approximation rules to mimic green-up and adjacency.

The results of the benchmarking analysis demonstrated that TSM will produce the same harvest flow forecast as FSSIM when TSM is run using the same data inputs, assumptions and modelling approach as FSSIM. The analysis revealed however, that although the same harvest flow forecasts could be obtained, slight differences did exist when other indicators such as growing stock were compared. This difference was shown to be caused by slight differences in how each model projects, evaluates and reports periodic values. When both models were run using annual period lengths, which in effect forced each model to perform and report the simulation in the same manner, all of the timber supply indicators between the two models were identical.

Comparing the results of TSM using a spatial simulation approach to the FSSIM aspatial simulation approach revealed that the spatial approach produced a significantly less optimistic harvest flow forecast. When the spatial forecast from TSM was compared to the TSR2 basecase flow projection, the TSM was able to achieve the harvest flow target over the short and mid-terms but fell short by 8% over the long-term. However, the short and mid-term timber supply projections were achieved by TSM only because surplus timber supply is available over these two time periods due to the TSR2 harvest flow policy requirement that the current AAC for the Lakes TSA be maintained rather than increased. When compared to the alternative maximum non-declining flow forecast used for sensitivity comparisons under TSR2, the spatial simulation forecast achieved by TSM fell short by 13% over the short-term, 0-25 years from now and by 12% over the mid-term, 26-110 years from now. The primary difference between the spatial and aspatial approaches tested, involved explicitly representing the forest cover requirements used under TSR2 to account for spatial green-up and adjacency requirements. Therefore, the differences in the harvest flow projections obtained between the two approaches indicate that the aspatial approximation rules implemented under TSR2 underestimate the actual amount of timber supply bound by adjacency when the rules are implemented explicitly using a spatial modelling approach. In addition, this outcome also reveals that significantly less surplus timber supply is available over the short and mid-terms relative to the estimates forecast through TSR2.

The simulated annealing sensitivities were implemented without allowing for resource target violations in order to ensure that any differences realized could be directly attributed to the modelling approach and not to changes in scenario parameters. However, without allowing for resource target violations, the annealing algorithm was unable to obtain a better timber supply forecast relative to the spatial or aspatial simulations.

Under most circumstances, the simulated annealing algorithm is implemented with the flexibility to violate some or all resource targets if the overall solution is improved. With input from stakeholders, each resource value identified under the analysis is assigned a relative weighting or penalty. The simulated annealing algorithm favors the targets with high penalties, often at the expense of those with low penalties permitting the algorithm to find a near optimal solution which attempts to balance the requirements of competing resource objectives based on inputs from stakeholders. Allowing for resource target violations inherently creates a new scenario with its own unique solution space. Therefore, comparing results obtained with a simulation based scenario where the targets could not be violated with an annealing scenario where target violations were allowed, would be misleading since the results could not be directly linked to the algorithm.

Based on the results of the benchmark analysis, Tesera recommends that a spatial step-wise simulation based approach be used across all the learning scenarios. The objective of the learning scenarios is to provide stakeholders with a clear understanding of the relationships and impacts of various resource objectives. This understanding can most effectively be achieved by applying a spatial step-wise simulation approach that allows for more rapid delivery of solutions and provides results which are easier to explain. Once the learning scenarios are complete and assessed by stakeholders, Tesera recommends that the decision scenario utilize a spatially sensitive simulated annealing based approach. With the knowledge gained from the learning scenarios, stakeholders will be able to make informed and timely resource trade-off decisions necessary to support the simulated annealing approach. The simulated annealing algorithm will then be able to find an optimized solution that best balances the requirements of competing resource objectives based on stakeholder objectives.

1.0 Introduction

Innovative Forest Practices Agreements (IFPAs) are agreements between forest licensees and the BC Ministry of Forests that are intended to encourage testing of new and innovative forest practices aimed at increasing forest productivity and/or improving forest stewardship. A core requirement of each IFPA is the development of a Forestry Plan that describes the intent of the IFPA, the activities that will be implemented, and that is supported by a timber supply analysis. The Regional Manager may approve an increase in Allowable Annual Cut (AAC) based upon the Forestry Plan and its associated timber supply analysis.

Public involvement is a key component of the Morice & Lakes IFPA, and is done through both Scenario Planning Team(s) (SPT) and Public Advisory Group(s) (PAG). The PAG includes local community residents and serves to provide input and feedback to the SPT in the development of resource values and objectives. The SPT is comprised of interested members of the public as well as resource professionals from government agencies and the forest industry. The role of the SPT is to identify resource values and interests – with PAG assistance – and develop possible forest management scenarios to evaluate the impacts of each on identified resource values. These forest management scenarios are referred to as *learning scenarios.* Learning scenarios represent a suite of possible forest management strategies appropriate to emphasize one or more resource values. The forest management objectives of each learning scenario are different and the intent of each scenario is to provide stakeholders with an understanding of the relationship between the proposed management strategy and the identified resource values. Knowledge gained from the learning scenarios facilitate development of a final suite of forest management strategies, referred to as a *decision scenario*, that best balances the values and interests of all stakeholders and offers the best hope of achieving the desired future forest condition. This decision scenario is a fundamental component of the Forestry Plan and will guide the on-the-ground operational activities of the IFPA.

The Morice & Lakes IFPA will be using the Tesera Scheduling Model (TSM) to assist in delivering the IFPA Forestry Plan and its associated timber supply analysis. While there are no specific requirements or limitations on the choice of timber supply model used for IFPAs, BC's Chief Forester has stated in a memorandum dated October 18, 1999 that "any model(s) to be used must be benchmarked with the [Forest Service Simulator] FSSIM to gain a clear understanding of how the model(s) function, and to ensure that timber supply effects can be attributed to innovative practices rather than model differences."

2.0 Purpose & Objectives

In order to satisfy the Chief Forester's requirement, Tesera Systems Inc. completed a benchmarking analysis between TSM and the FSSIM timber supply model used by the BC Forest Service. The results of this analysis are provided in order to demonstrate:

1. the functionality and modelling approaches of TSM relative to FSSIM;
2. that the results of TSM are reliable and consistent with those achieved by FSSIM when TSM utilizes the same data inputs, assumptions and modelling approaches; and,
3. how alternative modelling approaches might affect the results of an analysis under the same set of data inputs and assumptions.

3.0 Tesera Scheduling Model (TSM)

TSM is proprietary software developed by Tesera Systems Inc. beginning in July of 2000 and is based upon earlier conceptual prototypes developed at the McGregor Model Forest Association.

TSM is capable of providing solutions to forest management problems using a variety of modelling approaches as follows:

1. Aspatial Step-wise Simulation
2. Spatial Step-wise Simulation
3. Aspatial Simulated Annealing
4. Spatial Simulated Annealing

Each approach has both advantages and disadvantages and its utility in addressing forest management problems largely depends upon the objectives of the analysis.

3.1. Aspatial vs. Spatial Resolution

In an aspatial analysis, all the polygons within the landbase are generally aggregated into homogenous types regardless of geographic location. These homogenous types are often referred to as forest classes and are defined by the analyst based primarily on the biophysical features (e.g. species/site type) of the stands comprising the class. The analyst has full control over the level of aggregation and the magnitude of aggregation is largely guided by the analysis objectives. As a result of this aggregation, the computational size of the problem can be greatly reduced creating quicker solution times.

Although, not as explicit as a full spatial analysis, most aspatial analyses maintain some level of spatial resolution. When defining forest classes, there is often consideration to geographic location in order to consider resource values such as landscape level biodiversity. Implementation of landscape level biodiversity objectives requires spatial resolution at the landscape unit level. In order to account for this in an aspatial model, forest classes are partitioned by landscape unit. Therefore, instead of having one forest class represent all pine stands on good sites within the TSA, several forest classes are created to represent pine stands on good sites within each individual landscape unit.

Aspatial analyses are often used for strategic forest management planning. Strategic planning is concerned with the big picture implications of implementing various forest management strategies over long planning horizons (250+years). Decision-makers are most interested in general overall trends as a result of implementing various strategies and policies and are less concerned with details around how these strategies may play out on-the-ground in the short term. Concerns are more around "how much" and not "where" particular resource values occur throughout a planning horizon.

In a spatial analysis, results are linked to individual polygons within a landbase. Spatial relationships between neighboring polygons are maintained by the model through an adjacency input table. With this information, a model can ensure that activities are scheduled only when they satisfy the management requirements for block adjacency (e.g. green-up, opening size). In this regard, a spatial analysis is more operationally realistic and can easily be used to guide the development of operational plans and on-the-ground activities.

Spatial analyses allow stakeholders to better understand and interpret the results of an analysis. Results can be presented not only in tabular and graphical format but also in planimetric and 3D views. Stakeholders can not only see "how much" but also "where" the particular resource values occur through space and time. This visualization capability enables easier understanding and ultimately supports better decision-making.

The level of detail gained with a spatial analysis comes with a cost. For the spatial results to be meaningful, all the inventories supporting the resource values within the analysis need to be spatially explicit. Considerable time and resources are required to retrieve and process these inventories into a resultant file to be used by the model. The resulting datasets are quite large and often require workstation level computers and long solution times to solve.

Although TSM was designed primarily as a spatially sensitive model, it can be executed in both aspatial and spatial modes. In aspatial mode, unlike most true aspatial models, individual polygons are the basic scheduling unit. The model does not aggregate polygons into classes nor does it split classes or polygons when scheduling. The fundamental difference between aspatial and spatial modes in TSM is adherence to green-up and adjacency constraints. Solution times are similar for both modes and all results can be mapped.

Since one of the objectives of the Morice & Lakes IFPA is to support operational forest management planning, a spatial analysis will be conducted. The resulting schedule will show where and when activities should occur in order to support the resource objectives identified in the analysis. These results will be used to create forest development plans that will guide operational activities.

3.2. Simulation vs. Optimization

Timber supply models generally employ one of two scheduling algorithms: simulation or optimization. Both algorithms can be used effectively to provide solutions to forest management problems.

Simulation models project the forest inventory and schedule activities period by period, in sequence, using a specific set and schedule of management activities. In each period, candidate areas for treatment are ranked based on user defined rules (e.g. oldest first), and the model attempts to treat a specified amount of area from this candidate list. Most simulation models do not have "look ahead" capabilities. Scheduling decisions made in a given period do not consider scheduling implications for future periods. The analyst inspects the outputs from a given ‘run’ to determine whether it meets the specified management objectives. In order to find the best solution, the analyst runs the model several times, changing model parameters, such as harvest and treatment level targets, and then evaluates the outcomes. Given the large number of possible choices and combinations of treatments, harvest schedules and forest outputs, it is very unlikely that the simulation solution will be optimal. How close a solution is to optimal largely depends upon the skills and experience of the analyst.

Optimization models employ mathematical algorithms to find the best possible (optimal) treatment schedule. The analyst defines an objective function subject to constraints and the model determines the best combinations of treatments, harvest schedules and forest outputs. Objective functions typically maximize or minimize one or more resource values subject to a set of constraints. For example, an objective function may require that harvest levels be maximized, while ensuring that at least 10,000 ha of grizzly bear and 5,000 ha of moose habitat is maintained across the land base, subject to a million dollar per year silviculture budget. A common type of mathematical optimization algorithm used is linear programming. All the relationships between resource values are represented by linear equations and the model uses linear algebra to find the optimal solution. In contrast to simulation, optimization models search for a schedule of activities that will provide the best overall results for the entire planning horizon. Therefore, the implications of scheduling decisions made in a given period are considered by the algorithm for all other periods. This may lead the model to harvest a particular forest type on good sites in the first year of the forecast in order to permit more volume to be available 50 years from now, where there would otherwise be a short-fall in timber supply had other stands been harvested over the short-term.

In recent years, spatially explicit modelling has been at the forefront of forest management planning. Spatial modelling allows more explicit consideration of resource values that are impacted by the spatial arrangement of forest activities. However, since the spatial relationships amongst resource values cannot be explicitly represented linearly, optimization using linear programming is of limited value to spatial planning.

In response, several pseudo-optimization algorithms have been used for spatial modelling. One such algorithm is simulated annealing and is employed within TSM. Simulated annealing is a hybrid between simulation and optimization and is capable of providing near optimal solutions to spatial forest management problems. Near optimal solutions are found by the model’s ability to perform thousands of scheduling iterations. With each iteration, solutions that better achieve user-defined objectives for multiple resource values are accepted while the others are discarded. Iterations are conditionally accepted or rejected based on evaluation of the objective function. In simulated annealing, the objective function is a sum of all the penalty values associated with deviating from a particular resource target value across the entire planning horizon. Iterations that decrease the objective function value are accepted, while those that cause an increase are rejected. The iteration process continues until changes in the objective function value between iterations become negligible to the analyst and he or she stops the model and accepts the last solution provided. Since the annealing algorithm could potentially perform hundreds of thousands of iterations before a near optimal solution is found, the computer processing time required may be considerable, especially if the scenario is complex with many objectives and constraints being applied. However, to find a near optimal solution using a step-wise simulation based approach would require considerably more time since with this approach the analyst must be the optimizer, evaluating resource targets with each iteration and making the necessary scheduling adjustments to improve the solution.

For the IFPA analysis, we propose using TSM in both step-wise simulation and simulated annealing modes. The step-wise simulation approach is proposed for the learning scenarios, since this approach better facilitates the understanding of the forest dynamics acting on the land base and better reveals where resource values and their associated objectives are complimentary and where they may be in conflict. Knowledge gained from the learning scenarios can then be used to formulate a final decision scenario. Since the final decision scenario will form the basis of the IFPA Forestry Plan, it is important that the solution be optimized using a simulated annealing approach. Using optimization, trade-offs between competing resource objectives can be considered based on the knowledge gained from the learning scenarios. Ultimately the decision scenario will deliver a solution that best meets all of the objectives identified by stakeholders in both the Morice TSA and the Lakes TSA.

4.0 Methodology

TSM has the capability to address and provide solutions to forest management problems using a variety of modelling approaches as discussed in the previous section. Each of those approaches was applied under this benchmarking analysis and the results were compared with FSSIM using the Lakes TSA TSR2 dataset and modelling assumptions.

The Lakes TSA TSR2 dataset was obtained from the Ministry of Forest's Timber Supply Analyst. This dataset consisted of the spatial resultant file along with all the growth and yield information used under the TSR2 analysis. The scope and timeframes for this benchmarking analysis did not allow for any additional data to be generated beyond what was already available in the TSR2 dataset. As a result, any information which was aggregated, such as yield curves, forest cover targets, etc. that would otherwise be input explicitly under a spatial approach, were used "as is" under the spatial sensitivities.

To ensure the dataset received was identical to the dataset used under TSR2, the data was loaded into FSSIM by Tesera Systems Inc. and the forecasts obtained were then compared to the results documented in the Lakes TSA TSR2 analysis report. Outputs generated under this preliminary analysis were consistent with results documented in the analysis report thereby ensuring that the correct dataset was used by Tesera Systems Inc..

To facilitate comparisons between TSM and FSSIM, the period length was set to five years across the entire planning horizon for both models, as opposed to five-year periods for the first 20 years and 10-year periods thereafter as implemented in TSR2. TSM reports growing stock at the mid-point of each period as opposed to FSSIM which reports at the beginning and at the end of each period. A comparison of growing stock results between models is easier with shorter planning periods that are consistent throughout the entire planning horizon. With longer planning periods, it is very difficult to compare the growing stock values since the results reported by each model reflect totally different times within the planning horizon. For example, with 10-year periods, FSSIM will report growing stock at time 0 and at 10, 20, and 30 years into the future. TSM however will report growing stock at 5, 15, and 25 years into the future. As a result, the closest growing stock comparison between the models would be off by five years.

Several changes were made under TSR2 relative to TSR1, including lower minimum harvest ages for natural stands and increased site index estimates for managed stands. As a result of these changes under TSR2, over the short and mid-terms, significantly more volume is available for harvest relative to the AAC set under TSR1. However, TSR harvest flow objectives require that the previous AAC set for the TSA be maintained for as long as possible rather than increased.

Since the current harvest level is significantly lower than what the land base is capable of supporting over the short and mid-terms, it is completely insensitive to any changes in the data inputs and assumptions used under the analysis. Therefore, in order to provide meaningful results under the TSR2 sensitivity analysis, the Regional Analyst made comparisons relative to an alternative forecast based on a harvest flow objective that maximized the harvest over the short and mid-terms without allowing for any declines. Similarly, in order to show how varying the modelling approach might impact analysis results under this benchmarking analysis, the maximum non-declining flow forecast under TSR2 was used as the basis for the benchmarking comparisons rather than the basecase flow forecast.

The following sensitivities were completed in an effort to quantify, compare and explain the timber supply effects of using a variety of modelling approaches:

4.1. TSM in aspatial-step-wise simulation mode

Under this sensitivity, TSM was executed in "FSSIM-like" mode employing step-wise simulation algorithms and aspatial approximation rules to address spatially explicit planning issues (i.e. green-up and adjacency). Implementation of TSM under this sensitivity is described as "FSSIM-like" since harvest scheduling is still tied to spatially discreet fragment polygons using the TSR2 resultant coverage. In FSSIM, harvest areas are obtained from aspatial analysis unit classes where the size of the smallest unit is defined by the analyst as an input parameter. Ultimately, the intent of this sensitivity was to demonstrate that both TSM and FSSIM will produce the same results when TSM utilizes the same modelling approach and data inputs and assumptions as FSSIM.

4.2. TSM in aspatial-simulated annealing mode

The purpose of this sensitivity was to quantify the timber supply effects caused when harvest flow projections are obtained by applying simulated annealing algorithms instead of a step-wise simulation based modelling approach. Using a simulated annealing algorithm, TSM is capable of rearranging the timing of harvest events, evaluating the impact of this re-arrangement on the overall solution, and either conditionally accepting or rejecting this new solution. TSM maintains those solutions which better achieve the multiple resource objectives identified in the scenario, leading to a more optimal solution.

4.3. TSM in spatially explicit-step-wise simulation mode

The purpose of this sensitivity was to quantify the timber supply effects caused when harvest flow projections are obtained using a spatially explicit modelling approach. Under this sensitivity, there were two major changes to the modelling approach. Firstly, TSM applied spatially explicit harvest rules and secondly, harvest units were pre-defined using the Tesera Treatment Unit Model.

The aspatial approximation rules for green-up and adjacency used under TSR2 were converted to their spatially explicit equivalents and the resulting harvest schedule was tied to the mapable harvest unit polygons defined by the Tesera Treatment Unit Model. These harvest unit polygons are designed to provide operationally meaningful harvest openings or blocks. The Treatment Unit Model delineates these harvest units based on a number of user input parameters and spatial data sources to ensure the biophysical features of the landbase, harvesting systems to be utilized and any resource emphasis constraints that limit opening sizes are considered.

The treatment unit mapping used for this sensitivity was a draft version developed for the Lakes TSA in order to support other IFPA initiatives and therefore was not based on the same mapping as TSR2. As a result, blocks delineated by the Treatment Unit Model did not reflect the zonations and forest cover inventory information used under TSR, however, for the purposes of the benchmark analysis, it was decided that to re-run the Treatment Unit Model using the TSR2 dataset was not warranted since the purpose of the analysis is to demonstrate the impacts of modelling approaches and not to develop an operationally relevant forest management plan. In addition, the treatment unit mapping was incorporated into the TSR2 resultant by adjusting the treatment unit mapping linework to "best fit" the TSR2 resultant linework in order to avoid creation of a new dataset.

To approximate the timber supply effects of spatial green-up and adjacency requirements under TSR2, early seral forest cover constraints were applied. These constraints ensured that no more than a specified percentage of the timber harvesting landbase (THLB) within some resource emphasis zones were permitted to be below a required green-up height. In all cases, the green-up height requirements were converted to an area weighted average age using height over age curves. This was done under TSR2 since FSSIM does not have the capability to track height over age curves.

To reflect the spatially explicit nature of green-up and adjacency restrictions under this sensitivity, the early seral requirements used under TSR2 were replaced in TSM. This was accomplished by ensuring that when a block is harvested during the simulation, the adjacent blocks become unavailable for harvest until the trees within the harvested block achieve the required green-up height. TSM has the capability to track tree height growth using height over age curves, however, these curves were not preserved in the TSR2 dataset and new height curves could not be prepared under the scope and timeframes of this analysis. As a result, the area weighted average ages by resource emphasis zone reported under TSR2, were used to reflect the necessary adjacency delays required for stands to achieve green-up.

Table A below, lists the early seral forest cover requirements by resource emphasis zone, applied under TSR2 to account for the timber supply impacts of green-up and adjacency requirements, relative to the harvest scheduling rules implemented under TSM using a spatially sensitive modelling approach.

Table A: Green-up and adjacency parameters by Resource Emphasis Zone within the Lakes TSA

Resource Emphasis Zone	TSR2 green-up and adjacency approximation implemented	TSM spatially explicit green-up and adjacency harvest rule implemented	Comments
VQOs			
Significant Visual Retention	No green-up and adjacency approximations applied.	Consistent with TSR2, no green-up and adjacency restrictions applied.	The rate of harvest in visual polygons is regulated through maximum denudation targets set by VQO. District policy permits blocks to exceed 60 ha in size within visually sensitive areas.
Visual Retention			
Significant Visual Partial Retention			
Visual Partial Retention			
Caribou Migration Corridors			
Very High Value	No green-up and adjacency approximations applied.	Consistent with TSR2, no green-up and adjacency restrictions applied.	No harvesting is permitted within this zone except for mountain pine beetle salvage, however, no more than 2% of the THLB may be less than 29 years of age at any time.
High Value	No green-up and adjacency approximations applied.	Consistent with TSR2, no green-up and adjacency restrictions applied.	District policy within these zones require the creation of large contiguous openings through harvesting subject to maximum early and minimum mature and old seral forest cover targets.
Moderate Value			
Low Value	No more than 33% of the THLB may be less than 17 years of age at any time.	Harvested openings cannot exceed 60 ha in size and at least 17 years must elapse before adjacent blocks may be harvested.	FPC maximum 60 ha, 3-meter green-up adjacency requirements apply to this zone in addition to maximum early and minimum mature and old seral forest cover targets.

Other			
High Moose and Deer Winter Range	No more than 33% of the THLB may be less than 17 years of age at any time.	Harvested openings cannot exceed 60 ha in size and at least 17 years must elapse before adjacent blocks may be harvested.	FPC maximum 60 ha, 3-meter green-up adjacency requirements apply to this zone in addition to minimum mature seral forest cover targets.
Very High Value Deer Winter Range	No more than 25% of the THLB may be less than 27 years of age at any time.	Harvested openings cannot exceed 4 ha in size and at least 27 years must elapse before adjacent blocks may be harvested.	District policy requires that harvested openings not exceed 4 ha in size and that trees achieve 5 meters in height before adjacent areas may be harvested in addition to minimum mature seral forest cover targets.
Recreation Areas	No green-up and adjacency approximations applied.	Consistent with TSR2, no green-up and adjacency restrictions applied.	No maximum opening size restrictions are assumed, however, the rate of harvest in recreation areas is regulated through a maximum early seral target.
Backcountry Lakes	No green-up and adjacency approximations applied.	Consistent with TSR2, no green-up and adjacency restrictions applied.	No harvesting is permitted within this zone except for mountain pine beetle salvage, however, no more than 2% of the THLB may be less than 38 years of age at any time.
Grizzly Areas	No more than 33% of the THLB may be less than 28 years of age at any time.	Harvested openings cannot exceed 60 ha in size and at least 28 years must elapse before adjacent blocks may be harvested.	The FPC maximum 60 ha opening size restriction is applied, however, trees must achieve 5 meters in height before adjacent areas may be harvested in addition to minimum mature seral forest cover targets.
Integrated Resource Management Zones	No more than 33% of the THLB may be less than 17 years of age at any time.	Harvested openings cannot exceed 60 ha in size and at least 17 years must elapse before adjacent blocks may be harvested.	FPC maximum 60 ha, 3-meter green-up adjacency requirements apply to this zone in addition to landscape level biodiversity targets for early, mature and old seral forest.

4.4. TSM in spatially explicit-simulated annealing mode

The objective of this sensitivity was to quantify the timber supply effects of utilizing a near-optimal, spatially-explicit modelling approach toward obtaining results relative to the approach used by FSSIM under TSR2.

5.0 Results

5.1. Aspatial step-wise simulation

The results of the aspatial simulation component of the benchmarking analysis are illustrated in *Figures 1, 2,* and *3* following. As anticipated, the basecase harvest flow reported in the TSR2 analysis report was achieved by both models when executed in aspatial step-wise simulation mode *(Figure 1)*.

Figure 1, below, graphically illustrates the harvest flows obtained from TSM relative to the forecast generated by FSSIM when TSM was run in aspatial step-wise simulation mode utilizing the same data inputs and assumptions as those used under the Lakes TSA TSR2 basecase analysis.

Figure 1: Harvest flows obtained from TSM in aspatial step-wise simulation mode relative to the FSSIM TSR2 basecase

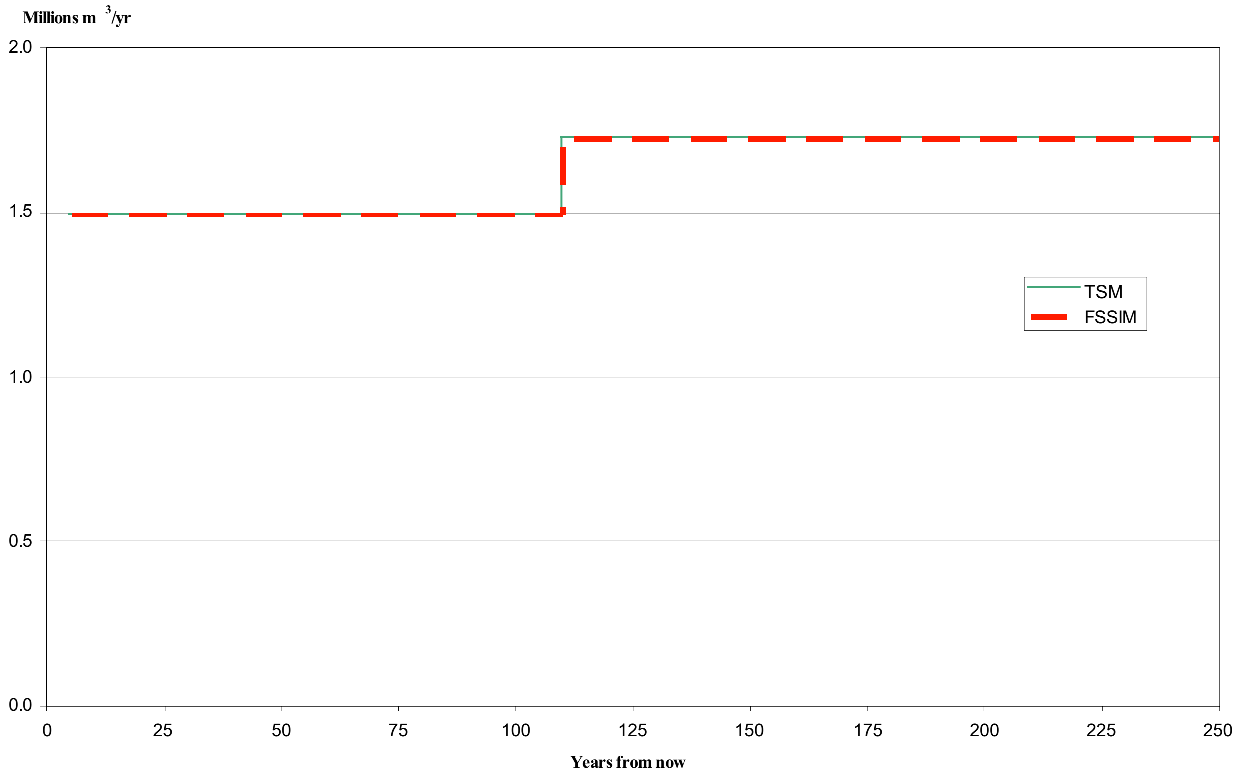

Table 1, following, shows the data from *Figure 1* above in tabular form.

Table 1: Harvest flows obtained from TSM in aspatial step-wise simulation mode relative to the FSSIM TSR2 basecase

Period Number	Years from Now	FSSIM Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	TSM Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	Percent Difference in Flow Relative to FSSIM
1	0-5	1,493,976	0%	1,493,976	0%	0%
2	6-10	1,493,976	0%	1,493,976	0%	0%
3	11-15	1,493,976	0%	1,493,976	0%	0%
4	16-20	1,493,976	0%	1,493,976	0%	0%
5	21-25	1,493,976	0%	1,493,976	0%	0%
6	26-30	1,493,976	0%	1,493,976	0%	0%
7	31-35	1,493,976	0%	1,493,975	0%	0%
8	36-40	1,493,976	0%	1,493,976	0%	0%
9	41-45	1,493,976	0%	1,493,976	0%	0%
10	46-50	1,493,976	0%	1,493,976	0%	0%
11	51-55	1,493,976	0%	1,493,975	0%	0%
12	56-60	1,493,976	0%	1,493,976	0%	0%
13	61-65	1,493,976	0%	1,493,975	0%	0%
14	66-70	1,493,976	0%	1,493,976	0%	0%
15	71-75	1,493,976	0%	1,493,976	0%	0%
16	76-80	1,493,976	0%	1,493,976	0%	0%
17	81-85	1,493,976	0%	1,493,976	0%	0%
18	86-90	1,493,976	0%	1,493,976	0%	0%
19	91-95	1,493,976	0%	1,493,976	0%	0%
20	96-100	1,493,976	0%	1,493,976	0%	0%
21	101-105	1,493,976	0%	1,493,976	0%	0%
22	106-110	1,493,976	0%	1,493,976	0%	0%
23	111-115	1,726,976	16%	1,726,976	16%	0%
24	116-120	1,726,976	0%	1,726,976	0%	0%
25	121-125	1,726,976	0%	1,726,976	0%	0%
26	126-130	1,726,976	0%	1,726,976	0%	0%
27	131-135	1,726,976	0%	1,726,976	0%	0%
28	136-140	1,726,976	0%	1,726,976	0%	0%
29	141-145	1,726,976	0%	1,726,976	0%	0%
30	146-150	1,726,976	0%	1,726,976	0%	0%
31	151-155	1,726,976	0%	1,726,976	0%	0%
32	156-160	1,726,976	0%	1,726,976	0%	0%
33	161-165	1,726,976	0%	1,726,976	0%	0%
34	166-170	1,726,976	0%	1,726,975	0%	0%
35	171-175	1,726,976	0%	1,726,976	0%	0%
36	176-180	1,726,976	0%	1,726,975	0%	0%
37	181-185	1,726,976	0%	1,726,975	0%	0%
38	186-190	1,726,976	0%	1,726,975	0%	0%
39	191-195	1,726,976	0%	1,726,976	0%	0%
40	196-200	1,726,976	0%	1,726,976	0%	0%
41	201-205	1,726,976	0%	1,726,976	0%	0%
42	206-210	1,726,976	0%	1,726,975	0%	0%
43	211-215	1,726,976	0%	1,726,976	0%	0%
44	216-220	1,726,976	0%	1,726,976	0%	0%
45	221-225	1,726,976	0%	1,726,976	0%	0%
46	226-230	1,726,976	0%	1,726,975	0%	0%
47	231-235	1,726,976	0%	1,726,976	0%	0%
48	236-240	1,726,976	0%	1,726,976	0%	0%
49	241-245	1,726,976	0%	1,726,976	0%	0%
50	246-250	1,726,976	0%	1,726,976	0%	0%

The resulting growing stock forecasts output from each model are also very similar – as shown in *Figure 2*, below, and *Table 2*, following.

Figure 2: Growing stock forecasts obtained from TSM in aspatial step-wise simulation mode relative to the FSSIM TSR2 basecase

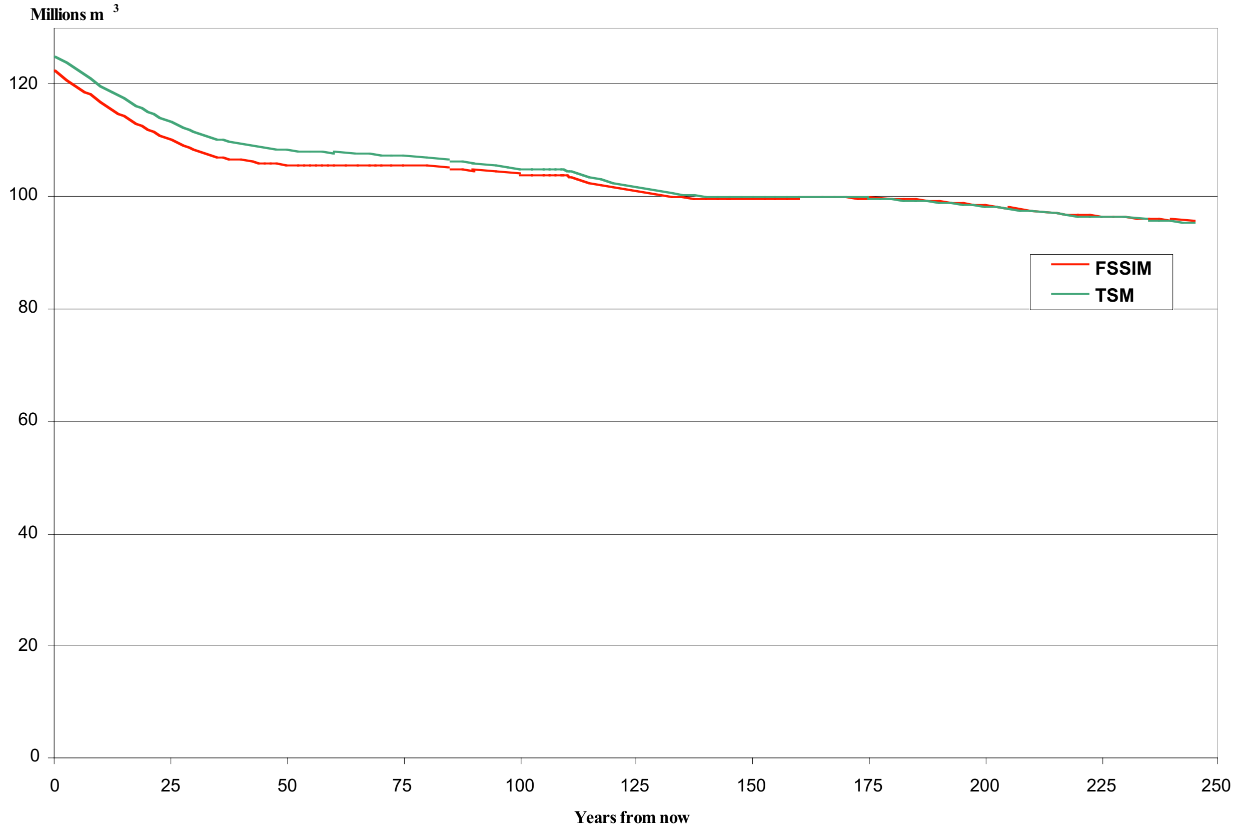

Table 2: Growing stock forecasts obtained from TSM in aspatial step-wise simulation mode relative to the FSSIM TSR2 basecase

Period	Years from Now	FSSIM THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	TSM THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	Percent Difference in Growing Stock Relative to FSSIM
1	0	122,292,672	0%	125,078,543	0%	2%
2	5	119,398,760	-2%	122,374,984	-2%	2%
3	10	116,782,808	-2%	119,786,400	-2%	3%
4	15	114,183,088	-2%	117,388,616	-2%	3%
5	20	111,875,128	-2%	115,128,408	-2%	3%
6	25	109,959,216	-2%	113,209,408	-2%	3%
7	30	108,291,616	-2%	111,461,580	-2%	3%
8	35	107,092,704	-1%	110,234,719	-1%	3%
9	40	106,459,968	-1%	109,398,151	-1%	3%
10	45	105,925,648	-1%	108,736,600	-1%	3%
11	50	105,685,832	0%	108,255,817	0%	2%
12	55	105,502,472	0%	107,972,462	0%	2%
13	60	105,626,856	0%	107,818,123	0%	2%
14	65	105,602,760	0%	107,624,046	0%	2%
15	70	105,690,104	0%	107,438,720	0%	2%
16	75	105,515,072	0%	107,130,744	0%	2%
17	80	105,317,568	0%	106,740,328	0%	1%
18	85	104,979,904	0%	106,312,800	0%	1%
19	90	104,589,280	0%	105,846,288	0%	1%
20	95	104,225,600	0%	105,423,335	0%	1%
21	100	103,911,664	0%	104,998,895	0%	1%
22	105	103,658,600	0%	104,696,031	0%	1%
23	110	103,599,800	0%	104,596,432	0%	1%
24	115	102,527,600	-1%	103,478,808	-1%	1%
25	120	101,647,728	-1%	102,518,720	-1%	1%
26	125	100,894,776	-1%	101,641,535	-1%	1%
27	130	100,253,112	-1%	100,917,784	-1%	1%
28	135	99,866,728	0%	100,418,104	0%	1%
29	140	99,555,808	0%	100,061,712	0%	1%
30	145	99,473,264	0%	99,882,016	0%	0%
31	150	99,518,848	0%	99,784,784	0%	0%
32	155	99,646,088	0%	99,783,136	0%	0%
33	160	99,708,168	0%	99,811,816	0%	0%
34	165	99,749,088	0%	99,796,525	0%	0%
35	170	99,738,624	0%	99,699,455	0%	0%
36	175	99,615,568	0%	99,568,938	0%	0%
37	180	99,508,448	0%	99,398,413	0%	0%
38	185	99,426,096	0%	99,227,757	0%	0%
39	190	99,160,424	0%	98,976,743	0%	0%
40	195	98,838,728	0%	98,647,702	0%	0%
41	200	98,370,360	0%	98,231,263	0%	0%
42	205	97,878,080	-1%	97,756,235	0%	0%
43	210	97,430,112	0%	97,349,479	0%	0%
44	215	97,038,528	0%	96,909,120	0%	0%
45	220	96,740,176	0%	96,522,039	0%	0%
46	225	96,420,560	0%	96,303,635	0%	0%
47	230	96,219,768	0%	96,071,375	0%	0%
48	235	95,951,512	0%	95,832,472	0%	0%
49	240	95,780,280	0%	95,615,607	0%	0%
50	245	95,605,168	0%	95,333,550	0%	0%

Table 2 reveals that initially, the growing stock reported by TSM is slightly higher than the growing stock reported by FSSIM. However, after 140 years into the projection, growing stock differences become negligible (<1%) for the remainder of the planning horizon.

The reason for the growing stock difference early in the planning horizon is attributable to a number of slight model differences. As explained earlier, TSM projects the inventory to the mid-point of each period prior to scheduling harvests. Since period length under the benchmark analysis was set at five years across the entire planning horizon, the inventory was projected consistently by three years in each period prior to harvest scheduling. FSSIM on the other hand, schedules its first period harvest based on the time 0 volumes and its second period harvest based on stand volumes five years into the projection. As a result, the inventory in TSM actually has a three year growth advantage over FSSIM at the beginning of the planning horizon prior to any harvest scheduling. As shown in *Table 2*, this difference results in 2% more growing stock being reported by TSM relative to FSSIM.

In contrast to TSM, FSSIM also has "look-ahead" functionality that allows the model to "look-ahead" to the end of the period to evaluate age-dependant factors such as achievement of minimum harvest age (MHA). If the "look-ahead" reveals that certain stands unavailable for harvest at the beginning of the period become available at some point during the period (e.g. due to achievement of MHA or because they are no longer bound by forest cover constraints), then FSSIM may schedule these stands for harvest, if required to achieve the harvest flow target. For example, in Period 1 MHA achievement in FSSIM is evaluated based on the time 0 age + five years.

TSM does not implement this type of "look-ahead" during sequential simulation. In each period, scheduling decisions are based solely on the projected age class structure of the forest at the mid-point of the current planning period. Therefore, in contrast to FSSIM, achievement of MHA in Period 1 in TSM is based on the time 0 age + three years compared with the time 0 age + five years in FSSIM. This "look-ahead" difference has some impact on the scheduling choices of each model during "pinch-points" and could ultimately have some impact on model results over the short and mid-terms.

The difference in growing stock reported by the models diminishes over time as the growing stock begins to stabilize and the forest becomes "normalized". The productive capacity of the forest is exactly the same in each model and given the same harvest level and management regime, the growing stock values will always stabilize at the same level in the long-term; regardless of initial forest state.

The impact of these model differences on results is more pronounced with longer planning periods. With 10-year periods for example, TSM will age all stands by five years at the beginning of the planning horizon before scheduling any harvests, giving the inventory a five year growth advantage over FSSIM. Also, in FSSIM with 10-year planning periods and its "look-ahead" functionality, stands will reach MHA five years sooner than in TSM.

Based on these functionality differences between FSSIM and TSM, it is anticipated that if the period length was set to one year in each model and the initial ages in FSSIM were increased by one year, then the growing stock reports for each would be identical. To test this, the initial ages in FSSIM were increased by one year and both models were re-run using one-year planning periods.

As anticipated, *Figure 3* and *Table 3*, following, reveal near identical growing stock levels when both models are executed with these changes.

Figure 3: Growing stock forecasts obtained from TSM relative to FSSIM when both models were executed in aspatial step-wise simulation mode with one-year planning periods

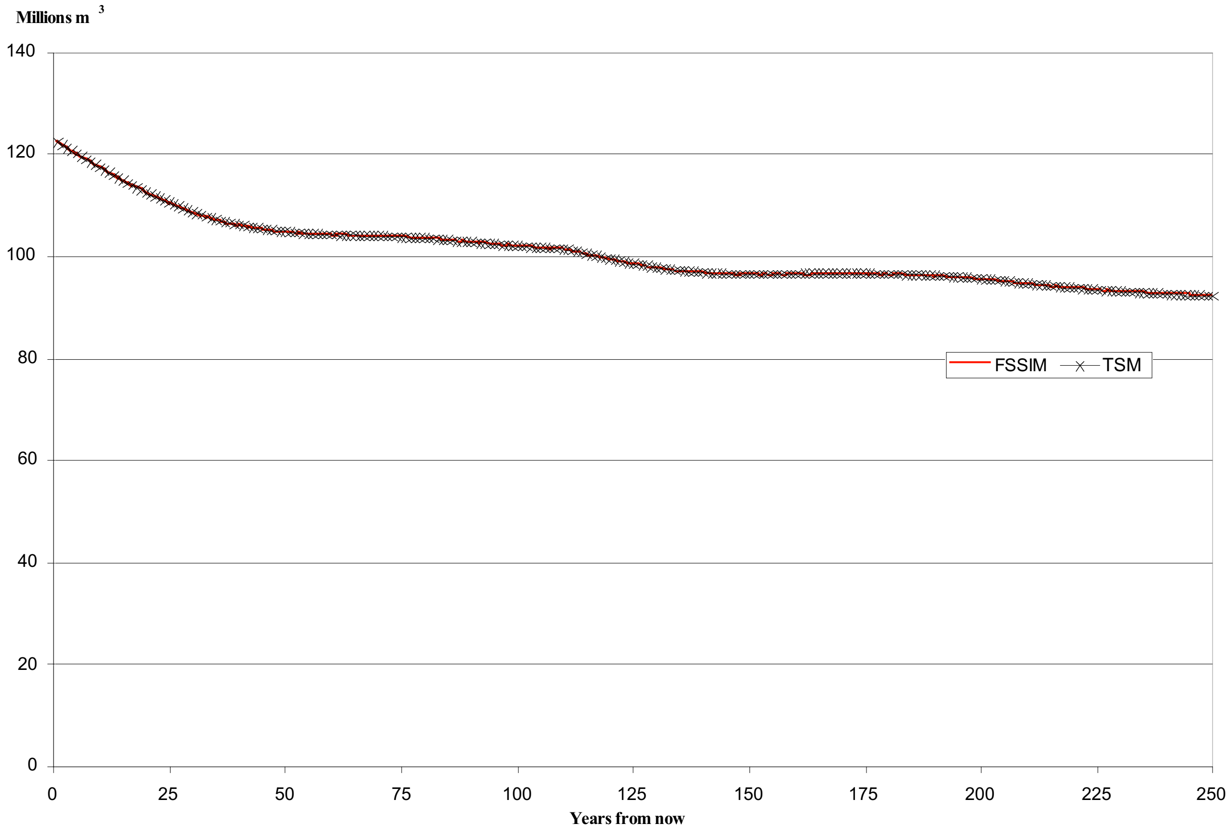

Table 3: Growing stock forecasts obtained from TSM relative to FSSIM when both models were executed in aspatial step-wise simulation mode with one-year planning periods

Period	Years from Now	FSSIM THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	TSM THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	Percent Difference in Growing Stock Relative to FSSIM
1	1	122,292,680	0%	122,301,895	0%	0%
5	5	120,011,240	-2%	120,021,576	-2%	0%
10	10	117,378,520	-2%	117,399,087	-2%	0%
15	15	114,799,880	-2%	114,831,472	-2%	0%
20	20	112,477,128	-2%	112,512,685	-2%	0%
25	25	110,374,608	-2%	110,468,239	-2%	0%
30	30	108,536,512	-2%	108,637,590	-2%	0%
35	35	107,003,080	-1%	107,144,707	-1%	0%
40	40	105,996,024	-1%	106,132,705	-1%	0%
45	45	105,244,232	-1%	105,370,006	-1%	0%
50	50	104,691,880	-1%	104,807,408	-1%	0%
55	55	104,282,152	0%	104,379,991	0%	0%
60	60	104,107,552	0%	104,196,928	0%	0%
65	65	103,965,232	0%	104,023,564	0%	0%
70	70	103,892,312	0%	103,930,670	0%	0%
75	75	103,715,928	0%	103,724,541	0%	0%
80	80	103,506,440	0%	103,510,119	0%	0%
85	85	103,147,272	0%	103,127,102	0%	0%
90	90	102,765,464	0%	102,751,972	0%	0%
95	95	102,325,080	0%	102,336,477	0%	0%
100	100	101,920,400	0%	101,962,246	0%	0%
105	105	101,543,752	0%	101,626,176	0%	0%
110	110	101,313,256	0%	101,420,896	0%	0%
115	115	100,352,056	-1%	100,478,960	-1%	0%
120	120	99,295,568	-1%	99,424,320	-1%	0%
125	125	98,418,264	-1%	98,544,244	-1%	0%
130	130	97,662,864	-1%	97,776,768	-1%	0%
135	135	97,085,224	-1%	97,186,848	-1%	0%
140	140	96,686,896	0%	96,788,855	0%	0%
145	145	96,421,760	0%	96,517,511	0%	0%
150	150	96,331,080	0%	96,418,487	0%	0%
155	155	96,355,656	0%	96,430,496	0%	0%
160	160	96,421,208	0%	96,509,944	0%	0%
165	165	96,460,120	0%	96,546,102	0%	0%
170	170	96,488,200	0%	96,584,088	0%	0%
175	175	96,447,880	0%	96,547,619	0%	0%
180	180	96,356,280	0%	96,464,920	0%	0%
185	185	96,227,016	0%	96,346,584	0%	0%
190	190	96,020,192	0%	96,186,188	0%	0%
195	195	95,708,096	0%	95,896,183	0%	0%
200	200	95,360,520	0%	95,555,766	0%	0%
205	205	94,923,592	0%	95,141,197	0%	0%
210	210	94,464,040	0%	94,617,984	-1%	0%
215	215	94,072,064	0%	94,184,743	0%	0%
220	220	93,693,496	0%	93,759,724	0%	0%
225	225	93,344,032	0%	93,387,078	0%	0%
230	230	93,063,048	0%	93,063,672	0%	0%
235	235	92,828,456	0%	92,817,014	0%	0%
240	240	92,596,776	0%	92,567,575	0%	0%
245	245	92,410,504	0%	92,339,719	0%	0%
250	250	92,238,040	0%	92,165,623	0%	0%

It is also important to mention that both FSSIM and TSM are capable of avoiding a "lock out" situation from occurring where constraints set for a resource emphasis zone are currently in violation at the start of the planning horizon. Both models use the same approach, where stands within a zone that are closest to the constraint's (e.g. old seral, maximum ECA by watershed, etc) target threshold parameter (old age, ECA percentage, etc) are sorted and the area for each is cumulatively summed until sufficient area is identified to satisfy the target. These stands are then temporarily made unavailable for harvest until the last stand identified in the list ages sufficiently to achieve the constraint's target threshold parameter, after which time, the stands are released for harvest. This approach therefore, allows for harvests to occur within the resource emphasis zone, even though targets are currently in violation, since the time required for the zone to achieve targets is not jeopardized due to the recruitment of stands made unavailable for harvest. In FSSIM, this feature is inherent within the model and is therefore always "on" in each run. In TSM, the analyst has full control over which zones they may wish to implement "lock out" until constraints are satisfied and in which zones they may wish to use the recruitment strategy under a particular scenario. The recruitment strategy produces a more optimistic timber supply forecast than "lock out", particularly within the short and mid-term periods of the planning horizon.

Figure 4, below, and *Table 4*, following, illustrate the average annual area harvested by TSM and FSSIM where both models are using an aspatial simulation approach and the identical data inputs and assumptions as per the Lakes TSA TSR2 basecase.

Figure 4: Average annual area harvested by TSM relative to FSSIM when both models were executed using an aspatial step-wise simulation approach

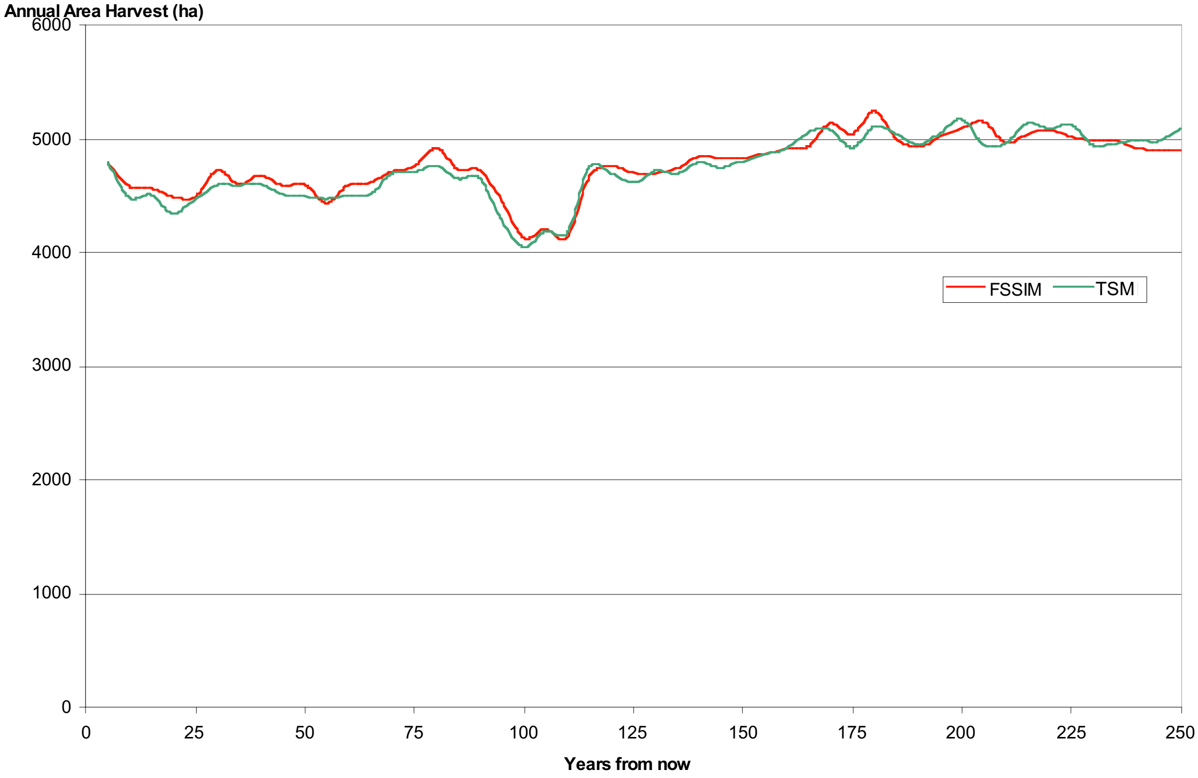

Table 4: Average annual area harvested by TSM relative to FSSIM when both models were executed using an aspatial step-wise simulation approach

Period Number	Years from Now	FSSIM Area Harvested Forecast (ha/yr.)	Percent Difference in Area Harvested Relative to the Previous Period	TSM Area Harvested Forecast (ha/yr.)	Percent Difference in Area Harvested Relative to the Previous Period	Percent Difference in Area Harvested Relative to FSSIM
1	0-5	4,784	0%	4,789	0%	0%
2	6-10	4,585	-4%	4,486	-6%	-2%
3	11-15	4,569	0%	4,509	1%	-1%
4	16-20	4,492	-2%	4,344	-4%	-3%
5	21-25	4,492	0%	4,468	3%	-1%
6	26-30	4,723	5%	4,595	3%	-3%
7	31-35	4,602	-3%	4,593	0%	0%
8	36-40	4,679	2%	4,604	0%	-2%
9	41-45	4,590	-2%	4,515	-2%	-2%
10	46-50	4,598	0%	4,494	0%	-2%
11	51-55	4,437	-4%	4,474	0%	1%
12	56-60	4,595	4%	4,499	1%	-2%
13	61-65	4,616	0%	4,514	0%	-2%
14	66-70	4,716	2%	4,697	4%	0%
15	71-75	4,757	1%	4,708	0%	-1%
16	76-80	4,920	3%	4,768	1%	-3%
17	81-85	4,736	-4%	4,651	-2%	-2%
18	86-90	4,724	0%	4,650	0%	-2%
19	91-95	4,455	-6%	4,286	-8%	-4%
20	96-100	4,132	-7%	4,049	-6%	-2%
21	101-105	4,209	2%	4,188	3%	-1%
22	106-110	4,133	-2%	4,174	0%	1%
23	111-115	4,670	13%	4,756	14%	2%
24	116-120	4,765	2%	4,694	-1%	-2%
25	121-125	4,701	-1%	4,615	-2%	-2%
26	126-130	4,699	0%	4,720	2%	0%
27	131-135	4,742	1%	4,696	-1%	-1%
28	136-140	4,844	2%	4,791	2%	-1%
29	141-145	4,834	0%	4,750	-1%	-2%
30	146-150	4,834	0%	4,805	1%	-1%
31	151-155	4,869	1%	4,865	1%	0%
32	156-160	4,915	1%	4,916	1%	0%
33	161-165	4,936	0%	5,060	3%	3%
34	166-170	5,139	4%	5,083	0%	-1%
35	171-175	5,042	-2%	4,924	-3%	-2%
36	176-180	5,245	4%	5,109	4%	-3%
37	181-185	5,012	-4%	5,049	-1%	1%
38	186-190	4,929	-2%	4,952	-2%	0%
39	191-195	5,016	2%	5,046	2%	1%
40	196-200	5,096	2%	5,175	3%	2%
41	201-205	5,152	1%	4,949	-4%	-4%
42	206-210	4,969	-4%	4,962	0%	0%
43	211-215	5,041	1%	5,138	4%	2%
44	216-220	5,082	1%	5,090	-1%	0%
45	221-225	5,021	-1%	5,128	1%	2%
46	226-230	4,990	-1%	4,945	-4%	-1%
47	231-235	4,991	0%	4,960	0%	-1%
48	236-240	4,919	-1%	4,991	1%	1%
49	241-245	4,900	0%	4,982	0%	2%
50	246-250	4,906	0%	5,093	2%	4%

Figure 4 reveals that over the short and mid-terms, TSM harvests 1.5% less area than FSSIM in order to achieve the same harvest flow target. Over the long-term, 111-250 years from now, the area harvested by both models is essentially identical.

As explained earlier, in contrast to FSSIM, TSM ages all forest stands by one-half the periodic length at the start of the planning horizon before any harvest scheduling. Consequently, the overall age of the forest in the TSM projection is three years older than in FSSIM at the beginning of the projection. Since older stands generally yield more volume, TSM doesn't have to harvest as much area as FSSIM in order to achieve the same target harvest level. As seen in *Figure 5*, TSM harvests consistently older stands than FSSIM over the short and mid-terms.

Figure 5, below, and *Table 5*, following, illustrate the periodic average area-weighted age harvested by TSM and FSSIM where both models are using an aspatial simulation approach and the identical data inputs and assumptions as per the Lakes TSA TSR2 basecase.

Figure 5: Periodic average area-weighted age harvested by TSM relative to FSSIM when both models were executed using an aspatial step-wise simulation approach

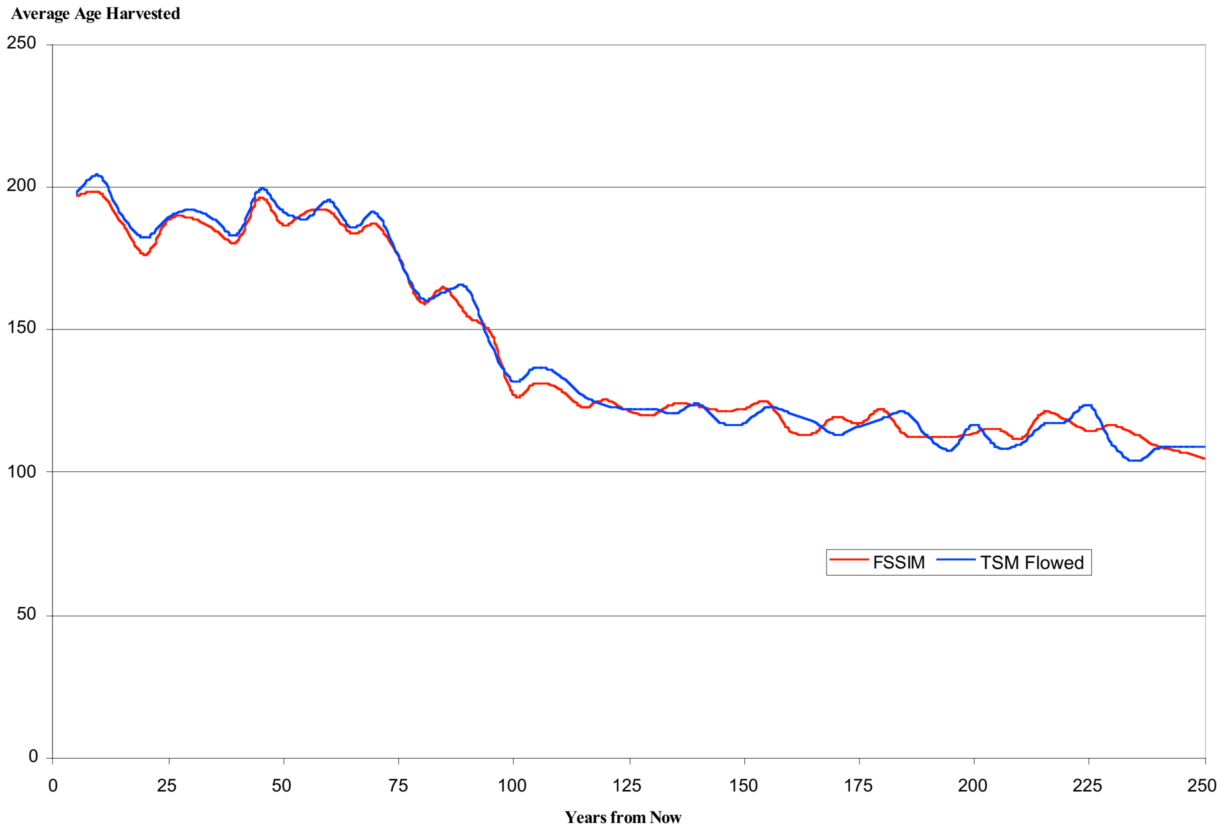

Table 5: Periodic average area-weighted age harvested by TSM relative to FSSIM when both models were executed using an aspatial step-wise simulation approach

Period Number	Years from Now	FSSIM Average Age Harvested	Percent Change Relative to the Previous Period	TSM Average Age Harvested	Percent Change Relative to the Previous Period	Percent Difference in Average Age Harvested Relative to FSSIM
1	0-5	197	0%	198	0%	1%
2	6-10	198	1%	204	3%	3%
3	11-15	187	-5%	190	-7%	1%
4	16-20	176	-6%	182	-4%	3%
5	21-25	188	7%	189	4%	1%
6	26-30	189	0%	192	1%	2%
7	31-35	185	-2%	189	-2%	2%
8	36-40	181	-2%	183	-3%	1%
9	41-45	196	8%	199	9%	2%
10	46-50	187	-5%	191	-4%	2%
11	51-55	191	2%	189	-1%	-1%
12	56-60	191	0%	195	3%	2%
13	61-65	184	-4%	185	-5%	1%
14	66-70	187	2%	191	3%	2%
15	71-75	176	-6%	175	-8%	0%
16	76-80	159	-9%	161	-8%	1%
17	81-85	165	3%	163	1%	-1%
18	86-90	155	-6%	164	1%	6%
19	91-95	149	-4%	145	-12%	-3%
20	96-100	127	-15%	132	-9%	4%
21	101-105	131	3%	137	4%	4%
22	106-110	129	-2%	134	-2%	4%
23	111-115	123	-5%	127	-5%	3%
24	116-120	125	2%	124	-3%	-1%
25	121-125	121	-3%	122	-1%	0%
26	126-130	120	-1%	122	0%	2%
27	131-135	124	3%	121	-1%	-3%
28	136-140	123	-1%	124	3%	1%
29	141-145	122	-1%	117	-5%	-4%
30	146-150	122	0%	117	0%	-4%
31	151-155	125	2%	123	5%	-1%
32	156-160	115	-8%	121	-1%	5%
33	161-165	114	-1%	118	-3%	4%
34	166-170	120	5%	113	-4%	-5%
35	171-175	117	-2%	116	2%	-1%
36	176-180	122	4%	119	2%	-3%
37	181-185	113	-7%	121	2%	7%
38	186-190	113	0%	112	-7%	0%
39	191-195	112	0%	108	-4%	-4%
40	196-200	114	1%	117	8%	3%
41	201-205	115	1%	109	-7%	-6%
42	206-210	112	-3%	110	1%	-2%
43	211-215	121	8%	117	6%	-4%
44	216-220	118	-2%	118	1%	-1%
45	221-225	115	-3%	123	5%	8%
46	226-230	116	2%	110	-11%	-6%
47	231-235	113	-3%	104	-6%	-9%
48	236-240	109	-4%	108	4%	0%
49	241-245	107	-2%	109	1%	2%
50	246-250	105	-2%	109	0%	4%

As the forest becomes "normalized" over the long-term, the age class distributions in both models more closely resemble one another. As a result, on average over the long-term, both models harvest stands at the same age and thus on average, harvest a similar amount of area to achieve the target harvest level.

Although, the average area and age harvested over the long-term is essentially identical in both models, the actual periodic comparisons are often quite different. The reasons for these differences are likely due to a number of slight model differences, some of which were explained earlier.

Although both models use the relative oldest first harvest queue method when scheduling harvests, TSM's scheduling unit is tied to individual polygons within the spatial resultant file. Therefore, when moving through the harvest queue, TSM must harvest the entire polygon. In cases where harvesting the entire polygon will exceed the harvest level target, TSM will continue moving down the queue into younger stands until it finds an eligible polygon that will not cause a harvest level violation.

FSSIM's scheduling unit however consists of forest classes that can be split down to a resolution of 0.1 ha if required, to more closely meet the target harvest level. Therefore when moving through the harvest queue, FSSIM will only harvest the portion of the class required to meet the target harvest level and since the unit resolution permitted by the model can be quite small, it can meet the target harvest level without moving further down the queue into younger aged stands.

As already mentioned, FSSIM also implements "look-ahead" for MHA and forest cover constraint (FCC) evaluation. As a result of this "look-ahead" to the end of the period, FSSIM may harvest stands before they reach MHA and may also harvest stands that violate FCC based on the premise that the requirements will be met before the end of the planning period. TSM however evaluates both MHA and FCC based strictly on the age-class distribution at the mid-point of the planning period.

These model differences will have some impact on the schedules produced by FSSIM and TSM and likely explains the periodic differences over the long-term revealed in *Figures 4* and *5*.

5.2. Spatial step-wise simulation

As described in Section 4.3, this sensitivity tests the timber supply effect of applying a spatial approach towards forecasting rather than the aspatial approach used under TSR. As mentioned, the two fundamental changes made to the basecase scenario parameters were to tie harvest scheduling to pre-defined treatment units or blocks rather than aspatial area classes where the smallest area unit available for harvest is defined by the analyst. In addition, the adjacency relationships between blocks are maintained within the input dataset through an adjacency table. Secondly, the aspatial approximation rules based on early seral forest cover constraints used in TSR to account for the binding effect of spatial green-up and adjacency requirements, were replaced by the explicit green-up age requirements specified in the TSR2 information package for each resource emphasis zone. Adjacency was then evaluated between the blocks delineated on the treatment unit mapping. All other data inputs and assumptions remained unchanged, relative to the TSR2 basecase scenario.

Figure 6 and *Table 6* illustrate the harvest flows obtained from TSM utilizing a spatially explicit, step-wise simulation based approach. The figure compares the unflowed and flowed forecast from TSM relative to the basecase forecast obtained under TSR2 using FSSIM.

Figure 6: Flowed and unflowed harvest flow forecasts obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 basecase harvest flow

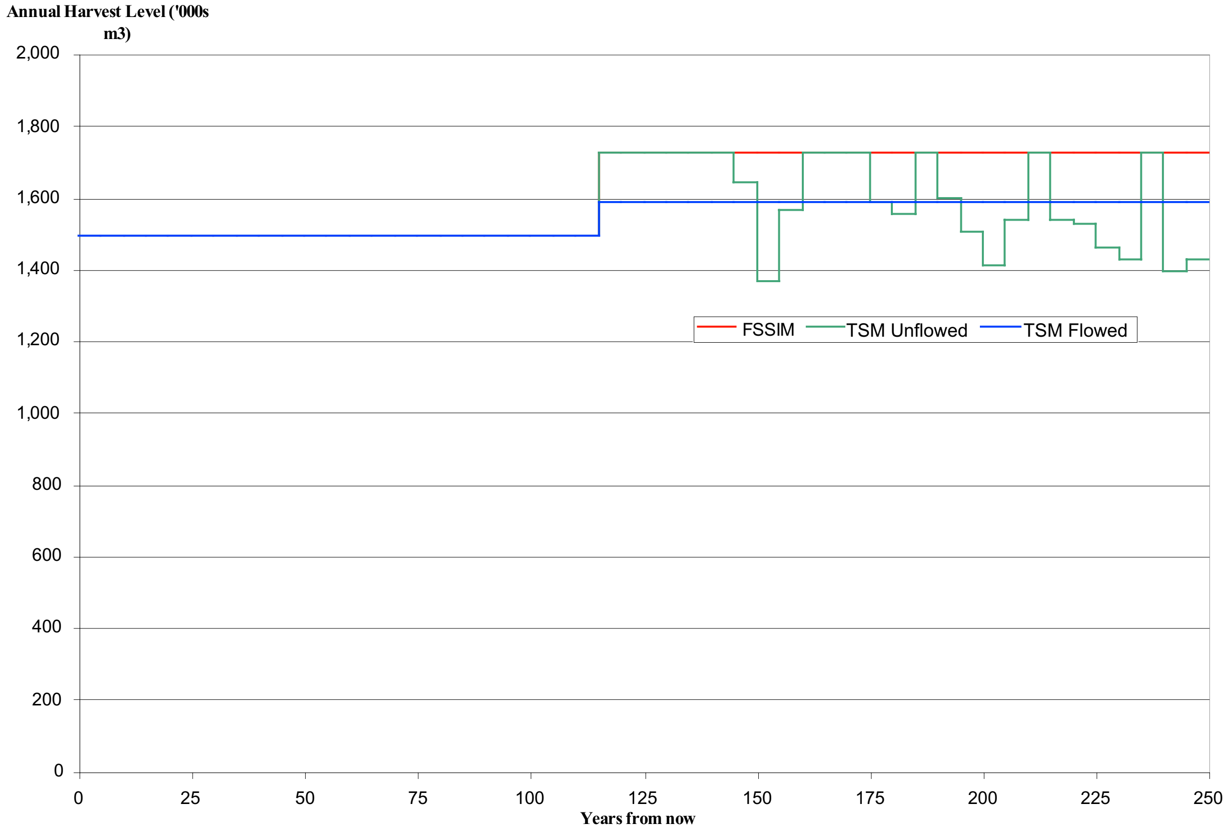

Table 6: Flowed and unflowed harvest flow forecasts obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 basecase harvest flow

Period Number	Years from Now	FSSIM Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	TSM Unflowed Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	Percent Difference in Flow Relative to FSSIM	TSM Flowed Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	Percent Difference in Flow Relative to FSSIM
1	0-5	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
2	6-10	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
3	11-15	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
4	16-20	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
5	21-25	1,493,976	0%	1,493,973	0%	0%	1,493,973	0%	0%
6	26-30	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
7	31-35	1,493,976	0%	1,493,970	0%	0%	1,493,970	0%	0%
8	36-40	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
9	41-45	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
10	46-50	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
11	51-55	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
12	56-60	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
13	61-65	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
14	66-70	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
15	71-75	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
16	76-80	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
17	81-85	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
18	86-90	1,493,976	0%	1,493,976	0%	0%	1,493,976	0%	0%
19	91-95	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
20	96-100	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
21	101-105	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
22	106-110	1,493,976	0%	1,493,975	0%	0%	1,493,975	0%	0%
23	111-115	1,726,976	16%	1,726,975	16%	0%	1,588,000	6%	-8%
24	116-120	1,726,976	0%	1,726,976	0%	0%	1,588,000	0%	-8%
25	121-125	1,726,976	0%	1,726,976	0%	0%	1,588,000	0%	-8%
26	126-130	1,726,976	0%	1,726,975	0%	0%	1,587,999	0%	-8%
27	131-135	1,726,976	0%	1,726,974	0%	0%	1,588,000	0%	-8%
28	136-140	1,726,976	0%	1,726,974	0%	0%	1,587,999	0%	-8%
29	141-145	1,726,976	0%	1,645,098	-5%	-5%	1,588,000	0%	-8%
30	146-150	1,726,976	0%	1,368,345	-17%	-21%	1,587,999	0%	-8%
31	151-155	1,726,976	0%	1,565,753	14%	-9%	1,587,999	0%	-8%
32	156-160	1,726,976	0%	1,726,976	10%	0%	1,587,999	0%	-8%
33	161-165	1,726,976	0%	1,726,976	0%	0%	1,588,000	0%	-8%
34	166-170	1,726,976	0%	1,726,976	0%	0%	1,587,999	0%	-8%
35	171-175	1,726,976	0%	1,585,607	-8%	-8%	1,587,999	0%	-8%
36	176-180	1,726,976	0%	1,552,518	-2%	-10%	1,588,000	0%	-8%
37	181-185	1,726,976	0%	1,726,972	11%	0%	1,587,999	0%	-8%
38	186-190	1,726,976	0%	1,598,415	-7%	-7%	1,588,000	0%	-8%
39	191-195	1,726,976	0%	1,503,724	-6%	-13%	1,588,000	0%	-8%
40	196-200	1,726,976	0%	1,408,167	-6%	-18%	1,588,000	0%	-8%
41	201-205	1,726,976	0%	1,535,235	9%	-11%	1,587,999	0%	-8%
42	206-210	1,726,976	0%	1,726,975	12%	0%	1,588,000	0%	-8%
43	211-215	1,726,976	0%	1,538,712	-11%	-11%	1,588,000	0%	-8%
44	216-220	1,726,976	0%	1,528,811	-1%	-11%	1,587,999	0%	-8%
45	221-225	1,726,976	0%	1,460,497	-4%	-15%	1,588,000	0%	-8%
46	226-230	1,726,976	0%	1,427,414	-2%	-17%	1,588,000	0%	-8%
47	231-235	1,726,976	0%	1,724,121	21%	0%	1,588,000	0%	-8%
48	236-240	1,726,976	0%	1,392,883	-19%	-19%	1,587,999	0%	-8%
49	241-245	1,726,976	0%	1,428,736	3%	-17%	1,588,000	0%	-8%
50	246-250	1,726,976	0%	1,655,234	16%	-4%	1,587,999	0%	-8%

Figure 6 reveals that no timber supply effects are realized over the short and mid-terms when the basecase is run spatially. However, over the long-term, beginning 111 years from now, significant short falls occur relative to the LTHL achieved under TSR2. The flowed forecast over the long-term, when spatial constraints are applied explicitly, indicate an 8% reduction in the LTHL, from 1.726 million cubic metres per year under an aspatial approach to 1.588 million cubic metres per year under a spatially explicit approach. This would indicate that the forest cover constraint applied under TSR2 to account for the binding effect of spatial adjacency requirements is insufficient.

As discussed in Section 4.0, the harvest flow objective under TSR required that the current AAC for the Lakes TSA be maintained for as long as possible, however, significantly more volume is available for harvest over the short and mid-terms relative to the current AAC. As a result, the harvest forecast over this period is very insensitive to any changes in data inputs, assumptions and modelling approaches. It is anticipated that under a tight forecast in which all of the available volume is harvested subject to an alternative harvest flow objective, that significant short-falls would be realized under a spatially explicit approach, relative to the forecast obtained using an aspatial approach based on the TSR2 spatial approximation rules.

The significant amount of slack over the short and mid-terms due to the harvest flow objectives specified in the TSR2 basecase was recognized in the TSR2 analysis report. As noted in Section 4.0, the sensitivity analyses performed under TSR2 were based on a maximum non-declining harvest flow objective rather than the basecase forecast which maintained the current AAC. This was done in an effort to show potential short and mid-term impacts due to uncertainties in the analysis, based on changes to data inputs and assumptions. Consistent with TSR2, the remaining three sensitivities will also use the maximum non-declining flow forecast as the basis for comparison so that similarly, any short and mid-term impacts as a result of varying modelling approaches are realized.

Figure 7 and *Table 7*, following, show the harvest forecast obtained by TSM in spatially explicit mode, relative to the maximum non-declining flow forecast obtained under TSR2 through an aspatial approach.

Figure 7: Flowed and unflowed harvest flow forecasts obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 maximum non-declining harvest flow forecast

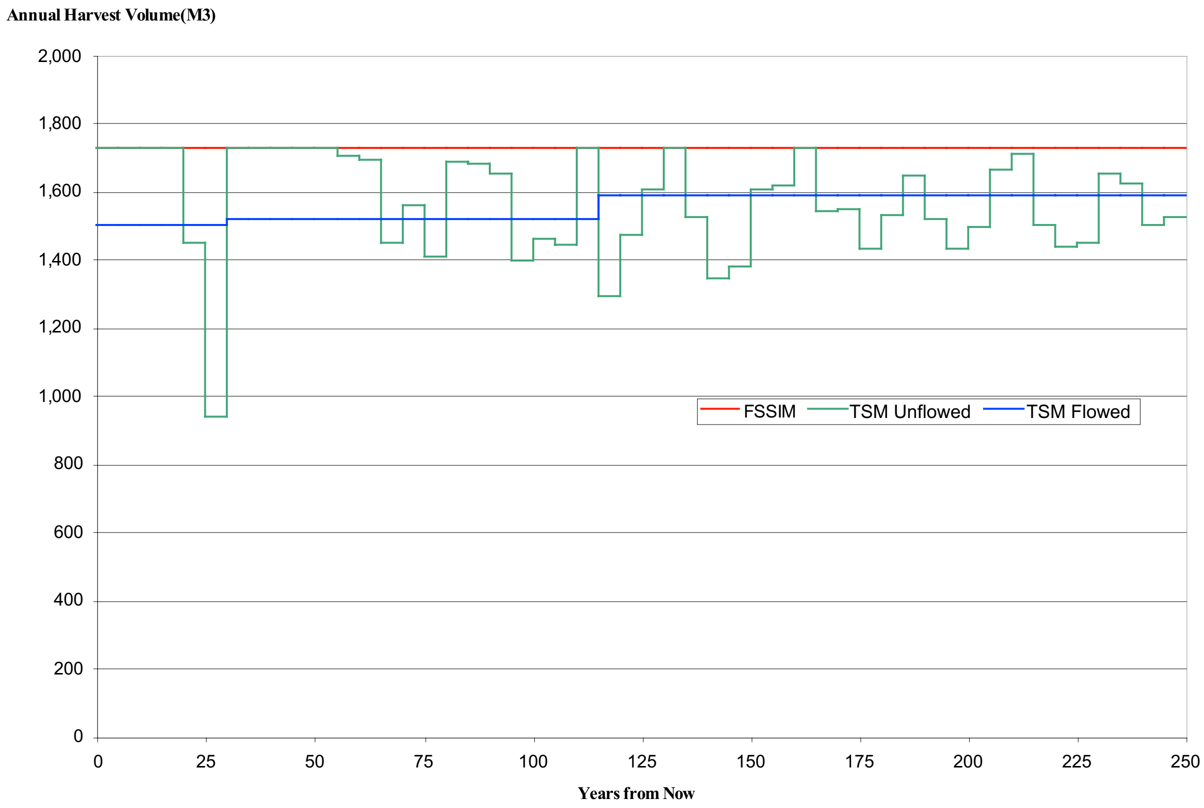

Table 7: Flowed and unflowed harvest flow forecasts obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 maximum non-declining harvest flow forecast

Period Number	Years from Now	FSSIM Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	TSM Unflowed Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	Percent Difference in Flow Relative to FSSIM	TSM Flowed Harvest Flow Forecast (m^3/yr.)	Percent Difference in Flow Relative to the Previous Period	Percent Difference in Flow Relative to FSSIM
1	0-5	1,726,976	0%	1,726,976	0%	0%	1,499,180	0%	-13%
2	6-10	1,726,976	0%	1,726,976	0%	0%	1,499,179	0%	-13%
3	11-15	1,726,976	0%	1,726,975	0%	0%	1,499,179	0%	-13%
4	16-20	1,726,976	0%	1,448,416	-16%	-16%	1,499,179	0%	-13%
5	21-25	1,726,976	0%	937,495	-35%	-46%	1,499,162	0%	-13%
6	26-30	1,726,976	0%	1,726,967	84%	0%	1,519,987	1%	-12%
7	31-35	1,726,976	0%	1,726,976	0%	0%	1,520,000	0%	-12%
8	36-40	1,726,976	0%	1,726,975	0%	0%	1,520,000	0%	-12%
9	41-45	1,726,976	0%	1,726,974	0%	0%	1,519,998	0%	-12%
10	46-50	1,726,976	0%	1,726,975	0%	0%	1,519,999	0%	-12%
11	51-55	1,726,976	0%	1,704,187	-1%	-1%	1,519,999	0%	-12%
12	56-60	1,726,976	0%	1,693,297	-1%	-2%	1,519,999	0%	-12%
13	61-65	1,726,976	0%	1,447,117	-15%	-16%	1,520,000	0%	-12%
14	66-70	1,726,976	0%	1,559,452	8%	-10%	1,519,999	0%	-12%
15	71-75	1,726,976	0%	1,405,854	-10%	-19%	1,520,000	0%	-12%
16	76-80	1,726,976	0%	1,685,147	20%	-2%	1,519,999	0%	-12%
17	81-85	1,726,976	0%	1,682,711	0%	-3%	1,520,000	0%	-12%
18	86-90	1,726,976	0%	1,651,802	-2%	-4%	1,520,000	0%	-12%
19	91-95	1,726,976	0%	1,397,864	-15%	-19%	1,520,000	0%	-12%
20	96-100	1,726,975	0%	1,458,054	4%	-16%	1,519,999	0%	-12%
21	101-105	1,726,976	0%	1,440,158	-1%	-17%	1,519,999	0%	-12%
22	106-110	1,726,976	0%	1,726,961	20%	0%	1,520,000	0%	-12%
23	111-115	1,726,976	0%	1,292,090	-25%	-25%	1,588,000	4%	-8%
24	116-120	1,726,976	0%	1,469,331	14%	-15%	1,588,000	0%	-8%
25	121-125	1,726,976	0%	1,603,758	9%	-7%	1,587,999	0%	-8%
26	126-130	1,726,976	0%	1,726,965	8%	0%	1,587,999	0%	-8%
27	131-135	1,726,976	0%	1,522,213	-12%	-12%	1,587,999	0%	-8%
28	136-140	1,726,976	0%	1,342,012	-12%	-22%	1,588,000	0%	-8%
29	141-145	1,726,976	0%	1,376,047	3%	-20%	1,587,999	0%	-8%
30	146-150	1,726,976	0%	1,607,196	17%	-7%	1,588,000	0%	-8%
31	151-155	1,726,976	0%	1,614,803	0%	-6%	1,587,999	0%	-8%
32	156-160	1,726,976	0%	1,726,974	7%	0%	1,587,999	0%	-8%
33	161-165	1,726,976	0%	1,540,536	-11%	-11%	1,587,999	0%	-8%
34	166-170	1,726,976	0%	1,544,496	0%	-11%	1,588,000	0%	-8%
35	171-175	1,726,976	0%	1,431,111	-7%	-17%	1,588,000	0%	-8%
36	176-180	1,726,976	0%	1,531,248	7%	-11%	1,588,000	0%	-8%
37	181-185	1,726,976	0%	1,645,706	7%	-5%	1,587,999	0%	-8%
38	186-190	1,726,976	0%	1,515,718	-8%	-12%	1,588,000	0%	-8%
39	191-195	1,726,976	0%	1,432,624	-5%	-17%	1,588,000	0%	-8%
40	196-200	1,726,976	0%	1,494,537	4%	-13%	1,587,999	0%	-8%
41	201-205	1,726,976	0%	1,662,652	11%	-4%	1,588,000	0%	-8%
42	206-210	1,726,976	0%	1,710,991	3%	-1%	1,588,000	0%	-8%
43	211-215	1,726,976	0%	1,500,742	-12%	-13%	1,587,999	0%	-8%
44	216-220	1,726,976	0%	1,437,667	-4%	-17%	1,588,000	0%	-8%
45	221-225	1,726,976	0%	1,448,412	1%	-16%	1,587,999	0%	-8%
46	226-230	1,726,976	0%	1,650,493	14%	-4%	1,587,999	0%	-8%
47	231-235	1,726,976	0%	1,620,916	-2%	-6%	1,588,000	0%	-8%
48	236-240	1,726,976	0%	1,502,520	-7%	-13%	1,588,000	0%	-8%
49	241-245	1,726,976	0%	1,520,913	1%	-12%	1,588,000	0%	-8%
50	246-250	1,726,976	0%	1,631,583	7%	-6%	1,588,000	0%	-8%

Figure 7 reveals significant shortfalls in timber supply over the entire planning horizon, relative to the maximum non-declining flow forecast obtained under TSR2. The flowed forecast using TSM in spatially explicit mode shows an initial harvest level of 1.499 million cubic metres per year increasing by 1%, 25 years from now, to 1.520 million cubic metres per year, and a further 4% increase, 110 years from now, to a LTHL of 1.588 million cubic metres per year. The timber supply effect of representing green-up and adjacency requires an average 12.5% reduction in harvest flow over the short and mid-terms, relative to the aspatial flow forecast obtained under TSR2. In addition, relative to the current AAC for the Lakes TSA of 1.493 million cubic metres per year, the maximum non-declining flow forecast achieved spatially over the short and mid-terms only represents an average timber supply increase of 1.1%, while aspatially, the increase reported was 16%. As a result, it can be concluded that the forest cover constraint applied in TSR to account for green-up and adjacency restrictions is underestimating the binding effect of the constraint over the short and mid-terms. In addition, the TSR2 results would indicate that more surplus volume is available for harvest over this time period than is actually the case.

Over the long-term, the timber supply effects when compared to the maximum non-declining flow forecast, remained the same relative to the earlier comparison made using the basecase harvest flow forecast.

Figure 8, below, and *Table 8*, following, illustrate the growing stock levels output by TSM, relative to FSSIM, under the alternative maximum non-declining flow forecast objective.

Figure 8: Growing stock forecast obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 maximum non-declining growing stock flow forecast

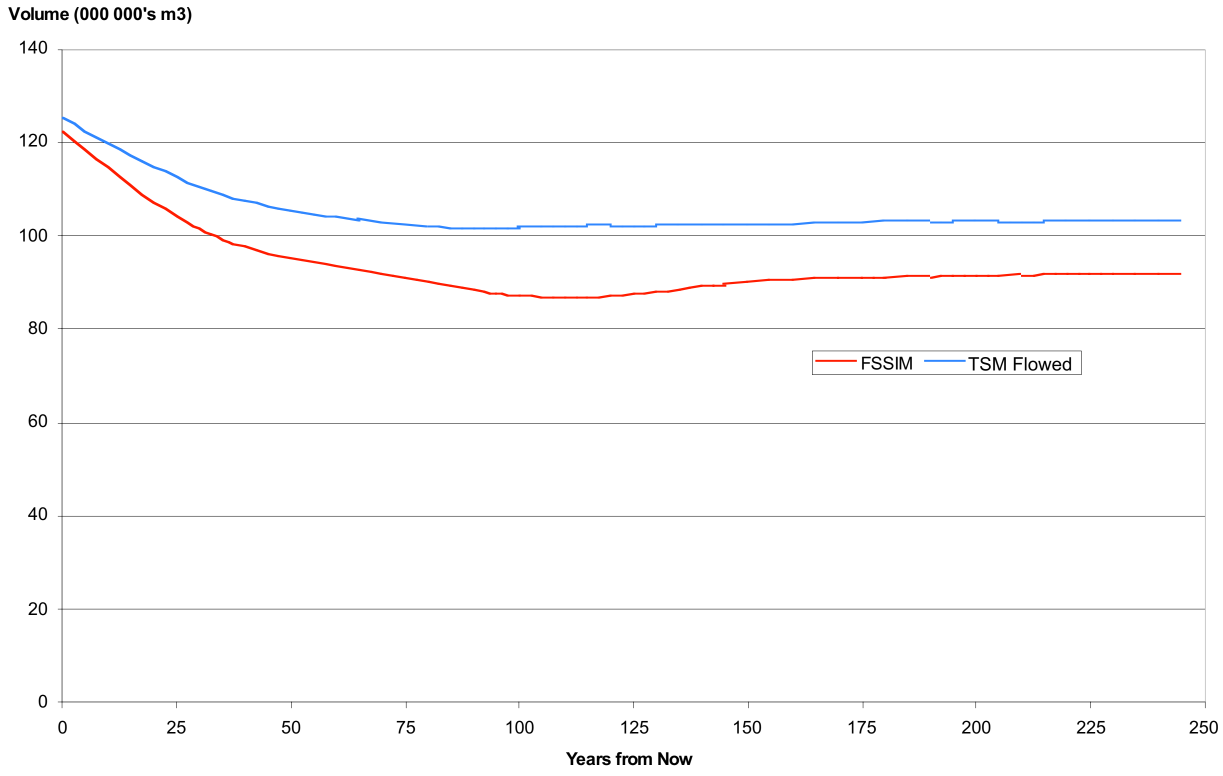

Table 8: Growing stock forecast obtained from TSM in spatial step-wise simulation mode relative to the FSSIM TSR2 maximum non-declining growing stock flow forecast

Period	Years from Now	FSSIM THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	TSM Flowed THLB Growing Stock (m^3)	Percent Change in Growing Stock Relative to the Previous Period	Percent Difference in Growing Stock Relative to FSSIM
1	0	122,292,672	0%	125,078,484	0%	2%
2	5	118,226,464	-3%	122,348,817	-2%	3%
3	10	114,427,288	-3%	119,719,832	-2%	5%
4	15	110,649,264	-3%	117,226,375	-2%	6%
5	20	107,140,472	-3%	114,791,128	-2%	7%
6	25	104,074,504	-3%	112,497,741	-2%	8%
7	30	101,285,808	-3%	110,327,343	-2%	9%
8	35	99,129,232	-2%	108,693,246	-1%	10%
9	40	97,534,648	-2%	107,342,096	-1%	10%
10	45	96,178,760	-1%	106,233,156	-1%	10%
11	50	95,101,816	-1%	105,248,973	-1%	11%
12	55	94,257,072	-1%	104,483,908	-1%	11%
13	60	93,584,416	-1%	103,886,207	-1%	11%
14	65	92,756,040	-1%	103,266,612	-1%	11%
15	70	91,913,528	-1%	102,732,302	-1%	12%
16	75	90,882,576	-1%	102,293,124	0%	13%
17	80	89,920,448	-1%	101,913,968	0%	13%
18	85	89,028,000	-1%	101,621,064	0%	14%
19	90	88,235,824	-1%	101,513,432	0%	15%
20	95	87,485,424	-1%	101,512,884	0%	16%
21	100	87,053,440	0%	101,640,962	0%	17%
22	105	86,697,680	0%	101,841,375	0%	17%
23	110	86,583,344	0%	102,049,679	0%	18%
24	115	86,636,824	0%	101,978,823	0%	18%
25	120	86,941,016	0%	101,936,036	0%	17%
26	125	87,339,024	0%	101,893,108	0%	17%
27	130	87,840,440	1%	101,976,861	0%	16%
28	135	88,441,416	1%	102,096,910	0%	15%
29	140	88,983,064	1%	102,176,997	0%	15%
30	145	89,390,256	0%	102,212,070	0%	14%
31	150	89,742,328	0%	102,235,210	0%	14%
32	155	90,079,480	0%	102,249,045	0%	14%
33	160	90,333,952	0%	102,325,065	0%	13%
34	165	90,513,552	0%	102,426,176	0%	13%
35	170	90,653,448	0%	102,523,880	0%	13%
36	175	90,749,368	0%	102,670,328	0%	13%
37	180	90,877,008	0%	102,786,179	0%	13%
38	185	90,973,600	0%	102,885,863	0%	13%
39	190	91,098,624	0%	102,942,247	0%	13%
40	195	91,166,240	0%	102,895,363	0%	13%
41	200	91,188,296	0%	102,850,816	0%	13%
42	205	91,311,408	0%	102,814,696	0%	13%
43	210	91,421,664	0%	102,809,045	0%	12%
44	215	91,552,424	0%	102,830,350	0%	12%
45	220	91,583,952	0%	102,853,724	0%	12%
46	225	91,653,096	0%	102,887,805	0%	12%
47	230	91,555,104	0%	102,913,558	0%	12%
48	235	91,492,720	0%	102,923,103	0%	12%
49	240	91,453,080	0%	102,886,262	0%	13%
50	245	91,443,672	0%	102,815,871	0%	12%

Figure 8 reveals that TSM maintains more growing stock throughout the planning horizon since TSM harvest levels are significantly lower as a result of spatially explicit green-up and adjacency restrictions. Over the short and mid-terms, TSM growing stock levels are on average 10% higher, relative to the levels maintained by FSSIM and over the long-term, growing stock levels are on average 14% higher. These percent differences in growing stock directly reflect the additional volume above minimum harvest age that are constrained by green-up and adjacency restrictions when the rules are applied explicitly.

Figure 9, below, and *Table 9*, following, show the average annual area harvested by TSM, relative to FSSIM, under the alternative maximum non-declining flow forecast objective.

Figure 9: Average annual area harvested by TSM in spatial step-wise simulation mode relative to the average annual area harvested by FSSIM under the TSR2 maximum non-declining harvest flow forecast

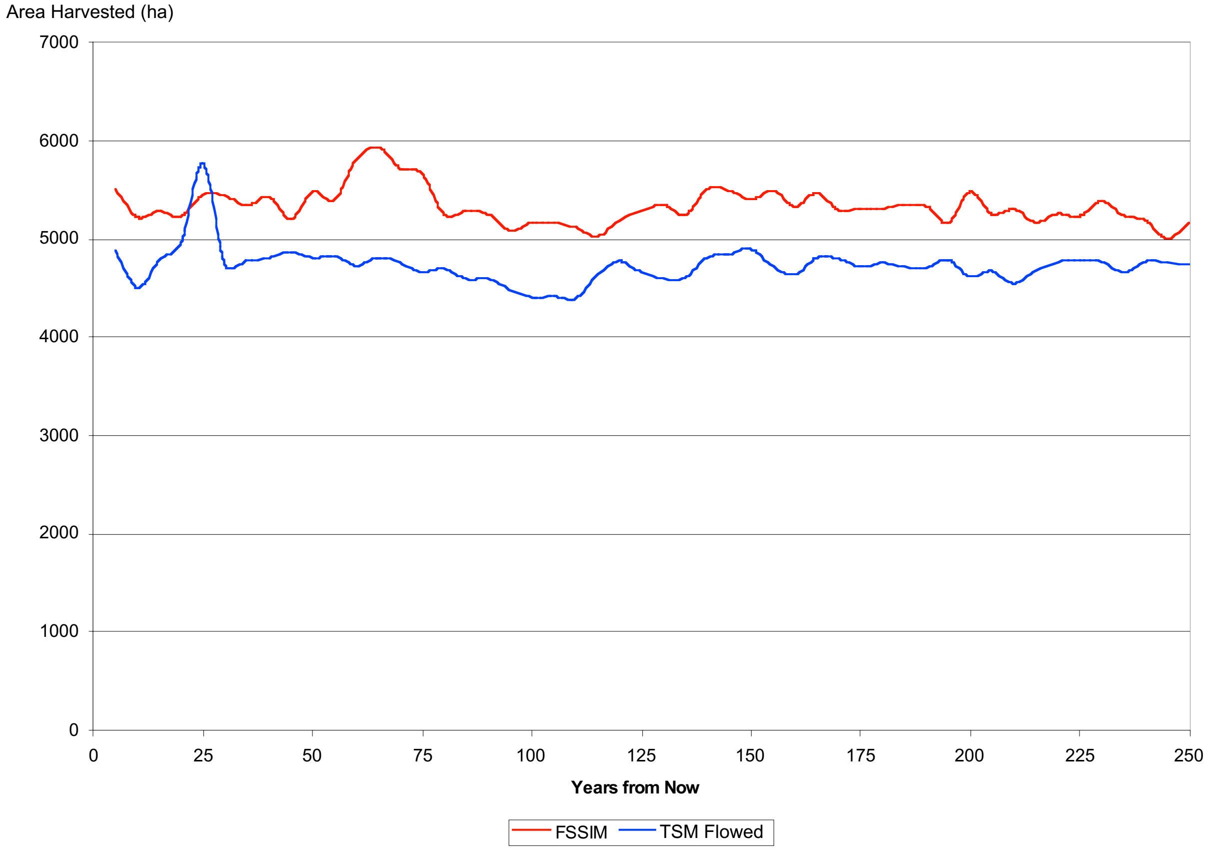

Table 9: Average annual area harvested by TSM in spatial step-wise simulation mode relative to the average annual area harvested by FSSIM under the TSR2 maximum non-declining harvest flow forecast

Period Number	Years from Now	FSSIM Area Harvested Forecast (ha/yr.)	Percent Difference in Area Harvested Relative to the Previous Period	TSM Area Harvested Forecast (ha/yr.)	Percent Difference in Area Harvested Relative to the Previous Period	Percent Difference in Area Harvested Relative to FSSIM
1	0-5	5,496	0%	4,871	0%	-11%
2	6-10	5,221	-5%	4,503	-8%	-14%
3	11-15	5,277	1%	4,781	6%	-9%
4	16-20	5,226	-1%	4,967	4%	-5%
5	21-25	5,446	4%	5,764	16%	6%
6	26-30	5,435	0%	4,732	-18%	-13%
7	31-35	5,339	-2%	4,773	1%	-11%
8	36-40	5,426	2%	4,808	1%	-11%
9	41-45	5,197	-4%	4,867	1%	-6%
10	46-50	5,476	5%	4,806	-1%	-12%
11	51-55	5,397	-1%	4,822	0%	-11%
12	56-60	5,802	8%	4,726	-2%	-19%
13	61-65	5,934	2%	4,810	2%	-19%
14	66-70	5,715	-4%	4,750	-1%	-17%
15	71-75	5,663	-1%	4,662	-2%	-18%
16	76-80	5,247	-7%	4,692	1%	-11%
17	81-85	5,278	1%	4,592	-2%	-13%
18	86-90	5,251	-1%	4,590	0%	-13%
19	91-95	5,081	-3%	4,482	-2%	-12%
20	96-100	5,162	2%	4,404	-2%	-15%
21	101-105	5,163	0%	4,413	0%	-15%
22	106-110	5,112	-1%	4,391	0%	-14%
23	111-115	5,023	-2%	4,633	6%	-8%
24	116-120	5,184	3%	4,771	3%	-8%
25	121-125	5,286	2%	4,657	-2%	-12%
26	126-130	5,344	1%	4,590	-1%	-14%
27	131-135	5,243	-2%	4,607	0%	-12%
28	136-140	5,505	5%	4,809	4%	-13%
29	141-145	5,494	0%	4,842	1%	-12%
30	146-150	5,399	-2%	4,895	1%	-9%
31	151-155	5,493	2%	4,716	-4%	-14%
32	156-160	5,327	-3%	4,635	-2%	-13%
33	161-165	5,463	3%	4,805	4%	-12%
34	166-170	5,289	-3%	4,799	0%	-9%
35	171-175	5,307	0%	4,710	-2%	-11%
36	176-180	5,308	0%	4,754	1%	-10%
37	181-185	5,348	1%	4,714	-1%	-12%
38	186-190	5,332	0%	4,708	0%	-12%
39	191-195	5,158	-3%	4,785	2%	-7%
40	196-200	5,474	6%	4,613	-4%	-16%
41	201-205	5,249	-4%	4,670	1%	-11%
42	206-210	5,299	1%	4,545	-3%	-14%
43	211-215	5,167	-2%	4,677	3%	-9%
44	216-220	5,253	2%	4,763	2%	-9%
45	221-225	5,229	0%	4,787	0%	-8%
46	226-230	5,382	3%	4,765	0%	-11%
47	231-235	5,237	-3%	4,657	-2%	-11%
48	236-240	5,184	-1%	4,768	2%	-8%
49	241-245	4,996	-4%	4,760	0%	-5%
50	246-250	5,159	3%	4,738	0%	-8%

Figure 9 reveals that generally, TSM harvested less area across the planning horizon, again because the TSM harvest level is significantly less, relative to the FSSIM forecast due to spatially explicit green-up and adjacency restrictions. In Period 5 however, TSM harvested 6% more area relative to FSSIM and 16% more area than it did at any other time throughout the planning horizon. The unflowed forecast in *Figure 7* revealed a significant shortfall in timber supply during this period 16 to 25 years from now. This indicates that a large percentage of the volume above minimum harvest age is unavailable for harvest due to green-up and adjacency restrictions during this time, which is not reflected in the aspatial approach employed by FSSIM. In all likelihood, this is because many existing openings across the THLB at the start of the planning horizon have not achieved the green-up requirements necessary to allow adjacent blocks to be harvested. Since TSM harvested more area in order to achieve the target harvest level over this five-year period, it is likely that adjacency restrictions caused by legacy harvests are binding the higher yield stands across the THLB. As a result, TSM was forced to harvest in lower yield stands, thereby requiring more area to be harvested in order to achieve the target harvest level. The lower yield stands harvested during this period may simply have lower yields either because they are younger on average than the stands bound by adjacency restrictions, or are growing on poorer sites.

The average area-weighted age at which stands were harvested by TSM and FSSIM are compared in *Figure 10*, below, and *Table 10*, following.

Figure 10: Periodic average area-weighted age harvested by TSM in spatial step-wise simulation mode relative to the average area-weighted age harvested by FSSIM under the TSR2 maximum non-declining harvest flow forecast

Table 10: Periodic average area-weighted age harvested by TSM in spatial step-wise simulation mode relative to the average area-weighted age harvested by FSSIM under the TSR2 maximum non-declining harvest flow forecast

Period Number	Years from Now	FSSIM Average Age Harvested	Percent Change Relative to the Previous Period	TSM Average Age Harvested	Percent Change Relative to the Previous Period	Percent Difference in Average Age Harvested Relative to FSSIM
1	0-5	196	0%	193	0%	-2%
2	6-10	196	0%	181	-6%	-8%
3	11-15	182	-7%	167	-8%	-8%
4	16-20	177	-2%	159	-5%	-10%
5	21-25	182	3%	143	-10%	-22%
6	26-30	179	-2%	188	32%	5%
7	31-35	177	-1%	185	-2%	4%
8	36-40	189	7%	177	-4%	-7%
9	41-45	180	-5%	180	2%	0%
10	46-50	178	-1%	184	2%	3%
11	51-55	178	0%	175	-5%	-1%
12	56-60	170	-5%	187	6%	10%
13	61-65	146	-14%	153	-18%	5%
14	66-70	152	4%	167	9%	10%
15	71-75	147	-3%	172	3%	17%
16	76-80	120	-18%	162	-5%	35%
17	81-85	131	9%	160	-1%	22%
18	86-90	113	-13%	194	21%	71%
19	91-95	111	-2%	149	-23%	34%
20	96-100	105	-6%	146	-2%	39%
21	101-105	103	-2%	134	-8%	30%
22	106-110	105	2%	120	-11%	14%
23	111-115	104	-1%	118	-1%	13%
24	116-120	102	-2%	117	-1%	14%
25	121-125	104	1%	119	2%	15%
26	126-130	98	-5%	124	4%	26%
27	131-135	105	6%	119	-4%	13%
28	136-140	99	-5%	110	-7%	11%
29	141-145	101	2%	108	-2%	7%
30	146-150	106	5%	111	3%	5%
31	151-155	108	2%	120	8%	11%
32	156-160	101	-7%	124	4%	23%
33	161-165	109	9%	116	-6%	6%
34	166-170	101	-7%	112	-4%	10%
35	171-175	105	3%	142	27%	36%
36	176-180	104	-1%	115	-19%	10%
37	181-185	102	-2%	119	4%	17%
38	186-190	108	6%	113	-5%	5%
39	191-195	103	-5%	103	-9%	0%
40	196-200	113	10%	117	14%	3%
41	201-205	104	-8%	113	-3%	8%
42	206-210	110	6%	117	4%	6%
43	211-215	106	-4%	127	8%	19%
44	216-220	104	-2%	111	-13%	7%
45	221-225	99	-5%	110	0%	12%
46	226-230	111	13%	111	0%	0%
47	231-235	105	-5%	110	-1%	4%
48	236-240	103	-2%	112	2%	9%
49	241-245	104	1%	116	3%	11%
50	246-250	104	0%	112	-4%	7%

Figure 10 reveals that on average, over the first 25 years of the forecast, the age at which stands are harvested by TSM is 10% lower on average, relative to the age at which stands were harvested by FSSIM. Consistent with the patterns revealed by *Figure 7* and *Figure 9*, a sharp decline in the average age harvested occurs 25 years from now. *Figure 10* therefore supports the conclusion that over the first 25 years of the forecast, many older stands within the THLB are unavailable for harvest due to green-up and adjacency restrictions caused by past harvesting activities and that the aspatial approximation rules used in TSR2 are unable to account for this dynamic.

Over the remainder of the mid-term, 26-110 years from now, the age at which TSM harvests stands is 14% higher relative to FSSIM indicating that significant areas within the THLB achieve green-up over this period resulting in the harvest of this older forest inventory that was unavailable over the first 25 years of the forecast. Over the long-term, the age at which TSM harvests stands is 11% higher relative to FSSIM indicating that spatial green-up and adjacency constraints delay the harvest of stands past minimum harvest age to a greater extent than the aspatial approximation rules implemented under TSR2 in FSSIM.

5.3. Aspatial and Spatial Simulated Annealing

The results of both sensitivities described in Sections 4.2 and 4.4, are discussed together under this section since the results indicated no significant differences between the TSM optimized forecasts using simulated annealing and the TSM simulation-based forecasts in either spatial or aspatial mode. A review of the outputs from TSM revealed that the simulated annealing algorithm was unable to improve the harvest forecasts obtained through simulation when only the harvest queue can be adjusted with each iteration. This indicates that the constraints implemented under the basecase, using both an aspatial and spatial approach, severely restrict harvest scheduling opportunities which may lead to improved harvest forecasts, subject to the basecase and maximum non-declining harvest flow objectives.

Although the simulated annealing algorithm was unable to improve the harvest flow forecasts under this benchmarking analysis, it is important to note that this conclusion cannot be extrapolated to other scenarios and/or land bases since the dynamics of a forest estate are very sensitive to the constraints implemented, the current age class structure, the growth and yield of the forest as well as the shape and distribution of openings and the timing of harvests. As a result, under another set of forest conditions, management constraints and/or harvest block patterns, the simulated annealing algorithm has been shown to identify alternative harvest scheduling options which significantly improve harvest flow forecasts under the same set of scenario parameters and harvest flow objectives.

That said, the utility of the simulated annealing algorithm is best realized when scenarios are designed that permit trade-offs to occur between competing resource objectives subject to a desired harvest flow. Under this type of scenario, constraints implemented to protect various resource values are allowed to be violated subject to specific penalty functions or weightings. Such an approach requires that stakeholders define the relative importance of each resource objective against another. For example, resource targets designed to create large contiguous clearcuts which attempt to mimic the temporal and spatial distribution of openings (i.e. biodiversity patch sizes) caused by natural disturbances, may conflict with watershed targets designed to regulate the rate of harvests in order to control sedimentation and flooding within riparian areas. Under this scenario, stakeholders may decide that the riparian values being protected through the watershed targets are more important than the achievement of landscape level biodiversity patch size objectives. As a result, the penalties associated with violating watershed targets would be more severe than those associated with patch size targets. The sum of the penalties for each resource target in violation is referred to as the objective function. Therefore, the simulated annealing algorithm is designed to rapidly test a variety of harvest scheduling options in an effort to minimize the overall objective function or penalty value for the scenario. The sum of all of the possible harvest scheduling options under a particular scenario is referred to as the solution space. If any one or more parameters of a scenario are altered, then a new solution space is created.

Within this benchmarking analysis, the simulated annealing algorithm was implemented in an attempt to improve the step-wise simulation based harvest flow forecasts without permitting any basecase resource constraint violations. The intent of the benchmark analysis was to evaluate the timber supply effects of implementing various modelling approaches and not to test outcomes under different scenarios or management practices. With this approach however, it became evident that without some flexibility to violate targets, the annealing algorithm made negligible improvements to harvest flow forecasts relative to the simulation based results using the Lakes TSA TSR2 dataset. If the benchmark analysis had allowed for target violations then this would inherently create a new scenario with its own unique solution space. Therefore, comparing the results obtained between a scenario run using annealing where target violations are allowed, with a simulation based scenario where the targets could not be violated, would be misleading since any timber supply improvements realized through annealing could not be directly linked to the algorithm.

6.0 Conclusions & Recommendations

The results of this benchmark analysis demonstrate that TSM will produce the same harvest flow forecasts as FSSIM when TSM is run using the same data inputs, assumptions and modelling approach as FSSIM. However, the analysis also revealed that although the same harvest flow forecasts can be obtained, slight differences did exist when other timber supply indicators such as growing stock and area harvested were compared. These differences were shown to be caused by how each model projects the forest inventory in each period and how each calculates harvested volumes. In addition, it was shown that although each model performs the sequential simulation differently, the same harvest flow forecast is obtained because where one model is conservative in its approach, the other is optimistic (and vice versa), thereby causing the inherent biases associated with each model's simulation algorithm to have no net effect on the timber supply reported. When both models were run using annual period lengths, in effect forcing each to perform the sequential simulation in the same manner, all of the timber supply indicators between the two models were near identical.

Comparing outcomes using a spatial simulation approach versus an aspatial simulation approach revealed that a spatial approach produces significantly less optimistic timber supply forecasts. This is because of two fundamental limitations that an aspatial approach has:

1. An aspatial approach can only account for the timber supply effects of spatial constraints such a green-up and adjacency through approximations typically implemented via early seral forest cover requirements. As a result, it is quite possible, as shown under this analysis, that the approximation rule used does not sufficiently constrain enough of the volume above minimum harvest age to fully capture the actual amount of volume bound by green-up and adjacency requirements when such rules are implemented explicitly. However, this can be corrected by adjusting the approximation rules used, so that they cause more area to be made unavailable for harvest.
2. The binding effect of a particular resource target on timber supply is significantly influenced by the spatial distribution, size and shape of forest patches of various age classes through time. An aspatial approach is incapable of accounting for the timber supply dynamics caused by the interaction between resource constraints and the spatial arrangement of age classes across the land base through time. For example, this analysis revealed that green-up and adjacency restrictions did not permit the harvest of stands in older age classes over the first 25 years of the forecast due to the spatial distribution of existing cutblocks below green-up age at the start of the planning horizon. As a result, stands in younger age classes had to be harvested in order to achieve harvest targets. Since an aspatial approach cannot identify which particular stands in the land base are unavailable due to green-up and adjacency, then it also cannot account for the proportion of area bound in each age class by spatial constraints. As a result, FSSIM initiated harvests within these older stands when in fact they were not spatially available. This results in a significant divergence between both timber and non-timber resource indicators output under each approach. For example, since FSSIM initiated harvests in older age classes over the first 25 years, while spatially TSM did not, the forest age class distributions output under the two approaches will be quite different. This in turn will also result in different outputs for other resource indicators such as wildlife habitat, hydrologic recovery, etc.

The conclusion that a spatial approach produces less optimistic forecasts of timber supply is supported by other analyses which have made similar comparisons. In fact, within the Lakes TSA AAC Rationale document, the Chief Forester acknowledged that a spatially explicit approach demonstrated that the long-term forecasts obtained through TSR2 are optimistic based on two prior spatially explicit analyses performed on the Lakes TSA. He further states however, that due to considerable flexibility in the short-term as a result of the harvest flow policy implemented, his projected harvest level could be maintained for at least the next five years. This determination is supported by the TSM spatial simulation results under the benchmark analysis. However, when the spatial simulation approach was compared to the alternative maximum non-declining flow forecast obtained under TSR2, significant reductions in timber supply were realized over the short and mid-terms. This indicates that although there is still flexibility over the short and mid-terms relative to the AAC chosen for the Lakes TSA, the amount of surplus unconstrained volume available over this time period is not nearly as great as that indicated by TSR.

Both the aspatial and spatial simulated annealing sensitivities were implemented without allowing any of the resource targets identified under the basecase to be violated. This was done in order to ensure that any differences in timber supply forecasts could be directly attributed to the modelling approach rather than to changes in scenario parameters. However, without allowing for any resource target violations, the annealing algorithm was unable to obtain a better timber supply forecast relative to the aspatial or spatial simulations. Under most circumstances, the simulated annealing algorithm is implemented with the flexibility to violate some or all resource targets if the overall solution is improved. With input from stakeholders, each resource value identified under an analysis utilizing an annealing approach is assigned a relative weighting or penalty. Resource targets with high penalties will not be violated since this will have significant impacts on the overall solution (objective function). The simulated annealing algorithm will favor the targets with higher penalties, often at the expense of those with lower penalties permitting the algorithm to find a near optimal solution which attempts to balance the requirements of competing resource objectives based on input from stakeholders.

Based on the results of the benchmark analysis, Tesera Systems Inc. recommends that a spatial step-wise simulation based approach be used across all of the learning scenarios since this approach will better facilitate identification of where resource objectives are in conflict and where they are complimentary. In addition, since the IFPA dataset is quite significant – with an estimated six to eight million polygons per TSA – and is compounded by the large number of resource targets and indicators which must be tracked by the model, a spatial step-wise simulation based approach will not only provide solutions more rapidly but will also make it easier to explain outcomes.

Once the spatial step-wise simulation based results of the learning scenarios have been assessed by stakeholders, Tesera Systems Inc. recommends that the decision scenario utilize a spatially sensitive simulated annealing based approach since stakeholders will be able to make informed and timely resource trade-off decisions using the knowledge gained from the learning scenario outcomes.