Appendix F

The Forest Estate Model

Introduction

This appendix describes the computer model, known as the forest estate model, used in calculating sustainable harvest levels for each of the alternatives analyzed in this final environmental impact statement (FEIS). This document describes the input data for the model, the scripts used to process data, and programming used to run the model.

Acronyms

DEIS	Draft environmental impact statement
DNR	Washington State Department of Natural Resources
FEIS	Final environmental impact statement
FVS	Forest Vegetation Simulator
GIS	Geographic Information System
1997 HCP	State Trust Lands Habitat Conservation Plan
LDO	Large Data Overlay
MBF	1,000 board feet
OESF	Olympic Experimental State Forest HCP Planning Unit
PAG	Plant Association Group

What is a Forest Estate Model?

A forest estate model is a mathematical computer model that is designed to find the optimal solution to the problem of deciding **where, when, and how many** forest management activities, such as harvest and thinning, should be conducted in order to meet DNR's fiduciary responsibilities pursuant to all state and federal laws. In building this model, DNR utilized

commercial software, Remsoft Spatial Planning System (Remsoft Inc., Fredericton, Canada), that is based on a mathematical programming technique known as "linear programming."

In a linear programming model, there is an "objective function," which is usually defined by a linear expression of decision variables and their associated coefficients. The objective function is subjected to one or more "constraints" expressed as linear equations of the following form:

Maximize:

$$C_1X_1 + C_2X_2$$

Subject to:

$$C_1X_1 >= 20$$

$$C_2X_2 >= 30$$

$$X_1 >= 0, X_2 >= 0$$

Where, X_1 and X_2 are decision variables and C_1 and C_2 are their coefficients, respectively. A coefficient can be negative and may be derived from a non-linear equation, for example, net present value.

The objective function of DNR's forest estate model is to maximize the "net present value" of revenue derived from forest management activities over 10 planning periods (decades) into the future subject to a set of constraints that reflect operational, ecological, financial, or other policy considerations. Some of the constraints in this model are termed as "hard," meaning such constraints must be met to achieve a feasible solution to the problem. There also "soft" constraints, mostly relating to a set of future desired forest conditions that do not exist today. These soft constraints involve a "slack variable," which assumes a level of shortfall in meeting that particular constraint. Therefore, if the forest condition today is not ready to meet a particular constraint, the expression of soft constraints allows the model to find a feasible solution depicting when such constraints can be met.

In a forest estate model, the forest management decision units upon which activities can be assigned and the potential outcome coefficients, such as timber volume, revenue, habitat acres, or the level of required forest cover, are to be known *a priori*. A solution to the model represents what is a known as a "harvest schedule" detailing the timing (decade to occur) and amount (acres) of activities (for example, planting, thinning, and regeneration harvest) that occur within specific decision units. In addition to the harvest schedule, the forest estate model also produces a report detailing the subsequent forest conditions resulting from the prescribed activities for each planning period. These two outputs representing the harvest schedule and the resulting forest conditions are reported in two separate databases known as

"activities" and "conditions" files, respectively (refer to What Data is Output From the Forest Estate Model on page F-21).

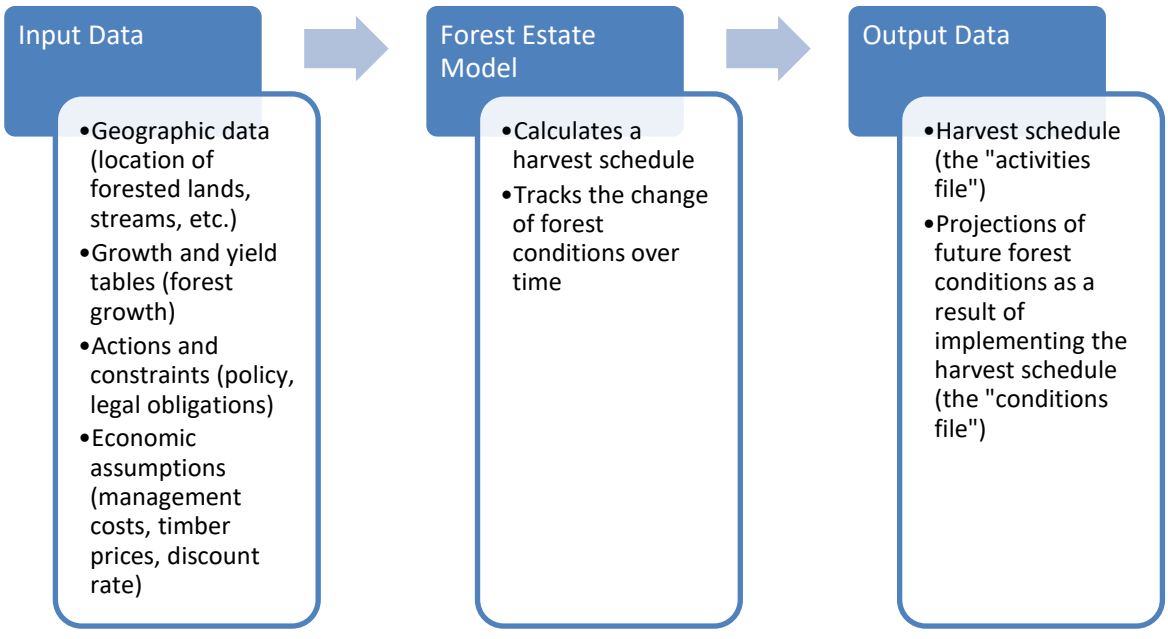
Since the forest estate model is an abstraction of real-world conditions, it is subject to inherent uncertainties. Key uncertainties include the effects of climate change; the timing, extent, and effects of disturbance; rates of forest development; and, site-specific considerations such as the location of streams, wetlands, and unstable slopes (refer to Uncertainty on page F-21).

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*, conservation strategies in the 1997 HCP, and forest practices rules (refer to Section 1.2 of the FEIS 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, growth and yield data, economic assumptions such as management costs, timber prices, discount rate, and mathematical representations for policy and law represented by actions and constraints.

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



Forest management decision units in DNR's forest estate model represent an abstraction (also known as "stratification") of forest lands in terms of unique growing conditions and a set of geographic variables

such as watershed administrative units, administrative districts, etc. Thus, a "stratum" represents a unique forest condition under a set of geographic attributes known as "themes." The details of each theme are described below in Table F.1.

Updates Since the Draft Environmental Impact Statement

For this FEIS, DNR updated the forest estate model in several ways from the version used in the *Draft Environmental Impact (DEIS) Statement on Alternatives for Establishment of a Sustainable Harvest Level for Forested State Trust Lands in Western Washington* (DNR 2016a). These updates were in response to new information, suggestions from University of Washington professor Sándor Tóth, who DNR contracted to perform a third-party review of the model, and comments received during the DEIS comment period. Below is a brief description of the changes.

Forest Vegetation Simulator Variant

For the FEIS, DNR is using only the Pacific Northwest Coast (PN) variant of the Forest Vegetation Simulator (FVS) to generate yields. In the DEIS, DNR used yields generated by both the PN and Westside Cascades (WC) variants. Analysis by DNR's forest informatics group conducted after the DEIS showed that the WC variant does not accurately project growth of the forest types present on DNR-managed lands. The WC variant is designed for high-elevation forests in the Cascade Range. DNR has little high-elevation forests in this area.

Flow

The flow constraint was previously applied to decadal harvest levels including arrearage, which restricted arrearage harvest. For the FEIS, the flow constraint of 15 percent was not applied to arrearage harvest. The resulting changes to harvest levels were not substantial because the model does not have suitable age classes available for harvest during the planning decade which maximize net present value. The flow constraint for decadal harvest levels in the DEIS was 5 percent for the OESF. For the FEIS the flow constraint for the OESF was changed to 15 percent, matching that of the other sustainable harvest units.

Yields

DNR developed new yields for the FEIS. The key changes to the yields are the use of only one variant of FVS instead of two, removal of the separate yields for each plant association group[1] (PAG), a reduction in the number of cover types, and adjustment of yields in eight of DNR's administrative units where projected volumes did not match historic cruised volumes.

Analysis of the yields by forest inventory staff showed that PAG had little effect on yields. For the FEIS, DNR simplified the yields by not producing separate yields for each PAG.

Cover type is based on species currently present on DNR-managed lands based on the forest inventory. The model used for the DEIS included six cover types based on dominant or co-dominant species. For the FEIS, DNR is using three cover types: Douglas fir, western hemlock, and red alder.

Forest Estate Model Themes

Since the yields no longer differ by FVS variant or PAG, DNR removed these themes from the model. DNR added western Washington county into one of the vacant themes to allow for reporting harvest information by county.

Financial Assumptions

DNR changed the discount rate used in the model from 2 percent to 3 percent based on analyses described in the "Discount rate" section of this Appendix.

DNR also updated both management costs and timber prices with data from fiscal years 2016 and 2017.

Inventory

DNR is continuously collecting new inventory data. The model for the FEIS uses data from January 12, 2018. Key updates in the inventory include updating data to reflect all recent and historic harvests and including lands recently acquired by DNR.

[1] Plant association groups are groupings of plant associations. A plant association is a concept that recognizes different plant communities as representing distinct ecological characteristics. Plant associations are defined by the presence, absence, and relative abundance, of key plant species. The presence, absence, and relative abundance of these indicator plants are direct and composite reflections of moisture, nutrient, and climatic gradients. As such, the plant association concept provides a useful predictor for site quality, productivity, and response to disturbance, such as timber harvesting.

Northern Spotted Owl Habitat Development

The model has updated projections of northern spotted owl habitat development. These projections are based on new inventory data that became available following the publication of the DEIS. In the new projections, development of northern spotted owl habitat is based on stand age instead of the decade in the modeling period. As a result of greater confidence in this new projection of spotted owl habitat, DNR removed the two decade restriction in the model on the harvest of spotted owl habitat and next best stands; however, threshold targets must still be met for harvest to occur (see "Northern spotted owl habitat" section). Variable retention harvest cannot occur in northern spotted owl habitat or next best stands ages 60 and above during the first decade. Also, moderate thinning (removal of 45 percent of basal area) is restricted in northern spotted owl habitat in the model. These changes to the model better reflect implementation of the 1997 HCP under which harvest of northern spotted owl habitat is only allowed upon attainment of certain habitat thresholds. Operationally, DNR staff will manage northern spotted owl habitat and next best stands consistent with the 1997 HCP.

Marbled Murrelet

New areas files were used for the marbled murrelet alternatives analyzed in the FEIS. These area files reflect multiples changes described in Appendix O of the *Final Environmental Impact Statement for the Marbled Murrelet Long-Term Conservation Strategy* (DNR 2019a).

Budget

Some alternatives in the DEIS model included a budget constraint that limited the total amount of money available to the model to pay for activities. DNR found that this constraint was non-binding. That is, it did not affect the harvest volume in the alternatives to which it was applied. DNR removed this constraint from the model and replaced it with a constraint that requires management activities to generate at least $1.5 million more than the costs of the activities per decade.

Uncertainty

The 10 percent uncertainty factor applied in the DEIS model was removed from the FEIS model. It was determined to be a non-binding constraint in the model. See the "Uncertainty" section for more details.

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 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 13, plus the age (in decadal units) of the forest in the polygon.

A “stratum” is a group of development types that share the same attributes in the first three themes. Yield curves (refer to Growth and Yield Data on page F-10) were developed for each stratum.

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

<table>
<tr><th>Theme number</th><th>Theme name</th><th>Description</th></tr>
<tr><td>THEME 1</td><td>Cover type</td><td>Tree species with highest basal area.</td></tr>
<tr><td>THEME 2</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 3</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 4</td><td>County</td><td>Western Washington county</td></tr>
<tr><td>THEME 5</td><td>District</td><td>DNR's administrative districts</td></tr>
<tr><td>THEME 6</td><td>Sustainable harvest unit</td><td>The sustainable harvest level is calculated at this sustainable harvest unit level. These units are defined in the Policy for Sustainable Forests (DNR 2006a, p. 29). There are 20 sustainable harvest units in Western Washington.</td></tr>
<tr><td>THEME 7</td><td>Trust</td><td>This theme identified surface trust. The surface trust identifies the beneficiary or beneficiaries of each parcel of land.</td></tr>
</table>

Theme number	Theme name	Description
THEME 8	Spotted owl management unit (SOMU)	SOMUs 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 HCP Planning Unit Forest Land Plan*, and the *OESF HCP Planning Unit Forest Land Plan*.
THEME 9	Watershed administrative unit	Watershed administrative 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 administrative units. HCP planning units are tracked in the model by aggregating watershed administrative units located in each planning unit.
THEME 10	Rain-on-snow sub-basin	This theme identifies sub-basins where DNR tracks forest cover to maintain hydrologic maturity described in the HCP (DNR 1997, p. IV.68). While sub-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 *OESF HCP Planning Unit Forest Land Plan FEIS*.
THEME 11	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 include northern spotted owl nest patches and potentially unstable slopes. General 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 12	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, *South Puget HCP Planning Unit Forest Land Plan*, and *OESF HCP Planning Unit Forest Land Plan*.
THEME 13	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 2018) using a collection of computer scripts developed by DNR staff in the Python coding language. The LDO combines and classifies data from over 150 data sources and is updated every 3 to 6 months to reflect ongoing changes in the forested landscape. It contains data for all DNR-managed lands in western Washington and forms the basis for an input file in 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-ways.[2] The process of developing the areas file from the LDO polygons includes consolidating several million polygons into about 80,000 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 FEIS, created January 12, 2018, reports a total of 1,572,544 acres of DNR-managed land in western Washington of which 1,478,491 are forested. The areas files contain about 14,000 fewer forested acres than the LDO (Table F.2). A different areas file is used for each of the FEIS 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	1,478,491	-	-
Alternative 1 areas file	1,464,772	13,720	0.93%
Alternative 2 areas file	1,464,778	13,713	0.93%
Alternative 3 areas file	1,464,815	13,676	0.93%
Alternative 4 areas file	1,464,827	13,664	0.92%
Alternative 5 areas file	1,464,772	13,720	0.93%
Alternative 6 areas file	1,464,833	13,659	0.92%

Growth and Yield Data

Growth and yield data provide projections of forest conditions and how they change over time. These changes may result from natural growth and/or harvest activities. A yield table was prepared for each stratum (cover type, site index class, and silvicultural prescription code) plus age.

DNR developed yield tables using the Pacific Northwest Coast variant of the Forest Vegetation Simulator, developed by the USDA Forest Service (Dixon 2002), which simulates forest vegetation change in response to natural success, disturbances, and management. 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.

[2] The width of the road right-of-way for forest roads is determined by slope and road type.

The initial conditions for developing yields are based on plot data collected for DNR's forest inventory. 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. 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 age in the stand.
YTOPHT	Average height (feet) of the 40 largest diameter live trees in the stand.
YBA3D5	The total basal area (square feet per acre) of live trees in the stand with diameter at breast height (dbh) greater than or equal to 3.5 inches.
YTPA3D5	A count of the number of live trees per acre with dbh greater than or equal to 3.5 inches.
YTPA20	A count of the number of live trees per acre with dbh greater than or equal to 19.5 inches.
YTPA30	A count of the number of live trees per acre with dbh greater than or equal to 29.5 inches.
YTPA39	A count of the number of live trees per acre with dbh greater than or equal to 38.5 inches.
YRD3D5	Curtis' relative density (unitless) of live trees in the stand with dbh greater than or equal to 3.5 inches.
YQMD3D5	Quadratic mean diameter (inches) of live trees in the stand with dbh greater than or equal to 3.5 inches.
YCFT	Volume (cubic feet per acre) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YMBFMV	Volume (Scribner board feet per acre) of live trees in the stand with dbh greater than or equal to 7.5 inches.
YNSOLAYER	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).
YSTCLS	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).
YSNAG20	A count of the number of dead, standing trees per acre with dbh greater than or equal to 19.5 inches.
YCWD	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 Forest Vegetation Simulator (FVS)-derived estimate of the additional input of coarse woody debris from tree mortality, as trees die, become snags, and fall down.
YSNAG30	A count of the number of dead, standing trees per acre with dbh greater than or equal to 29.5 inches.
YR1	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

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, the conservation objectives are to 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. The South Puget HCP planning unit has an additional threshold of maintaining at least 35 percent of dispersal habitat as movement, roosting, and foraging (MoRF) plus habitat and 15 percent as movement plus habitat (DNR 2019b). In the OESF, the conservation objective has an overall habitat threshold of 40 percent, which is further defined as restoring and maintaining at least 20 percent of each SOMU as Old Forest Habitat with the rest composed of structural or better habitat. (DNR 2019b). Once a spotted owl management unit threshold is reached, acres within the spotted owl management unit become 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 a habitat index. Mapped habitat represents the currently known locations of spotted owl habitat. Outside of mapped habitat, the habitat index is used to model the development of habitat. The habitat index determines acres of potential habitat in five categories of habitat quality (see Tables F.4, 5, and 6). The habitat index is based on percentages of each age class in each habitat type based on current inventory.

Table F.4. Northern Spotted Owl Habitat Development in Dispersal Management Areas[3]

Age class (decade)	Percent of coniferous forests modeled as dispersal habitat	Percent of coniferous forests modeled as movement, roosting, and foraging habitat
1	0%	0%
2	0%	0%
3	0%	0%
4	27%	0%
5	60%	0%
6	73%	0%
7	82%	17%
8	88%	31%
9	91%	35%
10	79%	60%
11	82%	60%
12	92%	60%
13	90%	60%
14	92%	60%
15 or greater	93%	60%

[3] Refer to DNR 2019b, Appendix A for habitat definitions.

Table F.5. Northern Spotted Owl Habitat Development in Nesting, Roosting, and Foraging Management Areas[4]

Age class (decade)	Percent of coniferous forests modeled as nesting, roosting, and foraging habitat
1	0%
2	0%
3	0%
4	0%
5	0%
6	0%
7	17%
8	31%
9	35%
10	60%
11	60%
12	60%
13	60%
14	60%
15 or greater	60%

Table F.6. Northern Spotted Owl Habitat Development in the OESF[4]

Age class (decade)	Percent of coniferous forests modeled as young forest habitat	Percent of coniferous forests modeled as old forest habitat
1	0%	0%
2	0%	0%
3	0%	0%
4	32%	0%
5	48%	0%
6	43%	0%
7	52%	0%
8	57%	13%
9	72%	23%
10	77%	31%
11	85%	53%
12	84%	55%
13	87%	70%
14	92%	71%
15 or greater	93%	71%

[4] Refer to DNR 2019b, Appendix A for habitat definitions.

Actions, Deferrals, and Constraints

The forest estate model uses actions, deferrals, and constraints to define implementation of harvest and thinning activities 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.[5]

- Moderate 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 moderate 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 two decades.

- No actions can occur in deferral areas (described in Deferrals in this appendix) or in places identified as "no manage" in the marbled murrelet management class (Theme 13).

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. Riparian areas in the OESF are 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*, DNR 2016d). 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 HCP Planning Unit Forest Land Plan*. Variable retention harvests are restricted in northern spotted owl habitat and next best stands during the planning decade beyond age class 6 (50-59). Moderate thinning can occur wherever variable retention harvest can

[5] 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 the existing stand is removed.

occur as well as certain uplands. However, moderate thinning cannot occur in northern spotted owl habitat.

Light thinning can occur wherever moderate thinning can occur plus non-deferred riparian areas in the five west-side planning units and OESF. Light thinning can also occur in the upland land class (described in Table F.1) in areas that are not deferred. In the first decade, light thinning is the only action allowed in mapped low quality spotted owl habitat or next best stands. After the first decade, light thinning can occur in structural habitat, dispersal 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 (see "Constraints" section), may also serve to exclude harvests from some areas. For example, modeling rules exclude harvest from areas deferred for northern 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
"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

Classification	Duration	Activities	Data source and query
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, meaning the forest estate model is bound by them. 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 FEIS alternatives each include one of three riparian thinning options for the five west-side planning units. The options are as follows (refer to Section 2.1 of the FEIS 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.
    - Thin riparian areas consistent with the 1997 HCP and the *Riparian Forest Restoration Strategy* (RFRS) (DNR 2006b) but do not include riparian volume when setting the sustainable harvest level. During implementation, volume harvested from riparian areas will count toward attaining the sustainable harvest level.
- A requirement that income into the management accounts exceed costs by at least $1.5 million (described in Management Costs in this appendix).
- An upper limit on the volume harvested each decade 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 reconveyed 8,800 acres to the county and retained 6,900 acres. Harvest on the 6,900 acres managed by DNR are subject to the Lake Whatcom Landscape Plan.

- 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 mean annual timber volume 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. These values were selected to maintain more similar harvest volumes between decades than a 25 percent constraint.

- A requirement to maintain northern spotted owl habitat. Area of habitat is calculated as the area of mapped habitat plus the area identified using a habitat index. The sum of these must equal or exceed the thresholds identified in the 1997 HCP, *OESF HCP Planning Unit Forest Land Plan*, or the *South Puget HCP Planning Unit Forest Land Plan*. This constraint was programmed 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 sub-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 2016c). In the other HCP planning units, the requirement follows the 1997 HCP that at least two-thirds of sub-basins managed for hydrological maturity contain hydrologically mature forest. This constraint was programmed as a goal since not all sub-basins managed for hydrologic maturity currently contain the required area of hydrologically mature forest.

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

- The no action alternative is also required to harvest 5.5 billion board feet in the planning decade to match the sustainable harvest level last set by the Board of Natural Resources in Board Resolution 1239 on July 3, 2007.

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.[6]

[6] 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.

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 cover type (Table F.7). These values were estimated from a review of fiscal year 2011-2017 DNR timber sales and prices per board foot by species. Timber sale prices were adjusted to 2017 dollars using the Producer Price Index (PPI) for lumber and wood products.[7]

Table F.7. Timber Sale Prices (Stumpage) Used in the Sustainable Harvest Calculation Model

Cover Type	Northwest Region	Olympic Region	Pacific Cascade Region	South Puget Sound Region
Douglas fir	$416	$320	$388	$396
Red alder	$522	$430	$558	$503
Western hemlock	$371	$229	$333	$276

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, 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.[8] 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 (thinning)
- Direct timber sale costs for variable density thinning in riparian areas (thinning (riparian))
- Silviculture costs
- Indirect timber sale costs

[7] 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.

[8] 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.

DNR calculated these costs per acre of harvest area from actual spending levels in fiscal years 2012-2017. DNR adjusted all prices into 2017 dollars using the Consumer Price Index for all urban consumers less food and energy (Federal Reserve Bank of St. Louis 2016). [9]

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. Direct costs for variable density thinning harvests in riparian areas are 12 percent more expensive than in other areas due to increased set-up 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[1]**
Variable retention harvest	$832	$1,490	$586	$2,907
Thinning	$832	$1,490	$0	$2,321
Thinning (Riparian)	$932	$1,490	$0	$2,422

[1]Totals do not equal sum of individual costs due to rounding.

The sustainable harvest calculation model is programmed to only complete harvests and thinning if it has enough money to do so. Consistent with current Board direction, the model retains a 25 percent management fee of the revenue generated from timber sales on State Forest Transfer Trust lands and 31 percent of the revenue generated from timber sales on other trusts lands toward management expenses. [10]

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

[9] 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.

[10] Management fees fund the two primary accounts used to fund management of state trust lands, the Resource Management Cost Account (RMCA) and the Forest Development Account (FDA). 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 has 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.

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 FEIS is to establish a sustainable harvest level for state trust lands in western Washington for a 10-year period (fiscal years 2015–2024), the trust mandate requires DNR to maintain intergenerational equality to avoid foreclosing future options (DNR 2006a, p. 3). 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 the lowest possible discount rates matter when considering returns in the distant future. They suggest discount rates no higher than 3.5 percent, with 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).

A 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 consistent with current department policies and procedures.

DNR also considered the rate of return from the Common School permanent fund, which is funded by Common School Trust lands. Since 2000, the rate of return on this fund has been slightly less than 4 percent in real terms.

Based on these considerations, and analysis of a range of discount rates from 1 percent to 5 percent in the forest estate model, DNR selected a 3 percent discount rate as the best rate to provide for intergenerational equity 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 3 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 soft constraint goal (Equation F.1). 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 soft constraint 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. Unlike revenues and costs, any incurred penalties are not discounted. By not discounting the penalty, it becomes more impactful 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

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

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, stakeholder involvement, special ecological features, visual impacts, cultural resources, catastrophic loss, legal access, equipment limitations, and excessive road costs.[11] Climate change is also a source of uncertainty in future yields. DNR considered these uncertainties when developing the forest estate model but expects them to have little effect on the harvest level for the 2015–2024 planning period.

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 modeling area as a result of implementing the harvest schedule. These data are outputs in a database known as the conditions file. Table F.10 describes 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.

[11] 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.

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.

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	Cover type (See Table F.1)
TH2	Site index class (See Table F.1)
TH3	Silvicultural prescription code (See Table F.1)
TH4	County (See Table F.1)
TH5	District (See Table F.1)
TH 6	Sustainable harvest unit (See Table F.1)
TH 7	Trust (See Table F.1)
TH 8	Spotted owl management unit (SOMU) (See Table F.1)
TH 9	Watershed administrative unit (WAU) (See Table F.1)
TH 10	Rain-on-snow sub-basin (See Table F.1)
TH 11	Land class (See Table F.1)
TH 12	Northern spotted owl habitat class (See Table F.1)
TH 13	Marbled murrelet management class (See Table F.1)
AGE	Age class of 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 = moderate 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	Cover type (See Table F.1)
TH2	Site index class (See Table F.1)
TH3	Silvicultural prescription code (See Table F.1)
TH4	County (See Table F.1)
TH5	District (See Table F.1)
TH 6	Sustainable harvest unit (See Table F.1)
TH 7	Trust (See Table F.1)
TH 8	Spotted owl management unit (SOMU) (See Table F.1)
TH 9	Watershed administrative unit (WAU) (See Table F.1)
TH 10	Rain-on-snow sub-basin (See Table F.1)
TH 11	Land class (See Table F.1)
TH 12	Northern spotted owl habitat class (See Table F.1)
TH 13	Marbled murrelet management class (See Table F.1)
AGE	Age class of development type
AREA	Acres in the development type
PERIOD	Modeling decade, period 1 is from July 1, 2015 to June 30,2024
OINV_MBF_T	Live standing volume in thousands of board feet per acre

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