Appendix F. Model

Introduction

This appendix describes the computer model, known as a forest estate model, used to calculate sustainable harvest levels for each of the alternatives analyzed in this DEIS. This document describes the input data for the model, scripts used to process data, and programming used to run the model.

What is a forest estate model?

A forest estate model is a mathematical computer model that can aid the decision-making process by finding an optimized solution to the problem of how to manage forest resources efficiently and effectively. It is a sophisticated analysis tool, integral to the forestland planning processes. It can tell us where and when to conduct timber harvests and thinning in order to meet DNR's many objectives. The computer software used by DNR to make this computer model is the Remsoft Spatial Planning System developed by Remsoft Incorporated.

The forest estate model uses an analysis technique known as *mathematical programming*. Mathematical programming can help answer questions about how to allocate limited resources among competing activities in an optimal way. In mathematical programming, the problem (how to manage the forest) is represented completely in mathematical terms, normally by means of a criterion which the model seeks to maximize or minimize. In mathematical programming terminology, the criterion is known as the *objective function*. The objective function is to maximize the financial return to the trust beneficiaries, as represented by *net present value* (for additional information, refer to Objective Function, p. F-17). The objective function is subject to a set of mathematical *constraints* that describe the requirements to which the decisions made by the model must adhere. These constraints may reflect ecological, financial, operational, or policy considerations (for additional information, refer to Constraints, p. F-12).

Collectively, the mathematical equations describing the problem are represented as a multi-dimensional matrix, for which the model seeks a solution. The forest estate model solves the problem using linear functions and is known as a *linear programming model*. The model allows for both hard and soft constraints to be applied. Hard constraints must be met for the model to produce any solution. If the constraint cannot be met, the model will not produce a result. Soft constraints are modeled using a technique known as *goal programming*. In goal programming, the constraints are not absolutely binding. That is, deviations from the constraints are allowed and individual constraints may be under- or over-achieved. Any deviations that do take place, however, incur a penalty which helps to minimize deviations. The penalty is $9,999 per acre for each goal that is not met. Using goal programming, it is sometimes possible to solve otherwise unsolvable problems. In particular, goal programming in a used when a constraint is not met by the initial conditions. For example, if a basin managed by DNR for hydrologic maturity does not initially have enough hydrologically mature forest to meet the constraint, goal programming must be used, or the model will not find a solution.

The solution provided by the forest estate model is a list of management activities known as a harvest schedule. It is a report of the recommended timing and types of harvest activities that are necessary to optimize the objective function (to maximize the financial return to the trust beneficiaries; for additional information, refer to Objective Function, p. F-17) and, to the greatest extent possible, meet the constraints. Using a modeling technique known as *simulation*, the forest estate model also provides a detailed report of future forest conditions across the entire DNR-managed lands in Western Washington as a result of implementing the harvest schedule. These data are reported out into two databases. The harvest schedule is known as the *activities* file; future forest conditions are reported in the *conditions* file.

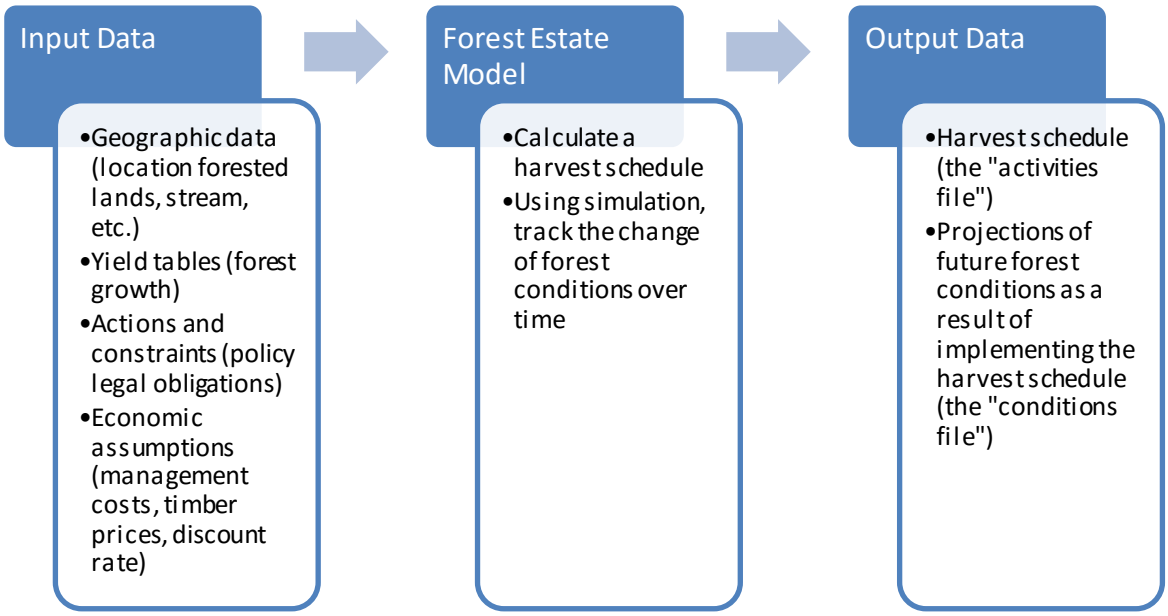
Since the forest estate model is an abstraction of real-world conditions, it is subject to inherent uncertainties. Key uncertainties include the effects of climate change; the timing, extent, and effects of disturbance; rates of forest development; and site-specific considerations such as the location of streams, wetlands, and unstable slopes.

What does the forest estate model represent?

The forest estate model is intended to represent both growing conditions of forests on DNR-managed lands in Western Washington and the legal and policy considerations of managing these lands. These considerations include policies in the Policy for Sustainable Forests, strategies in the HCP, and forest practices rules (refer to Chapter 1.2 for more information).

In order to represent forest growth, as well as legal and policy considerations, the forest estate model uses data from several sources. These sources are geographic data, yield tables, economic assumptions such as management costs, timber prices and discount rate, and mathematical representations for policy and law represented by actions and constraints. These inputs will be described in this appendix.

Figure F.1. Generalized Representation of the Forest Estate Model



Key terminology

A few key terms are used to describe parts of the forest estate model. These terms are theme, development type, and stratum.

A *theme* is an attribute used to describe the lands in the forest estate model. The themes simplify and classify the DNR-managed forestlands for use in the model. These themes are described in Table F.1.

A *development type* is a collection of polygons that have the same combination of values for Themes 1 through 14, plus the age of the forest in the polygon (in decadal units).

A *stratum* is a group of development types that share the same attributes in the first four themes. Yield curves (refer to Yield Tables on page F-6) were developed for each stratum.

Table F.1. Themes Used in the Forest Estate Model.

Theme number	Theme name	Description
THEME 1	Forest Vegetation Simulator (FVS) variant	FVS (Dixon 2002) is a stand-level growth and yield modeling program developed by the U.S. Forest Service (USFS) and used by DNR to generate yield curves. Yield curves provide strata-level projections of forest conditions and how they change over time. Numerous variants of FVS exists, each specialized for different geographical areas. For the sustainable harvest calculation, DNR used the Pacific Northwest and West Cascades variants of FVS. Nearly all DNR-managed lands in Western Washington are in areas for which the USFS recommends using one of these two variants. Some DNR-managed lands are in an area covered by the Southeast Alaska variant. These lands were instead modeled using the Pacific Northwest variant to limit the complexity of the model. The estimated yields for these lands are nearly identical between the Southeast Alaska and Pacific Northwest variants.
THEME 2	Plant association group (PAG)	A plant association is a grouping of plant communities based on potential vegetation development. Multiple plant associations can be combined into a group. DNR used a vegetation zone map by Henderson (2009) to classify DNR-managed lands into PAGs. The PAGs are used to set parameters in FVS that control the maximum stand density.

<table>
<tr><th>Theme number</th><th>Theme name</th><th>Description</th></tr>
<tr><td>THEME 3</td><td>Site index class</td><td>Site index is the average height of the dominate trees in a forest at a given age. Site index classes group a range of site indices into a single class. DNR used Douglas fir and red alder site indices in the sustainable harvest calculation model. Site indices for coniferous forests follow Douglas fir site indices. Where inventory data contain site indices for coniferous species other than Douglas fir, the site index is converted to Douglas fir site index. Deciduous stands follow red alder site indices. Where inventory data contain site indices for deciduous species other than red alder, the site index is converted to red alder site index. DNR defined four site index classes based on the following tables:

Douglas fir site index classes
<table>
<tr><td>Site index class</td><td>Site index range</td></tr>
<tr><td>I</td><td>≥ 134</td></tr>
<tr><td>II</td><td>≥ 114, < 134</td></tr>
<tr><td>III</td><td>≥ 95, < 114</td></tr>
<tr><td>IV</td><td>< 95</td></tr>
</table>

Red alder site index classes
<table>
<tr><td>Site index class</td><td>Site index range</td></tr>
<tr><td>I</td><td>≥ 114</td></tr>
<tr><td>II</td><td>≥ 94, < 114</td></tr>
<tr><td>III</td><td>≥ 75, < 94</td></tr>
<tr><td>IV</td><td>< 75</td></tr>
</table>
</td></tr>
<tr><td>THEME 4</td><td>Cover type</td><td>Tree species with highest basal area.</td></tr>
<tr><td>THEME 5</td><td>Silvicultural prescription code</td><td>This theme identifies a stratum's assigned yield curve. Initially, forests in development types over 25 years old are assigned to one of a set of yield curves (called UT curves) that assumes the stratum developed without leave trees present. Younger forests, and any stratum where the model applies a variable retention harvest, are assigned to a different set of yield curves (called R curves) which assume 8 leave trees per acre after harvest are present and are retained at each harvest. This represents the leave tree requirements in the 1997 HCP.</td></tr>
<tr><td>THEME 6</td><td>District</td><td>DNR's administrative districts</td></tr>
<tr><td>THEME 7</td><td>Spotted owl management unit</td><td>Spotted owl management units are areas managed for northern spotted owl habitat. In the OESF and South Puget HCP planning units, the term landscape is used instead of spotted owl management unit. Landscapes are also captured in this theme. Spotted owl habitat thresholds for spotted owl management units are identified in the 1997 HCP, the South Puget Forest Land Plan, and the OESF Forest Land Plan.</td></tr>
<tr><td>THEME 8</td><td>Watershed analysis unit</td><td>Watershed analysis units identify major watersheds in the state at the scale of tens of thousands of acres. Watersheds for large rivers, like the Chehalis River, encompass several watershed analysis units. HCP planning units are tracked in the model by aggregating watershed analysis units located in each planning unit.</td></tr>
</table>

Theme number	Theme name	Description
THEME 9	Rain-on-snow basin	This theme identifies basins where DNR tracks forest cover to maintain hydrologic maturity described in the HCP (DNR 1997, p. IV.68). While basins in the OESF are identified in this theme, the model follows a separate set of rules to maintain hydrologic maturity in the OESF. These rules come from the analysis model used in for the Final Environmental Impact Statement for the OESF Forest Land Plan.
THEME 10	Sustainable harvest unit	The sustainable harvest level is calculated that this unit level. These units are defined in the *Policy for Sustainable Forests* (DNR 2006, p. 29). There are 20 sustainable harvest units in Western Washington.
THEME 11	Trust	This theme identified surface trust. The surface trust identifies the beneficiary or beneficiaries of each parcel of land.
THEME 12	Land class	DNR uses three land classes in the sustainable harvest calculation model. These are riparian, upland, and general ecological management. Riparian lands are those surrounding streams and wetlands. Uplands are northern spotted owl nest patches and potentially unstable slopes. Ggeneral ecological management are all other lands. Land classes are used along with deferral year in the large data overlay to define areas where harvests and thinning can occur.
THEME 13	Northern spotted owl habitat class	This theme indicates whether an area is northern spotted owl habitat and, if it is, what type of habitat it contains based on the definitions in the 1997 HCP and the South Puget Forest Land Plan.
THEME 14	Marbled murrelet management class	This theme indicates the level of management under a marbled murrelet long-term conservation strategy alternative. The levels of management are no management, thinning only, or harvest allowed. Data in this theme differs for each conservation strategy alternative.

Geographic data

DNR maintains Geographic Information System (GIS) databases that includes data necessary for land management. DNR also has tabular data stored outside GIS that can be linked to GIS data.

These data are compiled into a single GIS database called the large data overlay (LDO) (Udo 2015). The LDO is created by a collection of computer scripts developed by DNR using the Python computer language. The LDO combines and classifies data from over 150 data sources and is updated every 3 to 6 months. The LDO contains data for all DNR-managed lands. Data for Western Washington in the LDO are the basis for an input file for the forest estate model called the *areas file*.

The areas file represents forested DNR-managed lands in the forest estate model. Only forested areas are included in the areas file since no timber harvest is expected from non-forested areas. Non-forested areas include water bodies, rock outcrops, and roads and associated rights-of-way.[1] The process of developing the areas file from the LDO polygons includes consolidating over 3 million polygons into about 80,000

[1] The width of the road right-of-way for forest roads was modeled as 50 feet. County roads and state highways have larger widths. For a description of the database query used to identify these areas, refer to the large data overlay documentation (Udo 2015).

development types. Part of this process includes removing development types that cover less than 0.5 acres to reduce the size of the areas file so that it is compatible with the modeling software. The area removed is small when compared with the total area of DNR-managed lands in Western Washington. For example, the LDO used to make the areas files for the alternatives in this DEIS, created September 28, 2015, reports a total of 1,567,022 acres of DNR-managed land in Western Washington of which 1,471,114 are forested. The areas files contain about 6,000 fewer forested acres than the LDO (Table F.2). A different areas file is used for each of the DEIS alternatives due to differences in marbled murrelet long-term conservation strategy.

Table F.2. Forested Acres in the LDO and the Areas File for Each Alternative

	Acres	Difference from LDO forested acres (acres)	Difference from LDO forested acres (percent)
LDO forested acres	1,471,114	-	
Alternative 1 areas file	1,465,122	5,992	0.41%
Alternative 2 areas file	1,464,702	6,412	0.44%
Alternative 3 areas file	1,464,811	6,303	0.43%
Alternative 4 areas file	1,464,820	6,294	0.43%
Alternative 5 areas file	1,464,917	6,197	0.42%

Yield Tables

Yield tables provide strata-level projections of forest conditions and how they change over time. These changes may result from natural growth or harvest activities. A yield table was prepared for each *stratum*. A stratum is a group of development types that share the same attributes in the first four themes (Forest Vegetation Simulator variant, plant association group, site index class, cover type).

DNR developed yield tables using the Pacific Northwest and West Cascades variants of the Forest Vegetation Simulator, developed by the USDA Forest Service (Dixon 2002). For each stratum there are two varieties of yield tables, those that represent stands regenerated in the last 25 years and those that represent older stands. For the younger stands, and any stand modeled as receiving a variable retention harvest in the future, the yield tables show slower growth due to retention of mature trees in variable retention harvest units. This change of yield tables reflects the change in management practices following the implementation of the 1997 HCP.

The initial conditions for developing yields were developed by DNR's inventory group. All yields started with stand densities of 800 trees per acre. Species composition varied by plant association group and cover type. Yields assumed pre-commercial thinning would not occur. The yield tables showed forest conditions in 10-year intervals for a 150 year period. Separate yield curves were developed to show the result of thinning a stratum in each decade from age 30 to 150.

Table F.3 lists the parameters included within the yield tables. The calculated parameters include the size, density, and volume of trees within a forest stand.

Table F.3. Stand-Level Forest Parameters Included in the Yield Tables for Each Stratum

Parameter name	Description
YAGE	A forest may be composed of multiple groups (or cohorts) of age classes. YAGE is a statistical estimate of the main tree cohort in the stand.
YTOPHTI	Average height (feet) of the 40 largest diameter live trees in the stand.
YBA8I	Basal area (square feet per acre) of live trees in the stand with a diameter at breast height (dbh) greater than or equal to 7.5 inches.
YRD8I	Curtis' relative density (unitless) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YBA3D5I	The total basal area (square feet per acre) of live trees in the stand with dbh greater than or equal to 3.5 inches.
YTPA8I	A count of the number of live trees per acre with dbh greater than or equal to 7.5 inches.
YTPA3D5I	A count of the number of live trees per acre with dbh greater than or equal to 3.5 inches.
YTPA20I	A count of the number of live trees per acre with dbh greater than or equal to 19.5 inches.
YTPA30I	A count of the number of live trees per acre with dbh greater than or equal to 29.5 inches.
YTPA39I	A count of the number of live trees per acre with dbh greater than or equal to 38.5 inches.
YRD3D5I	Curtis' relative density (unitless) of live trees in the stand with dbh greater than or equal to 3.5 inches.
YQMD8I	Quadratic mean diameter (inches) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YQMD3D5I	Quadratic mean diameter (inches) of live trees in the stand with dbh greater than or equal to 3.5 inches.
YCFTI	Volume (cubic feet per acre) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YBFTI	Volume (Scribner board feet per acre) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YSDII	Reineke's Stand Density Index, a unitless measure of stocking of trees within the stand.
YLAYERSI	The number of canopy layers in the stand (calculated using default settings for the Pacific Northwest variant of the U.S. Forest Service Forest Vegetation Simulator).
YSTCLSI	The number of structure classes in the stand (calculated using default settings for the Pacific Northwest variant of the U.S. Forest Service Forest Vegetation Simulator).
YSNAG20I	A count of the number of dead, standing trees per acre with dbh greater than or equal to 19.5 inches.
YCWDI	Estimated coarse woody debris (cubic feet per acre). Includes both an estimate of the coarse woody debris from the forest inventory (subject to decay over time) and an FVS-derived estimate of the additional input of coarse woody debris from tree mortality, as trees dies, become snags, and fall down.
YSNAG30I	A count of the number of dead, standing trees per acre with dbh greater than or equal to 29.5 inches.
YCFTR	Volume removal due to harvest, reported as cubic volume per acre of live trees in the stand with dbh greater than or equal to 7.5 inches.
YBFTR	Volume removal due to harvest, reported as Scribner board feet per acre of live trees in the stand with dbh greater than or equal to 7.5 inches.

Northern Spotted Owl Habitat Yield

DNR's northern spotted owl conservation strategy on the west-side consists of habitat threshold targets that differ by location. In all west-side HCP planning units except the OESF, restore and maintain at least 50 percent of designated nesting, roosting, and foraging and dispersal management areas at the spotted owl management unit (called "landscapes" in the South Puget HCP planning unit) scale as habitat. In the OESF, restore and maintain at least 40 percent of each landscape as nesting, rooting, and foraging habitat with at least 20 percent of each landscape as Old Forest Habitat (DNR 2016). Once a spotted owl management unit threshold is reached, acres within the spotted owl management unit becomes available for harvest.

The forest estate model tracks spotted owl habitat in two ways, using mapped habitat as indicated in the areas file and modeled habitat using the YHABI index. Mapped habitat represents the currently known locations of spotted owl habitat. Outside of mapped habitat, the YHABI index is used to model the development of habitat. YHABI determines acres of potential habitat in four categories of habitat quality (see Table F.4). Due to uncertainty in the actual development rate of habitat, the forest estate model was programed to only consider a portion of the area identified as potential habitat based on Table F.4 as actual habitat. Table F.5 shows the percentage of potential habitat considered actual habitat. DNR developed these percentages based on assumptions about the rate of development of woody debris, snags, and canopy gaps from Agee (1993). The total area of habitat was calculated by adding the area of mapped habitat and the area of modeled habitat.

In addition, as a way to mitigate for the uncertainty in projecting the development of spotted owl habitat, the model is restricted from scheduling harvests in mapped habitat or next-best stands in the first 2 decades of the model projection, including the fiscal year 2015–2014 planning period. During this same time period, thinning may be scheduled only in low-quality habitat (dispersal, movement, young forest, marginal, sub-mature, or movement, roosting, and foraging habitat) and next-best stands.

Table F.4. Age Classes Used by the Model to Determine Habitat Class.

Habitat class	Age (decade)
Non-habitat	0–3
Dispersal or movement habitat	4
Young forest marginal habitat	5–6
Sub-mature habitat or movement, roosting, and foraging habitat	7–12
Type A or better	>13

Note that these age classes apply only to coniferous cover types. Refer to DNR 2016 for habitat definitions.

Table F.5. Percent of Potential Northern Spotted Owl Habitat Based on the YHABI-Index-Considered Actual Habitat by Model Decade (Decade 1 represents the fiscal year 2015–2024 planning period)

Decade	Percent of acres
1	7%
2	20%
3	31%
4	41%
5	49%
6	56%
7	62%
8	67%
9	78%
10	76%

Actions and Constraints

The forest estate model uses actions and constraints to define implementation of harvest and thinning while considering policy and legal obligations.

Actions

Actions are the harvest and thinning treatments that the forest estate model can apply. The following actions are allowed in the forest estate model:

- Variable retention harvest—Development types must be at least 30 years old (Age Class 4) and yield at least 8,000 board feet (8 MBF) per acre.[2]

- Medium thinning—Moderate thinning allows for the removal of 45 percent of the development type basal area. The development type must be from 30 to 99 years old (Age Classes 4–10) and yield at least 8 MBF per acre. In both cases, thinning is assumed to be applied to all diameter classes. After medium thinning, no other activity can take place within the development type for 2 decades.

- Light thinning—Light thinning allows for the removal of 30 percent of the development type basal area. The development type must be from 20 to 69 years old (Age Classes 3–7) and yield at least 6 MBF per acre. After light thinning, no other activity can take place within the development type for 2 decades.

[2] A variable retention harvest is a type of regeneration or stand-replacement harvest in which elements of the existing stand, such as downed wood, snags, and leave trees (trees that are not harvested) are left for incorporation into the new stand. Variable retention harvest is different from a clearcut, in which all of the existing stand is removed.

No actions can occur in deferral areas (described in Management Costs in this appendix) or in places identified as "no manage" in the marbled murrelet management class (Theme 14).

Variable retention harvests can occur only on lands identified in the general ecological management land class (described in Table F-1) except in the OESF where variable retention harvests can occur in riparian areas in two cases, the most common is in the exterior riparian buffer. The riparian area in the OESF is defined in the LDO in a way that includes both the interior and exterior riparian buffer (for additional information, refer to the OESF HCP Planning Unit Forest Land Plan). The exterior riparian buffer in the OESF is applied to protect the interior riparian buffer from windthrow. Modeling used to assess the need for the exterior buffer in the OESF indicated that this buffer would not be applied frequently, though application of an exterior riparian buffer is at the discretion of the operations staff. Where the exterior riparian buffer is not applied variable retention harvest may occur. Variable retention harvest may occur on a limited number of acres of interior riparian buffers in the OESF, as described in the OESF Forest Land Plan.

Moderate thinning can occur wherever variable retention harvest can occur plus non-deferred OESF riparian areas. After the first two decades, moderated thinning can also occur in low-quality spotted owl habitat and next best stands (refer to DNR 2016 for definitions of habitat types).

Light thinning can occur wherever moderate thinning can occur plus riparian areas in the five west-side planning units excluding the OESF that are not deferred. Light thinning can also occur in the upland land class (described in Table F-1) in areas that are not deferred. In the first two decades, light thinning is the only action allowed in mapped low quality spotted owl habitat or next-best stands. After the first two decades, light thinning can occur in structure habitat, dispersals habitat, low-quality spotted owl habitat and next best stands.

DEFERRALS

Table F.6 describes areas deferred from harvest, the duration of the deferral, and the data source and queries used to identify the area in question. A stand may be subject to one or more deferrals. In such cases, the most restrictive deferral takes precedence. Most deferrals are based on assessments of current conditions. In addition, modeling rules known as constraints, may also serve to exclude harvests from some areas (refer to *Constraints*, p. F-11). For example, modeling rules exclude harvest from areas deferred for norther spotted owl and marbled murrelet conservation.

Table F.6 Deferral Status

Classification	Duration	Activities	Data source and query
Gene pool reserves	Long-term (Decades 1–10)	None permitted.	Data source: ROPA.GENEPOOL
Natural Area Preserves	Long-term (Decades 1–10)	None permitted.	Data source: LDO SUR_OWN_CD = 74
Natural Resources Conservation Area	Long-term (Decades 1–10)	None permitted.	Data source: LDO SUR_OWN_CD = 75
Administrative sites	Long-term (Decades 1–10)	None permitted.	Data source: LDO SUR_OWN_CD = 13

Classification	Duration	Activities	Data source and query
"Inoperable" stands	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 450
Low sites stands with no commercial value.	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 460
Research or permanent plots	Long-term (Decades 1–10)	None permitted.	Data source: ROPA.RESEARCH_AREA_POLY
Seral stage blocks (old growth research areas)	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 482
Upland Wildlife Management Areas	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 483
Recreation sites	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 610
Protected from harvest (general category)	Long-term (Decades 1–10)	None permitted.	Data source: LDO LANDUSE_CD = 640
Old growth forests	Long-term (Decades 1–10)	None permitted.	Data source: LDO WOGHI_INDX ≥ 38
Potentially unstable slopes and landforms; floodplain and all areas within 25 feet of the floodplain for Type 1 through 4 waters	Long-term (Decades 1–10)	None permitted.	Data source: LDO O_UNST_TY = 'i' or (O_RB_DIST > 0 and O_RB_DIST <= 25)
Northern spotted owl nest patches	Long-term (Decades 1–10)	None permitted.	

Constraints

Constraints describe modeling rules for the forest estate model to follow while achieving its objective of maximizing net present value. Some constraints are inviolate. That is, the forest estate model is bound by the constraint; if the constraint cannot be met, no solution can be found. Other constraints are treated as goals. The forest estate model may violate the goal, but any deviations incur a financial penalty of $9,999 per acre for each goal that is not met.

Constraints include:

- A requirement that all variable retention harvests must planted. This constraint results in silviculture costs being applied to all variable retention harvests.

- A riparian thinning constraint. The DEIS alternatives each include one of two riparian thinning options for the five west-side planning units. The options are as follows (refer to Chapter 2.1 for more details):

    - Thin in riparian areas in a decade an area up to 10 percent of the total riparian area in the five west-side planning units.

    - Thin in riparian areas in the five west-side planning units in a decade an area less than or equal to 1 percent of the acres thinned or harvested in non-riparian areas in these planning units in that decade.

- An uncertainty factor. To account for uncertainties described in Uncertainty on page F-17, DNR assumed that a maximum of 90 percent of any given acre will be harvested by any harvest.

- A requirement to retain at least $10 million in the management accounted (described in Management Costs in this appendix).

- An upper limit on the volume harvested each decade in from lands in the Lake Whatcom watershed based on the Lake Whatcom Landscape Plan adopted by the Board of Natural Resources in Board Resolution 1134 on November 2, 2004. The plan was based on a trust land area of 15,700 acres. In 2013, DNR reconvened 8,800 acres and retained 6,900 acres. Harvest on the 6,900 acres managed by DNR are subject to the Lake Whatcom Landscape Plan.

- A set of requirements limiting variable retention harvests and thinning in the OESF based on the OESF Forest Land Plan or the forest estate model used in the development of the Final Environmental Impact Statement for the plan. These requirements set maximum harvest and thinning levels for OESF riparian areas and maximum thinning levels in OESF as a whole.

- A requirement to limit fluctuation in harvest levels between decades called the *even flow* constraint. DNR's *Policy for Sustainable Forests* directs the agency to ensure inter-generational equity among beneficiaries by limiting the change in volume harvested between decades. The policy allows for flows to vary by up to 25 percent from the previous decade. The model constrains harvest volume from a sustainable harvest unit from varying up or down by more than 15 percent from the level of the preceding decade for all sustainable harvest units except the OESF. The OESF is constrained to 5 percent variation from the preceding decade. These value were selected to maintain more similar harvest volumes between decades than a 25 percent constraint.

- A set of requirements to maintain northern spotted owl habitat. The first requirement is that variable retention harvest is not allowed in all currently mapped northern spotted owl habitat or next-best stands for 2 decades. Thinning is still allowed in low-quality habitat and next best stands. After 2 decades, northern spotted owl habitat is tracked using the YHABI index described under "Northern Spotted Owl Habitat Yield" in this appendix. The second requirement is that area of habitat identified by the YHABI index must equal or exceed the thresholds identified in the 1997 HCP or the South Puget Forest Land Plan. This constraint was programed as a goal since the thresholds are not currently met in many areas managed for northern spotted owl.

- A requirement to maintain hydrologic maturity in certain basins. In the OESF, the area allowed for harvest was specified based on the forest estate model used for in the *OESF HCP Planning Unit Forest Land Plan Final Environmental Impact Statement* (DNR 2016). In the other planning units, the requirement follows the 1997 HCP that at least two-thirds of basins managed for hydrological maturity contain hydrologically mature forest. This constraint was programmed as a goal since not all basins managed for hydrologic maturity currently contain the required area of hydraulically mature forest.

- A requirement for only the no action alternative that the acres of thinning projected match the acres of variable retention harvest in each decade in the OESF, consistent with the Settlement Agreement described in Chapter 2.1, Developing the Sustainable Harvest Alternatives.

Economic assumptions

Timber prices

The sustainable harvest calculation only recognizes revenue from timber sales. Although DNR generates revenue from a variety of sources, those sources are not included because they have no impact on the harvest level. At a basic level, the gross revenue for any given timber sale is determined by two factors: 1) the price per volume that a purchaser pays DNR (usually reported as a dollar value per unit of wood volume, such as dollars per MBF), and 2) the volume of timber sold.[3]

Purchasers pay DNR for the value of the standing trees along with the right to harvest. This price is known as *stumpage*. By the time the trees have been harvested and delivered to the mill, the purchaser has incurred expenses (such as logging, road construction, transportation costs, and other fees). The *delivered value* of the timber represents the stumpage minus expenses, but is also influenced by other factors, such as trees species and the quality (known as the *grade*) of the timber. Additional factors that influence stumpage and delivered value include regional supply and demand, the number of bidders at auction, and inflation.

Timber prices used in the forest estate model reflect the average stumpage value. They vary by region and forest type timber grade (Table F.7). These values were estimated from a review of 2011-2015 DNR timber sales and prices per board foot by species. Timber sale prices were adjusted for inflation using the Producer Price Index (PPI) for lumber and wood products. [4]

Table F.7. Timber Sale Prices (Stumpage) Used in the Sustainable Harvest Calculation Model for Saw Logs and Chip and Saw (CNS), a Lower Quality of Log

	Northwest Region		Olympic Region		Pacific Cascade Region		South Puget Sound Region	
Cover Type	Saw	CNS	Saw	CNS	Saw	CNS	Saw	CNS
Douglas fir	$389	$167	$351	$151	$365	$157	$451	$194
Red alder	$507	$279	$404	$222	$419	$231	$519	$285
Western redcedar	$839	$839	$758	$758	$788	$788	$974	$974
Western hemlock	$350	$108	$241	$75	$336	$104	$263	$81
True fir species	$350	$108	$241	$75	$336	$104	$263	$81
Sitka spruce	$350	$108	$241	$75	$336	$104	$263	$81

[3] Standing timber can be sold as either a lump sum sale, or by scale. In a lump sum sale, trees are marked and tallied by a forester and sold outright, with payment in advance. Potential buyers know which trees they are bidding on and the estimated volume. In a scale sale, payment is received for the volume of trees removed.

[4] The Producer Price Index for lumber and wood products is an index of the prices received by domestic producers for these goods reported on an annual basis.

Management costs

DNR divided management costs into three groups, direct timber sales costs, silviculture costs, and indirect costs. Direct timber sales costs include all costs associated with timber sale set-up, compliance staff and marketing. Silviculture costs include site preparation, planting, vegetation management, pre-commercial thinning, and survey costs. Indirect costs include a wide range of activities that support land management such as planning, inventory, right-of-way management, legal support and research.[5] Direct timber sale costs were then divided into three sub-groups: variable retention harvests, variable density thinning, and variable density thinning in riparian areas.

Management costs are assigned for five total groups:

- Direct timber sale costs for variable retention harvest
- Direct timber sale costs for variable density thinning
- Direct timber sale costs for variable density thinning in riparian areas
- Silviculture costs
- Indirect timber sale costs

DNR calculated these costs per acre of harvest area from actual spending levels in the 2011–2013 and 2013–2015 biennia (fiscal years 2012-2015). DNR adjusted all prices into 2015 dollars using the Consumer Price Index for all urban consumers less food and energy (Federal Reserve Bank of St. Louis 2016). [6]

Direct timber sale costs for variable retention harvest and variable density thinning harvests were assumed to be the same. This is because documentation requirements are similar for these types of sales and while pre-sales field work may be greater for variable retention harvest sales, variable density thinning sales may require more compliance time. Variable density thinning harvests in riparian areas are 25 percent more expensive than in other areas due to increased pre-sale and compliance work load (Table F.8).

Table F.8. Management Costs Used in the Forest Estate Model.

	Cost per acre			
Harvest type	**Direct**	**Indirect**	**Silviculture**	**Total**
Variable retention harvest	$795	$1,519	$743	$3,057
Thinning	$795	$1,519	$0	$2,314
Thinning (Riparian)	$1000	$1,519	$0	$2,519

[5] For more information on indirect costs, refer to slide 25 of the May 2015 Board of Natural Resources presentation available at http://file.dnr.wa.gov/publications/em_bc_bnr_shc_may2016_presentation.pdf

[6] The Consumer Price Index is an index of the prices paid by consumers for a bundle of goods and services defined by the Federal Reserve Bank. The Federal Reserve Bank excludes food and energy from this bundle due to their price volatility.

The sustainable harvest calculation model is programed to only complete harvests and thinning if it has enough money to do so. The model tracks the budget in one or two ways depending on the alternative. Consistent with current board direction, the model retains a 25 percent management fee of the revenue from sales on State Forest Transfer Trust lands and 31 percent of revenue from sales on other trusts toward management expenses.[7] All alternatives include this constraint.

In Alternatives 1, 3, 4 and 5, a maximum budget is applied in the model for the first decade. The maximum budget for the first decade is $450 million. This is lower than recent budget levels, which passed on fiscal year 2011–2015 and were equivalent to $480 million (adjusted to 2015 dollars) per decade. The difference is due to uncertainty in future management fee rates. The budget was not a binding constraint in the model, so it did not result in less modeled harvest volume than would have been modeled without the constraint.

Discount rate

A discount rate is used in the model to calculate net present value. A discount rate is the rate at which future costs and revenues are adjusted to account for preferences in the timing of costs and revenue (also known as the time value of money), desired return on investments, and risk, among other things. The appropriate discount rate to use when assessing a decision depends on considerations about these factors and assumptions about the future. Due to the multiple factors involved in this decision, a variety of economic methodologies have been used by land managers with no universally accepted methodology or discount rate (U.S. Environmental Protection Agency 2009).

While the proposal in this DEIS is to establish a sustainable harvest level for state trust lands in Western Washington for a 10-year period (fiscal year 2015–2024), the trust mandate requires DNR to maintain intergenerational equality to avoid foreclosing future options (DNR 1996, p. 4). This long-term perspective must be considered when setting the discount rate. Moore and others 2004 show that when averaging a range of possible discount rates, larger discount rates have less effect on the average as the time horizon lengthens. The result of this is that only lowest possible discount rates matter when considering returns in the distant future. They suggest discount rates no higher than 3.5 percent, with

[7] Management fees fund the two primary accounts used to find management of state trust lands, the Resource Management Cost Account (RMCA) and the Forest Development Account. Maximum management fees are set by legislature while the Board of Natural Resources sets the actual management fee level. RCW 79.64.040 sets the maximum management fee for RMCA at 25 percent while RCW 79.64.110 sets the management maximum management fee for FDA at 25 percent for State Forest Transfer lands and 50 percent for State Forest Purchase lands. In recent biennia, the legislature as revised these maxima in budget legislation. Currently the maxima are 32 percent for RMCA, 27 percent for State Forest Transfer lands and 50 percent for State Forest Purchase lands. The board has set the actual management fee at 31 percent for RMCA, 25 percent for State Forest Transfer Trust lands and 50 percent for State Forest Purchase lands.

lower rates recommended for time horizons longer than 50 years. Similarly justified rates within this range are used by other forestry and public land management organizations (Freeman III 2003).

An additional consideration is that discount rate has an impact on timber harvest rotations and assumptions about the value of silvicultural treatments, all other things being equal. Higher rates would push timber rotations down, while making necessary young stand management treatments appear cost-prohibitive. Both of these results have an effect on the future harvest levels. In selecting an interest rate, DNR aimed to provide a sound representation of harvest cycles and silvicultural investment needs.

DNR analyzed a range of discount rates from 1 percent to 5 percent. Using data from these analyses, DNR selected a 2 percent discount rate as the best to provide for intergenerational quality and to avoid foreclosing future options.

Objective Function

The *objective function* is a mathematical criterion the model seeks to optimize. The objective function for all alternatives is to maximize or optimize the financial return to the trust beneficiaries, as represented by *net present value.* Net present value is a financial term referring to the sum of both current and future cash flow. It is the cash inflow (revenue from timber sales) minus cash outflow (costs of forest management). Future revenues and expenses are expressed in terms of their equivalent in today's dollars through a method known as discounted cash flow analysis. All future revenues and expenses are discounted 2 percent per year back to the present date. Discounted cash flow analysis is a quantitative means of representing that money in the future is not as valuable as money in the present. The discounted values (known as present values) for each decade are summed, and the forest estate model seeks to maximize this sum, known as the net present value. Since the forest estate model is structured as a decadal model, the discount is performed as if all cash flow occurred at the midpoint of the given decade.

Since DNR used a goal-programming forest estate model, the objective function also incorporates a term to account for the penalty incurred when deviating from a goal. The penalty serves as a financial incentive for the model to meet each goal to the best of its abilities. Under goal programming, deviations are allowed and individual goals may be under- or over-achieved. Any deviations from goals that do take place, however, incur a financial penalty of $9,999 per acre for each goal that is not met. Note that unlike revenues and costs, any incurred penalties are not discounted. By not discounting the penalty, in effect, it becomes stronger over time relative to revenue and costs. With each passing decade, the incentive to meet each goal increases.

Equation F.1. Generalized Form of the Objective Function

$$\boldsymbol{Maximize} \sum_{\boldsymbol{decade}=\mathbf{1}}^{\mathbf{10}} (\boldsymbol{revenue} - \boldsymbol{costs} - \boldsymbol{penalty})$$

Uncertainty

Unknown field conditions as well as uncertainty about decisions that impact the field implementation of a large-scale timber sales program remain. Examples of factors that produce uncertainty include imperfect data, unstable slopes, public reaction, special ecological feature, visual impacts, cultural resources, catastrophic loss, lack of legal access, equipment limitations, and excessive road costs.[8] Climate change is also a source of uncertainty in future yields. DNR selected a 10 percent uncertainty factor based on anecdotal review of recent timber sale schedules, which included sales that were planned and then later withdrawn due to any one of the factors listed above and to account for climate change. A timber sale proposal undergoes an intense review by stakeholders and private citizens through the all phases of the project from office and field reconnaissance to final SEPA determination. This uncertainty factor is applied in the model as a constraint (refer to Constraints, p. F-11).

What data is output from the forest estate model?

The solution provided by the forest estate model is a list of management activities known as a harvest schedule. It is a report of the recommended timing and types of harvest activities that are necessary to optimize the objective function and, to the greatest extent possible, meet the constraints. The harvest schedule is output in a database known as the *activities file*. Table F.9 describes each field contained in the activities file.

Using a modeling technique known as simulation, the forest estate model also provides a detailed report of site-specific future forest conditions across the entire OESF as a result of implementing the harvest schedule. These data are outputs in a database known as the c*onditions file*. Table F.10 describe each field contained in the conditions file. These data are outputs in two databases.

Both the activities file and the conditions file report data in decadal increments. The conditions file reports conditions at a moment in time. It is a "snapshot" of the forest at the start of the given decade. Decade 0 of the conditions file is a report of current conditions; Decade 1 is a report of projected conditions 10 years later; Decade 2, 20 years later; and so on. It is a report of instantaneous conditions.

The activities file, in contrast, reports harvests in 10-year intervals. Each decade in the activities file is a report of harvests scheduled for the preceding 10 years. For example, Decade 1 harvests will occur at some point in time between the end of Decade 0 and the start of Decade 1.

[8] Examples of uncertainty were presented at the Board of Natural Resources meeting in June 2016 (http://file.dnr.wa.gov/publications/em_bc_bnr_shc_june2016_presentation.pdf)

Activities file

Table F.9 describes the key fields contained in the activities file. In addition to the fields in Table F.9, the activities file includes acres and volume data by DNR district and region.

Table F.9. Key Fields Contained in the Activities File

Field name	Description
VARIABLE	Unique activity identifier.
TH1	Forest Vegetation Simulator (FVS) variant (See Table F-1)
TH2	Plant association group (PAG) (See Table F-1)
TH3	Site index class (See Table F-1)
TH4	Cover type (See Table F-1)
TH5	Silvicultural prescription code (See Table F-1)
TH 6	District (See Table F-1)
TH 7	Spotted owl management unit (SOMU) (See Table F-1)
TH 8	Watershed analysis unit (WAU) (See Table F-1)
TH 9	Rain-on-snow basin (See Table F-1)
TH 10	Sustainable harvest unit (See Table F-1)
TH 11	Trust (See Table F-1)
TH 12	Land class (See Table F-1)
TH 13	Norther spotted owl habitat class (See Table F-1)
TH 14	Marbled murrelet management class (See Table F-1)
AGE	Age class development type where the activity occurs
AREA	Acres of activity
ACTION	Action type, variable retention harvest (aR1), light thinning (a1LT), or moderate thinning (a1MT)
ACTNO	Action type identifier 1 = moderated thinning, 2 = light thinning, 3 = variable retention harvest

Conditions file

Table F.10 describes each field contained in the conditions file.

Table F.10. Fields Contained in the Conditions File

Field name	Description
TH1	Forest Vegetation Simulator (FVS) variant (See Table F-1)
TH2	Plant association group (PAG) (See Table F-1)
TH3	Site index class (See Table F-1)
TH4	Cover type (See Table F-1)
TH5	Silvicultural prescription code (See Table F-1)
TH 6	District (See Table F-1)
TH 7	Spotted owl management unit (SOMU) (See Table F-1)
TH 8	Watershed analysis unit (WAU) (See Table F-1)
TH 9	Rain-on-snow basin (See Table F-1)
TH 10	Sustainable harvest unit (See Table F-1)
TH 11	Trust (See Table F-1)
TH 12	Land class (See Table F-1)
TH 13	Northern spotted owl habitat class (See Table F-1)
TH 14	Marbled murrelet management class (See Table F-1)

Field name	Description
AGE	Age class development type
AREA	Acers in the development type
PERIOD	Modeling decade, period 1 is 2015-2024
OINV_MBF_T	Live standing volume in thousands of board feet per acre

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