Washington Wood Supply Study

A *Draft* Report to the State of Washington Department of Natural Resources

Submitted by Evergreen Economics

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1 Introduction

The Washington State Department of Natural Resources (DNR), through a competitive bidding process, selected Evergreen Economics and L&C Carbon (the "Evergreen team") to complete a wood supply study for Washington State and conduct scenario analysis related to the management of state forestlands. This Draft report focuses on wood supply in western Washington under DNR's current operations of state forestland, and the results presented in this report are subject to change as the Evergreen team continues to conduct the overall analysis.

In this study, we estimate the current and future supply and demand for wood in Washington State west of the Cascade crest based on the current forest practices of private forest landowners, state trust lands, and federal lands. To conduct the analysis, we used a spatial-oriented model, which we describe below, that allowed us to account for the geographic location of forest stands by species, age class, and site index, as well as the location of mills across western Washington. This modeling approach allowed the Evergreen team to assess whether there are local or regional gaps in wood supply that may impact the needs of sawmills and other forest products manufacturers.

The wood supply study, while providing estimates of current and future wood supply and demand in western Washington, also serves as the "business as usual" scenario of a broader economic analysis to examine alternative approaches for managing state trust lands in western Washington. Beginning in July 2024, the Evergreen team will analyze seven of the scenarios developed by the Carbon and Forest Management Work Group (the Work Group).[1] The scenarios, shown in Table 1, range from relatively simple changes in rotation length (e.g., Scenario 2: lengthen harvest rotation on general ecological management [GEM)] lands) to substantially more complex changes in forest management (e.g., Scenario 8: increase emphasis on silviculture, significantly increase thinning, and shorten harvest rotation on GEM lands). DNR staff will determine which seven of the scenarios the Evergreen team will analyze.

[1] For more information about the Carbon and Forest Management Work Group, please see: https://www.dnr.wa.gov/about/boards-and-commissions/carbon-and-forest-management-work-group

Table 1: Forest Management Scenarios Developed by the Carbon and Forest Management Work Group for Washington DNR-Managed Lands

Scenario	Description
1	DNR current operations (“business as usual” scenario)
2	Lengthen harvest rotation on GEM lands
3	Shorten harvest rotation
4	Significantly increase thinning
5	Lengthen harvest rotation and significantly increase thinning
6	Lengthen harvest rotation, significantly increase thinning, and increase deferrals
7	Increase emphasis on silviculture and significantly increase thinning
8	Increase emphasis on silviculture, significantly increase thinning, and shorten harvest rotation on GEM lands

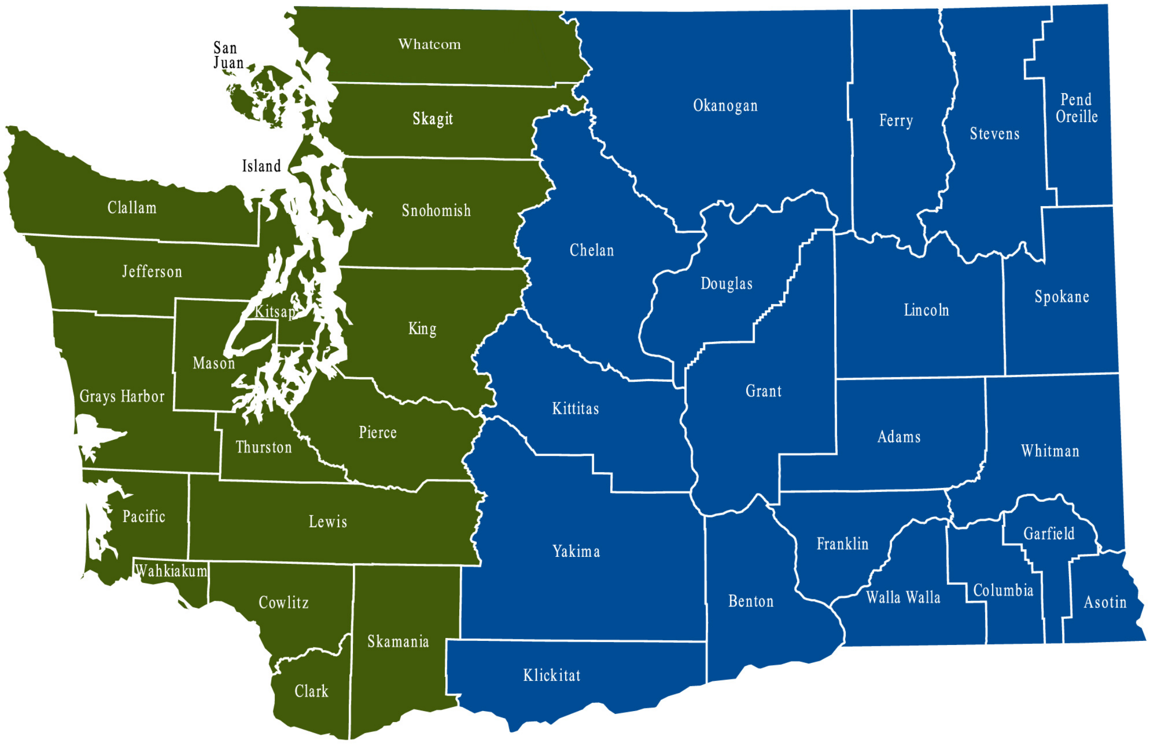
DNR recognizes that, though state trust lands make up only 13 percent of forest lands and 9 percent of harvest volume in western Washington, changes in management of these lands may affect management decisions of private forestland owners, impact short- and long-term wood supply for Washington mills, and may ultimately have economic impacts on local communities. The primary purpose of this wood supply study is to provide a baseline projection of timber harvests and wood products manufacturing in western Washington. In addition, the report provides an overview of the forest and forest products sectors in western Washington and estimates of the economic contributions the forest and forest products sectors have on the western Washington economy.

This report, however, is just the first phase of a much larger study to understand how potential changes in management practices on state lands might impact management of other western Washington forestlands and the competitiveness of the forest products industry in western Washington. The motivation for considering potential changes in the management of state forests is an effort to increase net carbon sequestration on state forestlands and, to a lesser extent, to promote increases in the provision of other ecosystem services. The next phase of the larger study will begin in July 2024 as the Evergreen team will begin analyzing how the scenarios developed by the Work Group and described in Table 1 might impact timber harvests, net carbon storage, and wood products manufacturing in western Washington.

1.1 Study Area

The study area is comprised of the 19 counties west of the Cascade crest; these counties are shown in green in Figure 1.

Figure 1: Western and Central/Eastern Washington Counties



1.2 Forest Carbon Markets in Washington

The development of the carbon offset market for forest carbon credits has evolved significantly over the past few decades, driven by increasing awareness of climate change and the growing interest in forests being sustainably managed. The demand is growing rapidly for high-quality forest carbon credits, as they offer an abundant and cost-effective means to mitigate climate change while providing a range of environmental and social co-benefits. These type of credits are generated through activities that enhance carbon removal and storage in forests, such as reforestation and improved forest management, and are an important component of natural climate solutions.

Initially, the carbon credit market was primarily driven by voluntary commitments from companies and individuals aiming to offset their carbon footprints. However, with the adoption of regulatory frameworks such as Washington Cap and Invest, and international agreements such as the Paris Agreement, there has been a marked increase in both the supply and demand for carbon credits.

Innovations in technology and improvements in monitoring and verification methods have also bolstered the credibility and attractiveness of forest carbon credits, encouraging more participation from various sectors.

In Washington State, the demand for forest carbon credits has been growing at an accelerated pace, fueled by strong corporate commitments to sustainability and progressive state policies. Companies based in Washington, particularly those in the technology and retail sectors, have been at the forefront of purchasing forest carbon credits to meet their carbon neutrality and sustainability goals. The state's regulatory environment, which includes initiatives such as the Clean Air Rule, has also incentivized companies to invest in carbon offsets. Additionally, Washington's abundant forest resources and a community of environmentally conscious consumers have further driven local businesses to engage in carbon offset projects. This growing demand from Washington State-based companies not only supports global climate goals but also promotes local forest conservation and management efforts, creating a beneficial cycle of economic and environmental sustainability.

Although there are only a handful of forest carbon offset projects registered and operating in Washington currently, there is growing interest among forest owners to learn more about the opportunities of participating in the voluntary and regulated markets. As the value of carbon credits rise, we anticipate participation by forest landowners will increase, especially as barriers to entry are addressed, such as upfront project development costs and project complexity.

2 Background

In this section, we briefly summarize the 2007 Washington Wood Supply Study, which characterized many aspects of the forest and forest products sectors as they existed in 2007 and discussed how the sectors had changed in previous years. We then discuss a number of peer-reviewed studies that either focus specifically on projecting wood supply in western Washington or other US regions using some form of a market model approach.

2.1 The 2007 Washington Wood Supply Study

A study by Lippke et al. (2007) analyzed the state of Washington's timber producing and wood products manufacturing sectors. The authors compared projections from the 1992 western Washington timber supply study (Adams et al. 1992) to actual harvests through 2005 by ownership type, the impacts of public policies on timber production, and changes in forest management strategies. The study provided an assessment of timber harvest levels, log supplies, ecological measures, and economic impacts across different forest ownership types and regions, but did not attempt to project forest inventories, timber harvests, or industry demand for forest products. The study also explored the implications of various management alternatives on forest structure, habitat, and carbon storage.

2.1.1 Review of Projections from the 1992 Wood Supply Study

The 2007 study by Lippke et al. found substantial discrepancies between timber supply projections developed as part of the 1992 Washington wood supply study and actual harvest levels, largely due to unanticipated policy changes and management practices. For example, federal harvest levels were substantially lower than projected, primarily because of stricter environmental regulations and shifts in management objectives towards ecosystem protection. This led to a considerable decline in overall harvests as timber inventories on private lands were not available to offset the reduction in federal timber harvests.

Lippke et al. found that the 1992 western Washington timber supply study overestimated the federal timber harvest levels based on overly optimistic assumptions about the outcomes of the 1992 Forest Service environmental impact statement (EIS) aimed at protecting the northern spotted owl. (USDA and BLM 1994). The actual federal harvest was 87 percent below the projected level and 97 percent below the baseline harvest of the late 1980s. This discrepancy was due to more stringent environmental regulations and a shift in federal land management objectives towards ecosystem protection rather than timber production.

Harvest levels on Washington Department of Natural Resources (DNR)-managed forests were also overestimated. The 1992 western Washington timber supply study projected a 3 percent increase in state-managed harvests, but Lippke et al. (2007) reported that actual harvest levels were 43 percent below the projections and 41 percent below the baseline. This decline was largely attributed to the implementation of the DNR Habitat Conservation Plan (HCP), which included extensive protections for various species and stream buffers.

Moreover, Lippke et al. (2007) reported that private harvests were 31 percent below the 1992 western Washington timber supply study projection and 34 percent below the baseline, despite only a modest anticipated decline in non-industrial and Tribal harvest volumes. Lippke et al. (2007) reported that this unexpected reduction in private harvests suggested that factors such as regulatory constraints and forestland lost to conversion to other uses significantly impacted the industry more than initially expected. Overall, the authors emphasized that policy changes and regulatory impacts were not adequately anticipated in the prior (1992) projection, leading to substantial overestimation of future timber supply.

2.1.2 Ecosystem Services Provided by Washington Forests

Lippke et al. (2007) explored the potential role that ecosystem services might provide to incentivize sustainable forest management practices. The study underscored the role forests can play in providing ecosystem services, with carbon sequestration being a major focus. The report highlights that managed forests can sequester significant amounts of carbon through both standing biomass and forest products. Specifically, commercial forests under a 45-year rotation schedule not only store carbon in forest biomass but also in long-lived wood products, which can offset carbon emissions from more energy-intensive building materials such as steel and concrete. This dual benefit emphasizes the importance of sustainable forest management practices that optimize both ecological and economic outcomes.

The authors found that forests managed for periodic harvesting and reforestation could sequester more cumulative carbon than unmanaged forests; this is because harvested wood products continue to store carbon and displace fossil fuel-intensive products over time, effectively increasing the total carbon offset. The research underscores the complexity of carbon accounting, advocating for a comprehensive approach that includes all stages from forest growth to product use and disposal.

The authors also addressed the opportunity costs of managing forests for ecosystem services such as old forest habitats. These costs represent the revenue losses landowners incur when extending rotations or implementing biodiversity pathways. For instance, managing forests to develop old growth-like structures requires significant investment, but it can yield substantial ecological benefits. The study suggests that integrating economic incentives with ecological goals can promote sustainable forest management practices that enhance carbon sequestration and biodiversity while maintaining economic viability for forest landowners.

2.1.3 Variations in Forest Management Affect Economic Impacts

Lippke et al. (2007) found that variations in forest management practices substantially affect the economic impacts of the forestry and forest products sectors. Management practices that prioritize shorter rotations and increased timber harvests generally generate higher economic returns. These practices boost regional economic activity by creating more jobs in logging, processing, and secondary manufacturing, thereby increasing state and local tax revenues. Regions with more intensive forest management practices show higher economic outputs compared to those with less intensive practices.

Conversely, management strategies aimed at improving forest health and reducing risks such as fire and insect infestations also yield significant economic benefits, albeit through different mechanisms. While thinning treatments and other forest health-focused practices may not generate high direct revenues, they offer substantial cost savings by avoiding expenses associated with fire and pest damage. These practices enhance long-term forest resilience, contributing to economic stability by reducing losses and sustaining forest productivity. The study emphasized that these forest health-oriented strategies may result in substantial labor income and state and local tax receipts compared to less intensive forest management practices.

The authors also highlighted the broader economic contributions of ecosystem service-oriented management practices. These practices, aimed at carbon sequestration and biodiversity enhancement, provide significant long-term economic and ecological benefits. They improve habitat conditions, contribute to global carbon offset markets, and attract funding and incentives for conservation. Integrating these practices with commercial objectives supports diversified economic benefits, balancing ecological health with sustainable economic growth.

2.2 Peer Reviewed Studies Focusing on Western Washington Wood Supply

A report by Adams, Alig, and Stevens (1994) explored the potential range of future timber harvests in western Washington and considered the characteristics of the resource base, owner behavior, and public policies that have substantial impacts on harvests over time. The authors considered uncertainties in projections related to variations in starting inventory data, rates of forestland loss to agriculture and urbanization, management intensity by private landowners, and future regulations affecting forest practices. The authors noted that there was limited volume of merchantable timber on private lands from which to draw near-term timber harvests and, therefore, regulations affecting the availability of older timber on public lands or the minimum age of harvest on all lands would have had substantial negative impacts on harvests in the near term.

To examine the impacts of the noted uncertainties, the authors developed a baseline projection (referred to as the “initial conditions”) and nine alternative management scenarios that they compared to the initial conditions. Of these scenarios, five have direct relevance to the current wood supply study.

1. Alternative Inventories

For industrial and non-industrial forestlands, the authors obtained alternative forest inventory data that suggested lower harvest potential (relative to Forest Inventory Analysis [FIA] data) due to lower current inventory volume, greater concentration of lands in medium and low productivity site classes, and more areas where Douglas fir forests are prevalent. The authors also compared inventory data obtained from the Washington DNR to FIA data from plots on DNR-managed lands and found that the DNR data reflected substantially lower volumes. They estimated that, relative to the baseline, total harvests across all owner classes would be 9 percent lower in the first 15 years of the forecast (1990–2005) and 6 percent lower in the last 15 years of the forecast (2070–2085).

2. No Timberland Loss

The authors fixed western Washington's timberland inventory at 1990 levels to reflect policies that fully and effectively preserve western Washington timberlands. Relative to the baseline model, which allows timberland to be converted to other uses, the scenario of no loss in timberlands has a substantial and increasing impact on average harvest volume as the effect of preventing timberland losses would be cumulative over time. They estimated that, relative to the baseline, total harvests across all owner classes would be 3 percent higher in the first 15 years of the forecast and 7 percent higher in the last 15 years of the forecast.

3. Fifteen Percent Yield Reduction and Shift in Management Intensity

For this scenario, the authors simulated the impact of restrictions on the ability of private forestland owners to conduct intensive management on future rotations by reducing reference yield curves by 15 percent. They estimated that, relative to the baseline, total harvests across all owner classes would be 5 percent lower in the first 15 years of the forecast and would be 12 percent lower in the last 15 years of the forecast.

4. No Shift in Management Intensity on Regenerated Stands

For this scenario, the authors eliminated intensive management practices on all regenerated stands. This scenario focused on industrial forestland, since intensive management is limited on non-industrial and publicly-owned timberlands. They found that total harvests across all owner classes were 6 percent lower relative to the baseline. They estimated that, relative to the baseline, total harvests across all owner classes would be no different in the first 15 years of the forecast but would be 6 percent lower in the last 15 years of the forecast.

5. Higher Minimum Harvest Ages

In the initial conditions projection, the minimum harvest age was set to the age at which a stand becomes merchantable. For the higher minimum harvest age scenario, the authors raised the minimum harvest age for all management units by 10 years. They found that, relative to the initial conditions, harvests on both Washington DNR and private industrial timberlands were reduced in the near term, but average volumes per acre and total harvests increased over the long term. Specifically, they estimated that, relative to the baseline, total harvests across all owner classes would be 13 percent lower in the first 15 years of the forecast, but 5 percent higher in the last 15 years of the forecast.

The 2007 study by Adams and Latta used a market model approach to project sustainable timber harvest levels for private lands in western Oregon and Washington through 2054. They found that in western Oregon, harvests could be maintained or even increased, while western Washington may have faced harvest reductions due to high harvest levels in the 1980s and to continued loss of forestlands to other uses. The spatial partial equilibrium market model approach used by the authors balanced US demand for wood products with supplies of harvested timber from regional log markets. Unlike flow-based analyses of timber supply potential, which rely on timber inventory and assumptions about forest growth and yield, the market model approach allowed future timber harvest—both the levels of harvests and the location of harvests—to periodically update through time (typically each 1, 5, or 10 years) based on regional log supply and demand. Regional log demand was derived from the demand for wood products and exports, which is sensitive to the delivered price of logs.

The authors focused on the Douglas-fir region log market, which they defined as western Oregon and Washington. Their spatial partial equilibrium market model approach explicitly recognized the geographic location, ownership, and associated management objectives of forestlands across the Douglas-fir region and the location of log processing facilities dispersed across the region. Regional lumber and plywood production are sensitive to delivered log prices; it is for this reason that the authors relied on a spatially oriented model that accounts for haul distance. In the short run, the supply of logs available to mills is dependent on the harvesting decisions of private timber owners, which are assumed to optimize the value of their timber investments given stand growth and interest rates. In the longer term, log supply depends on silvicultural and perhaps other investment decisions related to anticipated yield increments, management costs, interest rates, and price expectations.

Mills generate demand for delivered logs, which varies with log price up to the point of maximum mill capacity. Log demand shifts depending on prices for wood products, milling technology, other input costs, and milling capacity. The spatial partial equilibrium market model allows for arbitrage opportunities by log buyers (the mills), which can choose among log sources to minimize delivered cost per level of output. In the long run, mill capacity is allowed to vary based on product prices, equipment costs, depreciation, and interest rates.

Log sellers lie at various distances from the mills and have varying cost structures depending on types of forest management, logging conditions, and haul distances. From the perspective of log suppliers, market arbitrage involves choosing among different processing centers for the one(s) that provide the greatest net return. The log market is represented by harvests, flow patterns from forests to mills, and levels of output at the milling centers, which are determined by the competing objectives of buyers and sellers within each log market.

The authors used the 2005 Resource Planning Act Timber Assessment Update (Haynes et al. 2007) for assumptions about future prices of wood products, as well as for the costs of labor and other variable inputs. Harvest from public lands is determined by policies within the respective managing agencies and generally is not sensitive to log price over the five-year time interval used in this analysis. The authors treated public log supply as exogenous; for the base case they assumed public harvest would remain constant over the forecast at the average over the 2000–2002 period.

The authors found that forest industry lands in western Oregon and Washington could sustain harvests over the next 50 years near their recent historical average. However, they found that their projection for western Washington was roughly 30 percent lower than both the projections by Adams et al. (1992) and Larson and Wadsworth (1982) due to substantial reductions in the inventory and the land base of industrial forest owners, which reduced long-run supply potential. The authors found that timber inventory in western Washington would remain stable through

2034, but would rise as stands planted after 2004 reach the ages when the most rapid growth in board foot volume occurs.

The authors noted that the results of their base case projection were consistent with earlier studies in finding that regeneration-only or regeneration followed by pre-commercial thinning (PCT) dominated at the start of the projection, but were gradually replaced by regimes that included PCT, commercial thinning (CT), or both PCT and CT. They noted that the movement toward PCT plus CT was more extensive in western Washington than in western Oregon. While the authors projected that there would be a shift toward silvicultural regimes that included PCT and CT, their findings did not depend on any assumptions about genetic yield improvements or use of highly intensive methods.

The authors projected that the inventories on non-industrial private lands in western Oregon and Washington would follow roughly similar time paths. Through 2030, harvests were projected to exceed growth, and inventories were projected to fall. In western Washington, high harvests between 1990 and 2005 have resulted in substantial acreage of very young timber stands. The authors projected reduced inventory despite declining harvests. After 2029, inventories on non-industrial lands in western Oregon and Washington were projected to rise due to improved stocking in regenerated stands and maturation of large areas presently in the youngest age classes. The authors projected that management of non-industrial forestlands would be similar to that projected for industrial lands: initial concentration of regeneration-only management, followed by an increasing shift into regimes that include PCT and CT.

A study by Adams et al. (2019) examined alternative biofuel production sites in Longview, Washington and Springfield, Oregon using an intertemporal spatial partial equilibrium model of the western Oregon and Washington log market that accounted for the actual locations of harvesting activities, the transportation network and cost to haul residue to the two alternative biofuel production sites, and the characteristics of the forest resources that determine harvesting methods and residue collection costs.

Previous feedstock supply studies of forest biomass published for the western US have taken a wide variety of forms but have generally used simplified models of biomass supply dynamics. The intertemporal spatial partial equilibrium model employed by Adams et al. allowed the authors to assess the potential residue supply characteristics in western Oregon and Washington by integrating detailed forest resource data, log market dynamics, and spatial-temporal factors, including transportation networks and harvesting costs, to project residue supply over time.

The findings indicated that for a commercial-sized biofuel refinery to be viable, residue prices would need to range between US$64 and US$75 per bone dry metric ton. The choice of refinery location significantly affected wood costs and supply volumes, with Longview, WA, demonstrating a wood cost advantage over Springfield, OR, due to differences in timber ownership and spatial harvesting patterns. Additionally, the authors found that a 1 percent reduction in residue collection costs could result in a 0.6–0.9 percent increase in delivered supply at both locations, highlighting the sensitivity of supply to operational costs. The study underscored the complexity of forecasting supply and demand for forest biomass, and it emphasized the need for detailed economic and spatial analyses to understand the dynamics of the forest product markets and their implications for local investment decisions.

A report by Latta, Baker, and Ohrel (2018) projected localized forest carbon dioxide (CO^2) effects under different macroeconomic futures using a comprehensive spatial optimization model known as the Land Use and Resource Allocation (LURA) modeling system. The LURA model integrates detailed spatial data from over 130,000 forest plots and 2,300 forest product manufacturing facilities, enabling a nuanced understanding of how forest carbon dynamics interact with economic and market forces. The model uses empirical yield functions for log volume, biomass, and carbon, factoring in transportation costs derived from the distance between harvesting sites and processing facilities or ports, which influence the overall feasibility of forest product transportation. LURA operates through dynamic and static modeling phases; the static modeling phase uses linear programming to allocate forest resources to meet exogenous demand for forest products while minimizing costs and meeting various constraints. The dynamic modeling phase updates forest inventories, log demand, log trade levels, and forest products manufacturing capacities based on shifts in macroeconomic parameters. These methods allow for detailed scenario analysis under various economic conditions, reflecting how changes in gross domestic product (GDP) growth, housing starts, and energy prices can significantly influence forest carbon outcomes.

The authors concluded that macroeconomic conditions have a significant impact on forest carbon dynamics, with different economic growth scenarios affecting the rate at which forests either sequester or emit carbon. Increased economic activity, particularly in high growth scenarios, leads to higher demand for wood products and consequently higher rates of forest harvesting. This could potentially transform forest regions from carbon sinks into sources of emissions, depending on the intensity of the economic activity and associated forest management practices. The conclusions also highlight significant regional variations in how forest carbon fluxes respond to these economic changes, underscoring the importance of targeted forest management and economic policies to influence carbon sequestration outcomes effectively. The authors emphasized the need for spatially detailed models to accurately project and understand the impacts of economic and policy changes on forest carbon dynamics to formulate effective environmental policies and management strategies.

A study by Visser et al. (2022) focused on exploring the sustainability of increased wood pellet production in the US Southeast for international markets, specifically evaluating its impact on feedstock use, production costs, and carbon sequestration in forest areas. The researchers employed the LURA model to simulate the interaction between forest biomass supply and demand through supply-side logistics to determine optimal locations for new pellet mills based on wood supply, transportation costs, availability of logging residues, and other factors.

The findings of the study revealed that increasing pellet production leads to significant changes in feedstock allocation, with a notable increase in the use of roundwood, affecting the cost and sustainability of pellet production. In terms of carbon dynamics, the research highlighted that forests in the US Southeast would continue to act as net carbon sinks, although increased pellet production could reduce this effect. The study underscored the potential of using logging residues to reduce the carbon impacts associated with pellet production.

A report by Adams et. al (1996) examined the impact of changes in public harvest on intertemporal log markets while allowing log prices, harvests from private lands, and forest management decisions to be endogenously determined. The authors defined nine national timber supply regions:

1. PNW west (western Oregon and Washington)
2. PNW east (eastern Oregon and Washington)
3. Southeast states
4. Southcentral states
5. California
6. Rocky Mountains
7. Lake states
8. Corn belt
9. Northeast

The authors allowed intertemporal substitution between sawlogs, pulpwood, and fuelwood. The model they used estimates residues generated from sawlog processing, which can be substituted for roundwood pulpwood (within a species group). The model assumed a competitive (national) forest products market, a competitive capital market in which investments are free to vary over time, and perfect foresight throughout the 100-year model run. The authors acknowledged that these assumptions do not fully match the real world and that future research would consider "stickiness" in product and capital markets.

The model did not allow for interregional log flows. Instead, regional log supplies adjusted for transportation costs interact directly with a national log demand curve. While *actual* log flows do cross regional boundaries, transportation costs severely restrict such movements. The authors noted that, though this simplification departs from real world markets, it preserves the basic characteristics of interregional log price behavior. Manufactured wood products compete in national markets, and this competition—acting through the cost structures of regional processors—regulates regional log prices rather than directs the interregional log trade.

The authors found that changes in public timber harvests impact intertemporal patterns of private investment by in-region processors and private timberland owners, which act to reduce the price and aggregate harvest impacts associated with changes in public harvest over time. However, underlying these moderate market impacts are larger interregional shifts in harvest patterns than were found in earlier analyses; through changes in timberland management and investment, including conversion of lands from hardwood to softwood species types, some of the largest economic impacts may be realized outside of the regions in which public forestlands are concentrated.

3 Western Washington Timber Supply Model

The Western Washington Timber Supply Model (WWA model) is a partial spatial equilibrium market model of the forest and forest products industry in western Washington. The model consists of supply functions for log sellers (timberland owners and imports) and demand functions for log buyers (wood processors and exports), as well as the supply and demand functions for mill residues.[2] The model solves for market equilibrium—the price at which quantity demanded equals quantity supplied—for each five-year interval throughout the projection period ending in 2124. The model does so by maximizing the discounted sum of producer and consumer surplus,[3] subject to an array of constraints related to supply and demand balances in the log and (mill) residue markets, mill capacities over time, allocation of forestland by silvicultural regimes, and other constraints related to log flows over time and all relevant state and federal regulations.

The model relies on timber inventory data from the US Forest Service's National Forest Inventory and Analysis (FIA) sampling system and the Washington Department of Natural Resources (DNR), as well as information on the location, type, capacity, and input needs of wood processing centers in western Washington, Oregon, and Idaho within 100 miles of western Washington to project harvests at the stand level and wood products production at the mill level over a 50-year horizon.[4] The model framework is very similar to the approach used by Adams and Latta (2005) and Adams et al. (2019).

The WWA model has four basic components:[5]

1. Forest inventory data describing the forests and lands of interest;

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[2] A supply function is a quantitative representation of the willingness of a seller to offer specific quantities of a good or service at particular prices. Similarly, a demand function is a quantitative representation of the willingness of a consumer (e.g., a wood products manufacturer) to purchase specific quantities of a good or service at particular prices.

[3] Consumer surplus occurs when the price mills pay for logs is less than what they are willing to pay. Producer surplus occurs when the price landowners are willing to accept for logs is less than the amount they receive by selling the log at the market price.

[4] In fact, we estimated the WWA model over a 100-year period, but constrained inventory levels and age-class distributions in year 100 to a near fully-regulated state. In doing so, we likely introduced "terminal conditions bias" due to the constraints on ending inventories and age class distributions not fully aligning with the natural growth cycles of the forests and/or the long-term objectives of landowners. This bias can result in suboptimal decisions by the WWA model in later planning periods (after year 50), such as over- or underharvesting in certain periods.

[5] For the Western Washington Timber Supply Study, we did not include any assumptions about changes in forestland area through gains or losses to other uses or owners. We will consider potential changes in forestland area for the evaluation of the current management and alternative scenarios.

2. Assumptions about the future silvicultural regimes that will likely be applied to forestlands;
3. Projections of future timber yields under the alternative silvicultural regimes; and
4. A model that projects future harvests based on current forest inventory data, applies silvicultural regimes, and updates inventory over time.

For each five-year interval analyzed by the WWA model, tens of thousands of individual activities are determined, including if a stand should be harvested or receive commercial or precommercial thinning; if a stand is selected for harvest, how much wood is removed by species, size, and quality; to which mill(s) and/or port the logs should be sent; what products are produced from the logs; how much residues are produced as a biproduct; and to what pulp or other mill(s) are the residues shipped for processing.

3.1 Spatial Representation of the WWA Timber Supply Model

The WWA model explicitly links individual forest stands to individual lumber mills and other primary wood consumers through the existing network of federal (including Forest Service), state, and local roads. With this information, we know (approximately) the actual distance a truck must drive to deliver logs from any harvest site to any mill or port in western Washington or adjacent buffer area. This is important because it provides a realistic and tractable representation of the forest and forest products market in western Washington.[6]

3.1.1 Timber Supply – Forest Inventory Data

Timber supply in the WWA model is primarily represented by approximately 3,700 inventory sample plots in western Washington established by the FIA sampling system.[7] Each FIA plot is located in a non-urban forested area and is remeasured every 5 to 10 years depending on the state in which it is located. For each plot, information is collected on forest type, species, stand size class, regeneration status (natural/planted), tree density, overall tree conditions, and standing dead trees.

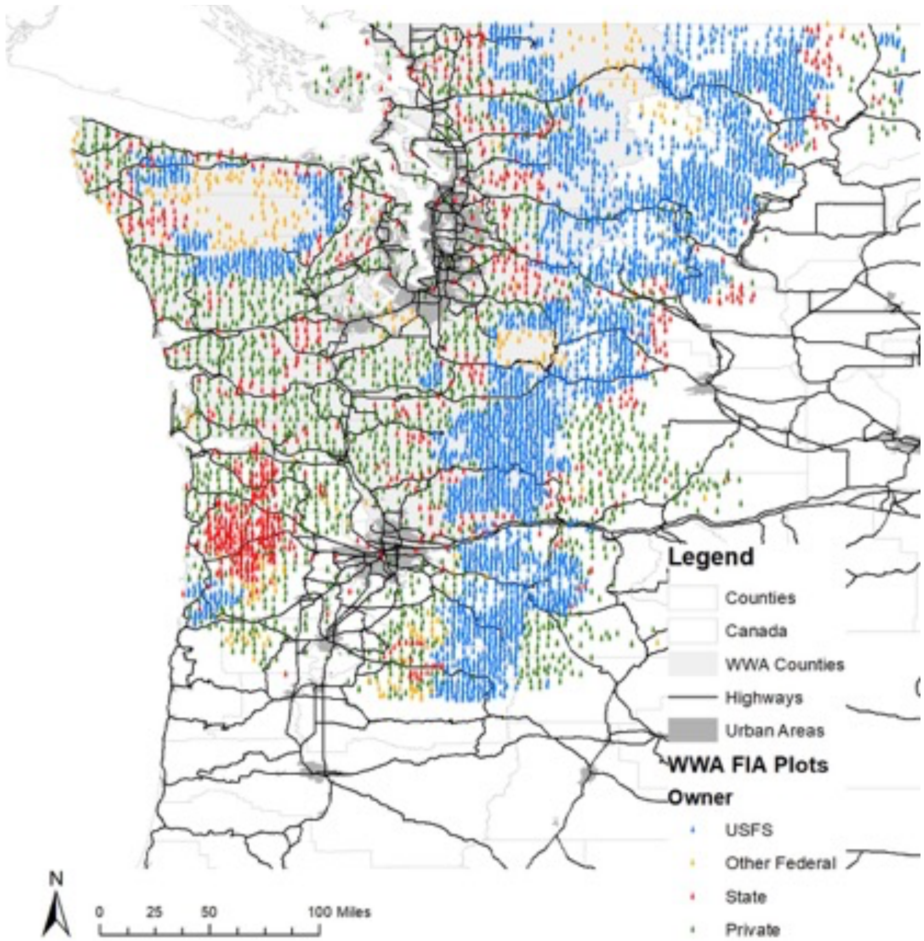
Figure 2 shows the distribution of FIA plots across western Washington (and in surrounding buffer areas), color coded by ownership: US Forest Service, other federal, state, or private. Federal forestlands—both Forest Service and National Park Service—tend to be concentrated at higher elevations in the Cascades and the Olympic Mountains. State and private forestlands are distributed across lower elevation areas and nearer to wood processing centers. While it is difficult

[6] In addition, when conducting our analysis of the alternative scenarios, we will be able to estimate changes in miles driven (relative to the "current condition" scenario) and associated fuel usage and carbon emissions associated with each scenario.

[7] We also include FIA plots in Oregon and eastern Washington (about 400) within a 100-mile buffer of western Washington. For more information on the FIA program, see https://www.fs.usda.gov/research/programs/fia

to tell in Figure 2, many state forestland areas are adjacent to private forestland areas on multiple sides.

Figure 2: FIA Plots by Ownership Across Western Washington Study Area and in Buffer Areas



Source: Analysis by Evergreen team of data from various sources.

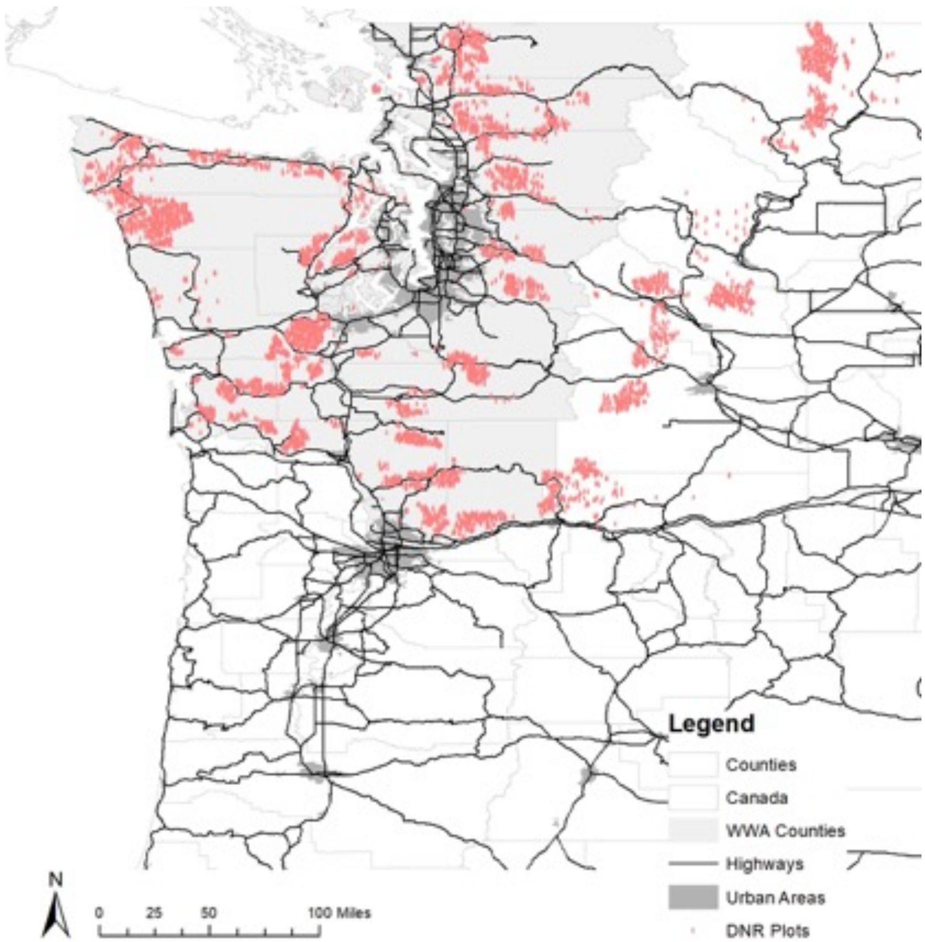
While we do have FIA plot data to represent Washington state forestland, we also have forest inventory data from DNR for all DNR-managed state forests, which we will integrate into our analysis of the scenarios.[8] In total, we will replace 391 FIA plots established on state forestlands in western Washington with 5,149 DNR-established plots. These 5,149 plots represent approximately 1.5 million acres of state forestlands. Within each plot, all trees are numbered, species are determined, and diameter at breast height (DBH) is measured. On a subset of trees within each plot, height, height to live crown (HTC), and crown ratio are measured. A smaller subset of trees is

[8] The inventory data from DNR will replace the FIA inventory data for all DNR-managed lands.

cored for data on growth and site tree age. In addition, snags and woody debris by species are counted.

Figure 3 shows the distribution of DNR-established forest inventory plots on DNR-managed lands in western Washington and across much of central and eastern Washington.

Figure 3: Washington DNR Forest Resource Inventory Plots



Source: Analysis by Evergreen team of data from various sources.

Table 2 shows the number of acres of forestland by ownership in western Washington and in the Oregon and central/eastern Washington buffer areas represented by the FIA and DNR forest inventory data. In total, the WWA model accounts for nearly 11.6 million acres of forestland in western Washington, with state forestlands representing approximately 13 percent and private forestlands (industrial, non-industrial, and Tribal) representing nearly 45 percent of the total. As the table also shows, there are substantial acres of forestlands in Oregon and central/eastern

Washington within the hundred mile buffer of western Washington from which some mills in and around western Washington may obtain logs.

Table 2: Acres of Forestland by Ownership Represented by FIA and DNR Forest Inventory Data

Ownership	Western Washington	Oregon Buffer*	Central/Eastern Washington Buffer**
National Forest	3,309,947	1,399,926	3,124,180
Other Federal	1,202,280	274,413	133,693
State	1,536,585	597,277	681,597
Local	385,152	87,913	18,452
Private, including Tribal	5,155,609	2,534,167	1,409,330
Total	**11,589,573**	**4,893,696**	**5,367,251**

* Non-urban forestland in Oregon within 100 miles of western Washington.
** Non-urban forestland in central and eastern Washington within 100 miles of western Washington.

3.1.2 Timber Demand – Mill and Port Data

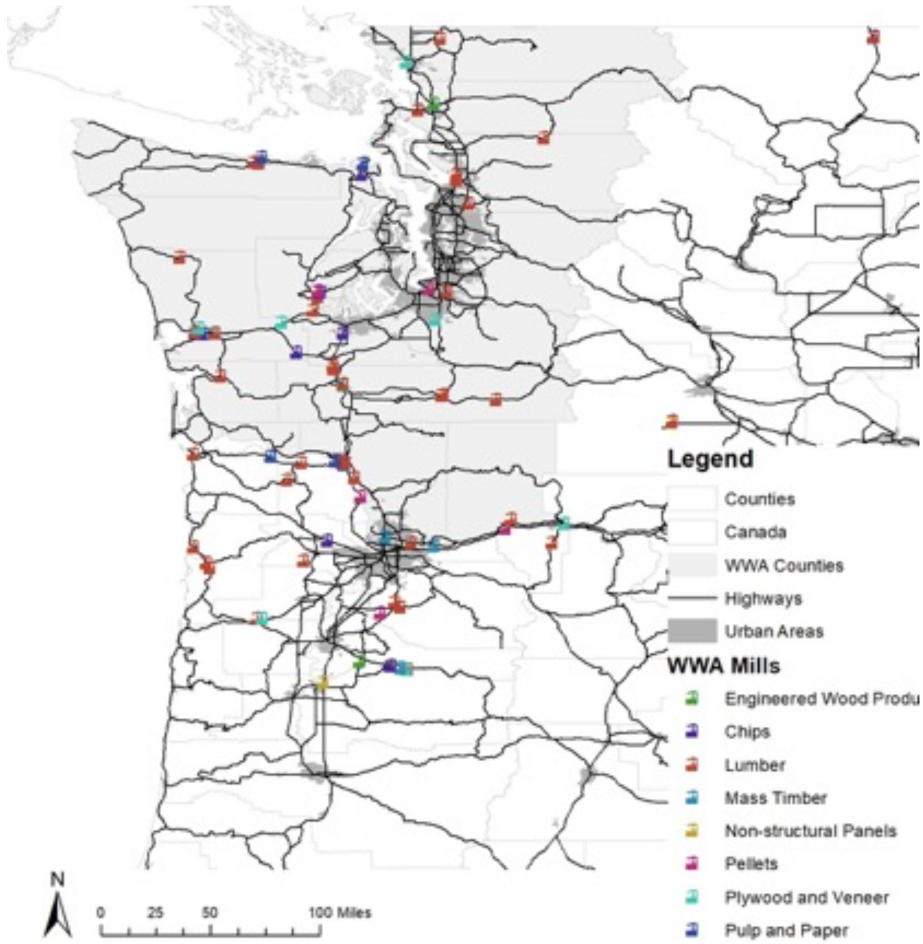
We obtained location and product information on the following primary and secondary wood products manufacturers from DNR and the Bureau of Business and Economic Research (BBER) at the University of Montana,[9] as well as drawing from the portfolio of forest products manufacturing facilities contained in the Land Use and Resource Allocation (LURA) database (Latta, Baker, and Ohrel 2018).

- Lumber mills
- Plywood and veneer mills
- Pulp and paper mills
- Pellet mills
- Wood chip mills
- Non-structural panel mills
- Engineered wood product manufacturers
- Mass timber manufacturers

[9] Information was obtained via mail and phone correspondence with analysts at BBER in February 2024. Information about the BBER Forest Industry Research program can be found at https://www.bber.umt.edu/FIR/default.asp

Figure 4 shows the location of wood products manufacturers by mill type in western Washington and in Oregon and eastern Washington that may utilize logs from western Washington.

Figure 4: Forest Products Manufacturers by Mill Type In or Near Western Washington

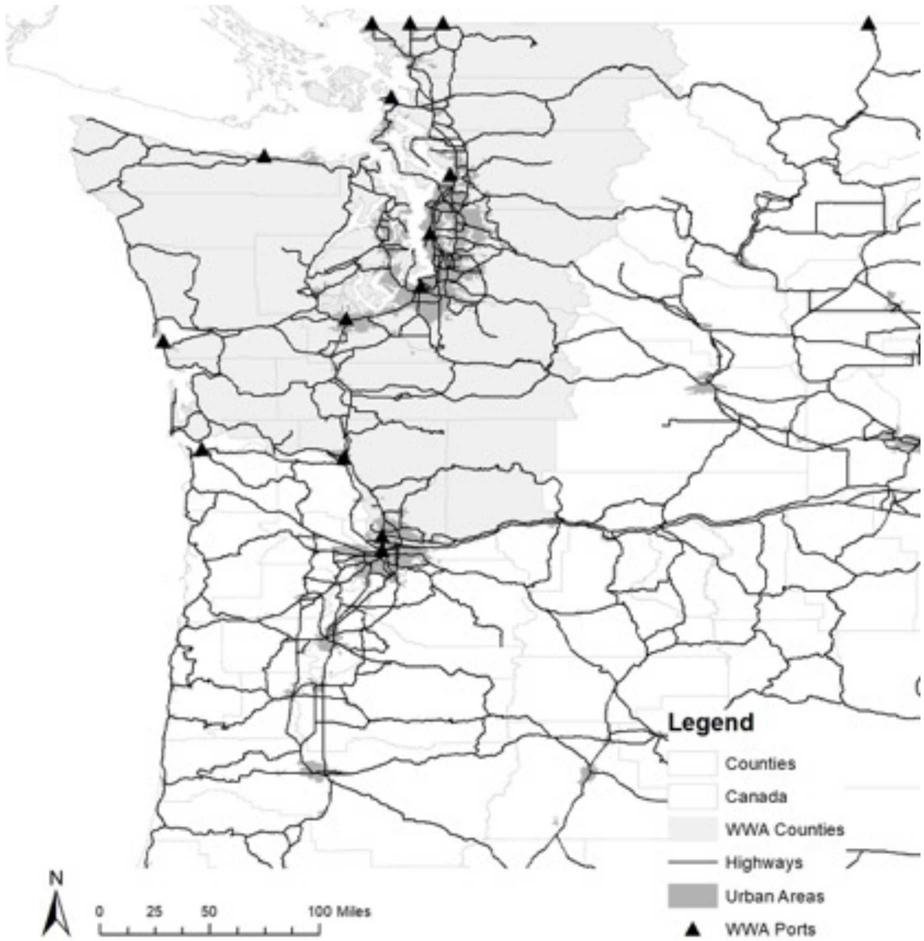


Source: Analysis by Evergreen team of data from various sources.

Not all timber harvested in western Washington is processed in Northwest mills. Some logs from non-public lands are exported.[10] Figure 5 shows the location of ports included in the WWA model from which logs harvested from private lands in western Washington may be exported. Within the WWA model, exports are exogenously determined and are held constant at the average annual level observed across all ports from 2018 through 2023.

[10] Logs from public lands—both federal and state—are banned from export. For more information on log export restrictions in Washington State, see https://app.leg.wa.gov/wac/default.aspx?cite=240-15

Figure 5: Ports Providing Imports and Exports of Forest Products to and from Western Washington



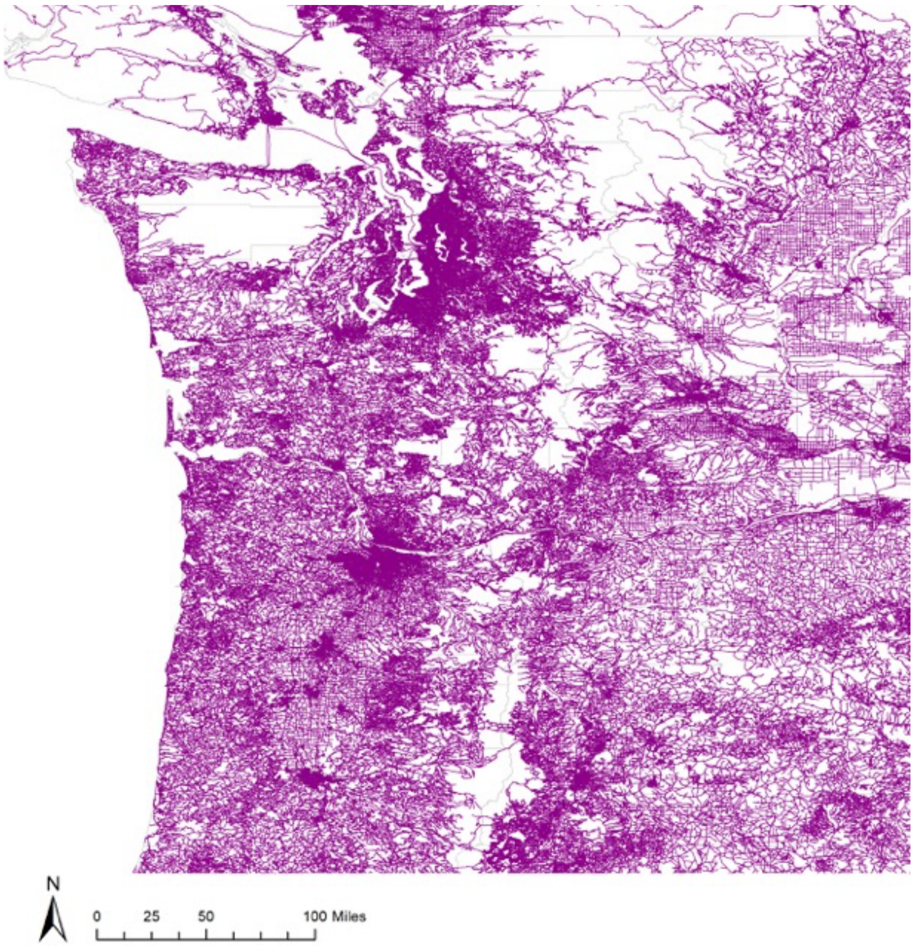
Source: Analysis by Evergreen team of data from various sources.

3.1.3 Linking Timber Supply and Demand – Road Network

Finally, the WWA market model links every timber stand in western Washington and the Oregon and central/eastern Washington buffer areas to every primary forest products mill, and every forest products mill that produces chips, sawdust, or shavings as a byproduct is linked by road to every forest products facility that uses such byproducts in their manufacturing. In addition to federal, state, and local roads, the road network within the WWA model includes many of the roads on Forest Service lands and other public forests, as well as many roads on forest industry lands that may or may not be accessible to the public.

Figure 6 shows the extensive detail of the road network within the WWA model, which includes all of Washington State, Oregon, and a small area of British Columbia.

Figure 6: Road Network Represented in WWA Model



Source: Analysis by Evergreen team of data from various sources.

4 Draft Findings

In this section, the Evergreen team presents the multidecade projection of timber harvests, forest inventory, and forest carbon storage for western Washington. As noted in the introduction of the report, these results represent a draft projection. We anticipate making a number of adjustments to the analysis, including swapping in DNR inventory plot data to represent inventories on state lands and reviewing, and possibly updating, some of the assumptions relied upon by the WWA model.[11] Nevertheless, we believe these draft findings provide a reasonable projection of harvests and inventories over the next 50 years.[12]

4.1 Projected Timber Harvests in Western Washington

A key underlying assumption in the harvest scheduling component of the WWA model is that private forest landowners and state land managers will maintain a relatively even flow of timber supply over the long run. We applied this assumption through a set of constraints that required harvests to vary by not more than +/- 5 percent over the 100-year projection period. While there are certainly reasons why a private landowner would choose to substantially increase or decrease harvests over a short time period, applying an even flow constraint is a standard assumption for long-term planning in forestry.

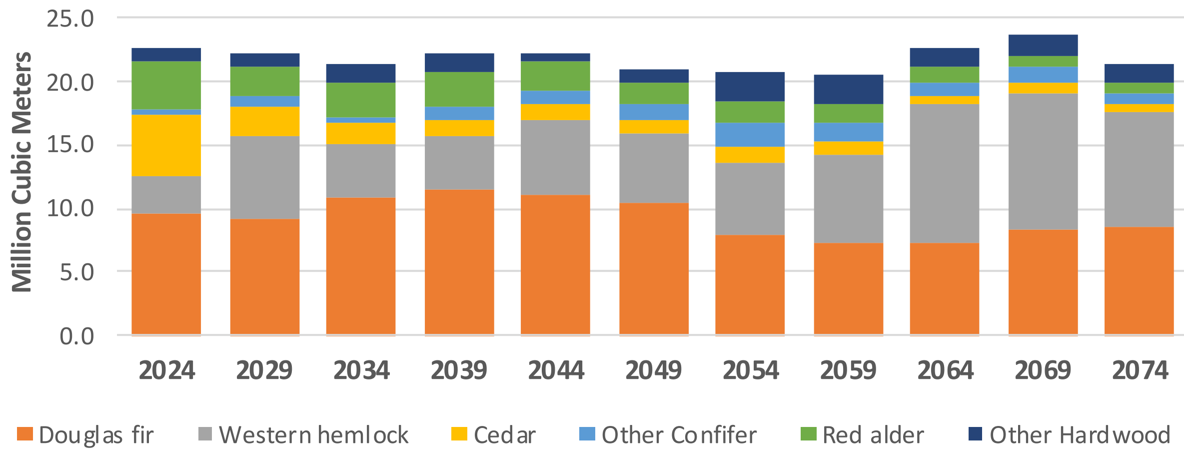
Figure 7 shows our harvest projection for private landowners (including Tribal lands) by species. While Figure 7 and all subsequent figures show data on a five-year interval, the values represent annual estimates (as opposed to five-year totals). While harvests vary year-to-year, they are relatively steady over the 50-year reporting period. In the first half of the reporting period (through 2049), Douglas-fir constitutes about half of the annual harvests. The relative importance of Douglas-fir decreases after 2049, and western hemlock harvest volumes increase.

The substantial harvest of cedar in 2024, relative to the rest of the reporting period, is likely due to the price assumptions in the model, which we will investigate. The projected harvest of red alder in 2024 was also substantial relative to the rest of the reporting period, which may be due to the model harvesting mature trees in stands that include set-asides for stream buffers.

[11] Assumptions we will review include (1) even flow restrictions on harvests, (2) restricting harvests in riparian areas, and (3) restricting harvests on state forest lands impacted by the state's habitat conservation plan (HCP).

[12] As discussed earlier, we conducted the analysis over a 100-year planning horizon, but only report results for the first 50 years (the "reporting period").

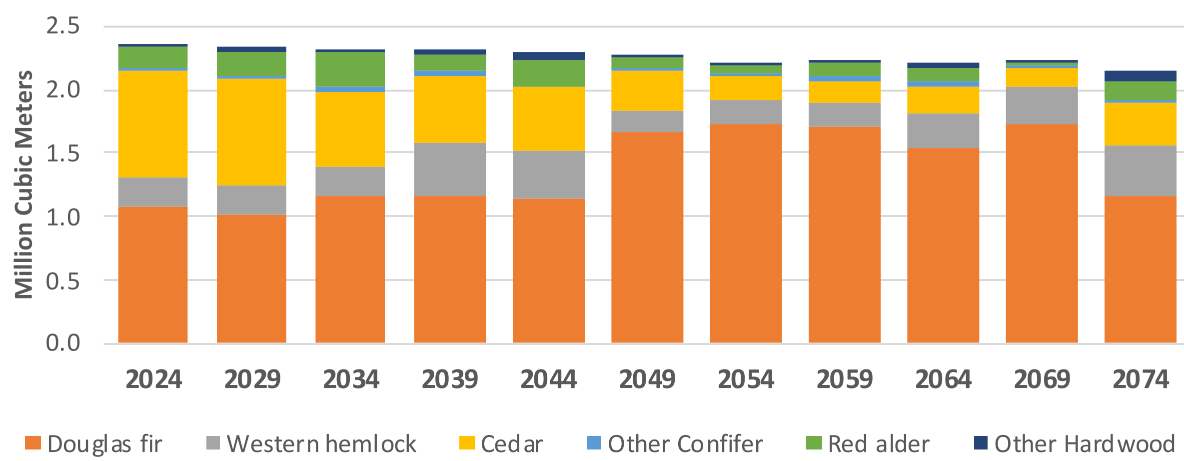
Figure 7: Projected Harvests on Private Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Projected harvests on state lands are about 10 percent of the projected harvests on private lands (see Figure 8 as compared with Figure 7). The species mix is different than the mix on private lands, with the harvest of Douglas-fir growing through 2054 to nearly 80 percent of total volume and then decreasing, but remaining above 50 percent of the harvest in each five-year period. Comparably, the harvest of western hemlock remains low throughout the reporting period. As we describe above, the substantial harvest of cedar in the first two decades is likely due to an anomaly in our model, which we will address.

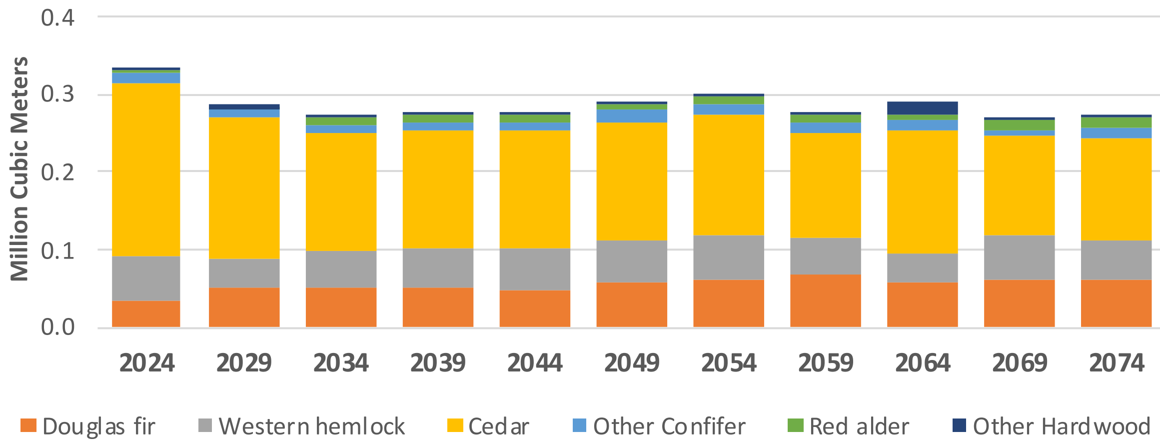
Figure 8: Projected Harvests on State Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

In recent years, harvests on federal lands have represented a tiny fraction of total harvests in western Washington (and across the Northwest). We assume this will continue and, therefore, we constrained the WWA model so that future harvests on federal lands will be equal to the average annual harvest over the past five years, +/- 5 percent.

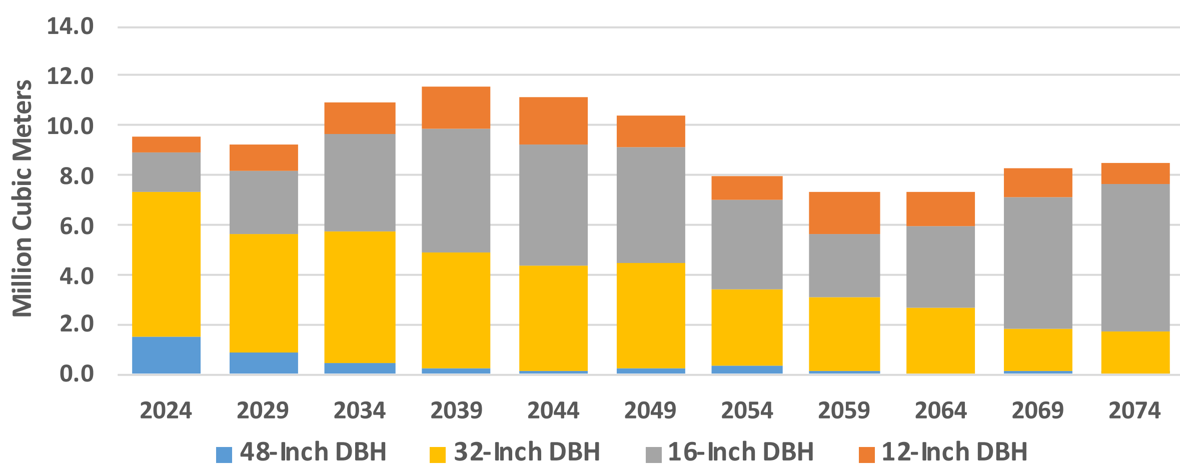
Figure 9: Projected Harvests on Federal Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Due to its historical and current importance to the forest products industry, the WWA model accounts for four Douglas-fir diameter classes: 12-inch, 16-inch, 32-inch, and 48-inch DBH.[13] Figure 10 shows the projected distribution of Douglas-fir harvests on private lands by DBH size class.

Figure 10: Projected Douglas-fir Harvests on Private Lands in Western Washington by DBH



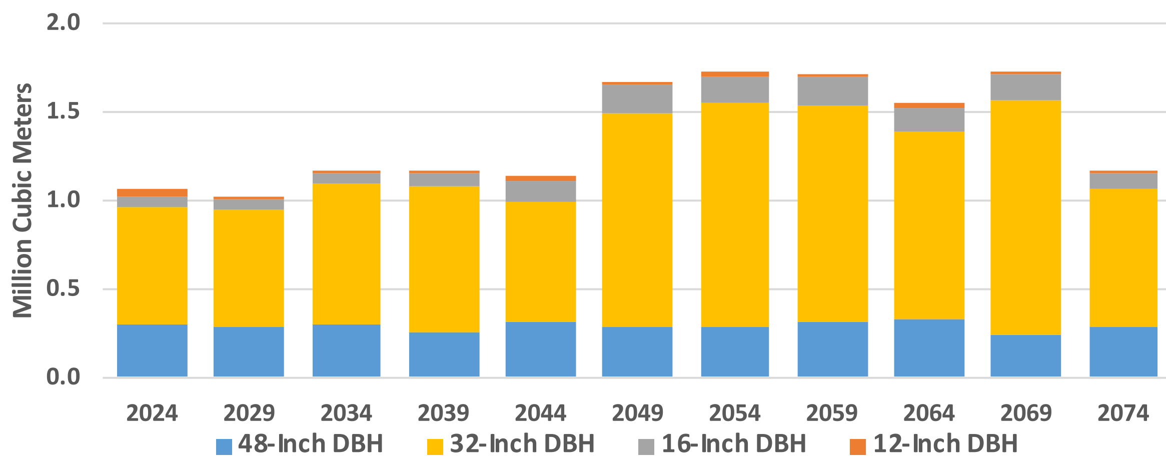
Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

[13] DBH or "diameter at breast height" is the diameter of a tree at 4.5 feet above the ground.

Relatively little of the Douglas-fir harvest volume on private lands in 2024 or 2029 is from the largest (48-inch) diameter class. After 2029, there is almost no volume from the 48-inch diameter class. The 32-inch diameter class constitutes most of the projected Douglas-fir volume through 2034, but its share is projected to decrease, dropping to 20 percent by 2074.

While constituting a relatively small share of the Douglas-fir harvest, the diameter distribution of Douglas-fir logs from state lands is substantially more weighted toward larger trees, with about 90 percent of harvests projected to be from logs with a DBH of 32 inches or more (Figure 11).

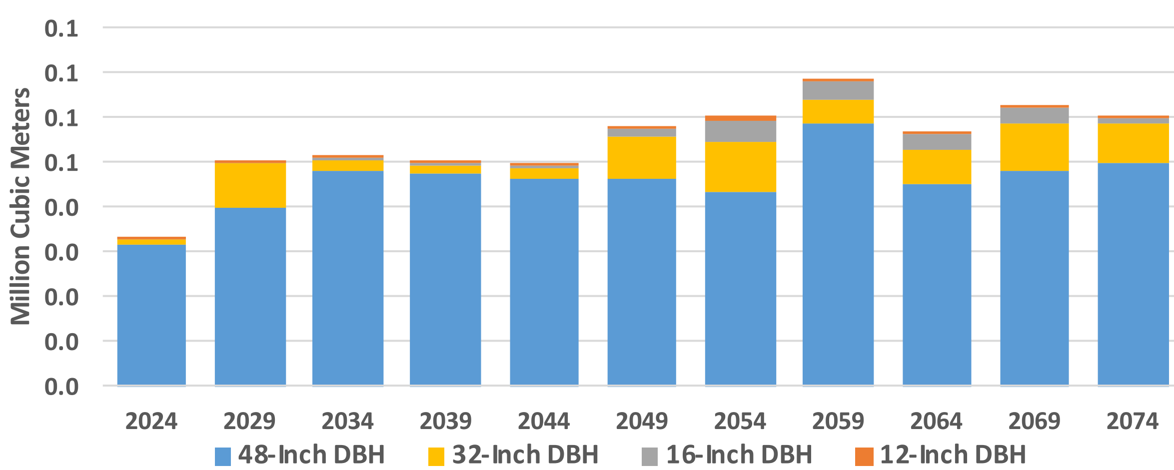
Figure 11: Projected Douglas-fir Harvests on State Lands in Western Washington by DBH



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Figure 12 shows the diameter distribution of Douglas-fir harvests from federal lands, which constitute about 1 percent of total Douglas-fir harvests in western Washington.

Figure 12: Projected Douglas-fir Harvests on Federal Lands in Western Washington by DBH

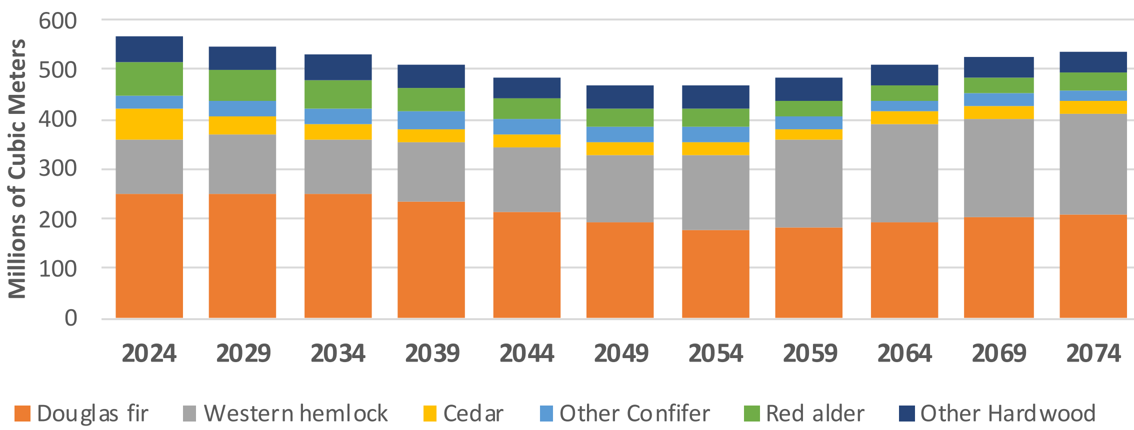


Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

4.2 Projected Forest Inventories in Western Washington

Figure 13 shows projected ending inventory by species on private forestlands in western Washington from 2024 through 2074, which somewhat mirrors projected harvests with respect to species distribution. We project that total inventories will decline through 2054 due largely to declines in the inventory of Douglas-fir. After 2054, we project that total inventories will begin to increase, led by increases in the inventories of western hemlock.

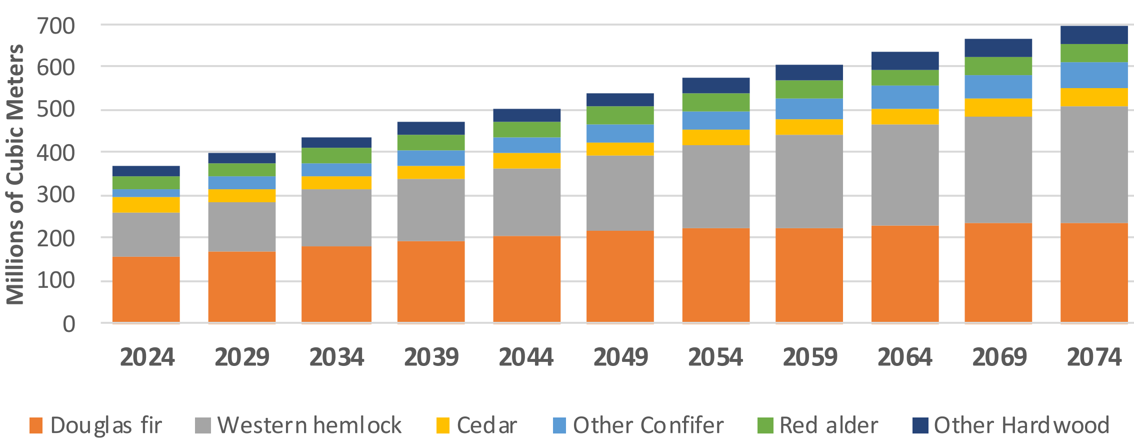
Figure 13: Projected Forest Inventory on Private Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

We project that inventories on state forestlands will experience substantial growth over the next 50 years, driven primarily by growth in inventories of western hemlock (see Figure 14).

Figure 14: Projected Forest Inventory on State Lands in Western Washington by Species

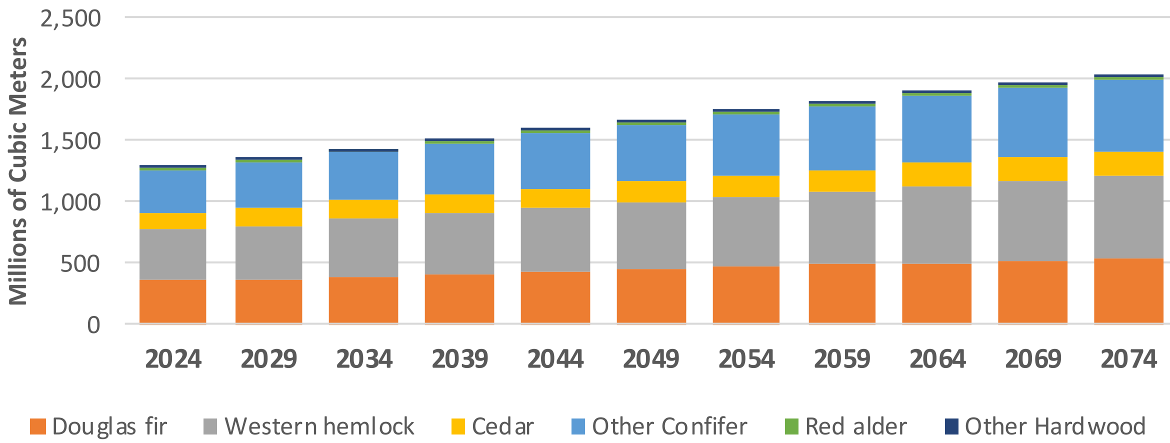


Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Despite state lands having a land base that is only about 30 percent the size of the aggregate land base of private forestland owners in western Washington, we estimate the 2024 ending inventory for state lands to be nearly two-thirds as great (371 [million] cubic meters versus 565 MM cubic meters). We project that by 2043, inventories will be approximately equal on private and state forestlands and that in 2074, forest inventories will be approximately 30 percent greater on state lands (700 MM cubic meters versus 535 MM cubic meters).

Due to our assumption that annual harvests on federal forestland will continue to be far below annual growth, we project inventories on federal lands will continue to grow over the 50-year reporting period, though growth will slow due to increased density and tree mortality (see Figure 15).

Figure 15: Projected Forest Inventory on Federal Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

4.3 Projected Forest Carbon Stocks in Western Washington

Forest carbon stocks refer to the amount of carbon stored in a forest ecosystem. This includes carbon contained in living biomass (trees and understory vegetation), deadwood, litter, and soil organic matter. Forests act as carbon sinks by absorbing carbon dioxide from the atmosphere through photosynthesis and storing it in various forms. Forests serve as a means of carbon storage and a mechanism for sequestering additional carbon from the atmosphere. For these reasons, there is increasing interest from policy makers, businesses, and the public in quantifying how much carbon is stored in forests under the "business as usual" scenario and how much additional carbon could be stored under alternative management practices (referred to as "additionality").

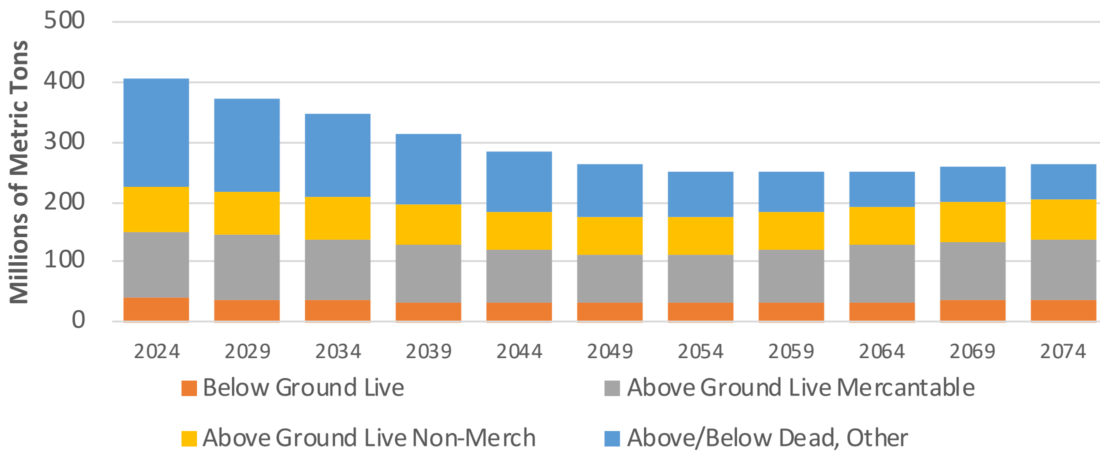
As part of this analysis, we project carbon storage on private, state, and federal lands over the 50-year reporting period, which we aggregate into four components:[14]

[14] As part of our broader analysis of scenarios developed by the Work Group, we will also estimate carbon stored in forest products.

1. **Below ground live**: The roots of live trees
2. **Above ground live merchantable**: The merchantable portion of live trees
3. **Above ground live non-merchantable**: The branches and foliage, but not the merchantable bole of live trees
4. **Above/below ground dead, other organic matter**:
    a. Below ground dead: the roots of dead and cut trees
    b. Standing dead: dead trees, including stems and any branches and foliage still present, but not including roots
    c. Forest down dead wood: all woody surface fuel, regardless of size
    d. Forest floor: litter and duff
    e. Herbs and shrubs

Figure 16 shows the stocks of carbon stored on private lands, which we project will decrease from just over 400 metric tons in 2024 to 260 metric tons in 2074. Most of the decrease in stored carbon is in above/below ground dead trees and organic matter. Dead trees and other organic matter currently on private lands will slowly decay and release carbon into the atmosphere, which will not be fully replaced due to timber harvesting and vegetation management.

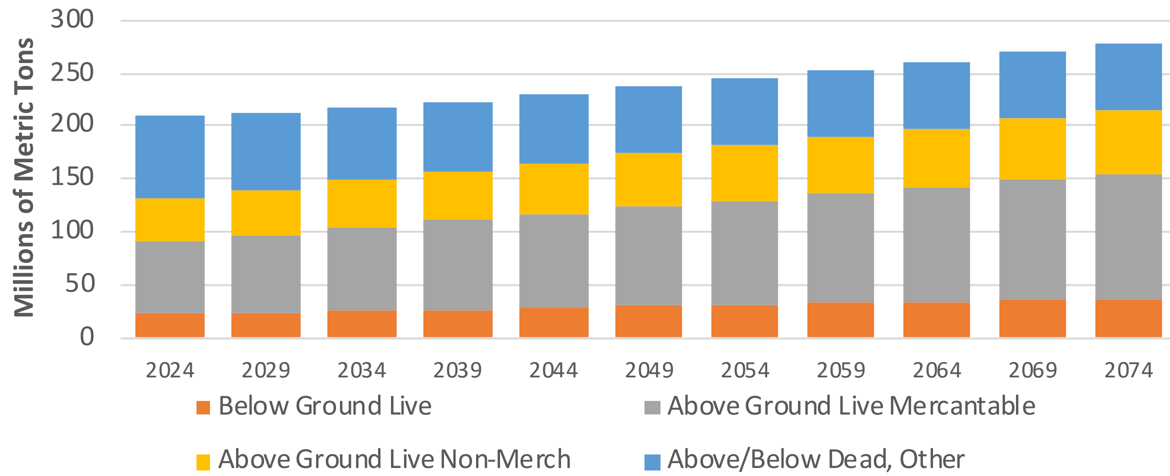
Figure 16: Projected Forest Carbon Stored on Private Lands in Western Washington



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Figure 17 shows carbon stocks on state lands, which we project will increase over the 50-year reporting period due primarily to increases in above ground merchantable timber.

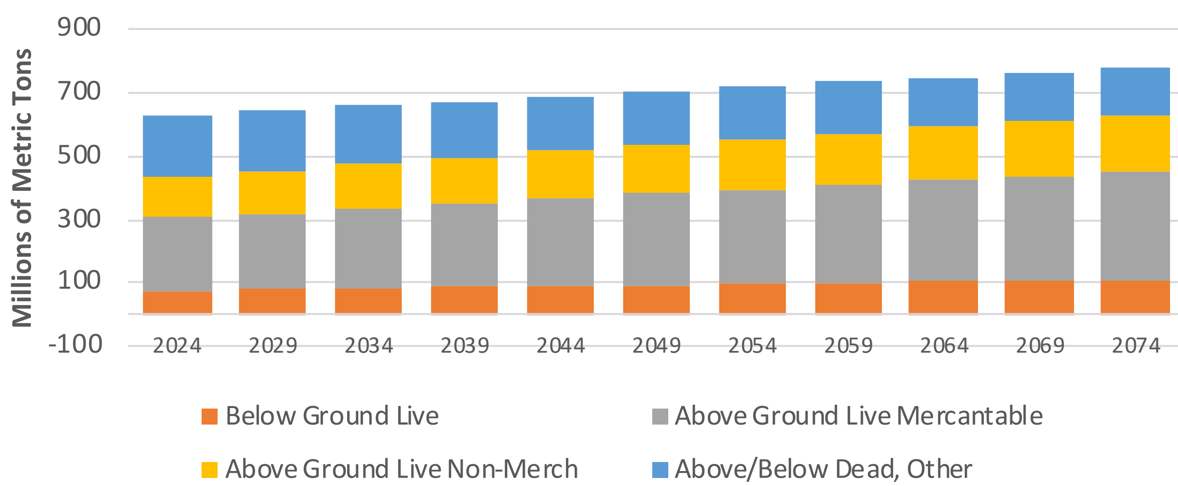
Figure 17: Projected Forest Carbon Stored on State Lands in Western Washington



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

Figure 18 shows carbon stocks on federal lands, which we project will also increase over the 50-year reporting period, but at a slower rate than state forests.

Figure 18: Projected Forest Inventory on Federal Lands in Western Washington by Species



Source: Analysis by Evergreen team of data from FIA, Washington DNR, and other sources.

5 Economic Contributions Analysis

The Evergreen team utilized IMPLAN software to determine the current contribution of relevant wood supply industries to the economies of Western Washington counties. We researched relevant North American Industry Classification System (NAICS) and IMPLAN industry codes, then conducted contribution analyses in IMPLAN for individual and combined counties and industries.

5.1 IMPLAN Economic Model

IMPLAN is a leading provider of economic data and analytical software used to estimate the impacts of current or proposed economic activities. IMPLAN software uses a comprehensive input-output modeling approach to define economic activities in a given region or regions, and can be used to develop estimates of employment, labor income, the value of economic output, associated taxes, and other economic variables. IMPLAN is primarily based on annual, county-level data from the US Bureau of Economic Analysis (BEA) and other vetted sources.

Regardless of the specific type of analysis, IMPLAN generates results at three levels (Demski 2020):

1. **Direct effects** are the first order economic impacts, representing the change in expenditures by households, businesses, and/or other entities directly affected by the select industry and/or event.
2. **Indirect effects** are the second order economic impacts that result from business-to-business purchases in the supply chain taking place in the region that stem from the initial industry input purchases.
3. **Induced effects** are the third order economic impacts that result from household spending of labor income by employees of the select industry/industries, after removal of taxes, savings, and commuter income.

5.2 Wood Supply Industries

To analyze the economic contribution of relevant wood supply industries to western Washington counties, the Evergreen team first determined the relevant industries based on a review of existing literature (see Pelkki and Sherman 2020) and by comparing IMPLAN industry codes to NAICS codes. Table 3 shows the complete list of industries we used in our analysis. Notably, IMPLAN codes for pulp mills, paper mills, and paperboard mills were combined into one industry for analysis purposes.

Table 3: IMPLAN Wood Supply Industries Selected for Analysis

IMPLAN Code	Description
15	Forestry, non-timber products, and timber tract production
16	Commercial logging
132	Sawmills
134	Veneer and plywood manufacturing
135	Engineered wood member and truss manufacturing
143	All other miscellaneous wood product manufacturing
144, 145, 146	Pulp and paper mills

5.3 Contribution Analysis

The Evergreen team conducted an industry contribution analysis in IMPLAN to estimate the economic contribution of the existing wood supply activities for selected wood supply industries in the western Washington economy. Whereas conventional economic impact analyses in IMPLAN involve a proposed or actual policy, event, or shock to the region that results in a change in economic activity, an industry contribution analysis measures the baseline effect of an industry or industries of interest. More specifically, a constraint is applied to the model by removing feedback linkages or buy backs to the industry being analyzed (Lucas 2019). This ensures that the output of an industry is not larger than the input value (e.g. the sawmill industry results should not show more employment than the total employment in the sawmill industry determined at the outset).

Table 4 shows the results of the ICA for each of the seven wood supply industries for the 19 combined western Washington counties. The economic variables presented in the table are defined[15] as:

- **Employment:** an industry-specific mix of full-time, part-time, and seasonal employment; an annual average that accounts for seasonality and is not equal to full time equivalents.
- **Labor Income:** the combined cost of total payroll paid to employees (e.g. wages and salaries, benefits) and payments received by self-employed individuals and/or unincorporated business owners.
- **Average Employee Compensation:** labor income divided by employment (includes the total value of all wages and benefits).

[15] Methodology of IMPLAN, https://support.implan.com/hc/en-us/sections/16901828150811-Methodology-of-IMPLAN

- **Value Added:** the difference between output and the cost of intermediate inputs.
- **Total Output:** the total annual production value of each industry or commodity.

The values for each industry in Table 4 are the cumulative direct, indirect, and induced effects supported by the given industry in the combined western Washington counties in 2022. For the separate direct, indirect, and induced effects for each industry, see Appendix D. Overall, the wood supply industries supported more than 34,000 employees and generated nearly $3 billion in labor income, for an average employee compensation amount of approximately $87,000. The value added (total output minus intermediate inputs) was nearly $5.6 billion, and the total output (2022 annual production value) was $10.7 billion.

Table 4: Economic Contribution of Individual Industries in Western Washington

Industry	Employment	Labor Income	Average Employee Compensation*	Value Added	Total Output
Forestry	960	$84,361,275	$87,843	$110,277,964	$147,106,713
Commercial Logging	6,762	$570,641,518	$84,396	$773,683,941	$1,107,312,883
Sawmills	16,064	$1,427,058,094	$88,837	$2,825,903,469	$5,664,786,731
Veneer and Plywood Manufacturing	2,104	$196,837,223	$93,560	$368,801,115	$746,858,333
Engineered Wood Manufacturing	2,438	$207,697,756	$85,191	$459,748,909	$949,055,494
Miscellaneous Wood Manufacturing	653	$52,947,374	$81,022	$105,220,474	$208,869,073
Pulp and Paper Mills	5,195	$457,482,353	$88,055	$933,770,498	$1,904,782,900
Total	**34,176**	**$2,997,025,593**	**$86,986**	**$5,577,406,370**	**$10,728,772,126**

*Includes total value of all wages and benefits.

In addition to conducting contribution analysis for individual industries across western Washington, the Evergreen team also conducted *multi*-industry contribution analysis for each individual western Washington county.[16] The results of this analysis are presented in Appendix D.

[16] That is, we combined the industries shown in Table 4 into a single sector and analyzed the impact of that sector on each individual western Washington county.

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Appendix A: Final Scenarios

The following document, Carbon and Forest Management Work Group Adopted Scenarios, courtesy of DNR, outlines the final scenarios the Evergreen team explored.

Carbon and Forest Management Work Group

Adopted Scenarios

Part 1: Introduction

This document describes the eight forest management scenarios that the Carbon and Forest Management Work Group has selected for carbon and economic impact modeling.

For the carbon analysis only, each scenario will be modeled two ways: with no climate change assumptions, and with moderate climate change assumptions (based on representative concentration pathway [RCP] 4.5). Under RCP 4.5, carbon emissions peak around 2040 and then decline.

All scenarios modify specific elements of DNR's current management. For example, some scenarios increase thinning, some lengthen or shorten harvest rotations, some defer additional areas from harvest, and some increase the amount of silvicultural treatments, such as site preparation and release treatments, that DNR performs on state trust lands.

The first four scenarios were selected at the March 10 work group meeting. They include the following:

- **Scenario 1** represents DNR's current management.
- **Scenarios 2 through 4** are "single dial" scenarios that change one aspect of DNR's current management. Single dial scenarios help the work group isolate the influence of a single management change on carbon, the timber market, jobs, and local economies.

Scenarios 5 through 8 were selected at the May 8 work group meeting. All four of these scenarios are "multi-dial" scenarios because they change multiple elements of DNR's management. These scenarios have been renumbered for ease of reporting in the next step of the project.

Table 1 shows all 8 scenarios, their components, and the number they had at the time of voting.

Table 1. Scenarios.

Scenario number	Component (s)			Original number
1	DNR current operations			1
Single-dial scenarios				
2	Lengthen harvest rotation			2
3	Shorten harvest rotation			3
4	Significantly increase thinning			4
Multi-dial scenarios				
5	Lengthen harvest rotation	Significantly increase thinning		8
6	Lengthen harvest rotation	Significantly increase thinning	Increase deferrals	10
7	Increased emphasis on Silviculture	Significantly increase thinning		11
8	Increased emphasis on silviculture	Significantly increase thinning	Shorten harvest rotation	16

Part 2: Scenario Descriptions

Following is a description of each scenario, including any adjustments that were made to the scenarios based on work group feedback. Background information on site class and structurally complex forest can be found in the appendices.

Scenario 1: DNR Current Management

Scenario 1 provides the foundation on which all other scenarios are built. Following are key details about this scenario. The description is broken out by three major land classes:

- **General ecological management (GEM)**: Lands available for harvest subject to the requirements of the *State Trust Lands Habitat Conservation Plan* (HCP), *Policy for Sustainable Forests*, and all relevant laws. GEM areas are the primary revenue-generating lands in the state trust lands portfolio.
- **Riparian**: Lands designated through the riparian and wetland habitat conservation strategy in the HCP. These lands include fish-bearing streams and wetlands plus protective buffers. Buffer widths depend on stream and wetland type. Only a limited amount of thinning is allowed within the buffers. Management in these areas is guided by both the HCP and the *Riparian Forest Restoration Strategy* (RFRS).
- **Uplands**: Lands that have specific ecological objectives that limit (but do not preclude) harvest per the HCP, *Policy for Sustainable Forests*, and all relevant laws. Examples include areas being managed for northern spotted owl conservation or for hydrologic maturity, and special habitat areas managed for marbled murrelets.

GEM Areas

- **Stand replacement harvest**: To be eligible for stand replacement harvest, forest stands typically have roughly 30,000 to 35,000 board feet per acre, although this range can vary from site to site. For Douglas-fir, this range translates to a harvest rotation of approximately 50-80 years depending on site class. Stand replacement harvest removes an average of 90 percent of the timber volume within each timber sale unit, although actual removals may vary widely depending on stand objectives and conditions.
- **Site preparation:** Over the past 10 years, DNR has done site preparation on approximately 75 percent of areas being replanted.
- **Stand regeneration:** About 60 percent of the seedlings that DNR plants on state trust lands are grown from improved seed stock. Improved seeds are gathered from orchard trees that have performed well in field testing across a wide range of environments.

  In general, DNR plants approximately 360 seedlings per acre across all GEM lands.

  On most sites, DNR plants at least two species. For example, in 2022, 72 percent of harvested sites were replanted with two or more species. Nearly 80 percent of these sites were planted with Douglas-fir, and secondary species included western hemlock (11 percent) and western redcedar (5 percent). Other species planted (1 to 2 percent) include Sitka spruce, red alder, white pine, and noble fir.

- **Release treatments:** Over the past 10 years, DNR has done release treatments (herbicide spraying or slashing) on roughly 75 percent of planted stands. Release treatments are typically done about two years after planting.
- **PCT:** Based on its most recent estimates, DNR has done PCT on approximately 50 percent of its forests in GEM areas, on average, over the past 10 years. Note that the amount of PCT (and release treatments) that DNR can perform from one year to the next is highly dependent on funding, so acres can vary widely from one year to the next. Recent PCT work has been funded through an appropriation from the Climate Commitment Act.

  PCT is done when stands are anywhere from 8 to 12 years of age, on average (earlier on more productive sites, later on less productive sites). Post-PCT tree densities range from 250 to 300 stems per acre if no commercial thinning is anticipated.

- **Commercial thinning:** Over the past 10 years, DNR has performed commercial thinning on less than approximately 8 percent of GEM lands. Depending on objectives, the technique can be an intermediate-type thinning, in which trees are removed in a regular pattern and remaining trees have similar growing space; or a variable density thinning but without large gaps. In either case, the volume removed in a thinning is roughly 30 percent of timber volume within the thinning boundary.

Riparian Areas

- **Stand replacement harvest**: Not allowed except under limited circumstances (such as hardwood conversions).
- **Commercial thinning**: Between 2019 and 2067, DNR anticipates thinning a total of 4,000 acres of riparian forest. That equates to 83 acres of riparian forest per year.
- **Pre-commercial thinning (PCT):** Currently, DNR does virtually no pre-commercial thinning in riparian areas.

Other upland areas:

- **Stand replacement harvest, pre-commercial thinning, commercial thinning**: Stand replacement harvest is only allowed in select areas. When performed, it has the same requirements as stand replacement harvest in GEM lands. Thinning (PCT and commercial) is allowed in some upland areas per the requirements of the HCP and other policies and laws. Thinning rules vary depending on habitat type and objectives. Commercial thinning in habitat areas is usually variable density with gaps ranging from a quarter to half acre each. PCTs in uplands have the same parameters as GEM lands.

- **Stand regeneration:** Only applicable in areas that have undergone stand replacement harvest. Parameters are the same as GEM lands.

Figure 1 shows current management practices. Currently, the top track (regenerate, harvest, regenerate) is far more common than the middle track (regenerate, thin, harvest, replant) or the lower track (thin only). Note that this simplified graphic does not show the silvicultural practices that DNR does now, such as release treatments or PCT.

Figure 1. Simplified schematic of DNR current management.

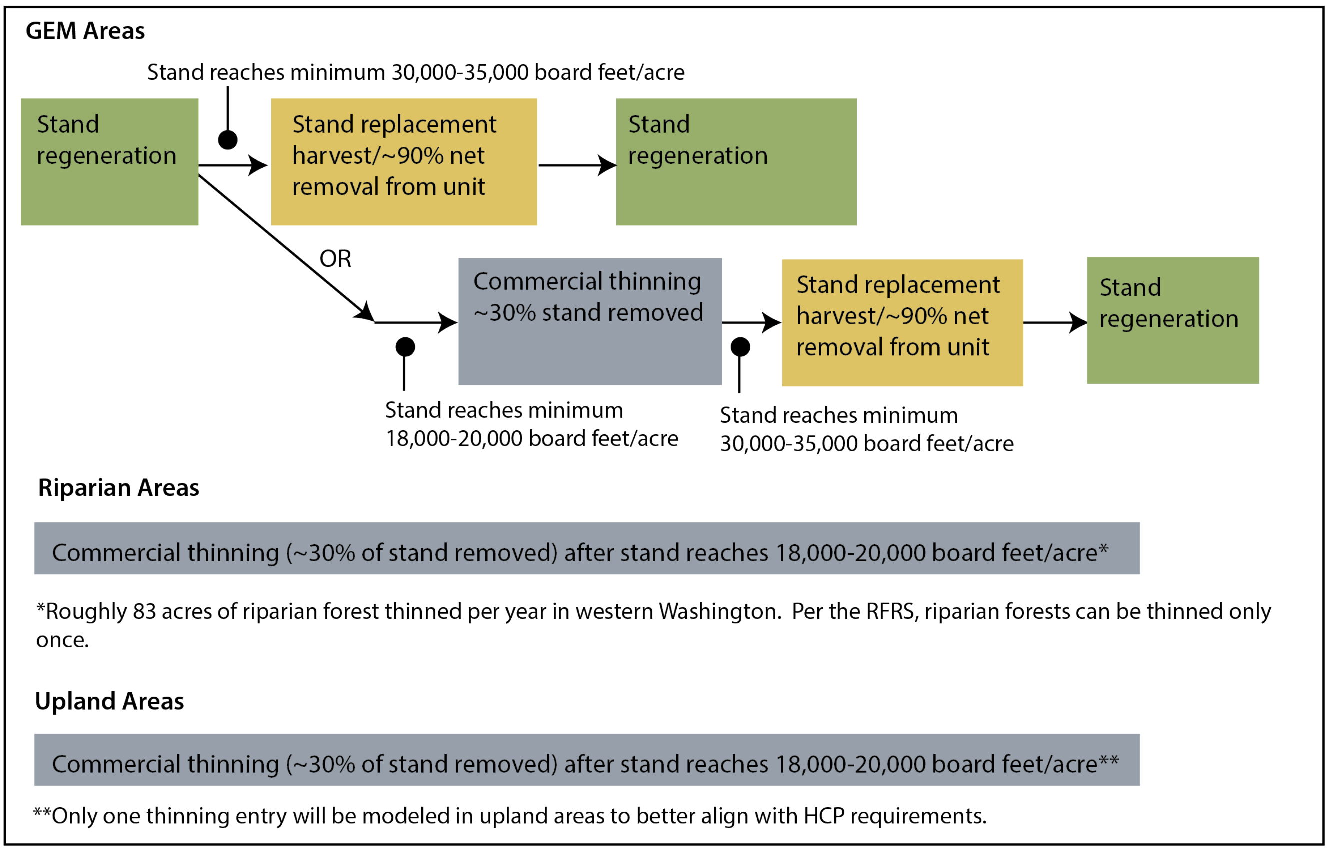
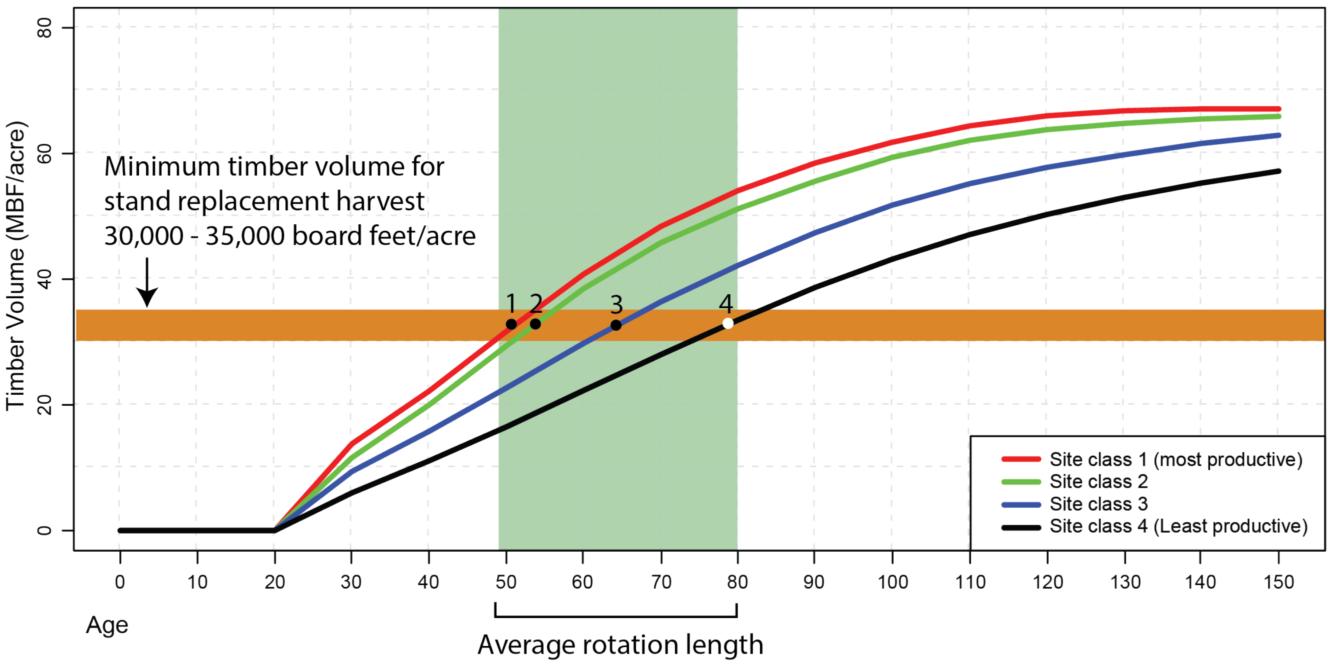


Figure 2 is sample yield curve for Douglas-fir in western Washington showing rotation age, based on a minimum harvest volume of 30,000-35,000 board feet per acre.

Figure 2. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 1.

Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.



Scenario 2: Lengthen Harvest Rotation (Single Dial Scenario)

Under this scenario, a forest stand in GEM areas must have a minimum of 50,000-55,000 board feet per acre to be considered available for stand replacement harvest. For Douglas-fir, this range translates to a harvest rotation age of roughly 75 to 130 years, depending on site class. Stand replacement harvest removes an average of 90 percent of the timber volume within the boundaries of each timber sale unit, although actual removals may vary widely depending on objectives and stand conditions.

This minimum board feet per acre requirement is much higher than DNR's current minimum of 30,000 to 35,000 board feet per acre. Increasing the minimum board feet per acre requirement will lengthen the harvest rotation, because it will take the forest stand longer to reach this timber volume. Refer to Figure 3 for a simplified schematic of this scenario and Figure 4 for a sample yield curve.

Figure 3. Simplified schematic of Scenario 2.

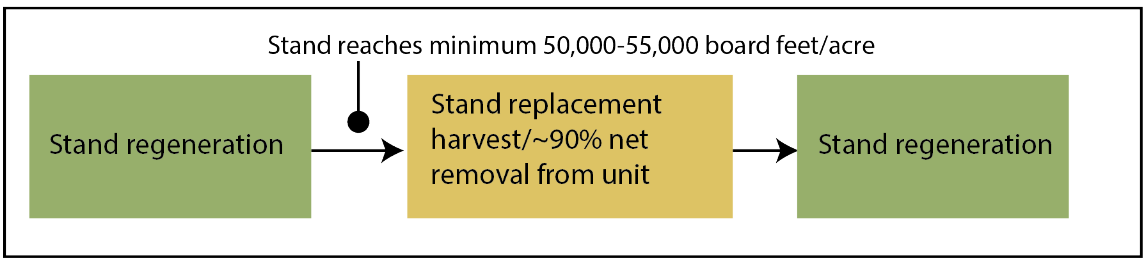
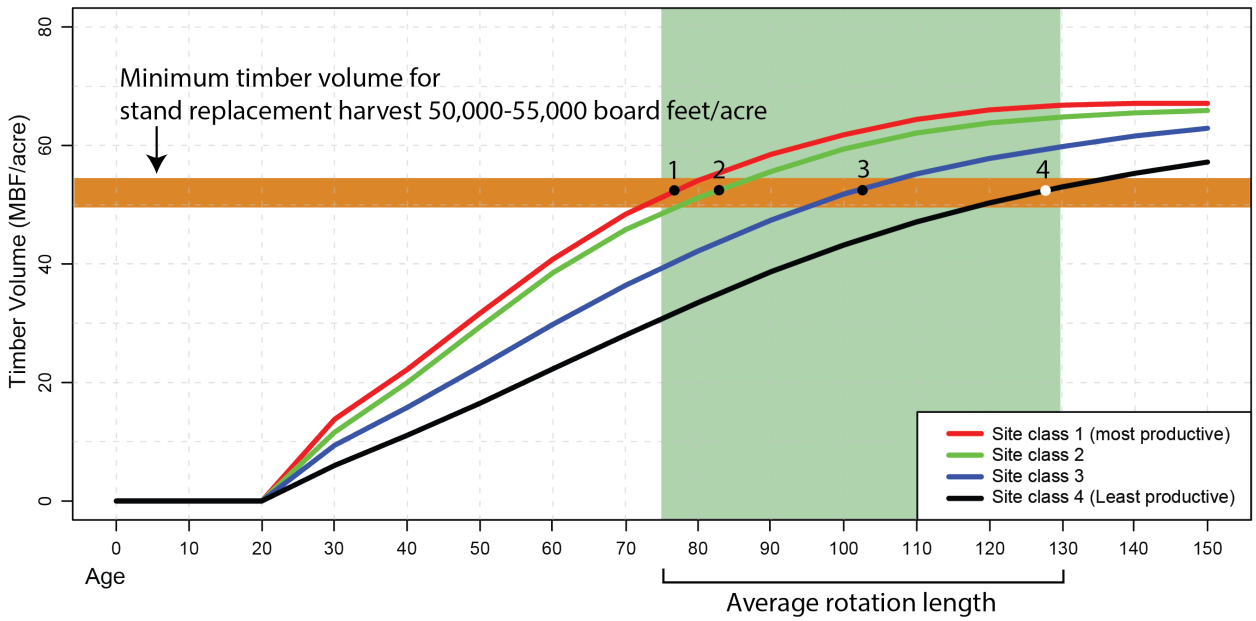


Figure 4. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 2.

Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.



Scenario 3: Shorten Harvest Rotation (Single Dial Scenario)

Under this scenario, a forest stand in GEM areas must have a minimum of 20,000-25,000 board feet per acre to be considered available for stand replacement harvest. For Douglas-fir, this range translates to a harvest rotation of roughly 40-60 years, depending on site class. Stand replacement harvest removes an average of 90 percent of the timber volume within each timber sale unit, although actual removals may vary widely depending on objectives and stand conditions.

This minimum board foot per acre requirement is lower than DNR's current minimum of 30,000-35,000 board feet per acre. Reducing the minimum board feet per acre will shorten the harvest rotation, because the forest stand will reach this volume sooner than it would if the board feet requirement were higher. Refer to Figure 5 for a simplified schematic of this scenario and Figure 6 for a sample yield curve.

Figure 5. Simplified schematic of Scenario 2.

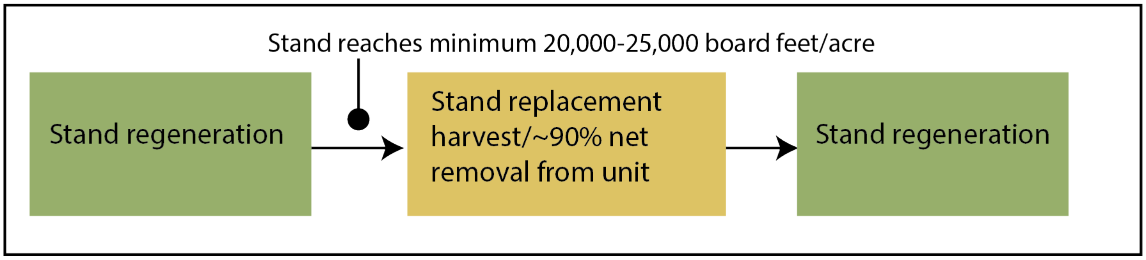
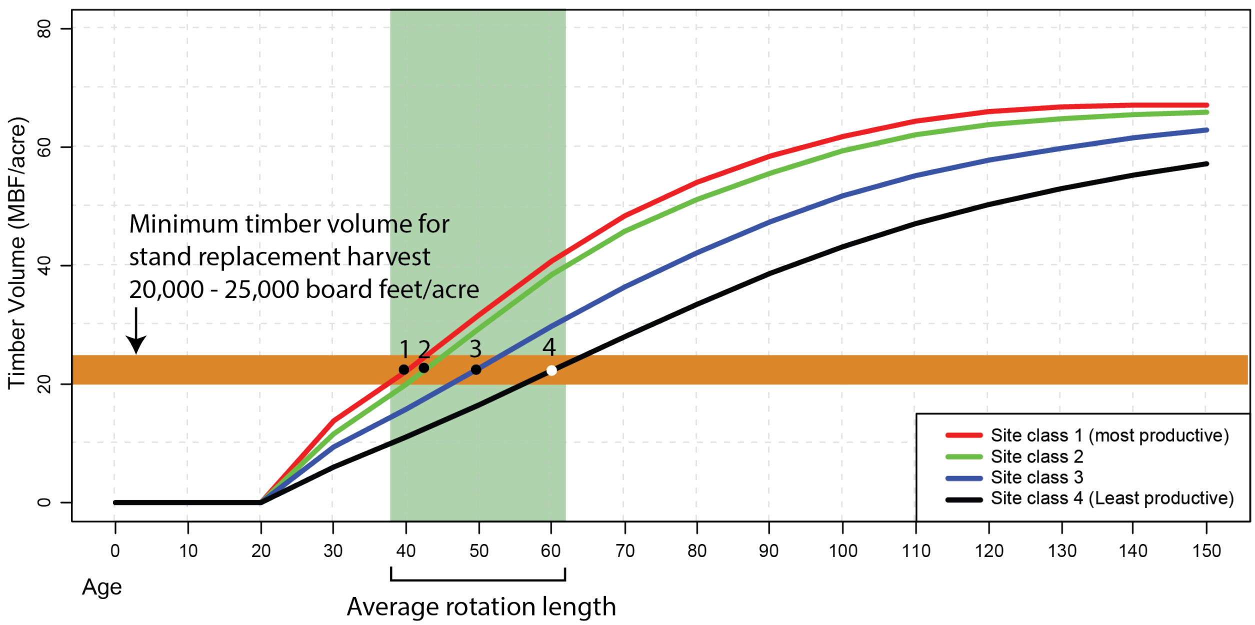


Figure 6. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 3.

Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.



Scenario 4: Significantly Increase Thinning (Single Dial Scenario)

This scenario increases both commercial and pre-commercial thinning.

In GEM areas, DNR will require one commercial thinning entry in each harvest rotation. The minimum timber volume for a thinning will be roughly 18,000-20,000 board feet per acre. In practice, the technique can be an intermediate-type thinning, in which trees are removed in a regular pattern and remaining trees have similar growing space, or a variable density thinning but without large gaps. The volume removed in a thinning is roughly 30 percent of timber volume within the thinning boundary.

Riparian areas are managed under the HCP and the RFRS. The RFRS allows riparian forests to be thinned only once for ecological objectives. In riparian areas, only one thinning entry will be modeled over the 100-year analysis period. The amount of thinning will be 91.3 acres per year, which is roughly a 10 percent increase in riparian thinning from Scenario 1 (DNR current management). Riparian stands to be thinned must have a minimum timber volume of 18,000-20,000 board feet per acre to be thinned, and 30 percent of the timber volume will be removed.

Upland areas are managed for ecological objectives according to the conservation strategies in the HCP, and each strategy has its own harvest rules. Upland thinnings are almost always variable density, and habitat areas are thinned from below. In practice, thinning intensity in habitat areas is variable and depends largely on stand objectives. Upland areas can be thinned only once after the stand reaches 18,000-20,000 acres, and 30 percent of the volume is removed.

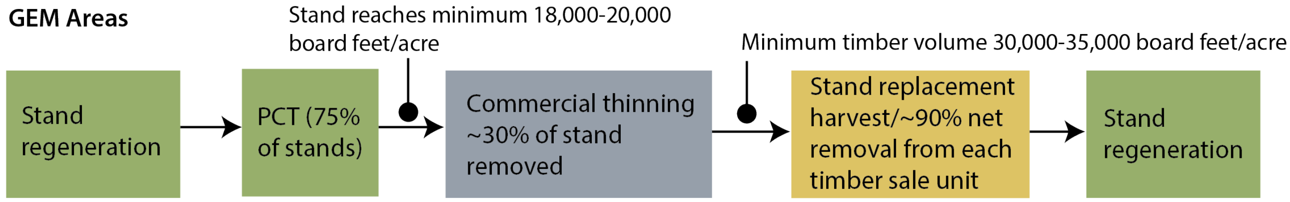
In addition, DNR will conduct PCT on 75 percent of forest stands. Stands should be roughly 8-10 years old, and the PCT should leave 300-350 TPA to ensure there are enough stems to support a later commercial thinning.

Why not 100% for PCT?

Whether to conduct a PCT is a stand-level decision. Some stands may benefit from a PCT, and others may not. DNR will capture this uncertainty in the model by applying PCT to only 75 percent of stands. Refer to Figure 7 for a simplified schematic of this scenario.

Figure 7. Simplified schematic of Scenario 4.

GEM Areas



Riparian Areas

Commercial thinning (~30% of stand removed) after stand reaches 18,000-20,000 board feet/acre*

*Roughly 91.3 acres of riparian forest will be thinned per year in western Washington (an increase of 10% from Scenario 1). Per the RFRS, riparian forests can be thinned only once.

Upland Areas

Commercial thinning (~30% of stand removed) after stand reaches 18,000-20,000 board feet/acre**

**Only one thinning entry will be modeled in upland areas to better align with HCP requirements.

Scenario 5: Lengthen Harvest Rotation and Significantly Increase Thinning (Multi-Dial Scenario)

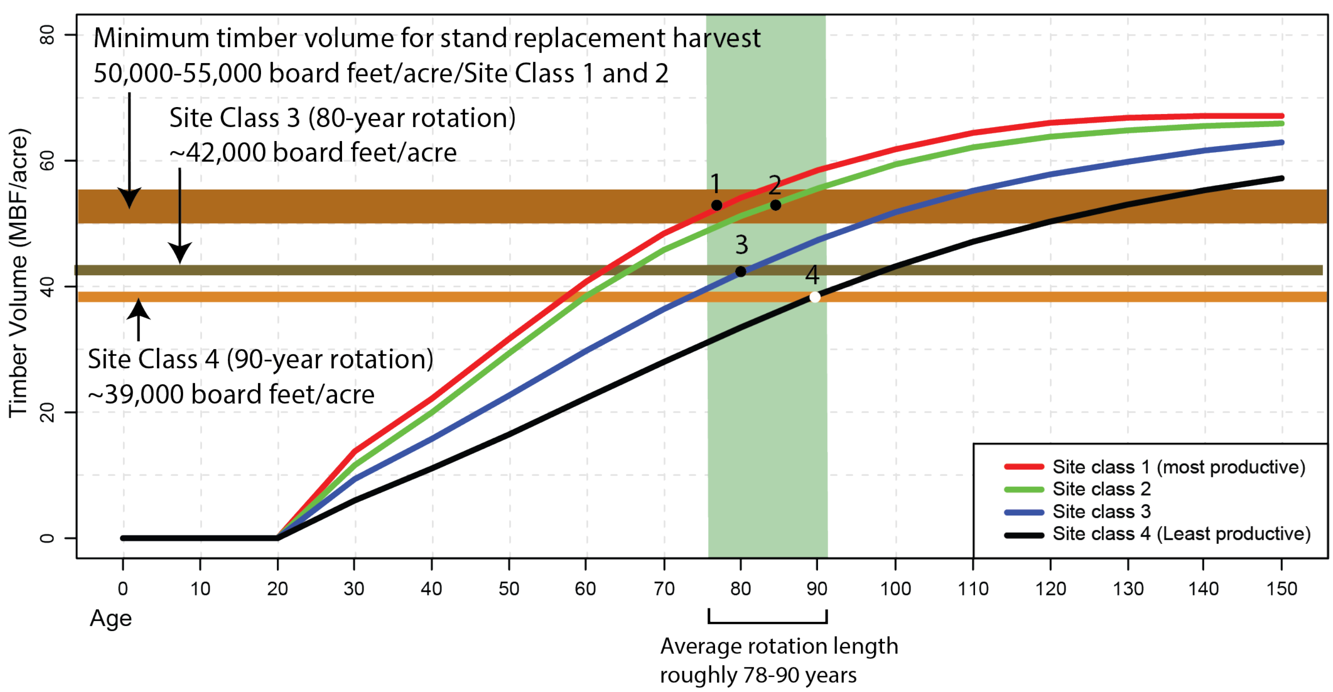
This scenario includes the following components:

Lengthen Harvest Rotation

This scenario includes a version of Scenario 2 that was partially modified based on work group input. Site Classes 1 and 2 are unchanged from Scenario 2; for those site classes, a stand becomes available for stand replacement harvest when it reaches 50,000-55,000 board feet per acre. However, Site Classes 3 and 4 can be harvested when they reach a specific age: 80 years for Site Class 3 and 90 years for Site Class 4. These ages correspond to an estimated timber volume of 42,000 board feet per are for Site class 3 and 39,000 board feet per acre for Site Class 4 (Figure 8).

Figure 8. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 5.

Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.

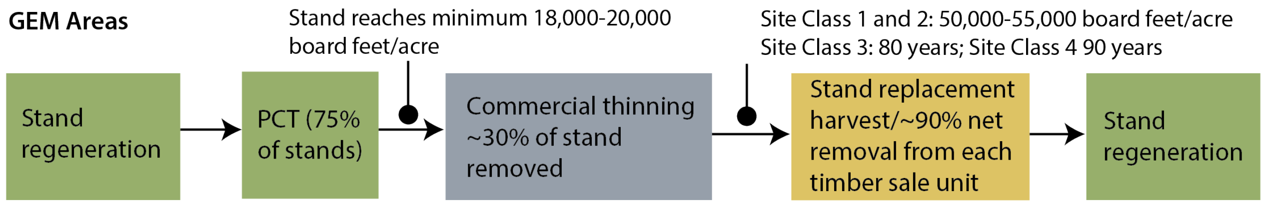


Significantly Increase Thinning

Refer to the description under Scenario 2. Figure 9 shows how the two components of this scenario interact.

Figure 9. Simplified schematic of Scenario 5.

GEM Areas



Riparian Areas

Commercial thinning (~30% of stand removed) after stand reaches 18,000-20,000 board feet/acre*

*Roughly 91.3 acres of riparian forest will be thinned per year in western Washington (an increase of 10% from Scenario 1). Per the RFRS, riparian forests can be thinned only once.

Upland Areas

Commercial thinning (~30% of stand removed) after stand reaches 18,000-20,000 board feet/acre**

**Only one thinning entry will be modeled in upland areas to better align with HCP requirements.

Scenario 6: Lengthen Harvest Rotation, Significantly Increase Thinning, and Increase Deferrals (Multi-Dial Scenario)

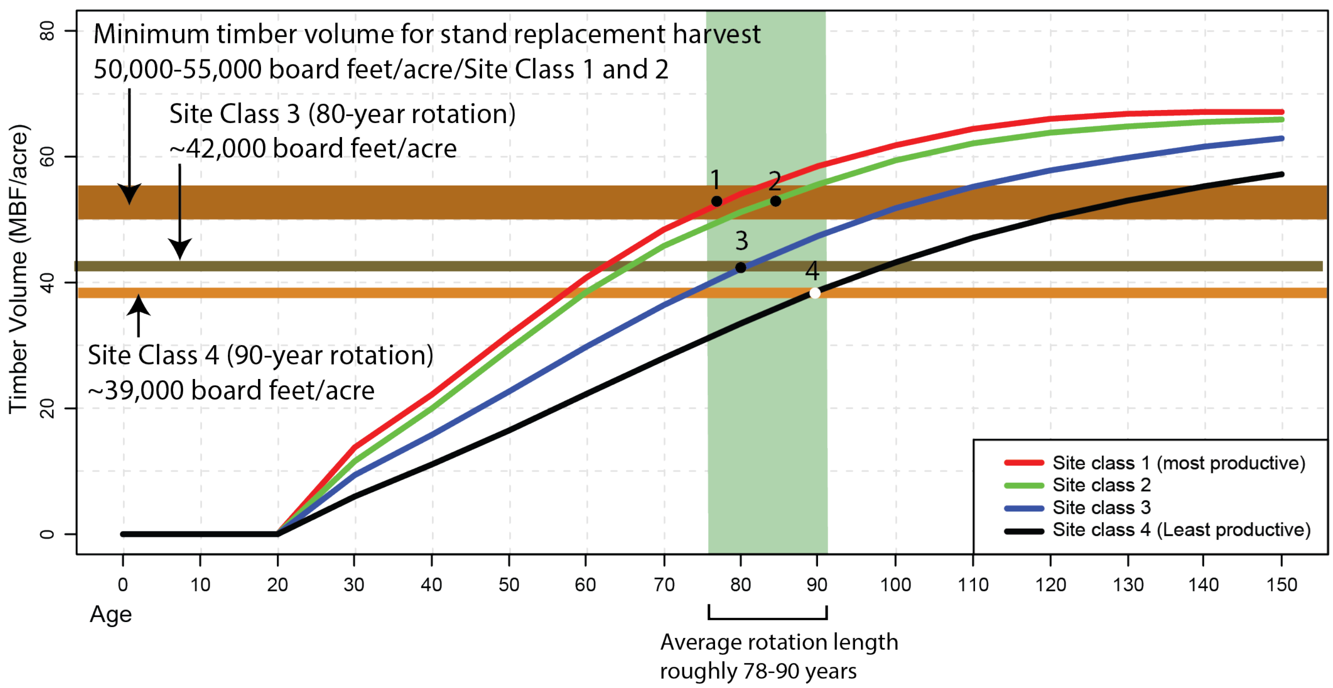
This scenario includes the following components:

Lengthen Harvest Rotation

This scenario includes a version of Scenario 2 that was modified based on work group input, as described under Scenario 5. Refer to Figure 10.

Figure 10. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 6.

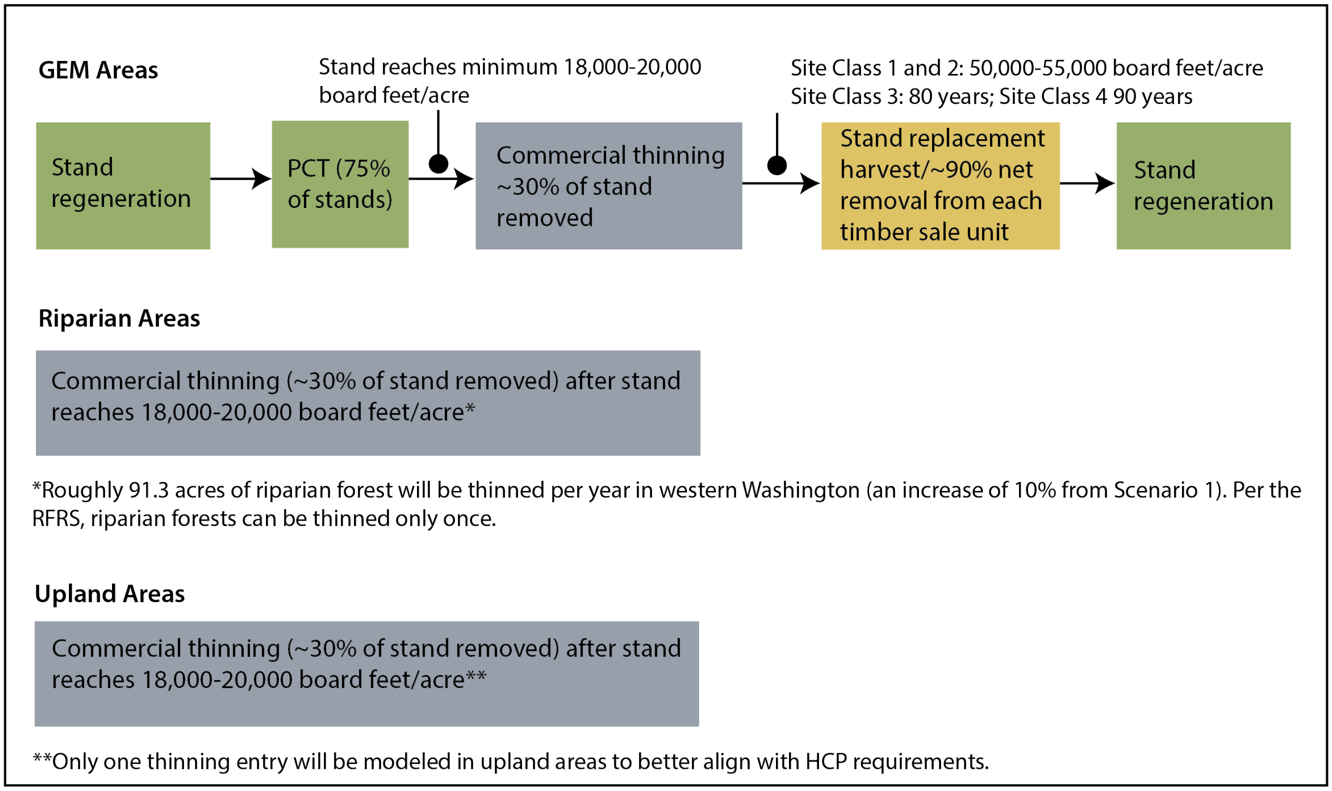
Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.



Significantly Increase Thinning

Refer to the description under Scenario 2. Figure 11 is a simplified schematic of this scenario.

Figure 11. Simplified schematic of scenario 6.



Increase Deferrals

Under this scenario, all forests in GEM areas that are 80 years old or older at the time of model development will be deferred from stand replacement harvest. Deferred areas will include all older, carbon-dense, structurally complex forest as DNR defines them in the *Policy for Sustainable Forests*. DNR will not conduct stand replacement harvest in deferred areas. However, these stands can be thinned if needed for forest health or other ecological objectives. Refer to Appendix 1 for more information on structurally complex forest.

This scenario uses age as a surrogate for structure. This approach mirrors the methodology used in the HCP. As noted in Franklin et. al. 2002[17], "The maturation stage typically begins at 80-100 years and may persist for 100-150 years in naturally regenerated Douglas-fir stands."

[17] Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and Structural Development of Natural Forest Ecosystems with Silvicultural Implications, Using Douglas-fir Forests as an Example. Forest Ecology and Management 155:399–423. Oliver, C. D. and B. C. Larson. 1996. Forest Stand Dynamics, update edition. John Wiley & Sons, New York, New York. 520 p.

DNR estimates the total number of acres deferred under this scenario to be approximately 66,725. This total excludes forests that are already deferred for other objectives, including the 2,000 acres of forest being deferred under Section 1(b) of this budget proviso (c 474 §3130).

Scenario 7: Significantly Increase Thinning and Increased Emphasis on Silviculture (Multi-Dial Scenario)

This scenario includes the following components:

Significantly Increase Thinning

Refer to the description under Scenario 2.

Increased Emphasis on Silviculture

This component is designed to increase the growth of forests through more intensive silvicultural practices.

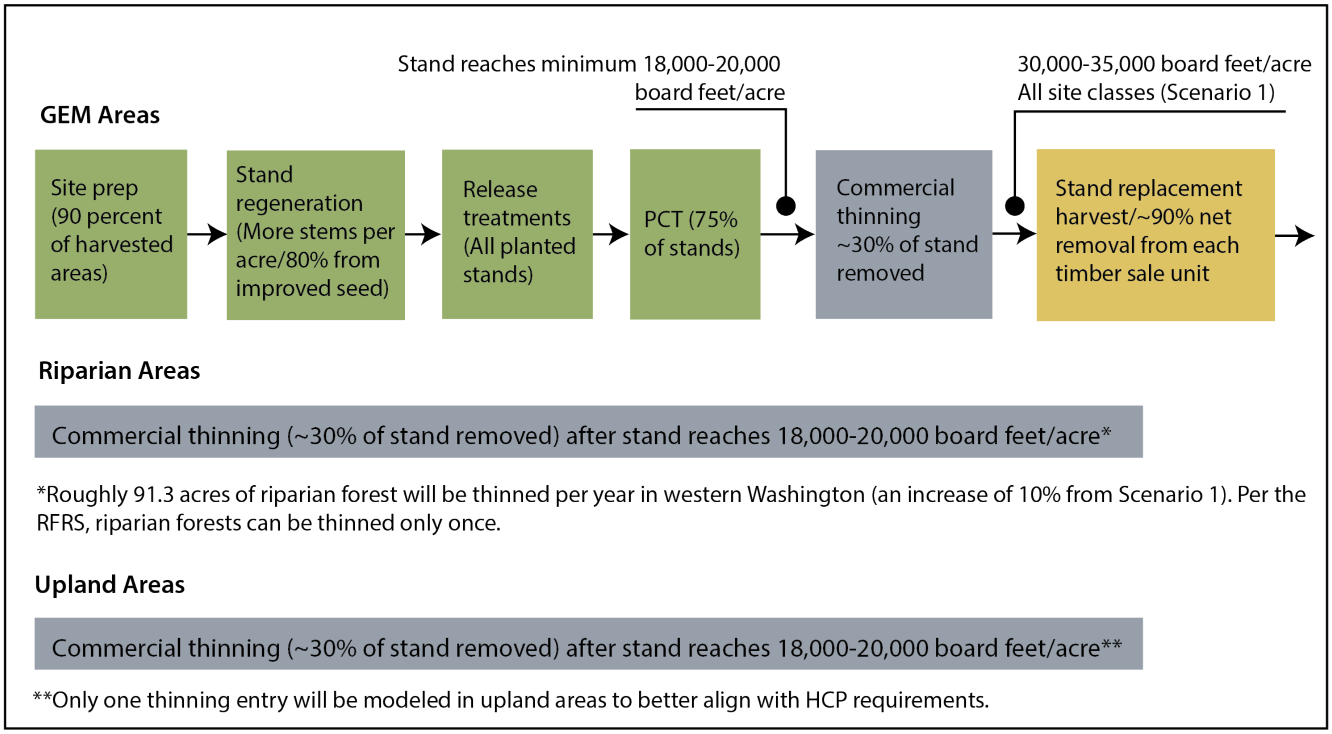
- **Seed and seedling improvement:** Across state trust lands, about 60 percent of the seedlings that DNR plants are grown from improved seed stock. Improved seeds are gathered from orchard trees that have performed well in field testing across a wide range of environments. This scenario would increase the percentage of improved seedlings to 80 percent, for a potential, average growth increase of about 10 percent. To simplify modeling, ESSA could assume a 2 percent growth increase across all GEM lands, relative to current practices.
- **Planting density:** Vary planting density by species:
    - Coastal low elevation sites: 400 TPA western hemlock
    - Mixed species stands: 275 Douglas-fir and 50 western hemlock
    - High elevation sites: 440 TPA noble fir

  Note that all sites will experience infill from natural regeneration.
- **Site preparation**: Increase site preparation from 75 to 90 percent of planted acres in GEM areas. Site preparation enhances seedling survival and growth through removal of competing vegetation. It also makes the site easier to plant.
- **Release treatment:** Increase release treatments from 75 to 100 percent of planted stands in GEM areas. Release treatments involve the removal of competing vegetation through mechanical or chemical means.

- **Pre-commercial thinning (PCT)**: Conduct PCT on 75 percent of stands in GEM areas. Each thinning would leave roughly 250 to 350 stems per acre, if a commercial thinning is desired.

Refer to Figure 12 for a simplified schematic of this scenario.

Figure 12. Simplified schematic of scenario 7.



Scenario 8: Shorten Harvest Rotation, Significantly Increase Thinning, and Increased Emphasis on Silviculture (Multi-Dial Scenario)

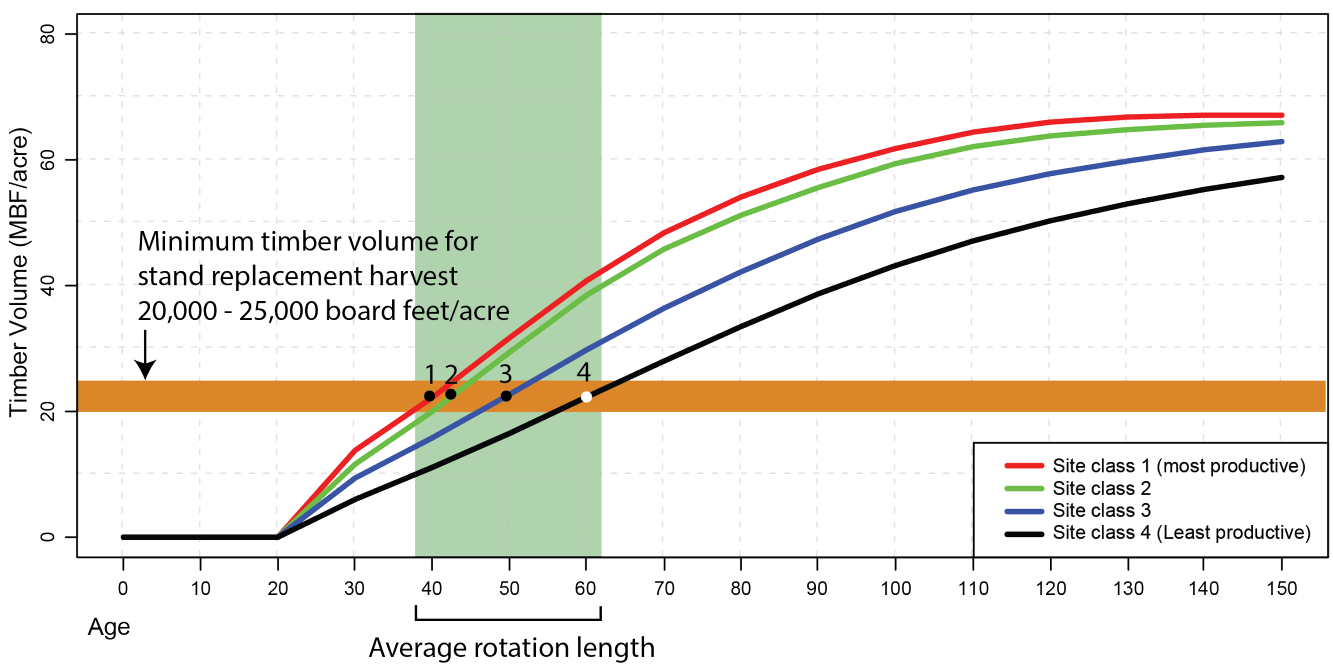
This scenario includes the following components:

Shorten Harvest Rotation

Refer to description under Scenario 3. Refer to Figure 13 for a sample yield curve.

Figure 13. Sample Douglas-fir yield curve for western Washington showing the relationship between minimum timber volume and stand age for Scenario 8.

Yield curve generated from RSFRIS inventory plots and stratified using information from DNR's inventory.



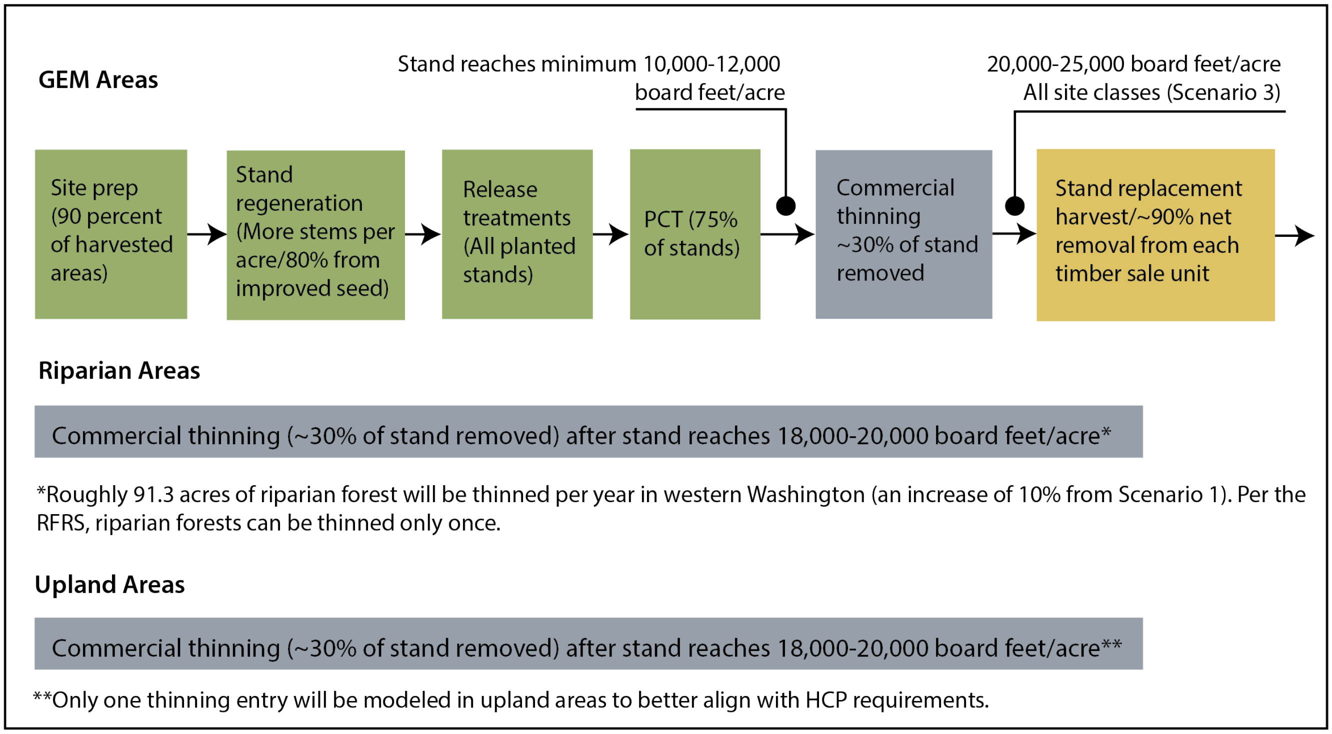
Increased Emphasis on Silviculture

Refer to description under Scenario 7.

Significantly Increase Thinning

Refer to the description under Scenario 2. Note that for this scenario only, the minimum harvest volume for a thinning has been reduced from 18,000-20,000 board feet per acre to 10,000-12,000 board feet per acre based on work group feedback at the May 8 meeting. Refer to Figure 14 for a simplified schematic of this scenario.

Figure 14. Simplified schematic of Scenario 8



Appendix A: Structurally Complex Forest

For the purposes of scenario development for the Carbon and Forest Management Work Group, DNR will use the definition of structurally complex stand in its 2006 *Policy for Sustainable Forest* *(Appendix C)*:

> A forest in the 'botanically diverse' 'niche diversification' or 'fully functional' stage of stand development. Forests in these phases have varying sizes of trees, understory vegetation and lichen, downed wood and snags, etc.

The Policy for Sustainable Forests uses stand development terms from the booklet *Identifying Mature and Old Forests in Western Washington* by Robert Van Pelt. These terms are different than the terms DNR used in the December 2023 work group meeting, which are based on a different stand classification system. Refer to the table below for a crosswalk between these terms and the general characteristics of each stage.

Term used in December 2023 work group meeting (based on Franklin et al. 2002.)[18]	**Term used in Van Pelt guide and the *Policy for Sustainable Forests* (based on Carey and Curtis 1996.)**[19]	**Characteristics**
Maturation II	Botanically diverse	Small gaps begin to form from natural disturbances such as wind, resulting in a understory developing with different tree species growing into the lower and middle tree (mid-story) canopy. Large pieces of down woody material (fallen trees) and large snags (standing dead trees) are few or absent in the stand.
Vertical diversification	Niche diversification	The lower and mid-story tree canopies have diversified, with more tree species and a greater range in tree diameters. The amount of large down woody material and number of snags has increased.

[18] Franklin, J.F., Spies, T.A., Van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C. and Bible, K., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest ecology and management*, *155*(1-3), pp.399-423.

[19] Carey, A.B. and Curtis, R.O., 1996. Conservation of biodiversity: a useful paradigm for forest ecosystem management. *Wildlife Society Bulletin*, *24*(4), pp.610-620.

Term used in December 2023 work group meeting (based on Franklin et al. 2002.)[18]	Term used in Van Pelt guide and the *Policy for Sustainable Forests* (based on Carey and Curtis 1996.)[19]	Characteristics
Horizontal diversification	Fully functional	The original trees from stand initiation are dying out more rapidly, resulting in abundant snags, large pieces of down woody material, and larger gaps in the upper tree canopy. Shade-tolerant trees have reached the upper tree canopy.

On the following page is a table that shows the stand development stages definitions to be used in modeling (botanically diverse, niche diversification, and fully functional).

Table A1. Stand development stage definitions to be used in modeling

Stages			Stand-level Variable and Associated Threshold Value									
							Management Activity					
Summarized	Detailed		QMD	Canopy Layer	RD	Stand Age	BioThin Age	Years Since BioThin	Thin Age	Years Since Thin	Snag Ratio1	CWD
Ecosystem Initiation	Ecosystem Initiation		<2									
Competitive Exclusion	Sapling Exclusion		>=2									
	Pole Exclusion		>5									
		or							>0	>=0		
	Large Tree Exclusion		>11									
		or	>11						>0	>=0		
	Understory Development		>=2	>1								
		or	>=2		>=MaxRD							
		or	>=2			>MaxRD Age						
		or	>=2				>0	>=0				
Structurally Complex	Botanically Diverse		>=2	>1								
		or	>=2	>1		>=MaxRD Age+60						
		or	>=2	>1			>0	>=0				
		or	>=2	>1	>=MaxRD							
		or	>=2		>=MaxRD	>=MaxRD Age+60						
		or	>=2		>=MaxRD		>0	>=0				
		or	>=2			>=MaxRD Age+60	>0	>=0				
		or	>=2				>0	>5				
		or	>=2	>1		>MaxRD Age						
		or	>=2			>=MaxRD Age+60						
		or	>=2			>MaxRD Age	>0	>5				
	Niche Diversification		>=2	>1		>=MaxRD Age+80					>0.07	>2400
		or	>=2	>1		>=MaxRD Age+80	>0	>0				
		or	>=2	>1			>0	>5				
		or	>=2		>=MaxRD	>=MaxRD Age+80					>0.07	>2400
		or	>=2		>=MaxRD	>=MaxRD Age+80	>0	>0				
		or	>=2		>=MaxRD		>0	>5				
		or	>=2			>=MaxRD Age+80					>0.07	>2400
		or	>=2			>=MaxRD Age+80	>0	>0				
		or	>=2			>MaxRD Age	>0	>5				
		or	>=2			>=MaxRD Age+80	>0	>=0			>0.07	>2400
		or	>=2			>=MaxRD Age+80	>0	>0				
		or	>=2				>0	>5			>0.07	>2400
	Fully Functional		>=2	>1		>=MaxRD Age+160					>0.07	>2400
		or	>=2	>1		>=MaxRD Age+160	>0	>0				
		or	>=2	>1			>0	>40				
		or	>=2		>=MaxRD	>=MaxRD Age+160					>0.07	>2400
		or	>=2		>=MaxRD	>=MaxRD Age+160	>0	>0				
		or	>=2		>=MaxRD		>0	>40				
		or	>=2			>=MaxRD Age+160					>0.07	>2400
		or	>=2			>=MaxRD Age+160	>0	>0				
		or	>=2			>MaxRD Age	>0	>40				
		or	>=2			>=MaxRD Age+160	>0	>=0			>0.07	>2400
		or	>=2			>=MaxRD Age+160	>0	>0				
		or	>=2				>0	>40			>0.07	>2400

Appendix B. Site Class

In General Ecological Management (GEM) areas, most state trust lands in western Washington (79%) are Site Class 2 or 3:Site Class 1: 5%

- Site Class 2: 41%
- Site Class 3: 38%
- Site Class 4: 12%
- *Site Class 5 and 6: 4%*

In the scenarios, DNR did not specify rotation lengths for Site Class 5 or 6 because there are few acres on the landscape and the growing conditions are poor. These “low” sites tend to have glacial till, glacial drift over bedrock, or gravel alluvium, and are rarely productive enough to actively manage for timber harvest.

Appendix B: WWA Model Formulation

This study takes a linear programming approach to maximizing the net present value of harvests in western Washington while constraining public harvests to remain at their reported 10-year average levels at the county level. This appendix details both the structure of the equations as well as providing the definitions of each of the sets over which the underlying data are categorized, the parameters which provide the known values, and then the variables which are the unknown values that the model is solving for. The model was solved for a 100-year timeframe using five-year time periods and a 6 percent discount rate.

The objective function used in the linear program

Equation A1 –Maximize Net Present Value: The model chooses a land allocation of silvicultural managements and harvest timings for the FIA forest plots that maximized the discounted sum of the net revenue from the forests of western Washington.

$$MAX \quad \sum_{t<t^n}[R(t) - C(t)]\,(1+i)^{-(d(t)-2024)} \qquad \text{(A1)}$$

Subject to the constraints

Equation A2 - Allocation of all available area: Each acre of each plot must be assigned a management prescription and final regeneration harvest period (which includes a “never” time period indicating no final harvest)

$$\sum_m \sum_t X(p,m,t) = a(p) \quad \forall p \quad \text{(A2)}$$

Equation A3 – Allocation of regenerated area: Upon final harvest of existing plots, all acres must be assigned a new management and final harvest period (again including a “never” option)

$$\sum_m \sum_{t*>t} N(p,m,t,t^*) = \sum_m X(p,m,t) + \sum_m \sum_{t*<t} N(p,m,t^*,t) \quad \forall p, t < t^n \text{ (A3)}$$

Equation A4 – Harvest accounting: Harvesting of each log product is determined by multiplying the acres allocated to each existing and regenerated acre by the yields of the different log species and size classes.

$$\sum_p \sum_m X(p,m,t) * y^X(p,m,t,x) * (1-f) + \sum_p \sum_m \sum_{e=t-t^*} N(p,t^*,t) * y^N(p,m,e,x) * (1-f) = H(x,t) \quad \forall x, t < t^n \qquad \text{(A4)}$$

Equation A5 – Revenue accounting: The harvesting accounting variable is multiplied by an array of exogenous log prices to get the gross revenue in each time period.

$$\sum_x H(x,t) * v(x,t) = R(t) \quad \forall t < t^n \quad \text{(A5)}$$

Equation A6 – Cost accounting: the costs incurred in each time period include costs that are a function of volume harvested *j* (per mbf costs), a function of acres harvested *k* (per acre costs) either upon harvesting or planting, and other costs *l*.

$$\sum_{s} H(x,t) * j + \left[\sum_{p}\sum_{m} X(p,m,t) + \sum_{p}\sum_{m}\sum_{t^*>t} N(p,m,t^*,t) + \sum_{p}\sum_{m}\sum_{t^*>t} N(p,m,t,t^*)\right] * k + l = C(t) \quad \forall t < t^n$$

(A6)

Equation A7 – Public harvest target levels: public harvest levels are constrained to match 10-year average observed levels for the public owner group within each county

$$\sum_{p\in o^{pub} and p\in c} \sum_m X(p,m,t) * y^X(p,m,t,x) * (1-f) + \sum_{p\in o^{pub} and p\in c} \sum_m \sum_{e=t-t^*} N(p,t^*,t) * y^N(p,m,e,x) * (1-f) = 5 * h\left(c, o^{pub}, t\right) \quad \forall c, \in pub, t < t^n \quad \text{(A7)}$$

Equation A8 – Private harvest level upper limit: private harvest levels are constrained to be less than 5% above the WWA-modeled 100-year average private harvest level within each county

$$\sum_{p\in o^{pvt} and p\in c} \sum_m X(p,m,t) * y^X(p,m,t,x) * (1-f) + \sum_{p\in o^{pvt} and p\in c} \sum_m \sum_{e=t-t^*} N(p,t^*,t) * y^N(p,m,e,x) * (1-f) \leq 1.05 * \frac{\left[\sum_{t'} \sum_{p\in o^{pvt} and p\in c} \sum_m X(p,m,t') * y^X(p,m,t',x) * (1-f) + \sum_{p\in o^{pvt} and p\in c} \sum_m \sum_{e=t'-t^*} N(p,t^*,t') * y^N(p,m,e,x) * (1-f)\right]}{5*n}$$

$\forall c, o^{pvt}, t < t^n$ (A8)

Equation A9 – Private harvest level lower limit: private harvest levels are constrained to be greater than 5% below the WWA-modeled 100-year average private harvest level within each county

$$\sum_{p\in o^{pvt} and p\in c} \sum_m X(p,m,t) * y^X(p,m,t,x) * (1-f) + \sum_{p\in o^{pvt} and p\in c} \sum_m \sum_{e=t-t^*} N(p,t^*,t) * y^N(p,m,e,x) * (1-f) \geq 0.95 * \frac{\left[\sum_{t'} \sum_{p\in o^{pvt} and p\in c} \sum_m X(p,m,t') * y^X(p,m,t',x) * (1-f) + \sum_{p\in o^{pvt} and p\in c} \sum_m \sum_{e=t'-t^*} N(p,t^*,t') * y^N(p,m,e,x) * (1-f)\right]}{5*n}$$

$\forall c, o^{pvt}, t < t^n$ (A9)

Equation A10 – Terminal condition: ending inventory levels are constrained to be at least as high as initial inventory levels for each owner group within each county. This eliminates the ability of the model to liquidate the forest in the final time periods.

$$\sum_{t<t^n} \sum_{p\in o\ and p\in c} \sum_m \sum_x X(p,m,t) * y^X(p,m,t^n,x) + \sum_{t^*<t^n} \sum_{p\in o\ and\ p\in c} \sum_m \sum_{e=t^n-t^*} N(p,t^*,t^n) * y^N(p,m,e,x) \geq \sum_t \sum_{p\in o\ and p\in c} \sum_m \sum_x X(p,m,t) * y^X(p,m,t^1,x) \quad \text{(A10)}$$

Sets

c the set of counties

e the set of regenerated stand ages

m the set of silvicultural management options available for the plot

o the set of forest owner groups with o^{pvt} being the subset of private ownership and o^{pub} being the subset of public owners (USFS, BLM and other federal, and State) *p* the set unique condition classes on FIA plots to be scheduled for management. The FIA plots can have attributes mapped to them including county c, owner o, forest type f, site class s,.

t the set of 5-year time periods over which the model will be run (2024, 2029…..)

x the set of log volume yield items which include species and tree size indicators (ex. DF12 would be Douglas-fir log volume in trees smaller than 12" dbh).

Parameters

a(p) the acreage of FIA plot (condition class on plot) p

d(t) the date of time period t

f reduction for defect and breakage (10%)

$h(c,o^{pub},t)$ the county-level harvest targets for public owners set as an average of the harvest in that county over the last ten years

i the discount rate (6%)

j costs incurred per unit of volume harvested basis (eg: harvest and haul costs)

k costs incurred per acre basis (eg: site preparation and planting)

l costs incurred per unit of time basis (eg: management costs)

v(x,t) log prices for yield items *x* in time period *t*

$y^N(p,m,o,x)$ the volume of log product *x* on plot *p* under management prescription *m* at age *o*

$y^X(p,m,t,x)$ the volume of log product *x* on plot *p* under management prescription *m* in time period *t*

Variables

C(t) costs incurred in time period t

H(x,t) harvest level of log product *x* time period *t*

$N(p,m,t,t^*)$ acres of regenerated FIAplot *p* under management prescription *m* planted in time period *t* and to be harvested in time period t^*

R(t) revenues received in time period t

*X(p,m,t)*acres of existing FIA plot *p* under management prescription *m* to be harvested in time period *t*

Appendix C: Single Industry IMPLAN Output

Tables 5 through 11 provide results from IMPLAN economic contribution analyses for relevant wood supply industries in the 19 combined western Washington counties. Each table presents the direct, indirect, induced, and total effects of the specific industry on employment, labor income, value added, and output across the combined counties. The values reflect the cumulative economic effects that the relevant industries supported in the combined counties in 2022.

Table 5: Forestry, Forest Products, and Timber Tract Production

Impact	Employment	Labor Income	Value Added	Output
Direct	588	$60,336,612	$68,370,772	$83,810,457
Indirect	143	$7,446,513	$8,732,379	$11,462,339
Induced	228	$16,578,151	$33,174,812	$51,833,917
Total	**960**	**$84,361,275**	**$110,277,964**	**$147,106,713**

Table 6: Commercial Logging

Impact	Employment	Labor Income	Value Added	Output
Direct	4,117	$391,970,071	$457,178,968	$620,761,022
Indirect	1,103	$66,866,233	$92,781,540	$136,983,474
Induced	1,542	$111,805,214	$223,723,433	$349,568,387
Total	**6,762**	**$570,641,518**	**$773,683,941**	**$1,107,312,883**

Table 7: Sawmills

Impact	Employment	Labor Income	Value Added	Output
Direct	5,170	$497,822,044	$1,251,880,638	$3,114,719,191
Indirect	7,025	$648,349,961	$1,011,860,252	$1,671,843,025
Induced	3,869	$280,886,089	$562,162,579	$878,224,515
Total	**16,064**	**$1,427,058,094**	**$2,825,903,469**	**$5,664,786,731**

Table 8: Veneer and Plywood Manufacturing

Impact	Employment	Labor Income	Value Added	Output
Direct	905	$95,984,728	$193,072,124	$460,581,415
Indirect	675	$62,852,245	$99,677,901	$167,457,539
Induced	524	$38,000,250	$76,051,090	$118,819,378
Total	**2,104**	**$196,837,223**	**$368,801,115**	**$746,858,333**

Table 9: Engineered Wood Member and Truss Manufacturing

Impact	Employment	Labor Income	Value Added	Output
Direct	1,046	$87,645,009	$226,426,345	$527,449,118
Indirect	840	$79,947,234	$153,049,716	$296,196,304
Induced	552	$40,105,514	$80,272,848	$125,410,072
Total	**2,438**	**$207,697,756**	**$459,748,909**	**$949,055,494**

Table 10: All Other Miscellaneous Wood Product Manufacturing

Impact	Employment	Labor Income	Value Added	Output
Direct	328	$24,304,473	$52,533,130	$117,114,891
Indirect	188	$18,628,687	$32,642,778	$60,438,700
Induced	138	$10,014,214	$20,044,566	$31,315,481
Total	**653**	**$52,947,374**	**$105,220,474**	**$208,869,073**

Table 11: Combined Mills (Pulp, Paper, Paperboard)

Impact	Employment	Labor Income	Value Added	Output
Direct	3,540	$465,111,074	$727,438,502	$2,868,490,936
Indirect	4,942	$490,311,353	$901,465,225	$1,674,355,873
Induced	3,181	$231,064,433	$462,560,080	$722,438,884
Total	**11,663**	**$1,186,486,861**	**$2,091,463,808**	**$5,265,285,693**

Appendix D: County Level Contribution Analysis

Tables 12 through 30 provide estimates of the aggregate economic contribution of the forest and forest products sectors in each of the 19 western Washington counties. Each table presents the direct, indirect, induced, and total effects on employment, labor income, value added, and output in the given county. Additionally, state and local tax estimates are provided.

Table 12: King County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	785	$126,545,217	$184,483,979	$396,420,055	$19,124,954
2 - Indirect	287	$31,484,290	$55,343,921	$90,865,713	$5,541,042
3 - Induced	313	$25,237,208	$49,502,521	$72,870,550	$5,163,246
Total	**1,385**	**$183,266,715**	**$289,330,420**	**$560,156,318**	**$29,829,242**

* No Paperboard Mills industry

Table 13: Whatcom County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	663	$50,321,481	$79,351,996	$194,500,507	$13,147,512
2 - Indirect	245	$14,415,253	$25,484,964	$47,958,773	$3,225,163
3 - Induced	232	$12,782,720	$26,172,459	$42,899,036	$3,779,746
Total	**1,140**	**$77,519,453**	**$131,009,419**	**$285,358,316**	**$20,152,422**

* No Pulp Mills or Paperboard Mills industries

Table 14: Skagit County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	853	$97,541,816	$200,944,218	$441,791,005	$22,367,740
2 - Indirect	150	$9,769,704	$19,462,563	$36,142,145	$1,057,991
3 - Induced	226	$11,445,080	$26,221,682	$41,667,470	$2,650,398
Total	**1,229**	**$118,756,600**	**$246,628,463**	**$519,600,620**	**$26,076,129**

* No Pulp Mills or Paperboard Mills industries

Table 15: Snohomish County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	708	$79,524,976	$153,615,199	$346,641,832	$14,742,234
2 - Indirect	134	$9,289,568	$15,922,908	$27,685,826	$387,400
3 - Induced	179	$10,103,241	$21,469,502	$32,350,739	$1,757,754
Total	**1,021**	**$98,917,786**	**$191,007,608**	**$406,678,397**	**$16,887,389**

* No Veneer and Plywood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 16: Lewis County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	1,973	$225,998,365	$489,308,174	$1,073,851,639	$62,822,482
2 - Indirect	631	$45,408,151	$88,295,669	$159,702,723	$6,189,397
3 - Induced	665	$33,384,005	$74,014,477	$118,940,449	$8,760,555
Total	**3,269**	**$304,790,522**	**$651,618,319**	**$1,352,494,811**	**$77,772,433**

* No Pulp Mills, Paper Mills, or Paperboard Mills industries

Table 17: Cowlitz County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	3,783	$456,360,741	$781,158,418	$2,499,314,240	$98,434,897
2 - Indirect	1,747	$130,821,212	$276,876,041	$520,208,642	$26,447,546
3 - Induced	1,378	$70,031,569	$158,961,582	$254,745,967	$16,712,644
Total	**6,909**	**$657,213,522**	**$1,216,996,041**	**$3,274,268,849**	**$141,595,086**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, or Pulp Mills industries

Table 18: Clark County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	916	$77,522,457	$149,177,341	$401,753,571	$25,819,804
2 - Indirect	248	$17,646,655	$31,643,735	$62,346,822	$2,223,396
3 - Induced	249	$13,833,781	$29,002,386	$45,165,547	$2,933,949
Total	**1,413**	**$109,002,893**	**$209,823,462**	**$509,265,941**	**$30,977,149**

* No Pulp Mills or Paperboard Mills industries

Table 19: Skamania County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	95	$8,242,689	$15,318,149	$46,764,126	$1,203,086
2 - Indirect	34	$2,366,167	$3,918,596	$8,418,150	$118,073
3 - Induced	12	$472,648	$1,573,564	$2,564,509	$113,132
Total	**141**	**$11,081,504**	**$20,810,309**	**$57,746,785**	**$1,434,291**

* No Engineered Wood Manufacturing, Miscellaneous Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 20: Wahkiakum County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	66	$4,488,268	$5,466,568	$8,393,275	$455,760
2 - Indirect	14	$905,555	$1,009,584	$1,363,248	$17,396
3 - Induced	4	$110,885	$487,030	$878,924	$12,240
Total	**85**	**$5,504,709**	**$6,963,182**	**$10,635,447**	**$485,397**

* No Forestry and Forest Products, Sawmills, Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Miscellaneous Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 21: Pacific County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	184	$15,469,737	$22,179,273	$44,733,074	$2,881,578
2 - Indirect	57	$1,397,895	$2,499,350	$4,819,160	$133,435
3 - Induced	34	$1,121,848	$3,254,099	$5,611,113	$194,472
Total	**275**	**$17,989,479**	**$27,932,722**	**$55,163,347**	**$3,209,485**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Miscellaneous Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 22: Thurston County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	903	$55,312,300	$81,348,355	$199,165,682	$15,602,896
2 - Indirect	277	$18,105,523	$30,513,687	$53,188,557	$3,894,128
3 - Induced	210	$12,753,486	$25,763,872	$40,376,999	$2,895,253
Total	**1,390**	**$86,171,308**	**$137,625,914**	**$292,731,238**	**$22,392,277**

* No Veneer and Plywood Manufacturing or Pulp Mills industries

Table 23: Grays Harbor County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	1,515	$124,581,851	$268,827,369	$707,864,116	$40,427,937
2 - Indirect	601	$34,209,720	$63,045,406	$130,351,078	$8,068,396
3 - Induced	394	$16,929,156	$40,746,779	$68,391,292	$5,434,956
Total	**2,510**	**$175,720,727**	**$372,619,554**	**$906,606,486**	**$53,931,289**

* No Paperboard Mills industry

Table 24: Mason County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	443	$38,072,289	$64,006,360	$165,562,654	$8,204,016
2 - Indirect	137	$8,570,279	$16,040,363	$33,188,818	$953,259
3 - Induced	71	$3,074,290	$8,374,650	$14,010,677	$520,239
Total	**651**	**$49,716,859**	**$88,421,372**	**$212,762,149**	**$9,677,514**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 25: Pierce County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	1,533	$148,996,622	$294,717,548	$821,257,853	$45,346,244
2 - Indirect	587	$42,873,060	$86,563,399	$162,864,356	$8,673,798
3 - Induced	459	$28,805,655	$57,869,915	$88,045,449	$6,166,894
Total	**2,578**	**$220,675,337**	**$439,150,862**	**$1,072,167,657**	**$60,186,936**

* No Pulp Mills industry

Table 26: Kitsap County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	219	$15,667,135	$19,787,475	$32,807,955	$3,041,371
2 - Indirect	0	$0	$0	$0	$0
3 - Induced	0	$0	$0	$0	$0
Total	**219**	**$15,667,135**	**$19,787,475**	**$32,807,955**	**$3,041,371**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Miscellaneous Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 27: Jefferson County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	147	$20,803,335	$31,656,511	$100,090,664	$3,799,933
2 - Indirect	61	$3,620,722	$7,601,309	$15,823,402	$507,222
3 - Induced	47	$1,929,444	$4,740,373	$7,852,889	$373,485
Total	**255**	**$26,353,500**	**$43,998,193**	**$123,766,955**	**$4,680,641**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 28: Clallam County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	824	$74,776,840	$131,684,214	$304,149,975	$17,193,224
2 - Indirect	220	$10,130,507	$17,854,031	$37,495,711	$872,467
3 - Induced	222	$9,767,070	$23,155,950	$38,497,793	$2,095,625
Total	**1,267**	**$94,674,417**	**$172,694,195**	**$380,143,479**	**$20,161,316**

* No Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Pulp Mills, or Paperboard Mills industries

Table 29: Island County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	23	$2,261,053	$2,526,827	$3,439,059	$282,615
2 - Indirect	13	$250,862	$294,079	$409,978	$6,612
3 - Induced	6	$230,191	$581,244	$946,430	$34,259
Total	**42**	**$2,742,106**	**$3,402,151**	**$4,795,467**	**$323,486**

* No Sawmills, Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Miscellaneous Wood Manufacturing, Pulp Mills, Paper Mills, or Paperboard Mills industries

Table 30: San Juan County

Impact	Employment	Labor Income	Value Added	Output	State and Local Tax
1 - Direct	61	$686,839	$1,342,506	$4,425,750	$292,507
2 - Indirect	29	$678,099	$910,052	$1,396,287	$85,796
3 - Induced	3	$122,912	$324,352	$530,897	$19,114
Total	**93**	**$1,487,850**	**$2,576,910**	**$6,352,934**	**$397,417**

* No Sawmills, Veneer and Plywood Manufacturing, Engineered Wood Manufacturing, Pulp Mills, or Paperboard Mills industries