Phase 1 Progress Report
Minnesota Department of Natural Resources
Sustainable Timber Harvest Analysis

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1 Introduction

Mason, Bruce & Girard is pleased to present this progress report on Phase 1 of the Minnesota Department of Natural Resources (MN DNR) Sustainable Timber Harvest Analysis (STHA). In this report we describe the data used for the Phase 1 model runs, the methods deployed for modeling various management assumptions, and compare the results from the different model runs.

The overarching purpose of Phase 1 was to learn more about the factors that are key to the MN DNR forest management plan, and to assess how these factors should be modelled during Phase 2 of the project. We therefore set ourselves the following objectives for Phase 1:

- Gain an understanding of MN DNR data sets (inventory, GIS, yields), how it was compiled, how it could be used, and what the limits of use will be
- Identify key elements of the current state of the forests that will have to be accounted for in the long term plan
- Investigate the land management activities currently being used, and how these can be modelled with available data
- Explore the impact of various assumptions on forest management plans, and identify key factors to incorporate into the Phase 2 analysis

To this end we gathered all of the available inventory and performed a preliminary inventory analysis to identify key issues and trends in this data set. We also gathered all available yield data, and investigated the methods by which they were derived. Finally we built a pilot land management planning model, and used it to evaluate various assumptions.

The results from these models are reported on in detail in this report. These results should not be considered as candidate solutions for the MN DNR forest management plan, since none of them are comprehensive with regards to their assumptions. This was by design, because we wanted to incrementally add assumptions to each model scenario, in order to observe the implications of each assumption by itself. These results will serve as building bricks for the Phase 2 model runs, but do not constitute comprehensive solutions by themselves.

During Phase 2 we look forward to expanding on the forest management models built for Phase 1. During Phase 1 we used NPC Growth Stages as a proxy for non-timber values, and we will expand on this approach to be more comprehensive in our modelling of non-timber values. We will also perform additional analysis on the growth and yield predictions to assess whether they adequately represent the growth potential of MN DNR lands.

We wish to thank the MN DNR for the opportunity they have given us to partner with them on this project. The level of cooperation we have received from the Project Team has made our job a lot easier, and we look forward to continuing our work with them in Phase 2. We would also like to thank the Stakeholder Advisory Group for the inputs they have made to our modeling efforts thus far, and we look forward to engaging with them in Phase 2.

2 Inventory Analysis

Information about the MN DNR land base is stored and maintained in an inventory database. In this section we describe the inventory data received from the MN DNR, and provide a summary of the main data elements and our initial analysis.

2.1 Data

MB&G received the inventory data in the form of an ESRI Shapefile ®. This file had 200,796 records and covered a land area of 5,447,138 acres. These records represented 197,731 unique stands, based on the stand identifier attribute. Each stand is described by over 190 attributes, including information about administrative designations, operational class, cover type, standing inventory, site characteristics and age.

The inventory information contained within this database was compiled from timber cruise data, and included individual tree measurements collected from sample plots. These data were compiled into a stand level summary, which represents the average condition within the stand at the time of measurement. Once compiled, the tree level data are no longer available, so we only had the stand level data at our disposal.

As a result, the inventory database represents the condition of the stand at the time of measurement, which is not necessarily the current stand condition. Without the tree level data, there is no way to grow the inventory forward (using a growth and yield model) to represent the current condition of stands. Therefore, the inventory data were of limited use for this study, and we used only used those data elements that were representative of the current state of the inventory.

2.2 Summary

The MN DNR land base covers 5.4 million acres. These acres contain land parcels that are not-manageable, non-forested and non-merchantable. It was decided to remove these acres from the analysis since they either did not possess a cover type that could be used for commercial timber harvest (i.e., non-forested and non-merchantable), or they couldn't be managed for timber (not-manageable). A total of 637,333 (12%) acres were classified as non-manageable, and included inoperable land, old growth forest, Representative Sample Areas and all land from the Prairie Parklands Province. In addition only lands administered by Forestry, Wildlife, Fisheries in Lake County, DNR MPL (Minnesota Power Lands) and DNR LUP (Land Utilization Project) were considered manageable. 1,680,094 (31%) acres were classified as non-forested, since their cover types included vegetation such as grass and brush, as well as other land uses such as roads, agriculture, recreation and permanent water. 2,431,936 (45%) acres were classified as non-merchantable, since their cover types do not produce merchantable timber. These included stagnant and off-site species, as well as non-merchantable species such as willow and cottonwood. Combined, the non-manageable, non-forested and non-merchantable areas accounted for 2,697,192 (50%) acres. The net acres therefore considered for the sustained yield calculation was 2,749,945. Please see Figure 1 for further details.

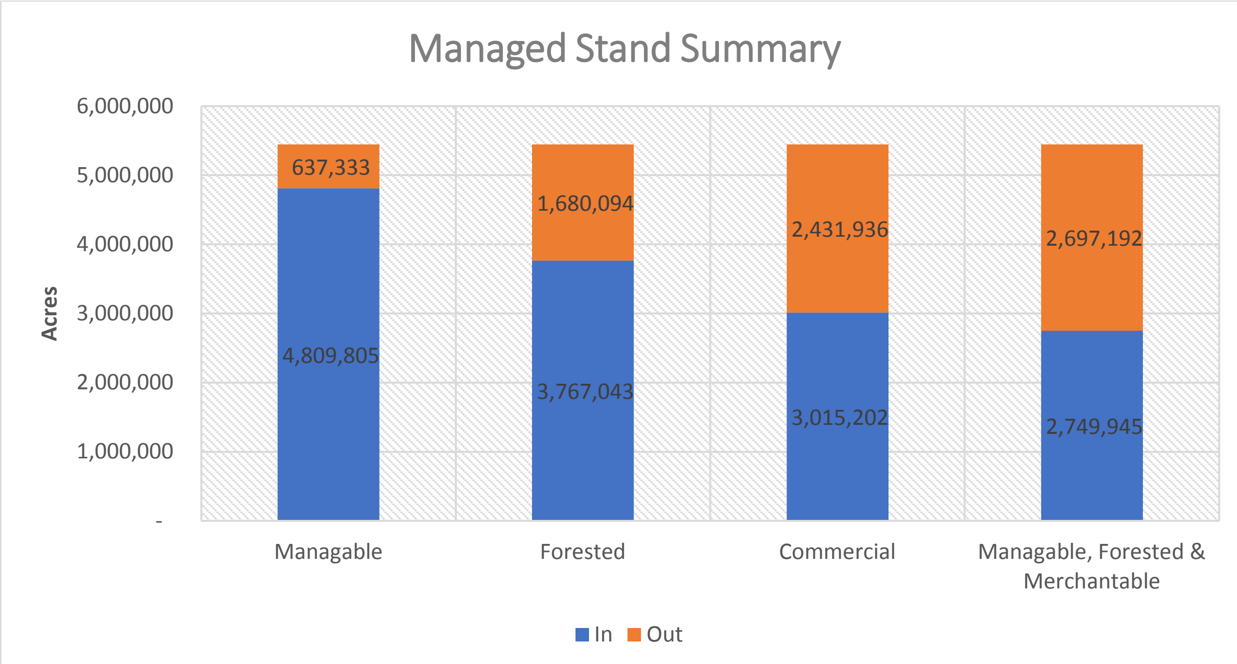

Figure 1: Summary of Managed Stand Acres

Figure 2 shows the sum of the acres for each survey year. The inventory data on 1,938,188 (70%) acres is older than five years, and 1,232,528 (45%) acres is older than ten years. These acres were based on the total manageable, forested and merchantable acres (2.7 million acres). Since much of the inventory data is dated, we did not rely on the inventory for stand characteristics, such as size, density, basal area, volume, and etc.

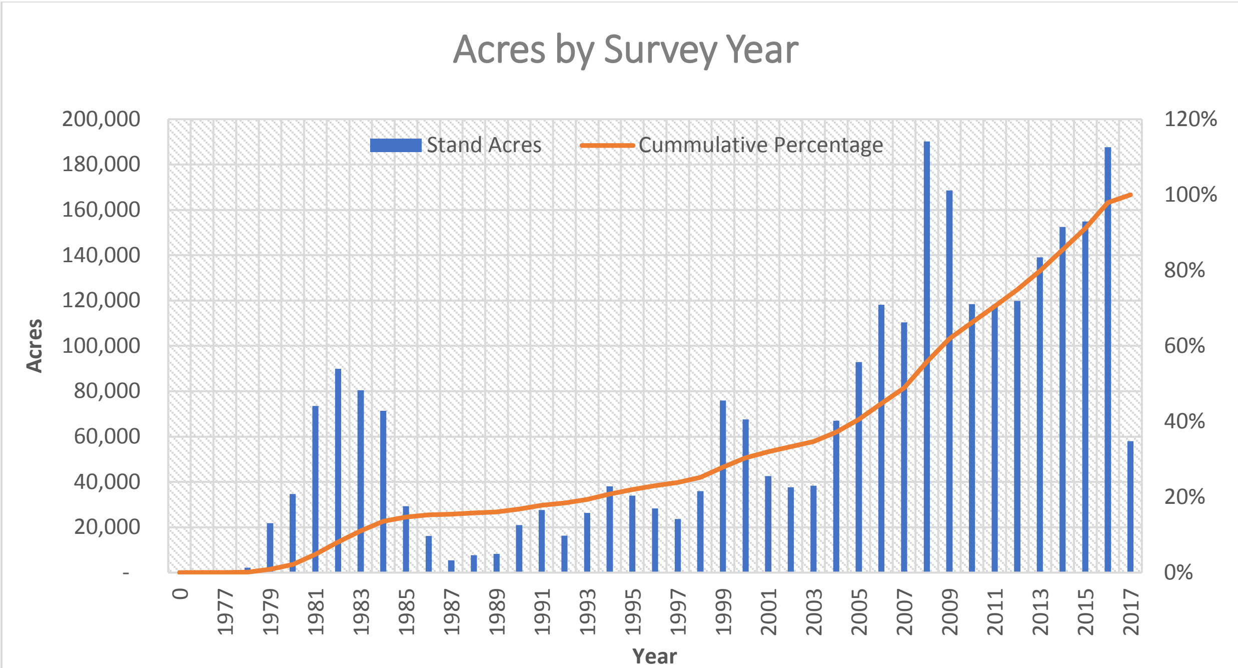

Figure 2: Survey Year of Inventory

Figure 3 shows acres for each planning area. Four planning areas, MDLP, NMOP, NSU, and WSU represent 93% (2,566,606) of the acres. These acres were based on the total manageable, forested and merchantable acres (2.7 million acres). MN DNR developed area-specific yield tables for each of these four areas (see section 4.3).

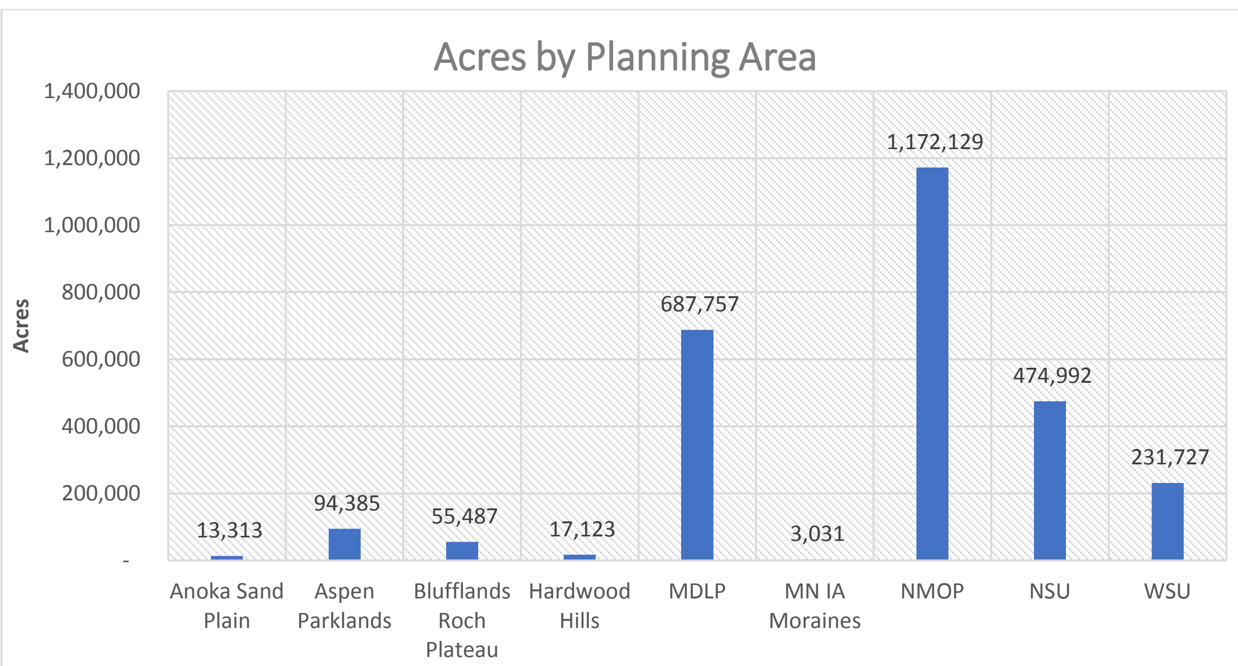

Figure 3: Planning Area Size

Figure 4 shows the age class distribution of the acres used for the model. 53% of the acres were less than 50 years old, and 83% less than 100 years. The 17% of the acres older than 100 can be attributed to species such as Black Spruce and Tamarack which are on longer rotations.

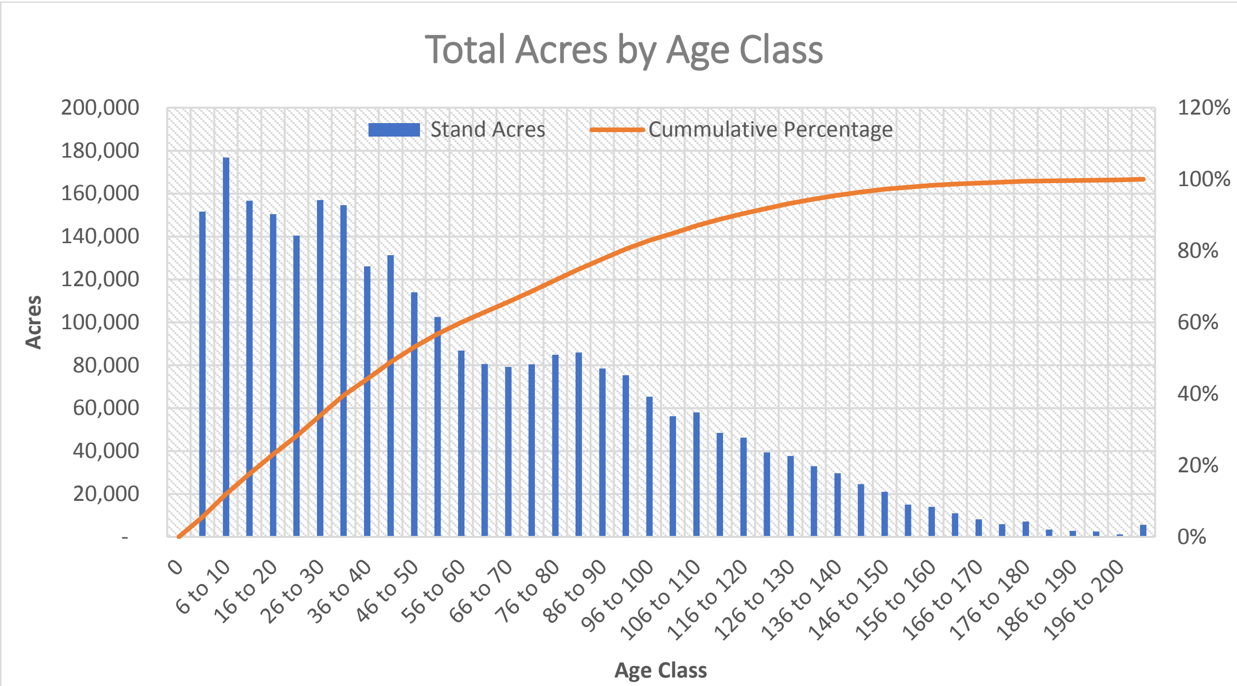

Figure 4: Age Distribution

Figure 5 shows the site index distribution for the manageable, forested and merchantable acres. Site index is a measure of productivity and is expressed in terms of the height of dominate and co-dominate trees at age 50. Most of the acres had a site index of less than 80, while about half of the acres had a site index of less than 50.

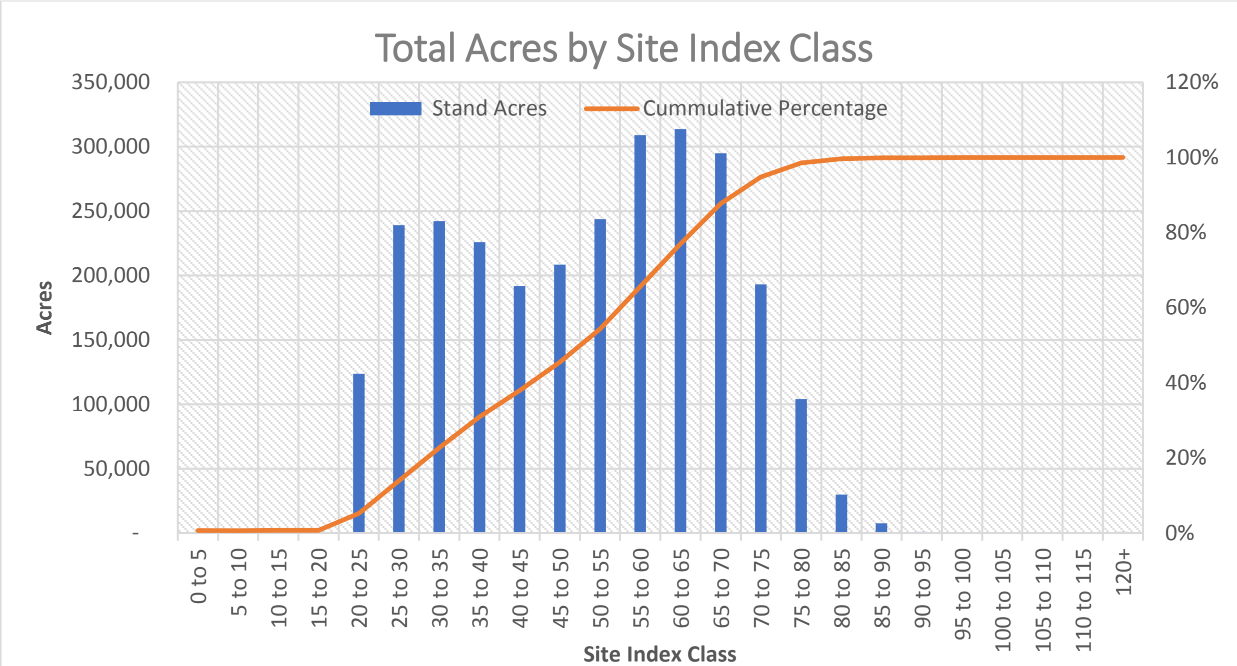

Figure 5: Site Index Distribution

3 Model Description

We used Woodstock to develop a forest management model to make calculations of sustained timber harvest levels. Woodstock is a commercially available forest management modeling system developed and sold by RemSoft (www.remsoft.com). It is widely used by private and public land managers to develop and evaluate long term timber harvest schedules. Woodstock is an optimization model that uses linear programming (LP) to find solutions that maximize some objective while meeting a set of management constraints and/or limitations on management activities.

In this section, we describe how we used the DNR inventory data to develop the basic Woodstock model. We will start by describing the land-base that was incorporated into the model, and how we organized and classified the different types of land. We will follow this by a description of the management activities we introduced into the model. These activities represent the management decision points, and is used to change the development trajectory of stands. This will be followed by a description of the yields that we used in the model. Yields tell us what the condition of a piece of land is in terms of inventory and age, at a given point in time, under a given management prescription. Finally we will define and explain the model scenarios that we developed.

3.1 Land-base

The land-base used for this analysis was derived from the ESRI Shapefile ® provided by the MN DNR. This file contained both the spatial location and extent of each stand, as well as 190 attribute fields describing various aspects of the stand. For the Woodstock model, we defined the landscape in terms of 13 different themes as in Table 1:

Table 1: Model Theme Definitions

Theme	Name	Description	Used
1	Stand ID	Unique numeric identifier for each stand. Not used in this version because resulting model was too large.	No
2	Section	Used to identify planning areas and applicable data such as yield tables.	Yes
3	Land Status	Means by which the stand was obtained by the MN DNR to manage in accordance with different mandates and management objectives. Identifies Trust lands, for example. Intended for reporting activities and outputs and can be used to modify assumptions per land status.	No
4	Cover Type	Main vegetation cover type of the stand. Non-Forested lands grouped under one code. Plantations	Yes

Theme	Name	Description	Used
		separated from natural regeneration. Used to identify appropriate yield table.	
5	Administrator	Identifies the MN DNR land administrator. Used to classify land as available and unavailable for timber management. This would allow differing assumptions or results analysis per administrator. Collapsed to reduce model size for most, but not all, of the analysis since Theme 6 also captures this criteria.	Yes
6	Managed Acres	Yes/No indicates which lands are available for timber management or not. Used to make management actions applicable or not.	Yes
7	Site Class	50 Year site index class of each stand. Grouped the site index from MN DNR data into 5 ft. classes. Used to identify appropriate yield table.	Yes
8	NPC Code	Unique identifier for the Native Plant Community (NPC) class the stand belongs to. Not all stands belong to a NPC.	Yes
9	Rotation Status	Identifies the rotation the stand is on. Tracks management status through time.	Yes
10	Operability	An identifier of operability/inoperability due to steepness of terrain.	Yes
11	Old Growth	Identifier of old growth stands. Limits the applicability of management actions.	Yes
12	Treatments	Used to identify the thin and regulated harvest entry number. Tracks management status through time.	Yes
13	Exclude	Intended to exclude stands with problematic data from the model, as well as the reason for exclusion. Not used in this version.	No

In addition to these thematic layers, the model also required the age and acres for each stand. The age and acres were gathered from the MN DNR inventory data. Age was aggregated into five-year age classes. The planning horizon used for this model was 150 years, partitioned into 30 planning periods (5 years per period).

Land is described in a Woodstock model as development types. A development type is all parcels of land with the same combination of theme values and age. A total of 200,796 stand polygons were processed, resulting in 47,889 unique development types.

3.2 Management Activities

The forest management model incorporated four types of prescriptions, namely commercial thinning, clear-cut, uneven-aged management, and regulated uneven-aged management. These offer the model a variety of management options, each with a different range of outcomes. The model can then pick the best management option for each stand, given the objective of the model and the associated constraints.

The thinning action allowed for periodic entries into the stand, removing only a portion of the standing volume. The purpose of this entry would be to stimulate growth in overstocked stands, and deliver intermediate timber harvest. Only a limited number of entries were allowed, and they could only occur over a certain age range. Oak cover types delivered 8 cords per acre at each entry, while all other cover types delivered 10 cords per acre. Thinning regimes were defined by cover type and site index, and each had a maximum number of entries, age range of thinning, and interval length between thinnings. These values are shown in Table 2.

Table 2: Thinning Regime Definition and Condition

Cover Type	Site Index	Max Entries	Min Age	Max Age	Entry Interval
Red Pine Planted and Natural	45+	6	30	100	10 Years
Planted White Spruce	ALL	3	40	340	15 Years
Ash, Lowland Hardwoods, Northern Hardwoods, Oak, Central Hardwoods	60+	3	30	70	15 Years

The clear-cut actions removed all standing inventory from the stand, followed by regeneration. Regeneration was typically natural, except for plantations. Clear-cut options were only available between a given minimum and maximum age, for each unique combination of cover type, planning area and site index. These clear-cut criteria are defined in Appendix A: Clear-Cut Regimes. These regimes typically retained 5% of the standing volume after harvest, except for the Timber Potential scenarios.

The uneven-aged regimes simulate group selection harvest, where openings are created in the forest canopy to promote the development of diverse forest structure. These regimes are defined by cover type, planning area and site index. Eligibility was determined by age, basal area, and standing volume. The re-entry interval was 20 years. Table 3 summarizes the treatment criteria.

Table 3: Uneven Aged Regime Definition and Condition

Cover Type	Planning Area	Site Index	Min Age	Min Basal Area	Min Volume	Entry Interval
Ash	ALL	45+		90	15	20 Years
Lowland Hardwoods	ALL	45+		90	21	20 Years
Northern Hardwoods	ALL		30	100		20 Years
Oak	ALL		60			20 Years
Central Hardwoods	No BRP		30	100		20 Years
White Pine Natural	ALL		125			20 Years
White Pine Plantation	ALL		125			20 Years
White Spruce	ALL		80			20 Years
White Cedar	ALL		80			20 Years

The regulated uneven-aged management regimes are an extension of the uneven-aged regimes, since a stand has to receive an uneven-aged regime before it can receive a regulated uneven-aged regime. These regimes are also defined by cover type, planning area and site index, and simulated group selection harvest on a regulated basis. Eligibility for this regime is determined by whether an uneven-aged regime has been applied, site index, and age (in some cases planning period). The entry interval was 20 years. Table 4 shows a complete definition of the criteria.

Table 4: Regulated Uneven Aged Regime Definition and Condition

Cover Type	Planning Area	Site Index	Planning Period	Min Age	Entry Interval
Ash	ALL	45+	<6		20 Years
Lowland Hardwoods	ALL	45+	<6		20 Years
Northern Hardwoods	ALL			50	20 Years
Oak	ALL			80	20 Years
Central Hardwoods	No BRP			50	20 Years
White Pine Natural	ALL			145	20 Years
White Pine Plantation	ALL			145	20 Years
White Spruce				100	20 Years
White Cedar				100	20 Years

3.3 Yields

The yield section provides information about the state of each development type in each planning period. A number of yield types were incorporated into the forest management model, including species level multipliers for cover type volume, stumpage prices, thinning volumes, uneven aged management volumes, and inventory volumes. Together these yields are used to calculate the standing inventory, harvest volume, and revenue.

The species level multipliers are used to determine the harvest volume of each species. Inventory data were brought into the model at the cover type level, and to disaggregate these into species volumes, we multiplied the inventory volume with the species level multipliers. These yield values (multipliers) can be referenced in Appendix B: Yield Tables. The NMOP and NSU planning areas had multipliers specific to those areas, while the rest of the planning areas used state level multipliers. All of these values were provided by the MN DNR and are based on recent FIA data.

The stumpage prices were defined predominantly by species. In the case of red pine, stumpage prices were also defined by age and management regime. The stumpage prices were multiplied with the species level volumes (described above) to obtain stumpage revenue. All of these values were provided by the MN DNR and are based on 2014 through 2017 price data. The prices are listed below in Table 5.

Table 5: Stumpage Prices

	Stumpage ($/Cord)		
Species	**Aspen Parklands**	**Blufflands Roch Plateau**	**Other**
Aspen	$ 3.50	$ 30.00	$ 35.00
Balm of Gillead	$ 2.80	$ 20.00	$ 28.00
Birch	$ 1.50	$ 23.00	$ 15.00
Basswood	$ -	$ 35.00	$ 14.00
Oak	$ -	$ 150.00	$ 32.00
Maple	$ -	$ 140.00	$ 14.00
Ash	$ 1.20	$ 45.00	$ 12.00
Elm	$ -	$ 22.00	$ 6.00
Black Walnut	$ -	$1,250.00	$ -
Cotton Willow	$ -	$ 10.00	$ 5.00
Other Hardwoods	$ 1.00	$ 25.00	$ 10.00
Balsam Fir	$ 1.80	$ 9.00	$ 18.00
Black Spruce	$ 2.40	$ 12.00	$ 24.00
Jack Pine	$ -	$ 15.00	$ 30.00
Red Pine Non-RP CT	$ -	$ 29.00	$ 42.00
Red Pine Thin 30	$ 15.00	$ 15.00	$ 15.00
Red Pine Thin 40	$ 25.00	$ 25.00	$ 25.00
Red Pine Thin 50	$ 35.00	$ 35.00	$ 35.00
Red Pine Thin 60	$ 50.00	$ 50.00	$ 50.00
Red Pine CC 60	$ 80.00	$ 80.00	$ 80.00
Red Pine CC 90	$ 85.00	$ 85.00	$ 85.00
Red Pine CC 95+	$ 75.00	$ 75.00	$ 75.00
Tamarack	$ 0.60	$ 3.00	$ 6.00
White Pine	$ -	$ 22.00	$ 32.00
White Spruce	$ -	$ 13.00	$ 26.00
White Cedar	$ 0.80	$ 4.00	$ 8.00

Thinning volume yields are used to account for the volume removed during commercial thinning actions. For our model, we relied on DNR's approach to thinning projections – a fixed amount if volume is removed at each commercial thinning entry with no reduction in inventory. This assumes that the reduction in inventory from the thinning is recouped through accelerated growth in the subsequent years. For the oak cover type the commercial thinning volume was assumed to be 8 cords/acre, and 10 cords/acre for all other cover types.

The uneven-aged yields represent the volume removed from a stand during the group selection harvest action. These yields are assumed to be a fraction of the standing inventory -- 50% for Ash and Northern Hardwoods cover types, and 33% for all others.

The regulated-uneven aged yields represented the volume removed from a stand with the regulated group selection harvest. These yields were defined by cover type and site index, and are listed in Table 6

Table 6: Regulated Uneven-Aged Harvest Volumes

Cover Type	Site Index	Cords/Acre
Ash	45Minus	5.0
	50	5.3
	55	5.5
	60	5.8
	65	6.0
	70Plus	6.5
Lowland Hardwoods	45Minus	5.0
	50	5.3
	55	5.5
	60	5.8
	65	6.0
	70Plus	6.5
Northern Hardwoods	45Minus	7.0
	50	7.5
	55	8.0
	60	8.5
	65	9.3
	70	10.0
	75	11.0
	80	12.0
	85	12.0
	90	12.0
Oak	45Minus	7.0
	50	7.5
	55	7.5
	60	7.8
	65	8.0
	70Plus	9.0
Central Hardwoods	45Minus	7.0
	50	7.5
	55	8.0
	60	8.5
	65	9.3

Cover Type	Site Index	Cords/Acre
	70	10.0
	75	11.0
	80	12.0
	85	12.0
	90	12.0
White Pine	45Minus	6.0
	50	7.3
	55	7.8
	60	8.3
	65	9.2
	70	10.0
	75	11.0
	80	11.0
	85	11.0
	90	11.0
White Spruce	ALL	4.0
White Cedar	ALL	4.0

The inventory yields represents the standing inventory in each development type at a given point in time. They were defined by planning area, cover type, site index and age. In addition to volume, these yield tables also contained basal area. The MN DNR compiled the yields and used the curve fitting techniques published by (Walters & Ek, 1993)[1], as well as the ZEO mortality effects published by (Zobel, Ek, & O'Hara, 2014)[2]. These techniques used observed values of age, basal area and volume to formulate a function to predict inventory at a given age.

3.4 Scenarios

Three different scenarios were identified for the Phase 1 portion of the sustainable timber harvest analysis. These scenarios were designed to span the range of hypothetical management options, in order to assess the behavior of the model under various management assumptions. The purpose of these initial scenarios were not to provide final answers, but to serve as a launching point for the analysis in Phase 2.

The scenarios that were defined for Phase 1 are summarized in Table 7. In Phase 1, management objectives were assumed to be the same for all lands (e.g., School Trust Land and Wildlife Management Area objectives were identical for each scenario). Three main scenarios were defined, namely Timber Potential, Million Cords and NPC Growth Stages Goals. Timber Potential explored the capability of MN DNR to grow trees for timber production under various assumptions of timber flow. Million Cords explored the capability of MN DNR forests to produce

[1] Walters, D. K., & Ek, A. R. (1993). Whole stand yield and density equations for fourteen forest types in Minnesota. *Northern Journal of Applied Forestry*(10), 75-85.

[2] Zobel, J. M., Ek, A. R., & O'Hara, T. J. (2014). ZEO Yield and Mortality Model Application. University of Minnesota Digital Conservancy.

1 million cords per year, and the impact of this harvest level on the long term timber yield. NPC Growth Stages Goals explored the potential of MN DNR lands to reach certain vegetation structural goals, using different levels of goal calibration. The Timber Potential and Million Cords scenarios were timber focused and did not incorporate non-timber values. The NPC Growth Stages Goals used native plant community (NPC) targets as a proxy for non-timber values, but it was not comprehensive enough to include all non-timber values.

Three types of constraints were present in all scenarios, namely non-declining inventory, even flow timber volume, and even flow timber volume with departure. The non-declining inventory constraint prevented a decrease in standing inventory over the last 5 periods. LP forest management models have a tendency to liquidate standing inventory over the last few periods in the planning horizon, which would paint a false picture of long term sustained yield beyond the planning horizon. Ideally you would want to see the inventory settle at level where growth equals harvest, and an inventory level that remains constant towards the end of the planning horizon is an indication of this. In Phase 2 we will explore a more explicit ending inventory constraint, but the constraint used here is sufficient for the Phase 1 modeling runs.

The even flow constraint required harvest volumes to be exactly the same for each planning period. This is a very restrictive constraint, and can have a major impact on long term sustained yield. The rationale behind using such a constraint is that a stable and predictable timber flow is better for the MN DNR and local industry. Timber flow does not need to be exactly the same period on period though, so that's why we also introduced even flow with departure. This constraint will allow a departure from the average harvest level, within a specified limit. For Phase 1 we decided on a departure of 30% up or down from the average, but this is rather subjective number and will need more consideration during Phase 2. Even flow with departure was only used for species level volumes in the Phase 1 model runs.

Some of the scenarios also incorporated a harvested volume reduction. The purpose of this was to simulate the fact that MN DNR policies typically result in merchantable trees being unharvested or left in field to promote the development of complex forest structure. This reduction was applied by decreasing the available harvest volume by 5%, and was only applied against the clear-cut harvest actions.

All of scenarios used present stumpage revenue (PSR) in their objective functions. The PSR was calculated as the sum of the discounted revenues from stumpage over the planning horizon. A discount rate of 3% was used. Stumpage revenues were calculated by multiplying the species level volume with the stumpage price for the given planning area. The NPC Growth Stages Goals also incorporated deviations from the NPC goals in the objective function.

PSR maximization was selected over a volume maximization for two reasons. First, volume maximizing functions have a tendency to hold on to inventory for as long as possible and accelerate harvest over the last few planning periods. This requires constraints on harvest volume over the last few planning periods, and does not represent how forest inventory would ordinarily be managed. Second, the PSR function incorporates both value and growth optimization, while a volume maximization would only optimize growth.

Table 7: Forest Management Scenarios

<table>
<tr><th>Scenario</th><th>Description</th><th>Objective</th><th>Constraints</th><th>Volume Reduction</th></tr>
<tr><td>1</td><td colspan="4">Timber Potential</td></tr>
<tr><td>1a</td><td>Unconstrained</td><td rowspan="4">Maximize PSR</td><td>Non-Declining Inventory P26 to P30</td><td rowspan="4">None</td></tr>
<tr><td>1b</td><td>State Even Flow</td><td>Non-Declining Inventory P26 to P30
Even Flow on Total Volume</td></tr>
<tr><td>1c</td><td>Planning Area Even Flow</td><td>Non-Declining Inventory P26 to P30
Even Flow on Planning Area Volume</td></tr>
<tr><td>1d</td><td>Species Even Flow</td><td>Non-Declining Inventory P26 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume</td></tr>
<tr><td>2</td><td colspan="4">Million Cords</td></tr>
<tr><td>2a</td><td>10 Years</td><td rowspan="3">Maximize PSR</td><td>Non-Declining Inventory P26 to P30
5.0 Mil Cords P1 to P2
4.3 Mil Cords P3 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume</td><td rowspan="3">5%</td></tr>
<tr><td>2b</td><td>15 Years</td><td>Non-Declining Inventory P26 to P30
5.0 Mil Cords P1 to P3
4.3 Mil Cords P4 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume</td></tr>
<tr><td>2c</td><td>20 Years</td><td>Non-Declining Inventory P26 to P30
5.0 Mil Cords P1 to P4
4.3 Mil Cords P5 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume</td></tr>
</table>

<table>
<tr><th>Scenario</th><th>Description</th><th>Objective</th><th>Constraints</th><th>Volume Reduction</th></tr>
<tr><td>3</td><td colspan="4">NPC Growth Stages Goals</td></tr>
<tr><td>3a</td><td>Low Weight</td><td rowspan="2">Maximize PSR and NPC Goals</td><td>Non-Declining Inventory P26 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume
NPC Goals with Multiplier = 1</td><td rowspan="2">5%</td></tr>
<tr><td>3b</td><td>High Weight</td><td>Non-Declining Inventory P26 to P30
Even Flow on Planning Area Volume
Even Flow with 30% Departure on Species Volume
NPC Goals with Multiplier = 10,000</td></tr>
</table>

3.4.1 Timber Potential

Timber Potential (Scenario 1) was sub-divided into four separate scenarios. The objective was to incrementally add timber flow constraints, in order to assess the individual impacts of the different levels of constraints. All of the scenarios maximized PSR. None of these scenarios applied the volume reduction, since the objective of these scenarios was to determine total timber yield potential. Scenario 1a (Unconstrained) had no constraints on timber flow, except the non-declining inventory constraint over the last 5 planning periods. The purpose of this scenario was to evaluate the timber potential in the absence of flow constraints. The other three scenarios incrementally added flow constraints. Scenario 1b (State Even Flow) added strict even flow on the total (state level) harvest, to evaluate the addition of even flow to the total harvest volume. Scenario 1c (Planning Area Even Flow) added strict even flow at the planning area level (each planning area had the same harvest total volume every period), to evaluate the impact of even flow at the planning area level. Scenario 1d (Species Even Flow) added even flow with a 30% departure on species level volume (species level volumes cannot fluctuate substantially), to evaluate the impact of even flow with departure on timber products. Non-timber resources were not considered in this scenario, since the focus was primarily to establish the timber potential under various assumptions of even flow.

3.4.2 Million Cords

The Million Cords scenario investigated the length of time over which 1 million cords could be sustained. Our approach to this question was to determine surplus merchantable timber currently on MN DNR land, and what the long term sustained harvest level would be once the surplus was removed. The answer to this was determined by running the model with even flow for only period 2 through 30. In addition we also used the non-declining inventory, even flow on planning area volume, and even flow with departure on species volume. A 5% volume reduction was applied. This left period 1 unconstrained, and the results told as what the long term sustained timber yield would be after the surplus is removed, as well as the magnitude of the surplus. This run showed that the long term sustained timber yield was 873,565 cords per year (126,434 cords per year short of 1 million), and that the surplus inventory was 2,159,544. This surplus was sufficient to drive a 1 million cord harvest for at least 17 years. Non-timber resources were not considered in this scenario, since the focus was primarily to establish the potential for a million cord harvest.

Once we determined the surplus inventory we ran three sub-scenarios for the Million Cords scenario. All of the scenarios maximized PSR and utilized the 5% volume reduction. The volume reduction was included to account for implementation of MFRC site-level guidelines. Scenario 2a (10 Year) applied non-declining flow on inventory, 5.0 million cords in period 1 and 2 (1 million cords per year), 4.3 million cords in periods 3 through 30 (0.86 million cords per year), even flow at the planning area level, and even flow with 30% departure for species level volumes. The assumptions for Scenario 2b (15 Year) were the same, except for 5.0 million cords in periods 1 through 3, and 4.3 million cords in periods 4 through 30 (lengthened the 1 million cords per year harvest by one period). The assumptions for Scenario 2c (20 Year) were the same, except for 5.0 million cords in periods 1 through 4, and 4.3 million cords in periods 5 through 30 (lengthened the 1 million cords per year harvest by one period).

The reason why the model was capable of sustaining 4.3 million cords over the long run is because we determined that as the harvest level that could be sustained after removing the surplus inventory. The model was also able to maintain the 1 million cords for longer than the anticipated 17 years, because of inventory growth over the initial periods. In Phase 2 we will explore additional analytical approaches to determining the harvest levels for this scenario.

3.4.3 NPC Growth Stages Goals

The NPC Growth Stages Goals scenario assessed the impact of vegetation structural goals on the sustained timber harvest level. We recognize that the Native Plant Community (NPC) goals does not comprehensively represent non-timber values, but we elected (NPC) because we could rapidly implement them, and they would provide an adequate assessment (for the purposes of Phase 1) of potential impacts of non-timber values on sustained timber harvest.

The Native Plant Communities (NPC) approach is intended to represent the vegetation community that would naturally occur on the landscape under estimated natural disturbance regimes, and would approximate the historical forest age class distributions by NPC class at the time of the Public Land Survey in MN (1848 - 1907). It establishes goals for maintaining a given amount of NPC acres in certain growth stages (age classes). The MN DNR developed a list of NPC Growth Stages and the associated stands, using techniques developed by (David C. Wilson,

2017) [3]. In addition they also supplied the age classes for each NPC, as well as the proportion of acres within each NPC class that is desired to be within each age class (See Appendix C: NPC Growth Stages). This information was adapted from work completed by scientists within the MN DNR studying pre-Euro settlement. Using this information we associated each NPC with a set of stands in the model to derive the total acres. We then used the age classes and acre proportions to determine the amount of acres desired to be in each unique combination of NPC and age class. Finally we established a set of constraints that ensured that the adequate amount of acres were maintained in each NPC and age class combination. These are referred to as the NPC constraints.

This resulted in 140 individual constraints. It is highly unlikely that the model would be able to find a feasible solution with this number of constraints, and resolving the infeasibilities would take an extraordinary amount of time. In addition, it is also very likely that many of the NPC constraints are not feasible currently, and that they can only become feasible through management over time. For these reasons it was decided to implement the NPC constraints as goals. These goals set aspirational targets for the NPC age classes, since there is a strong incentive to meet them, but it's not required. The incentive in this case comes in the form of the objective function, since every acre that does not meet the NPC goal is subtracted from the objective function. Therefore, in maximizing the objective function the model has to minimize the number of acres not meeting their NPC goals.

The objective function was to maximize PSR minus the NPC deficit. The 5% volume reduction was also implemented. Ending inventory was controlled by the non-declining inventory constraint. Timber flow was controlled by even flow at the planning area level, and even flow with 30% departure at the species volume level.

Scenario 3a (Low Weight) implemented a goal weight of 1, while 3b (High Weight) used 10,000. These weights were used to scale the importance of the NPC goals relative to PSR, since each deviation from these goals were multiplied by the relevant weight factor. The higher the weight, the greater the reduction in the objective function for each acre deviating from its goal, and thus the harder the model will try to meet the goal. The opposite will be true for low goal weights.

4 Preliminary Results

The following section presents the results from the different model runs. We will investigate the impact of the different sets of assumptions on stumpage revenue, harvest volume, inventory, growth rates, NPC acre goals, and clear-cut age. As a reminder, the following results should not be considered as candidate solutions for the MN DNR forest management plan, since none of them are comprehensive with regards to their assumptions. The focus here is sustained yield from a timber perspective. More work is needed in Phase 2 to account for non-timber objectives.

[3] David C. Wilson, A. R. (2017). Imputing plant community classification from associated forest inventory and physiographic data in Minnesota, USA. *Ecological Indicators*, 73-82.

4.1 Present Stumpage Revenue (PSR)

The present stumpage revenue (PSR) of the scenarios were compared to see if any of the assumptions had a significant impact on the economic value of the management plan. Figure 6 shows that scenario 1a (Timber Potential – Unconstrained) had the highest value, while scenario 3b (NPC Growth Stages Goals – High Weight) had the lowest. This is to be expected, since 1a is the least constrained, while 3b is the most constrained. It's interesting to note that the values of scenarios 1b through 2b change very little, despite the fact that they had different even flow assumptions. For instance, there's a 9% drop in value adding the state level even flow, but adding the planning area and species level even flow only reduced value by 1%. Also, there was not a substantial difference in value between scenario 1d and the Million Cord scenarios. Finally, using the NPC goals with the larger weights (NPC Growth Stages Goals – High Weight) reduced value by 39% over the Million Cord scenarios. Using the lighter goals (NPC Growth Stages Goals – Low Weight) only reduced value by 4% from the Million Cord scenarios.

Note: Management costs are not included in stumpage revenue calculations.

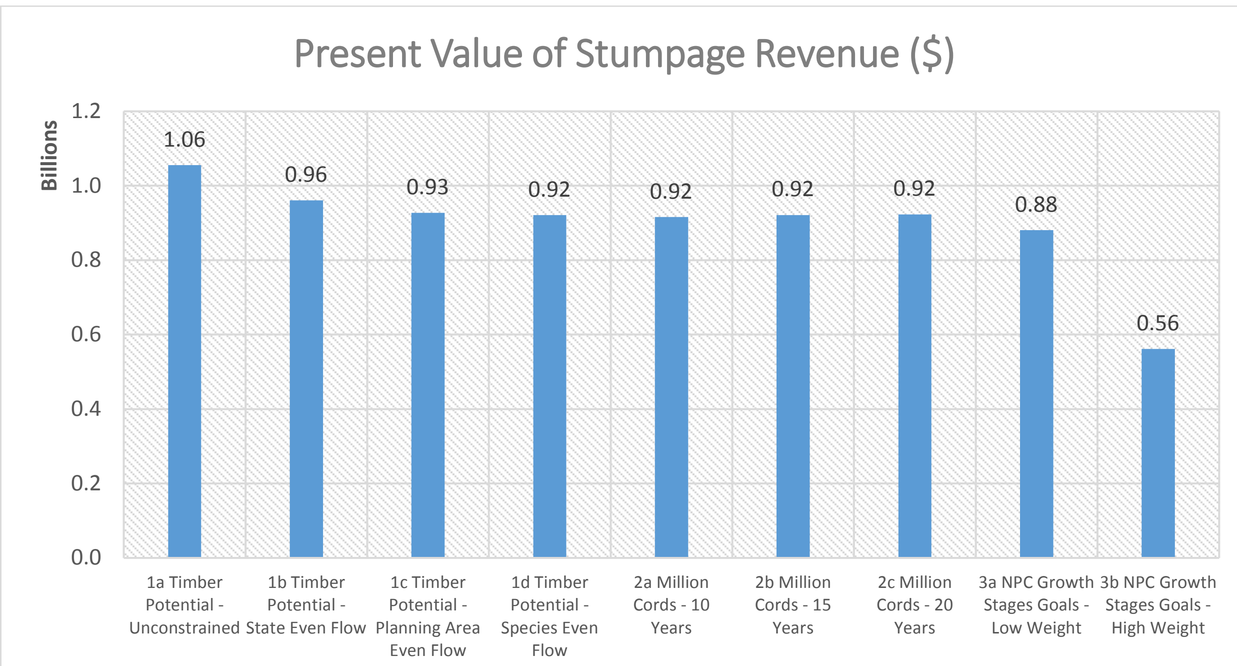

Figure 6: Present Stumpage Revenue of Scenarios

4.2 Harvest Volume

The annual total harvest volumes of the different scenarios were compared to assess the impact of the assumptions on harvest levels. Figure 7 shows the harvest levels with unprocessed results for scenario 1a. Scenario 1a has a large period 1 harvest, making it hard to observe the other scenarios. Figure 8 was therefore introduced to illustrate the average result for scenario 1a.

Figure 7 shows that results for scenario 1a has large fluctuations. Period 1 had a harvest of 3.5 million cords per year, followed by harvest levels that ranged between 0.5 and 1.5 million cords per year. The large harvest removal in period 1 suggests that MN DNR forests are overstocked, from a timber perspective. We will investigate this finding further in Phase 2, and will include the requirements of non-timber objectives.

Figure 8 shows the same harvest levels, but with scenario 1a averaged. These results show that all of the Timber Potential scenarios were clustered together at 0.92 to 0.93 million cords per year. The implication here is that the addition of even flow constraints do not have a substantial impact on statewide harvest levels. Also, the average for scenario 1a was calculated over all planning periods. If we leave the first period departure harvest out of the average, then the average would be 0.84 million cords per year. This suggests it may be possible to perform a departure harvest, but it could reduce the long term sustained yield by 9%.

This messaged was mirrored by the three 1-Million Cord scenarios. Here it was possible to harvest at 1 million cords for up to 20 years, but the long term sustained yield dropped to 0.87 million cords per year (5% lower than scenario 1d with all even flow constraints)

Finally, we see that the NPC Growth Stages Goals – High Weight scenario produced 0.57 million cords per year, a reduction of 38% compared to scenario 1d. In comparison, the NPC Growth Stages Goals – Low Weight scenario produced 0.89 million cords per year, a reduction of 4% from scenario 1d.

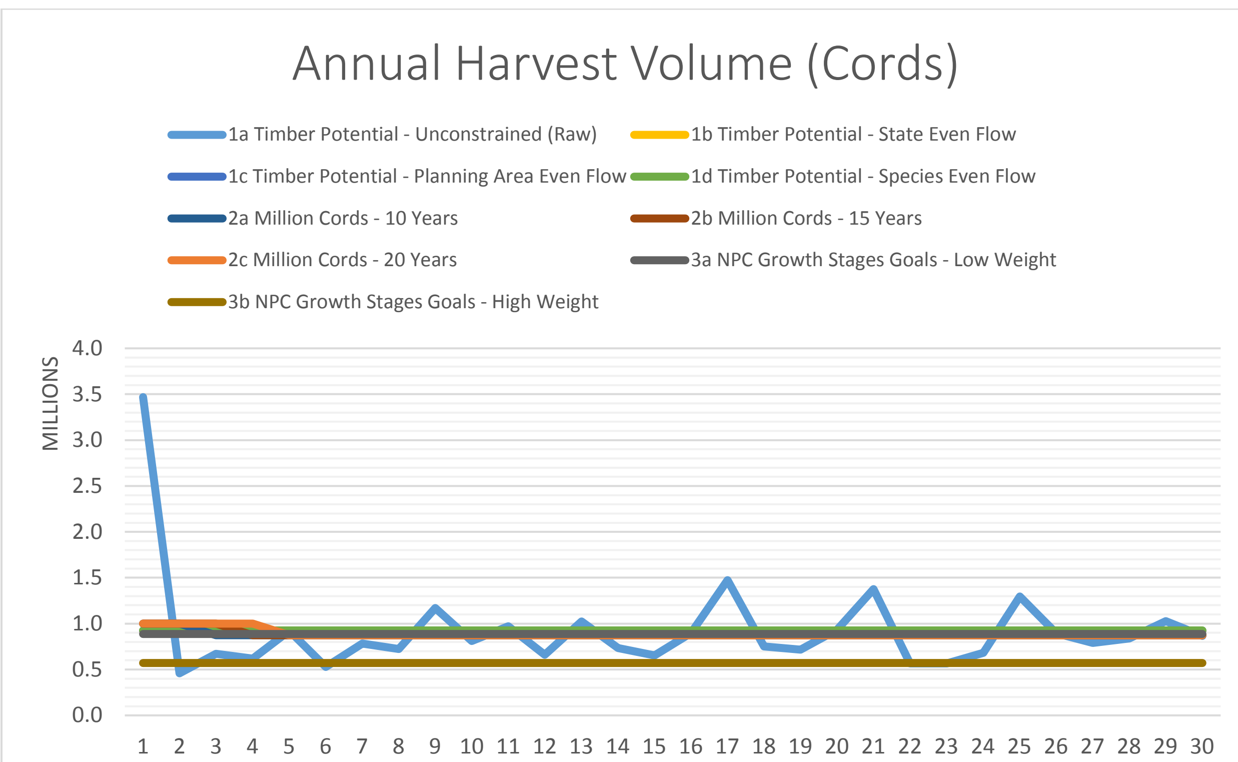

Figure 7: Annual Harvest Volume with Scenario 1a Unprocessed

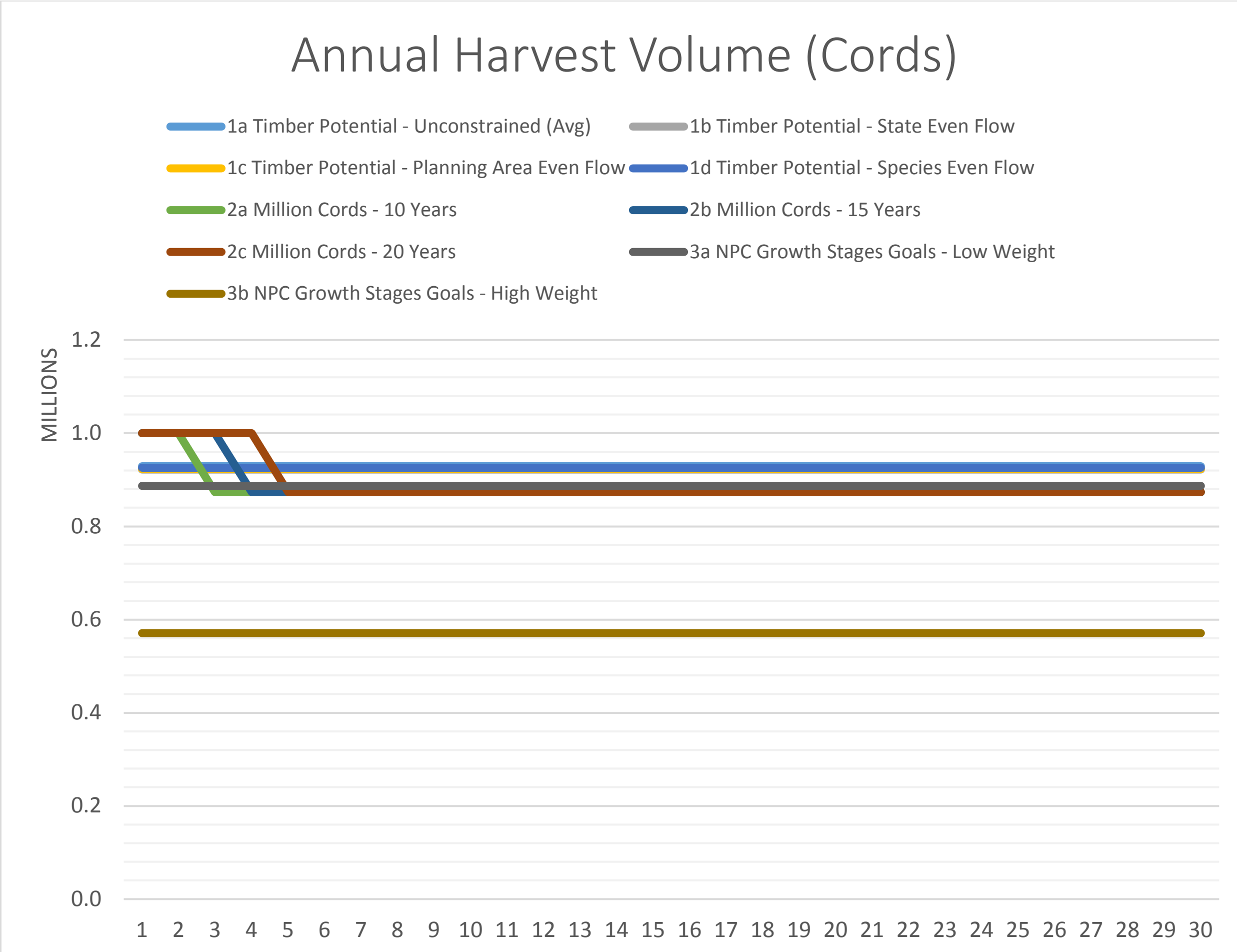

Figure 8: Annual Harvest Volume with Scenario 1a Averaged

4.3 Inventory

The inventory levels of the various scenarios were compared to assess the impact of the different assumptions on standing inventory levels over time. In assessing the inventory it is important to determine if the starting inventory level is acceptable, and that the inventory is managed by the model on a sustainable basis. There are a number of ways to determine the latter. One approach would be to calculate the inventory level if the forest is fully regulated, and to ensure that the inventory does not end below this level. A second could be to determine if inventory levels diminishes over time and to place constraints on inventory movement over the last few periods. For this model we applied the latter, but in Phase 2 we will expand our inventory analysis to include estimates of what the ending inventory should be.

Figure 9 shows the standing inventory for each scenario over time. The starting inventory for all scenarios were 36.6 million cords. This volume was calculated from the 2.7 million acres that are manageable, forested and merchantable. This results in an average inventory of 13.3 cords per acre from these lands.

The results also shows that scenario 1a reduced the standing inventory to 22.0 million cords in period 1, a reduction of 40%. Scenarios 1b through 2c reduced inventory by 2 to 4% over the first period, which is more compatible with growth rates. Of these, scenarios 2a through 2c had the larger reductions, while the reductions grew incrementally from scenario 1b through 1d. This is an expected result given how the constraints were applied.

Finally, the Timber Potential and 1 Million Cord scenarios leveled out at an inventory level between 25 and 30 million cords. This seems to be the sustainable inventory range (in the absence of non-timber values), and supports the notion that, from a timber perspective, the forests are currently overstocked by about 11 million cords. The NPC Growth Stages Goals – High Weight scenario had an ending inventory of 37.4 million cords. This is 3% more than currently standing, and about 50% more than the other scenarios (including the NPC Growth Stages Goals – Low Weight scenario).

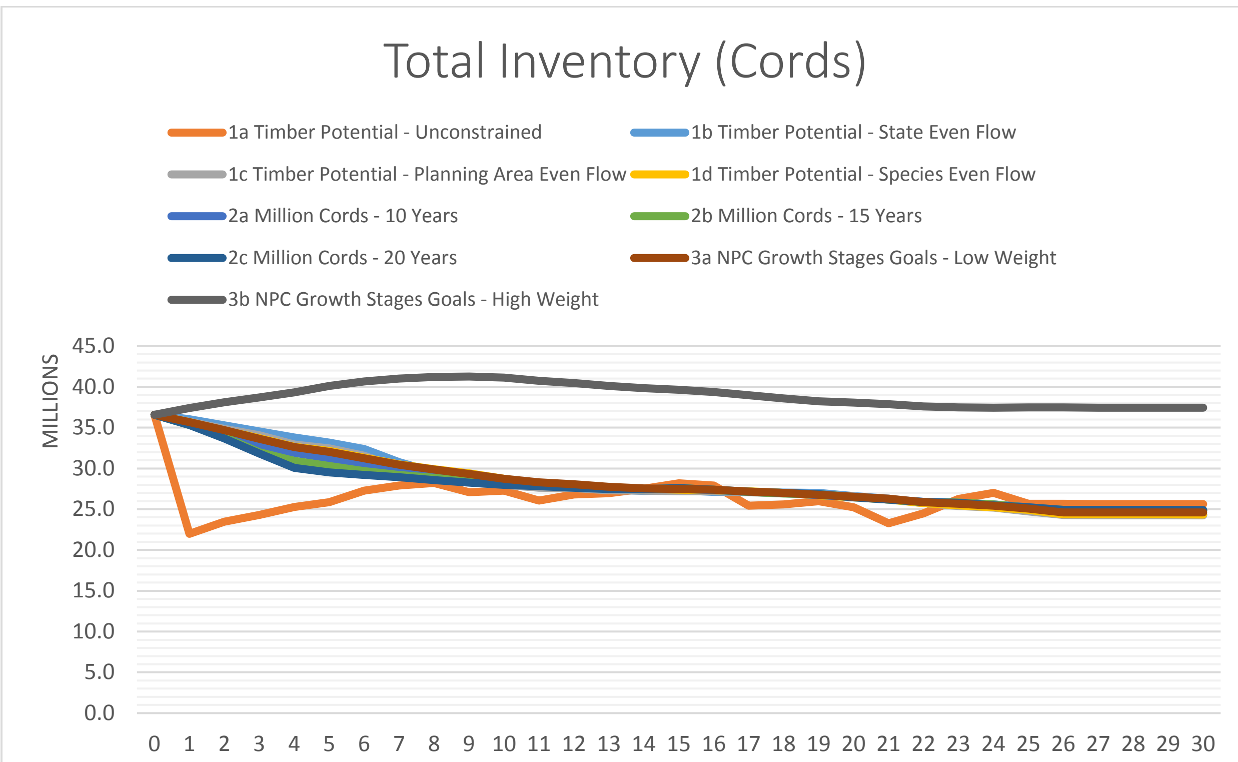

Figure 9: Standing Inventory

4.4 Growth Rates

We compared the growth rates of the various scenarios. Figure 12 shows that scenarios 1a through 2b had similar growth rates at about 0.71 million cords per year. It also shows that scenario 1a had the highest growth rates of the group, while scenario 1d had the lowest. The implication here is that relaxing the even flow constraints allows the model to schedule harvest closer to the culmination of growth, resulting in overall higher growth rates.

Of concern here is that the average annual growth was lower than the harvest level (0.71 million cords per year growth, vs. 0.92 million cords per year harvest). This phenomena needs to be investigated further, but if this is truly the case then we would have to be concerned about the viability of the long term sustained timber yield.

Average growth rates for the NPC Growth Stages - High Weight scenario were 0.5 million cords per year (average across all periods). This is a reduction of ±30% from scenario 1d, which is attributable to the age class distributions required by the NPC goals. These goals require more acres to be kept in the older age classes for a longer time. These older stands are therefore exposed to the mortality effects that have been built into the yield tables, resulting in loss of growth. The NPC Growth Stages Goals – Low Weight scenario did not exhibit the reduced growth levels, and that can be attributed to the fact that scenario did not sacrifice growth in order to meet the NPC goals.

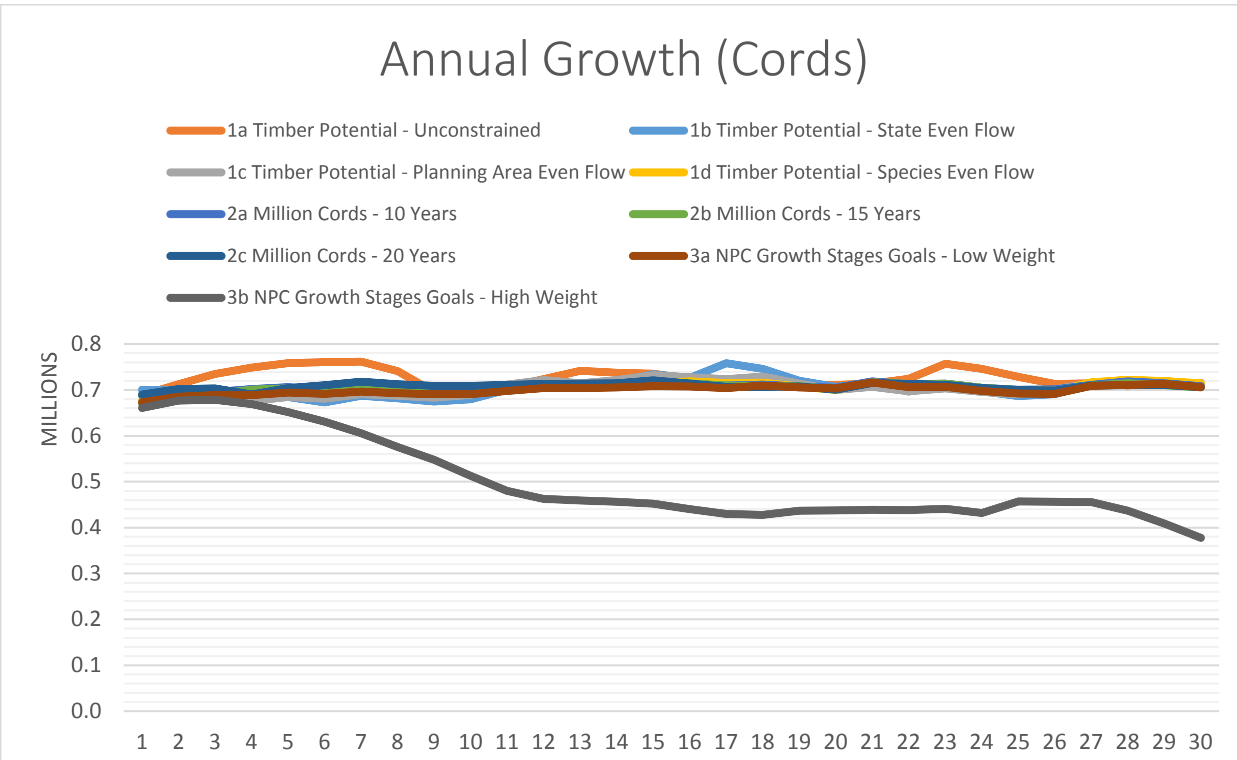

Figure 10: Average Annual Growth

4.5 NPC Acre Goals

We assessed the degree to which each scenario met the NPC goals, by subtracting the acres in each NPC age class from its corresponding goal, and summing the absolute deviations for each period. Here a number closer to zero implies that more of the NPC goals were met.

Figure 11 illustrates the absolute deviations for each scenario. It shows clearly that the NPC Growth Stages Goals – High Weight scenario had fewer deviations from the NPC goals than the other scenarios (55% less than scenario 1d). In contrast, the NPC Growth Stages – Low Weight scenario was almost indistinguishable from the timber orientated scenarios. This implies that the goal programming approach can be effective at incorporating non-timber values, but that it will be dependent on how the goals are calibrated.

The rest of the scenarios were fairly clustered and showed increasing deviations from NPC goals over time. Scenario 1a consistently showed the largest deviations. The differences between scenarios 1b through 2c were fairly small, but the deviations did decrease with more even flow constraints.

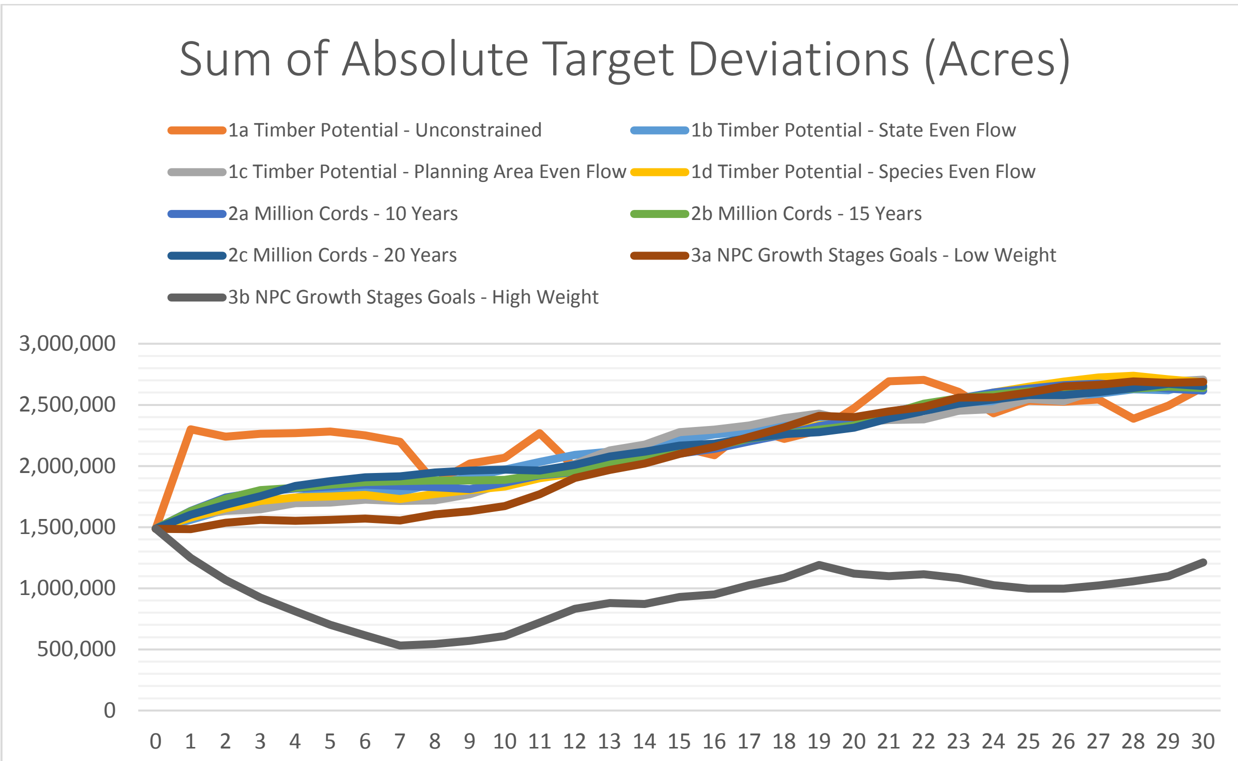

Figure 11: Absolute Deviations from NPC Goals

4.6 Average Clear-Cut Age

We compared the average statewide harvest age of the various scenarios (Figure 12). The average harvest age for the NPC Growth Stages Goals – High Weight scenario was ±90 years, compared to ±64 years for the other scenarios. This is due to how the NPC Goals scenario was established. The model can only harvest from the older age classes to meet the NPC goals and the younger age classes must grow into the older age classes before the model can harvest surplus timber. This might be part of the reason why the harvest levels are so much lower in the NPC Growth Stages Goals – High Weight scenario compared to the other scenarios (Figure 9).

For scenarios 1a through 2c, average harvest age started at about age 90, and slowly declined until it leveled out at about age 54. This suggests, from a timber perspective, that MN DNR forests are overstocked with older timber. We will investigate this finding further in Phase 2, including from the perspective of meeting non-timber objectives.

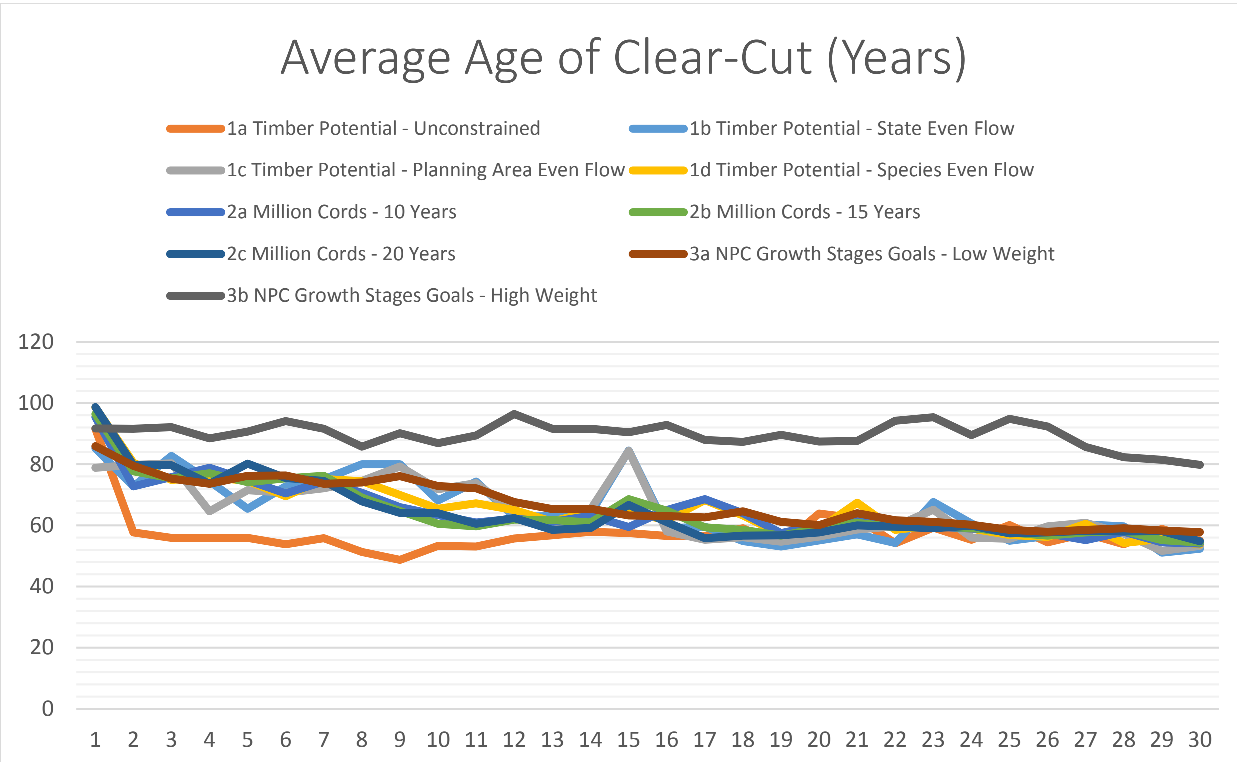

Figure 12: Average Harvest Age

5 Discussion

In this section we will discuss the main issues that were identified from the results of the Phase 1 model runs, and the potential implications for the Phase 2 analysis:

5.1 Even Flow Constraints

In Phase 1 we used a range of even flow constraints, in order to assess the potential impact on sustained timber harvest. The range of options included no constraints at all, to strict even flow, to even flow with a departure (slight deviation from even flow). We also applied these constraints at various management levels, ranging from state level, to planning area level, to species level.

The results that we obtained were slightly counter intuitive. We would normally expect the introduction of even flow to be accompanied by a reduction in timber harvest levels. Although we did observe this phenomena in the results, it was not of the magnitude that we would have expected. In addition, we would have expected a sharper decline in harvest volumes when applying even flow at the planning area level as opposed to the state wide level. The rational here is that management options are reduced when flow constrains are introduced, and also when they are applied at the planning area level vs. the state level. We would therefore expect an accompanying drop in harvest levels.

During Phase 2 we will look deeper into this aspect of the model. One hypothesis could be that the extensive land-base provides so many alternative options, that the limits put in place by the even flow constraints does not have a substantial impact. Another hypothesis could be that harvest is being limited by a base assumption (such as clear-cut age) that was present in all the scenarios, and that this factor limits the options to such a degree that there is very little opportunity to optimize in the absence of flow constraints.

5.2 Overstocked Inventory

It was observed in the results that the MN DNR has about 2,159,544 cords of surplus inventory (from a timber harvest perspective). This is inventory currently standing, that is theoretically ready for harvest. We also showed how this surplus inventory could be used to drive accelerated harvest levels for at least twenty years.

What was not accounted for was the contribution that this surplus inventory is making towards non-timber values. From this perspective one would not describe it as surplus, but rather as essential. For instance, the scenario that was most focused on non-timber values (NPC Growth Stages Goals – Heavy Weights) actually accumulated more inventory over time than is currently standing. I.e. the current inventory was not enough to sustain the NPC goals. It will therefore be essential in Phase 2 of the project to establish a representative set of non-timber constraints, and evaluate how they are affected by the reduction of standing inventory.

It will also be critical for Phase 2 to assess how much of the surplus inventory is truly accessible. We will therefore perform additional analysis on the inventory to identify and describe the surplus inventory, and to assess whether it is operationally available.

5.3 Growth Rates

The results showed that the growth rates observed through the model results were substantially lower than the sustained harvest levels. This poses a problem, because it implies the harvest levels are not sustainable. Sustained harvest levels should match growth in the long run, because then you are harvesting only the growth on an annual basis. In the short term one can deviate from this, since most forest inventories are not at the fully regulated state.

This discrepancy can be caused by a number of factors. We will perform additional tests on the model to ensure it's giving us accurate results. We will also benchmark the yield tables against observed growth and industry norms, in order to verify the growth projections from the yield tables.

5.4 Non-Timber Values

In this model we used NPC goals as a proxy for the non-timber values. These goals are not comprehensive in their representation of non-timber values, and will need further refinement for Phase 2. What was evident though is that these goals can have substantial impact on the sustainable harvest level. It is therefore paramount to address this issue as accurately as possible, since it has the potential to be a major driver in the final solution.

6 Appendix A: Clear-Cut Regimes

Table 8: Clear-Cut Regime Definition and Condition

Cover Type	Planning Area	Site Index	Min. Age	Max. Age
Aspen/BG	NMOP	<65	50	75
		65+	40	75
	WSU	<65	50	60
		65+	40	60
	NSU	<65	50	90
		65+	40	90
	MDLP	<65	50	80
		65+	40	80
	AP	<65	50	65
		65+	40	65
	BRP	<65	50	60
		65+	40	60
	MNIM	<65	50	60
		65+	40	60
Birch	NMOP	ALL	50	65
	WSU	ALL	50	60
	NSU	<60	55	90
		60+	60	90
	MDLP	ALL	50	80
	AP	ALL	45	55
	BRP	ALL	60	80
	MNIM	ALL	45	55
Jack Pine	NMOP	ALL	50	65
	WSU	ALL	40	60

Cover Type	Planning Area	Site Index	Min. Age	Max. Age
	NSU	ALL	60	90
	MDLP	ALL	45	65
	AP	ALL	50	70
	BRP	ALL	60	80
	MNIM	ALL	35	55
Balsam Fir	NMOP	ALL	45	55
	WSU	ALL	60	70
	NSU	ALL	50	70
	MDLP	ALL	45	55
	AP	ALL	50	60
	BRP	ALL	45	60
	MNIM	ALL	45	60
Black Spruce Lowland	NMOP	23-29	120	165
		30-39	100	135
		40+	80	100
	WSU	23-29	120	180

Cover Type	Planning Area	Site Index	Min. Age	Max. Age
		30-39	100	150
		40+	80	100
	NSU	23-29	120	180
		30-39	100	140
		40+	80	110
	MDLP	23-29	120	180
		30-39	100	135
		40+	80	100
	AP	23-29	120	180
		30-39	100	140
		40+	80	100
	BRP	23-29	120	170
		30-39	100	135
		40+	80	95
	MNIM	23-29	120	170
		30-39	100	135
		40+	80	95
Tamarack	NMOP	<40	95	145
		40+	70	115
	WSU	<40	100	150
		40+	60	140
	NSU	<40	100	150
		40+	75	120
	MDLP	<40	75	125
		40+	65	110
	AP	<40	100	160
		40+	80	120
	BRP	ALL	85	125
	MNIM	ALL	85	125
Red Pine Planted	NMOP	<55	70	100
		55-64	65	100
		65+	60	100
	WSU	<55	70	120
		55-64	65	120
		65+	60	120
	NSU	<55	70	115
		55-64	65	115
		65+	60	115
	MDLP	<55	70	100
		55-64	65	100
		65+	60	100
	AP	<55	70	100

Cover Type	Planning Area	Site Index	Min. Age	Max. Age
		55-64	65	100
		65+	60	100
	BRP	<55	70	125
		55-64	65	135
		65+	60	135
	MNIM	<55	70	125
		55-64	65	135
		65+	60	135
Red Pine Natural	NMOP	ALL	100	165
	WSU	ALL	120	180
	NSU	ALL	115	235
	MDLP	ALL	100	180
	AP	ALL	120	150
	BRP	ALL	115	140
	MNIM	ALL	115	140
Black Spruce Uplands	NMOP	ALL	60	75
	WSU	ALL	40	60
	NSU	ALL	65	85
	MDLP	ALL	45	65

Cover Type	Planning Area	Site Index	Min. Age	Max. Age
	AP	ALL	50	70
	BRP	ALL	35	55
	MNIM	ALL	35	55
Oak	NMOP	ALL	60	165
	WSU	<75	120	150
		75+	150	180
	NSU	ALL	85	240
	MDLP	<60	50	120
		60+	80	120
	AP	ALL	60	120
	BRP	ALL	80	165
	MNIM	ALL	60	165

7 Appendix B: Species Volume Conversions

The following table shows the cover type to species level volume conversions for the NMOP planning area:

NMOP																
Cover Type	**ASP**	**BAG**	**BIR**	**JP**	**WP**	**RP**	**WS**	**BF**	**BS**	**TAM**	**WC**	**BASS**	**OAK**	**ELM**	**MAP**	**ASH**
Ash	0.0967	0.0224	0.0550	0.0017	-	-	0.0114	0.0361	0.0069	0.0407	0.0444	0.0243	0.0044	0.0204	0.0067	0.6227
Lowland Hardwoods	0.0967	0.0224	0.0550	0.0017	-	-	0.0114	0.0361	0.0069	0.0407	0.0444	0.0243	0.0044	0.0204	0.0067	0.6227
Aspen	0.5723	0.2423	0.0247	0.0028	0.0001	0.0018	0.0134	0.0398	0.0219	0.0145	0.0148	-	0.0068	0.0073	0.0001	0.0372
Birch	0.0945	0.0080	0.2615	-	-	-	0.0315	0.1379	0.2387	0.1241	0.0398	-	-	-	-	0.0641
Balm of Gilead (used	0.5723	0.2423	0.0247	0.0028	0.0001	0.0018	0.0134	0.0398	0.0219	0.0145	0.0148	-	0.0068	0.0073	0.0001	0.0372
Northern Hardwoods	0.0658	0.0110	0.0789	-	-	-	-	0.0189	-	-	-	0.2333	0.1646	0.0141	0.3159	0.0949
Oak	0.0526	-	0.0174	-	-	-	-	-	-	-	-	0.1299	0.6933	0.0090	0.0508	0.0381
Central Hardwoods	0.0658	0.0110	0.0789	-	-	-	-	0.0189	-	-	-	0.2333	0.1646	0.0141	0.3159	0.0949
White Pine Natural	0.0911	-	0.0629	0.0042	0.5935	0.1499	0.0107	0.0053	-	-	-	0.0419	0.0101	-	0.0281	-
White Pine Planted	0.0911	-	0.0629	0.0042	0.5935	0.1499	0.0107	0.0053	-	-	-	0.0419	0.0101	-	0.0281	-
Red Pine-Natural	0.0247	-	0.0181	0.0607	0.0094	0.8455	0.0138	0.0095	0.0050	-	0.0043	-	-	-	-	-
Red Pine-Planted	0.0091	-	0.0003	0.0214	0.0056	0.9586	0.0026	0.0021	0.0001	0.0001	-	-	-	-	-	-
Jack Pine	0.0424	-	0.0268	0.7734	0.0521	0.0112	0.0187	0.0645	0.0079	-	-	-	0.0031	-	-	-
White Spruce-Natural	0.0614	0.0149	0.0258	-	-	-	0.6396	0.0981	0.0047	0.0442	0.0814	-	-	0.0299	-	-
White Spruce-Planted	0.0655	0.0118	0.0021	0.0207	0.0043	0.0094	0.8418	0.0146	0.0178	0.0062	0.0003	-	0.0005	0.0002	-	0.0014
Balsam Fir	0.0938	0.0399	0.0667	-	-	-	0.0505	0.4218	0.0991	0.0101	0.1544	-	-	-	-	0.0634
Black Spruce Lowlands	-	-	-	-	-	-	-	-	0.7783	0.1998	0.0219	-	-	-	-	-
Tamarack	-	-	0.0068	-	-	-	-	0.0020	0.1132	0.7940	0.0819	-	-	-	-	0.0020
Black Spruce Uplands	-	-	-	-	-	-	-	-	0.7783	0.1998	0.0219	-	-	-	-	-

The following table shows the cover type to species level volume conversions for the NSU planning area:

NSU																
Cover Type	**ASP**	**BAG**	**BIR**	**JP**	**WP**	**RP**	**WS**	**BF**	**BS**	**TAM**	**WC**	**BASS**	**OAK**	**ELM**	**MAP**	**ASH**
Ash	0.0816	0.0303	0.0765	-	0.0132	0.0004	0.0295	0.1011	0.0152	0.0172	0.0593	0.0018	0.0027	0.0022	0.0489	0.5109
Lowland Hardwoods	0.0816	0.0303	0.0765	-	0.0132	0.0004	0.0295	0.1011	0.0152	0.0172	0.0593	0.0018	0.0027	0.0022	0.0489	0.5109
Aspen	0.5659	0.0403	0.0730	0.0082	0.0125	0.0055	0.0487	0.1133	0.0336	0.0054	0.0062	0.0008	0.0012	0.0016	0.0494	0.0311
Birch	0.1368	0.0102	0.4744	0.0117	0.0118	-	0.0422	0.1166	0.0313	0.0083	0.0599	0.0012	0.0012	0.0003	0.0487	0.0401
Balm of Gilead	0.5659	0.0403	0.0730	0.0082	0.0125	0.0055	0.0487	0.1133	0.0336	0.0054	0.0062	0.0008	0.0012	0.0016	0.0494	0.0311
Northern Hardwoods	0.0763	0.0056	0.0830	0.0092	0.0317	-	0.0275	0.0650	0.0042	-	0.0354	0.0471	0.0139	0.0045	0.4885	0.0416
Oak	0.0526	-	0.0174	-	-	-	-	-	-	-	-	0.1299	0.6933	0.0090	0.0508	0.0381
Central Hardwoods	0.0763	0.0056	0.0830	0.0092	0.0317	-	0.0275	0.0650	0.0042	-	0.0354	0.0471	0.0139	0.0045	0.4885	0.0416
White Pine	0.0342	0.0024	0.0448	0.0277	0.6817	0.0858	0.0509	0.0342	0.0168	-	-	-	0.0024	-	0.0174	0.0013
Red Pine-Natural	0.0906	-	0.0665	0.1223	0.0751	0.5051	0.0589	0.0222	0.0097	-	0.0062	-	0.0021	-	0.0315	-
Red Pine-Planted	0.0252	-	0.0058	0.0090	0.0575	0.8551	0.0344	0.0063	0.0018	0.0011	0.0011	-	-	-	0.0011	-
Jack Pine	0.0846	-	0.0408	0.6475	0.0121	0.0370	0.0209	0.0413	0.1025	-	0.0067	-	-	-	0.0060	-
White Spruce-Natural	0.1030	0.0046	0.0178	0.0415	-	0.0363	0.6818	0.0503	0.0520	0.0126	-	-	-	-	-	-
White Spruce-Planted	0.0539	0.0060	0.0171	0.0124	0.0025	0.0458	0.7845	0.0518	0.0092	0.0008	0.0061	-	-	0.0003	0.0063	0.0011
Balsam Fir	0.1540	0.0039	0.0945	0.0131	0.0194	0.0092	0.1053	0.2836	0.2061	0.0116	0.0430	-	-	0.0002	0.0417	0.0126
Black Spruce Lowlands	0.0092	-	0.0199	0.0070	0.0067	0.0039	0.0093	0.0235	0.7606	0.1498	0.0094	-	-	-	-	-
Tamarack	0.0122	-	0.0248	0.0253	-	-	-	0.0359	0.1889	0.6496	0.0530	-	-	-	-	0.0094
Black Spruce Uplands	0.0092	-	0.0199	0.0070	0.0067	0.0039	0.0093	0.0235	0.7606	0.1498	0.0094	-	-	-	-	-

The following table shows the cover type to species level volume conversions for the rest of the state:

State																
Cover Type	**ASP**	**BAG**	**BIR**	**JP**	**WP**	**RP**	**WS**	**BF**	**BS**	**TAM**	**WC**	**BASS**	**OAK**	**ELM**	**MAP**	**ASH**
Ash	0.0400	0.0400	0.0200	-	0.0100	-	-	0.0200	-	-	0.0400	0.0300	0.0300	0.0400	0.2000	0.5100
Lowland Hardwoods	0.0400	0.0400	0.0200	-	0.0100	-	-	0.0200	-	-	0.0400	0.0300	0.0300	0.0400	0.2000	0.5100
Aspen	0.6089	0.0823	0.0468	0.0128	0.0050	0.0058	0.0203	0.0665	0.0116	0.0068	0.0060	0.0087	0.0318	0.0116	0.0337	0.0335
Birch	0.1355	0.0106	0.4005	0.0150	0.0117	0.0106	0.0420	0.1084	0.0376	0.0424	0.0278	0.0069	0.0255	0.0111	0.0505	0.0498
Balm of Gilead	0.6089	0.0823	0.0468	0.0128	0.0050	0.0058	0.0203	0.0665	0.0116	0.0068	0.0060	0.0087	0.0318	0.0116	0.0337	0.0335
Northern Hardwoods	0.0900	0.0300	0.0500	0.0100	0.0100	0.0200	0.0100	0.0200	0.0100	-	-	0.1800	0.1200	0.0300	0.3700	0.0500
Oak	0.0889	0.0028	0.0315	0.0050	0.0042	0.0053	0.0030	0.0023	-	0.0010	0.0002	0.1290	0.5253	0.0378	0.0400	0.0413
Central Hardwoods	0.0900	0.0300	0.0500	0.0100	0.0100	0.0200	0.0100	0.0200	0.0100	-	-	0.1800	0.1200	0.0300	0.3700	0.0500
White Pine Natural	0.0714	0.0017	0.0400	0.0324	0.5554	0.1023	-	0.0321	0.0107	0.0038	-	0.0076	0.0679	0.0002	0.0290	0.0054
White Pine Planted	0.0714	0.0017	0.0400	0.0324	0.5554	0.1023	-	0.0321	0.0107	0.0038	-	0.0076	0.0679	0.0002	0.0290	0.0054
Red Pine-Natural	0.1300	0.0003	0.0520	0.1563	0.0573	0.4889	0.0204	0.0191	0.0062	-	0.0013	0.0008	0.0434	0.0009	0.0187	0.0009
Red Pine-Planted	0.0452	0.0036	0.0154	0.0361	0.0227	0.8178	0.0163	0.0166	0.0050	-	0.0010	0.0005	0.0070	0.0007	0.0083	0.0001
Jack Pine	0.0730	0.0025	0.0299	0.6425	0.0234	0.0720	0.0167	0.0551	0.0565	0.0044	-	-	0.0156	0.0016	0.0021	0.0022
White Spruce-Natural	0.0660	0.0024	0.0445	0.0104	-	0.0213	0.6489	0.1154	0.0198	0.0053	0.0275	0.0002	-	0.0237	0.0025	0.0067
White Spruce-Planted	0.0512	0.0038	0.0184	-	0.0036	0.0048	0.7847	0.0661	0.0062	0.0064	0.0094	0.0055	0.0182	0.0008	0.0093	0.0038
Balsam Fir	0.1116	0.0199	0.0809	0.0098	0.0298	0.0237	0.0678	0.2984	0.1437	0.0850	0.0735	-	0.0053	0.0010	0.0180	0.0629
Black Spruce Lowlands	0.0141	0.0005	0.0121	0.0144	0.0066	0.0031	0.0041	0.0240	0.7088	0.1947	0.0155	-	-	-	0.0012	0.0007
Tamarack	0.0035	0.0013	0.0109	0.0020	0.0042	0.0037	0.0018	0.0092	0.1264	0.7867	0.0408	-	0.0007	-	0.0010	0.0059
White Cedar	0.0182	0.0084	0.0414	-	0.0052	0.0350	-	0.0412	0.0502	0.0631	0.7276	-	-	0.0019	0.0021	0.0220
Black Spruce Uplands	0.0141	0.0005	0.0121	0.0144	0.0066	0.0031	0.0041	0.0240	0.7088	0.1947	0.0155	-	-	-	0.0012	0.0007

8 Appendix C: NPC Growth Stages

The following table shows the NPC growth stages goals used in the model:

Table 9: Native Plant Community Growth Stages

NPC	Age Class	Percentage of Acres
APn80	0-55	30%
APn80	55-205	70%
APn81	0-55	38%
APn81	55+	62%
FDc12	0-55	76%
FDc12	55-115	22%
FDc12	115+	2%
FDc23	0-55	73%
FDc23	55-75	18%
FDc23	75-155	8%
FDc23	155+	1%
FDc24	0-55	71%
FDc24	55-75	18%
FDc24	75-155	10%
FDc24	155-195	1%
FDc24	195+	0%
FDc25	0-55	40%
FDc25	55-135	57%
FDc25	135+	3%
FDc34	0-55	47%
FDc34	55-95	31%
FDc34	95-135	13%
FDc34	135-175	3%
FDc34	175+	6%
FDn12	0-55	61%
FDn12	55-75	17%
FDn12	75-195	20%
FDn12	195+	2%
FDn22	0-55	59%
FDn22	55-75	16%
FDn22	75-115	14%
FDn22	115+	11%
FDn32	0-55	57%
FDn32	55-95	25%

NPC	Age Class	Percentage of Acres
FDn32	95+	18%
FDn33	0-35	14%
FDn33	35-55	27%
FDn33	55-125	44%
FDn33	125+	15%
FDn43	0-35	17%
FDn43	35-55	30%
FDn43	55-95	31%
FDn43	95-115	5%
FDn43	115+	17%
FDs27	0-55	19%
FDs27	55+	81%
FDs36	0-35	29%
FDs36	35-75	56%
FDs36	75-135	12%
FDs36	135-175	2%
FDs36	175+	1%
FDs37	0-75	79%
FDs37	75+	21%
FDs38	0-55	26%
FDs38	55-135	72%
FDs38	135+	2%
FDw24	0-35	69%
FDw24	35+	31%
FDw34	0-35	64%
FDw34	35+	36%
FDw44	0-35	69%
FDw44	35+	31%
FFn57	0-55	31%
FFn57	55-95	45%
FFn57	95+	24%
FFn67	0-55	30%
FFn67	55-95	52%
FFn67	95+	18%
FFs59	0-35	7%
FFs59	35-155	85%
FFs59	155+	8%
FFs68	0-35	21%
FFs68	35-155	70%

NPC	Age Class	Percentage of Acres
FFs68	155+	9%
FPn62	0-55	14%
FPn62	55+	86%
FPn63	0-55	11%
FPn63	55-115	36%
FPn63	115+	53%
FPn71	0-55	27%
FPn71	55+	73%
FPn72	0-55	13%
FPn72	55+	87%
FPn81	0-55	34%
FPn81	55+	66%
FPn82	0-55	23%
FPn82	0-55	23%
FPn82	55+	77%
FPn82	55+	77%
FPs63	0-55	19%
FPs63	55+	81%
FPw63	0-55	27%
FPw63	55+	73%
MHc26	0-35	21%
MHc26	35-55	31%
MHc26	55-135	45%
MHc26	135+	3%
MHc36	0-35	7%
MHc36	35-95	75%
MHc36	95+	18%
MHc37	0-55	40%
MHc37	55-135	57%
MHc37	135+	3%
MHc47	0-55	23%
MHc47	55-155	73%
MHc47	155+	4%
MHn35	0-55	39%
MHn35	55-95	51%
MHn35	95-205	8%
MHn35	205-295	1%
MHn35	295+	1%
MHn44	0-35	24%

NPC	Age Class	Percentage of Acres
MHn44	35-95	60%
MHn44	95-195	14%
MHn44	195+	2%
MHn45	0-75	29%
MHn45	75-95	16%
MHn45	95-155	38%
MHn45	155-195	3%
MHn45	195+	14%
MHn46	0-35	17%
MHn46	35-95	68%
MHn46	95+	15%
MHn47	0-55	34%
MHn47	55-75	31%
MHn47	75-195	32%
MHn47	195+	3%
MHs37	0-55	24%
MHs37	55-95	60%
MHs37	95+	16%
MHs38	0-35	7%
MHs38	35-75	35%
MHs38	75+	58%
MHs39	0-35	4%
MHs39	35-75	50%
MHs39	75+	46%
MHs49	0-55	18%
MHs49	55+	82%
MHw36	0-55	69%
MHw36	55+	31%
WFn53	0-55	32%
WFn53	55-75	10%
WFn53	75-105	34%
WFn53	105-155	15%
WFn53	155+	9%
WFn55	0-75	54%
WFn55	75-195	43%
WFn55	195+	3%
WFn64	0-75	55%
WFn64	75-135	35%
WFn64	135+	10%

NPC	Age Class	Percentage of Acres
WFs57	0-55	18%
WFs57	55+	82%
WFw54	0-55	52%
WFw54	55-105	21%
WFw54	105+	27%