Appendix G

Riparian

In the following appendix, DNR provides additional information regarding the analysis of the No Action and Landscape alternatives. For the Pathways Alternative, refer to the FEIS.

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Methods

DNR analyzed impacts to the riparian ecosystem on state trust lands in the OESF using criteria and indicators. Criteria are broad concepts, such as forest health or functioning riparian habitat. Indicators are the specific, quantitative means by which the criteria are measured. Indicators can provide information about current environmental conditions and how they change over time. These changes may result from forest management activities (such as timber harvest or road building), natural forest growth and development, or natural disturbances (such as landslides or windstorms).

■ What are the Criteria for Assessing Riparian Areas?

The criterion for assessing riparian areas is functioning riparian habitat.

■ What are the Indicators for Assessing Riparian Areas?

The indicators for assessing riparian areas are:

1. Large woody debris recruitment
2. Leaf and needle litter recruitment
3. Coarse sediment delivery[1]
4. Fine sediment delivery[1]
5. Water quantity (peak flow)
6. Stream shade
7. Microclimate
8. Composite watershed score

Each of these indicators represents an ecosystem process that takes place in and around riparian areas. Together, these processes describe the numerous interactions between in-stream, stream side, and upslope areas. The condition of the riparian ecosystem is the end-result of a variety of such processes, and their integrity can be used as a gauge of the riparian ecosystem as a whole. It is the condition and interaction of these processes that determine the amount, quality, and complexity of riparian habitat, and whether that habitat is capable of supporting viable salmon populations and other species that depend on in-stream and riparian environments.

An additional indicator, the *composite watershed score*, combines the individual indicators in order to characterize the riparian ecosystem as a whole.

■ At What Scale Were Impacts Analyzed?

All riparian impacts were first evaluated at the reach level. Reach-level impacts were then aggregated to the Type 3 watershed level. The distribution of watershed level impacts was used to assess impacts across the entire OESF.

■ What is a Reach?

A reach was defined as a segment of the stream network with consistent channel and floodplain characteristics, namely gradient and confinement. Reaches are typically a few hundred feet in length. Reaches were used as the basis for the riparian impact analysis because that is the scale at which many riparian species interact with the environment and the scale at which many ecological processes create or maintain habitat.

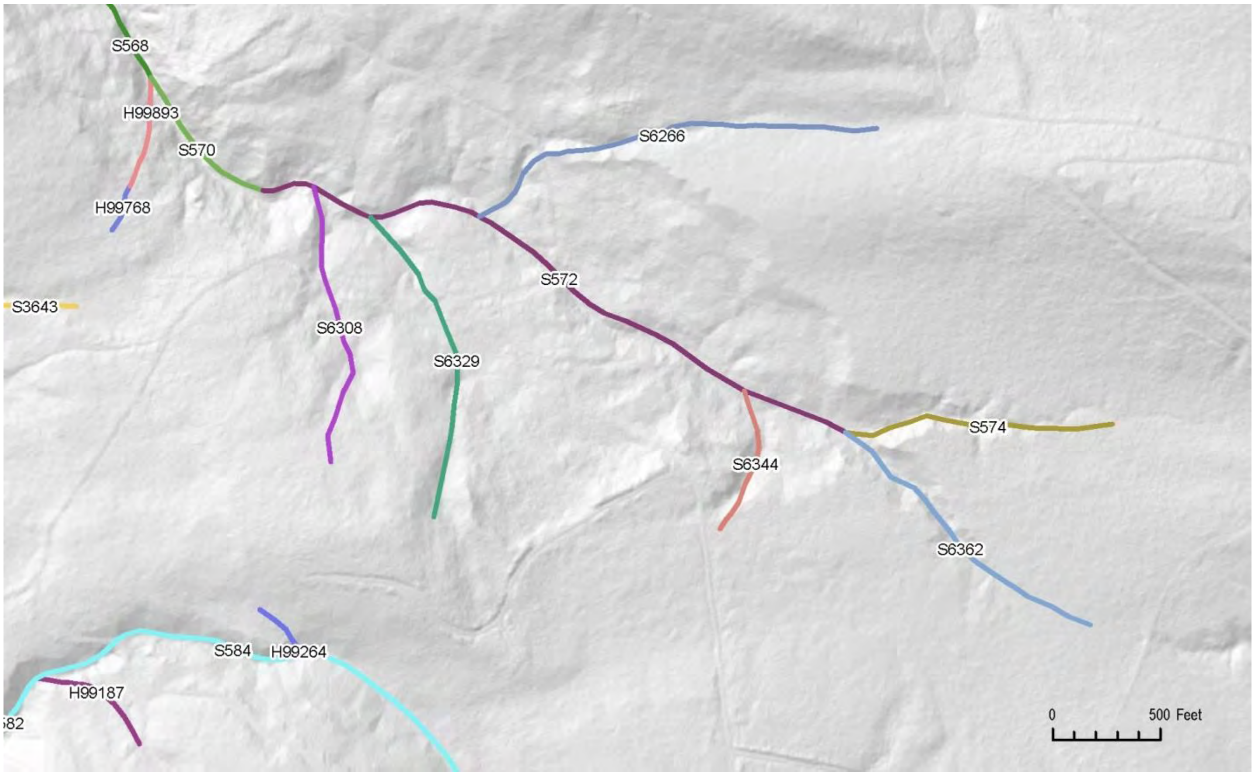
Reaches were identified using a combination of field-collected and remotely-sensed data, following guidelines established by the Washington DNR Forest Practices Division and the Timber, Fish, and Wildlife Monitoring Program of the Northwest Indian Fisheries Commission (Pleus and Schuett-Hames 1998).

Spatial data delineating these reaches is stewarded by the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP), co-managed by the Northwest Indian Fisheries Commission and the Washington Department of Fish and Wildlife. The foundation of the SSHIAP data system is a 1:24,000-scale cleaned and routed hydrography layer. This hydrography layer provides a consistent spatial data foundation for integrating a wide variety of habitat information and for subsequent analyses.

Each stream reach contained in the SSHIAP hydrography was assigned a unique identifier. The SSHIAP identifier was transferred, or conflated, onto DNR's propriety hydrography using a combination of automated (spatial join) and manual processes. Some smaller, non-fish bearing streams (for example, some Type 4 and 5 streams) were not represented in the SSHIAP hydrography and therefore lacked a SSHIAP identifier. For these streams, a unique identifier known as the "HYDRO_UID" from the DNR hydrography was used to identify stream reaches. The "HYDRO_UID" is an artifact of the Geographical Information System used to create the spatial data, and although it was not defined according to physical channel or floodplain characteristics, it does loosely correspond to relevant hydrological features in the stream network such as arcs between vertices defined by changes in stream order (tributary confluences) or type breaks (changes in stream type) (refer to Figure G-1). The HYDRO_UID provided a convenient means of representing reaches along the stream network in areas lacking a SSHIAP identifier.

Figure G-1. Stream Reaches

Each reach is symbolized with a different color and labeled with its identifier. Identifiers with an "S" prefix were derived from the SSHIAP identifier; those with an "H" prefix were derived from the HYDRO_UID id.



What is a Type 3 Watershed?

Generally, a Type 3 watershed is the area drained by a Type 3 stream. There are 601 Type 3 watersheds located within DNR-managed lands on the OESF (Map 3-5 of the FEIS). A subset of these watersheds was selected for further analysis; only those watersheds in which DNR manages 20 percent of the land area were evaluated (427 out of 601 watersheds). This ownership threshold was used to identify areas where DNR manages enough of the watershed that its management practices could influence watershed conditions.

The use of such a threshold followed recommendations from federal watershed monitoring programs (Reeves and others 2004, Gallo and others 2005). Reeves and others recommended using a minimum 25 percent federal ownership threshold in order for a given watershed to be included in the monitoring program. As described by Gallo and others (2005), this threshold was selected to avoid sampling watersheds in which "the contribution of federal lands to the condition of the watershed was insignificant." On federal lands, a 25 percent ownership criterion excluded about 10 percent of the federal lands in the study area from the analysis. DNR used a more stringent 20 percent threshold in this analysis since it most closely corresponded to a similar level of exclusion. Using a threshold of greater than 20 percent DNR-managed lands, excludes approximately 10 percent of the DNR land base at the hydrologic scales of analysis used in this document.

■ What Area was Analyzed for Each Indicator?

Each riparian indicator used in this analysis had a defined area (hereafter, the "area of influence") in which it was considered to have an influence on the stream channel. The configuration of each area of influence varied by indicator and was broadly classified as one of two types: "proximity-based" or "hydrologically-based." A general summary follows; refer to subsequent discussions under each indicator for more detailed information.

■ What is a Proximity-Based Area of Influence?

Proximity-based areas of influence included all areas within a specified distance of the stream channel (Figure G-2). For example, large woody debris recruitment via processes such as tree mortality or windthrow generally takes place within one tree height of the stream channel (FEMAT 1993). For all proximity-based indicators, the area of influence included the 100-year floodplain plus an additional distance.

Streams are dynamic and many studies to date that make recommendations for the recruitment of large woody debris have not considered how stream channels migrate over time (Murphy and Koski 1989, Robison and Beschta 1990, McDade and others 1990, WFPB 1994 as cited in DNR 1997b). To account for lateral stream migration across the floodplain, recruitment to the floodplain was considered equivalent to the recruitment to the stream channel. Large woody debris in the floodplain provides riparian function during flood events (DNR 1997b), and in time, will eventually become in-stream large woody debris as streams migrate. Therefore, the area of influence for all proximity-based indicators included the floodplain itself plus an additional distance. In this manner, recruitment to the 100-year floodplain was treated as equivalent to recruitment to the stream channel. The width of the 100-year floodplain was defined by stream type, measured outward horizontally from the center of the stream channel along both sides of the stream (Table G-1).

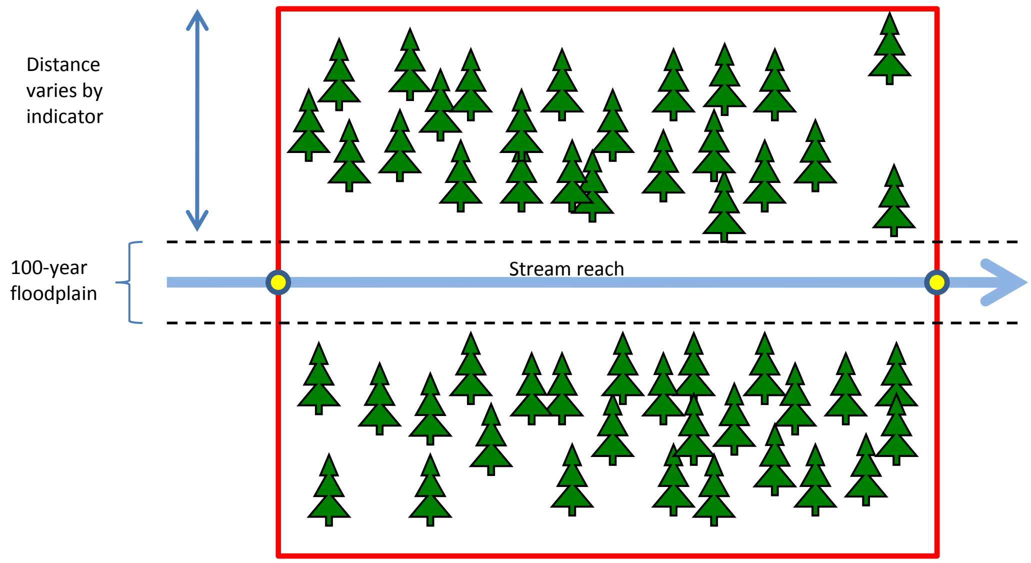
Table G-1. Width of 100-Year Floodplain, by Stream Type
All Distances Measured Horizontally, Along Each Side of the Stream Channel

Stream type (modified State Trust Lands water type)	100-year floodplain along each side of the stream (feet)	Total width of 100-year floodplain (feet)
1	150	300
2	30	60
3	15	30
4	3.75	7.5
5	0	0
9	0	0

DNR adjusted the stream type prior to delineating a 100-year floodplain, in an attempt to reconcile discrepancies between DNR's state trust lands water typing and forest practices water typing systems.

Type 4, 5, and 9 streams (non fish-bearing) with a Forest Practices water type code of 'F' (fish-bearing) were treated as if they were Type 3 streams.

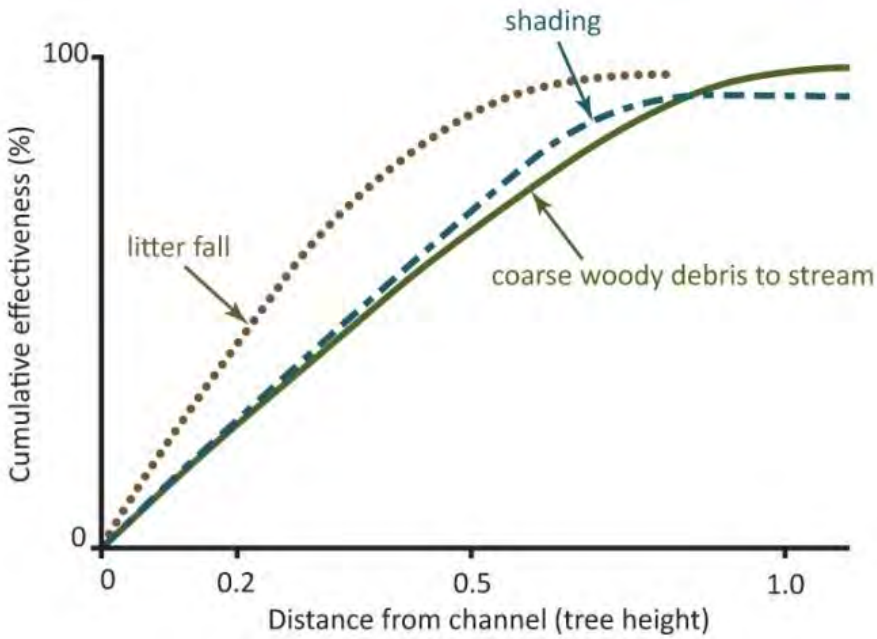
Figure G-2. Reach-Level Area of Influence, Based on Proximity to the Stream Channel



The width of the proximity-based area of influence was based on a review of available literature (VanSickle and Gregory 1990; McDade and others 1990; Beschta and others 1987; FEMAT 1993, Bisson and Wondzell 2009). For proximity-based indicators, the magnitude of their effect on the stream channel decreases as one moves further from the stream. Areas beyond a threshold distance are unlikely to influence riparian conditions. This threshold distance can vary by riparian indicator, but for most, it is approximately equivalent to one site potential tree height.

The President's Northwest Forest Conference in 1993 and the subsequent development of the federal Northwest Forest Plan (1994) resulted in a thorough re-examination of the ecological functions of riparian zones with consideration given to protecting habitat for entire communities of fish and wildlife. Based on research information available at the time, federal scientists developed presumed relationships concerning the role of different riparian functions at increasing distances from the edge of the stream channel. Those relationships, shown in Chart G-1, coupled with more recent findings, where applicable, formed the basis for determining the extent of the riparian area analyzed. Refer to subsequent discussions under each indicator for more detailed information.

Chart G-1. Generalized Curves of Riparian Function with Increasing Distance from the Stream Channel
Adapted from Forest Ecosystem Management Assessment Team Report (FEMAT 1993)



DNR delineated the area that contributes to any specific stream reach using the ArcGIS Euclidean allocation function. This function divides the riparian area by assigning each area of influence to the single, closest stream reach. Euclidean allocation is a raster-based process and the DNR hydrography was first rasterized at a two meter resolution. The rasterized hydrography was used to produce an allocation raster at two meter resolution, from which a vector layer was created (Figure G-3). A two meter cell size was selected based on computational limitations.

Along tributary junctions, a given location may be part of the floodplain of a larger mainstem stream, but closer the tributary. Euclidean allocation assigns the location to the tributary stream (Figure G-4).

Figure G-3. Reach-Level Proximity-Based Area of Influence

Each reach is labeled with its identifier. Identifiers with an "S" prefix were derived from the SSHIAP segment id; those with an "H" prefix were derived from the HYDRO_UID id. Note that stream type may change within reaches defined by the SSHIAP segment id.

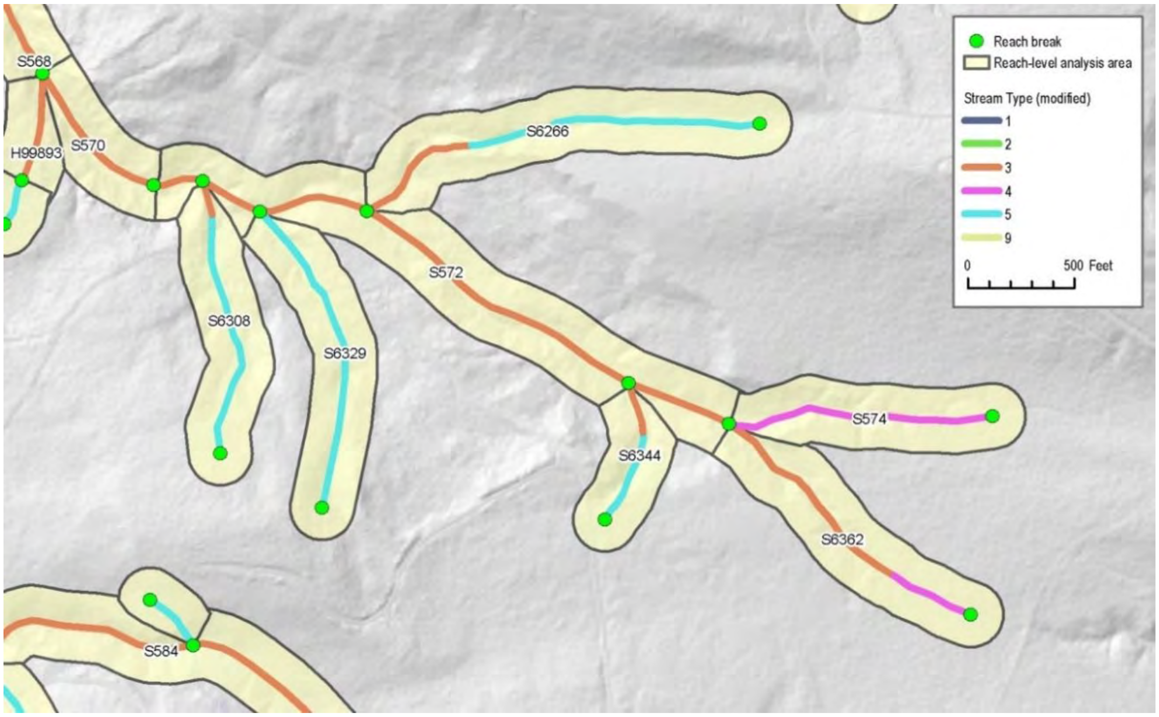
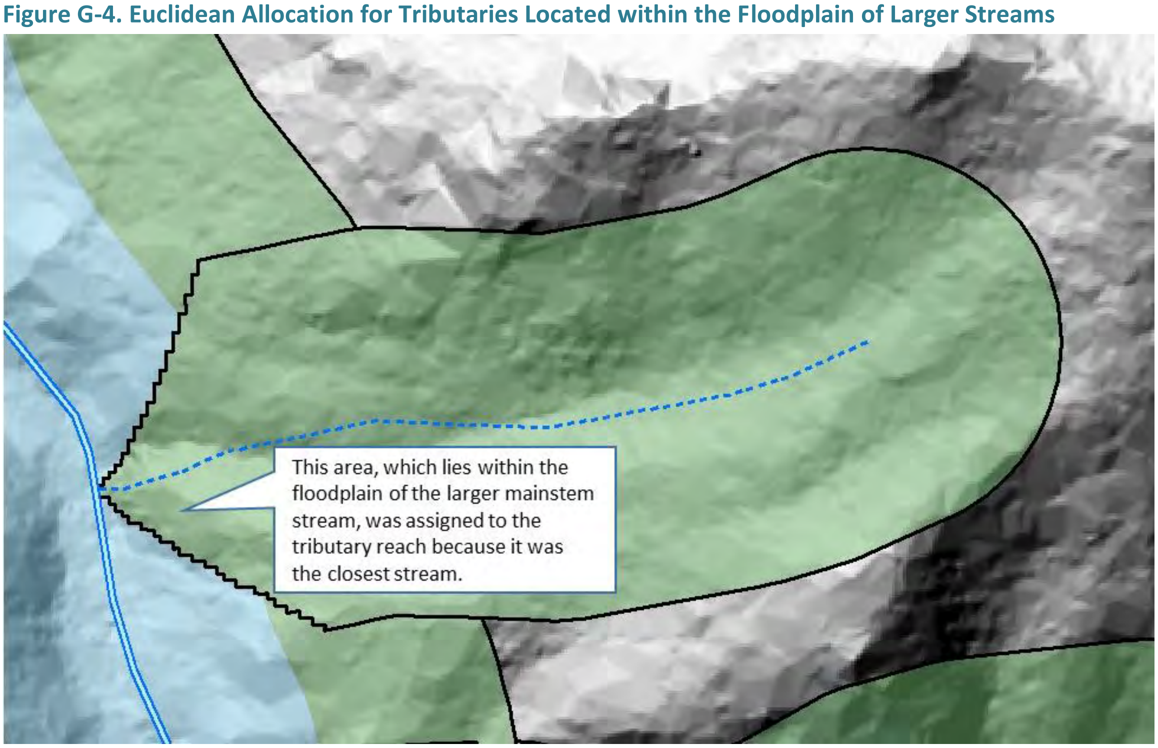


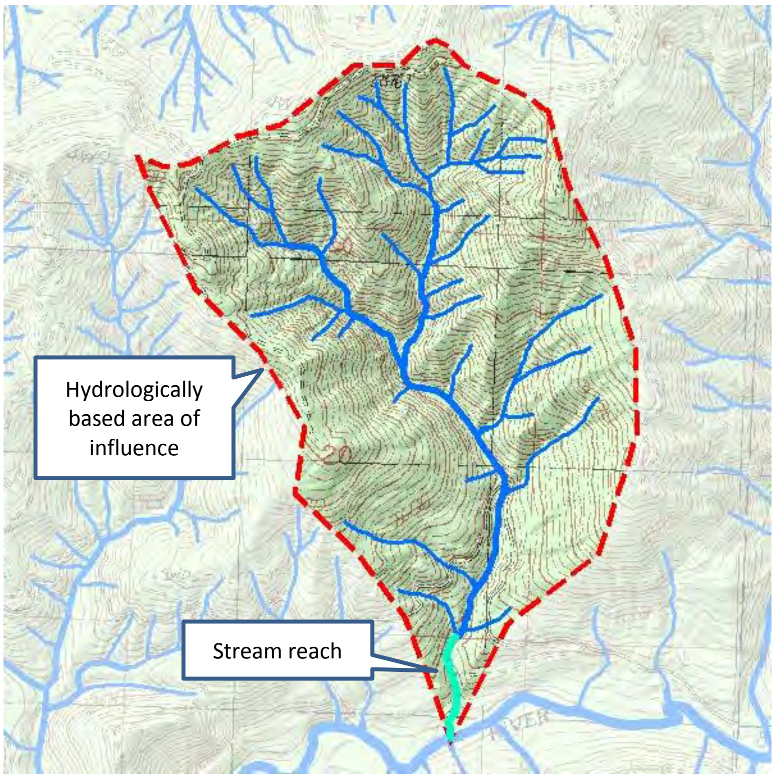
Figure G-4. Euclidean Allocation for Tributaries Located within the Floodplain of Larger Streams



What is a Hydrologically-Based Area of Influence?

Hydrologically-based areas of influence were defined by the contributing basin for the reach in question (Figure G-5). For example, the analysis of impacts to a given stream reach resulting from changes in peak flow examined the hydrologic maturity of the forests within the contributing basin for that reach. For this analysis, the Type 3 watershed was used in place of a reach-level basin delineation. All stream reaches within a given Type 3 watershed were treated as if their contributing basin were the entire Type 3 watershed. Refer to Map 3-5 of the FEIS for the location of Type 3 watersheds within the OESF.

Figure G-5. Reach-Level Hydrologically-Based Area of Influence



How Were Reach-Level Impacts Assessed?

For most indicators[2], DNR used two factors to assess impacts at the reach-level: potential and sensitivity.

POTENTIAL[3] is an assessment of how well the area of influence provides the given riparian function. For example, forest conditions were evaluated within one site-potential tree height of and including the floodplain as a measure of the potential for the forest to provide large woody debris. For all indicators, POTENTIAL is scaled from 0 (detrimental) to 1 (beneficial).

SENSITIVITY is a qualitative rating (for example, "high", "medium", or "low") of how the stream reach is expected to respond to changes in the indicator. Some reaches are more sensitive than others. It is most important to maintain or restore riparian conditions along highly sensitive reaches, as those are the areas where the stream is most responsive and the greatest impacts are most likely to occur. DNR used sensitivity ratings from watershed analyses that were performed (either initiated or completed and approved) in the OESF per Forest Practices rules. For stream reaches for which watershed analyses were not available, DNR based sensitivity primarily on gradient and confinement.

In the case of large woody debris, for example, highly sensitive reaches are those in which large woody debris is considered a critical element in maintaining the shape of the channel; forming habitat features such as pools; trapping sediment and gravel; and protecting the stream bank. Low sensitivity reaches are those where large woody debris is not considered a primary structural element, often found only along the outer margin of the stream. A complete description of how the sensitivity ratings were derived is provided in subsequent discussions under each indicator.

Scores for both the `SENSITIVITY` and `POTENTIAL` were reported on a numerical scale ranging from 0 (low) to 1 (high). For sensitivity ratings, values of 0, 0.5, and 1 corresponded to low, medium, and high sensitivities respectively. Depending on the indicator in question, sensitivity ratings were either discrete values of 0, 0.5, or 1; or continuous (ranging from 0 to 1 inclusive).

`POTENTIAL` ratings for each indicator were normalized to a scale of 0 to 1 inclusive, using mathematical constructs known as a “fuzzy curves”. Fuzzy curves are a means of implementing “fuzzy logic”, a branch of mathematics concerned with the quantification of imprecise information about variables, their interpretation, and the relation between variables. Ecosystems have no arbitrary point at which “fair” conditions give way to “good” conditions; a gradient exists, where “fair” gradually transitions into “good.” This vague transition or gradient is what fuzzy logic tries to display.

The value calculated by the fuzzy curve represents an assessment of the truth or falsehood of whether the given area of influence provides the desired riparian function. A value of 0 corresponds to “false”; the area in question does not provide the desired function. A value of 1 corresponds to “true”; the area in question does provide the desired function.

Using a common scale for all indicators facilitated the evaluation of multiple parameters, each measured using disparate units, which would have been difficult to compare or aggregate otherwise. The shape and breakpoints for each curve determined how each value was normalized. Fuzzy curves for each parameter were adapted from multiple sources, including available literature (Gallo and others 2005), watershed analysis methods (DNR 1997a), or consultation with DNR scientific staff. A description of each fuzzy curve is provided in subsequent discussions under each indicator.

DNR combined the `SENSITIVITY` and `POTENTIAL` ratings to form the *stream reach score*, which was intended to quantify not only the ability of the area of influence to provide riparian function, but also the expected channel response to changes in function. The stream reach score was calculated in a two-step process: DNR first combined `SENSITIVITY` and `POTENTIAL` to derive a stream reach impact score (Equation G-1); which was then normalized and reversed to form the stream reach score (Equation G-2).

Equation G-1. Stream Reach Impact Score

$$stream\ reach\ impact\ score = \sqrt{w * SENSITIVITY^2 + (1 - POTENTIAL)^2}$$
$$where\ w = (1 - POTENTIAL)$$

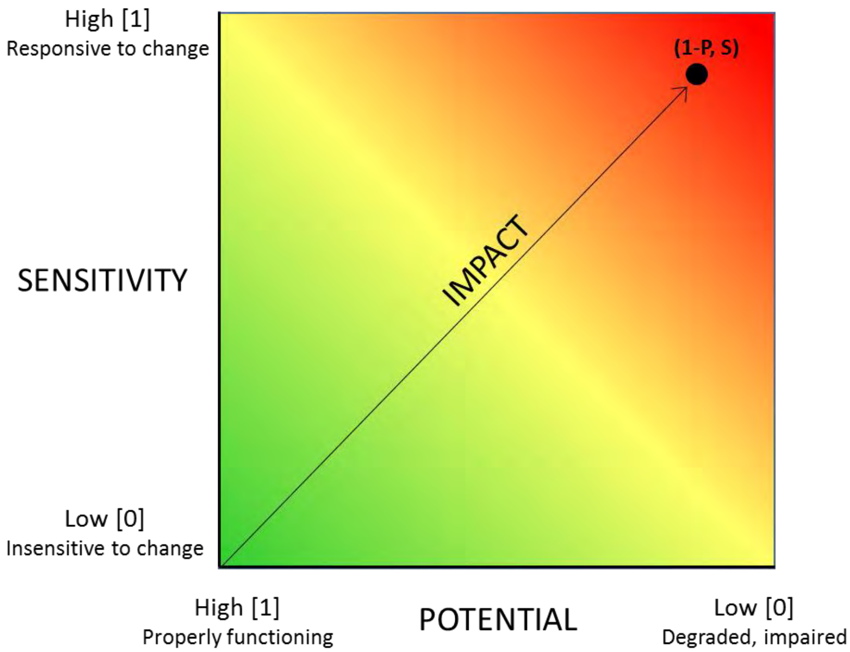
Equation G-2. Stream Reach Score

$$stream\ reach\ score = 1 - PERCENTRANK(stream\ reach\ impact\ score)$$

DNR's methodology for cacluating the stream reach impact score was adapted from InVest (Sharp and others 2016) and is based, conceptually, on the distance in 2-dimensional space, where one axis represents SENSITIVITY and the other represents POTENTIAL. The impact for any given combination of SENSITIVITY and POTENTIAL was based on the length of the vector from the origin (P = 1, S = 0) to the point in question (Figure G-6). The impact was directly proportional to the SENSITIVITY and inversely proportional to the POTENTIAL. That is, the impact was highest along highly sensitive reaches (S = 1) with low POTENTIAL (P = 0).

Figure G-6. Impact, as a Function of SENSITIVITY and POTENTIAL

Colors indicate level of impact: greens (low impact), yellows (medium impact), red (high impact). Adapted from InVest (Sharp and others 2016).



SENSITIVITY was held static for each stream reach, and therefore did not change over time. POTENTIAL, however, varied as conditions within the area of influence changed over time. Regardless of SENSITIVITY, the optimal condition (that is, the lowest impact) for a given reach is achieved when POTENTIAL is at its maximum (P = 1). DNR introduced a weighting factor, w = (1-P), to adjust the role that SENSIVITY plays in the calculation. In this manner, reaches with a high POTENTIAL were assigned a low impact. Conversely, when POTENTIAL is low (P = 0), channel sensitivity matters greatly and is reflected in the impact score. This method also allowed for a full range of impact ratings (low, medium, high) for all possible channel sensivity ratings.

The impact score calculated using Equation G-1 ranges from a minimum of 0 to a maximum of √2. To calculate the stream reach score, DNR normalized the impact score to a scale of 0 to 1 using the PERCENTRANK function in MS-Excel 2013. The normalized score was then converted from a measure of impact (0 = low impact, good; 1 = high impact, bad) to a measure of condition (0 = poor condition, bad; 1 = properly functioning condition, good) by subtracting it from 1. The resulting normalized condition scores were divided into tertiles in order to assign qualitative impact rankings of high (0 to 0.33), medium (0.33 to 0.67), or low (0.67 to 1.00) impact

Figures G-7 and G-8 show the impact score and the corresponding stream reach [condition] score for a range of `SENSITIVITY` and `POTENTIAL` values. DNR developed a 4-th order polynomial regression equation (Equation G-3, $r^2 = 0.998$) relating the values in Figure G-7 to those in Figure G-8, thus replicating the effect of PERCENTRANK function (Equation G-2) and and allowing for the calculation of a stream reach score for any combination of `SENSITIVITY` and `POTENTIAL`.

Equation G-3. Stream Reach Score

Stream reach score = 0.3533074511330200 * stream reach impact score^4 - 0.5031304736872930 * stream reach impact score^3 - 0.0240198407861953 * stream reach impact score^2 - 0.6576066748724540 * stream reach impact score + 1.0003178863655500

Figure G-7. Stream Reach Impact Scores for Selected SENSITIVITY and POTENTIAL Values

Stream Reach Impact = √[(1-POTENTIAL)^2 + w(SENSITIVITY^2)], where w = (1-POTENTIAL)

SENSITIVITY	**High**	**1.00**	0.00	0.23	0.33	0.42	0.49	0.56	0.62	0.69	0.75	0.81	0.87	0.92	0.98	1.04	1.09	1.15	1.20	1.25	1.31	1.36	1.41
		0.95	0.00	0.22	0.32	0.40	0.47	0.54	0.60	0.66	0.72	0.78	0.84	0.89	0.95	1.00	1.06	1.11	1.17	1.22	1.27	1.33	1.38
		0.90	0.00	0.21	0.30	0.38	0.45	0.51	0.58	0.64	0.70	0.75	0.81	0.86	0.92	0.97	1.03	1.08	1.13	1.19	1.24	1.29	1.35
		0.85	0.00	0.20	0.29	0.36	0.43	0.49	0.55	0.61	0.67	0.73	0.78	0.84	0.89	0.94	1.00	1.05	1.10	1.16	1.21	1.26	1.31
		0.80	0.00	0.19	0.27	0.34	0.41	0.47	0.53	0.59	0.64	0.70	0.75	0.81	0.86	0.92	0.97	1.02	1.07	1.13	1.18	1.23	1.28
		0.75	0.00	0.18	0.26	0.33	0.39	0.45	0.51	0.57	0.62	0.68	0.73	0.78	0.84	0.89	0.94	0.99	1.04	1.10	1.15	1.20	1.25
		0.70	0.00	0.16	0.24	0.31	0.37	0.43	0.49	0.54	0.60	0.65	0.70	0.76	0.81	0.86	0.91	0.96	1.02	1.07	1.12	1.17	1.22
		0.65	0.00	0.15	0.23	0.29	0.35	0.41	0.47	0.52	0.57	0.63	0.68	0.73	0.78	0.83	0.89	0.94	0.99	1.04	1.09	1.14	1.19
		0.60	0.00	0.14	0.21	0.28	0.33	0.39	0.44	0.50	0.55	0.60	0.66	0.71	0.76	0.81	0.86	0.91	0.96	1.01	1.06	1.12	1.17
		0.55	0.00	0.13	0.20	0.26	0.32	0.37	0.43	0.48	0.53	0.58	0.63	0.68	0.74	0.79	0.84	0.89	0.94	0.99	1.04	1.09	1.14
		0.50	0.00	0.12	0.19	0.24	0.30	0.35	0.41	0.46	0.51	0.56	0.61	0.66	0.71	0.76	0.82	0.87	0.92	0.97	1.02	1.07	1.12
		0.45	0.00	0.11	0.17	0.23	0.28	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.79	0.85	0.90	0.95	1.00	1.05	1.10
		0.40	0.00	0.10	0.16	0.22	0.27	0.32	0.37	0.42	0.47	0.52	0.57	0.62	0.68	0.73	0.78	0.83	0.88	0.93	0.98	1.03	1.08
		0.35	0.00	0.09	0.15	0.20	0.25	0.31	0.36	0.41	0.46	0.51	0.56	0.61	0.66	0.71	0.76	0.81	0.86	0.91	0.96	1.01	1.06
		0.30	0.00	0.08	0.14	0.19	0.24	0.29	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.79	0.84	0.89	0.94	0.99	1.04
		0.25	0.00	0.07	0.13	0.18	0.23	0.28	0.33	0.38	0.43	0.48	0.53	0.58	0.63	0.68	0.73	0.78	0.83	0.88	0.93	0.98	1.03
		0.20	0.00	0.07	0.12	0.17	0.22	0.27	0.32	0.37	0.42	0.47	0.52	0.57	0.62	0.67	0.72	0.77	0.82	0.87	0.92	0.97	1.02
		0.15	0.00	0.06	0.11	0.16	0.21	0.26	0.31	0.36	0.41	0.46	0.51	0.56	0.61	0.66	0.71	0.76	0.81	0.86	0.91	0.96	1.01
		0.10	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
		0.05	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
	low	**0.00**	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
			1.00	**0.95**	**0.90**	**0.85**	**0.80**	**0.75**	**0.70**	**0.65**	**0.60**	**0.55**	**0.50**	**0.45**	**0.40**	**0.35**	**0.30**	**0.25**	**0.20**	**0.15**	**0.10**	**0.05**	**0.00**
			0.00	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
			High																				**Low**
			POTENTIAL (1-POTENTIAL shown in red)																				

Figure G-8. Stream Reach Scores for Selected SENSITIVITY and POTENTIAL Values

Stream reach score = 1 – PERCENTRANK(stream reach impact score). Color indicates qualitative ranking of impact level for each stream reach score: greens = low impact, (stream reach score 1.00 – 0.67); yellows = medium impact (stream reach score 0.67 – 0.33), reds = high impact (stream reach score 0.33 - 0.00).

			Low impact				Medium Impact						High Impact										
SENSITIVITY	High	1.00	1.00	0.84	0.76	0.69	0.63	0.56	0.51	0.45	0.40	0.34	0.28	0.23	0.18	0.13	0.09	0.06	0.04	0.03	0.01	0.01	0.00
		0.95	1.00	0.85	0.78	0.71	0.64	0.59	0.53	0.47	0.42	0.37	0.31	0.26	0.21	0.16	0.11	0.08	0.06	0.04	0.02	0.01	0.00
		0.90	1.00	0.86	0.79	0.72	0.67	0.60	0.55	0.50	0.44	0.39	0.34	0.29	0.23	0.19	0.14	0.10	0.07	0.05	0.03	0.02	0.01
		0.85	1.00	0.87	0.80	0.74	0.68	0.62	0.57	0.51	0.46	0.41	0.36	0.31	0.26	0.21	0.16	0.12	0.09	0.06	0.04	0.02	0.01
		0.80	1.00	0.88	0.81	0.75	0.70	0.64	0.59	0.54	0.49	0.44	0.39	0.34	0.29	0.24	0.19	0.14	0.10	0.07	0.05	0.03	0.02
		0.75	1.00	0.89	0.82	0.77	0.72	0.66	0.61	0.56	0.51	0.46	0.41	0.36	0.32	0.27	0.22	0.17	0.12	0.09	0.06	0.04	0.03
		0.70	1.00	0.89	0.84	0.78	0.73	0.68	0.63	0.58	0.54	0.49	0.44	0.39	0.34	0.29	0.24	0.19	0.15	0.11	0.08	0.05	0.04
		0.65	1.00	0.90	0.85	0.80	0.75	0.69	0.65	0.60	0.55	0.50	0.46	0.41	0.36	0.32	0.27	0.22	0.18	0.13	0.09	0.07	0.05
		0.60	1.00	0.91	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.53	0.48	0.43	0.38	0.33	0.29	0.24	0.20	0.15	0.11	0.08	0.06
		0.55	1.00	0.91	0.87	0.82	0.77	0.73	0.68	0.64	0.59	0.54	0.50	0.45	0.41	0.36	0.31	0.27	0.22	0.17	0.13	0.10	0.07
		0.50	1.00	0.92	0.88	0.83	0.79	0.74	0.70	0.65	0.61	0.56	0.52	0.47	0.42	0.38	0.33	0.28	0.24	0.19	0.14	0.11	0.08
		0.45	1.00	0.92	0.89	0.84	0.80	0.76	0.72	0.67	0.63	0.59	0.54	0.49	0.45	0.40	0.35	0.31	0.26	0.21	0.17	0.12	0.09
		0.40	1.00	0.93	0.89	0.85	0.81	0.77	0.73	0.69	0.64	0.60	0.55	0.51	0.46	0.42	0.37	0.32	0.28	0.23	0.18	0.14	0.10
		0.35	1.00	0.94	0.91	0.86	0.83	0.78	0.74	0.70	0.66	0.61	0.57	0.52	0.48	0.43	0.38	0.34	0.30	0.25	0.20	0.15	0.11
		0.30	1.00	0.94	0.91	0.88	0.84	0.80	0.76	0.71	0.67	0.63	0.58	0.54	0.49	0.45	0.40	0.36	0.31	0.26	0.22	0.17	0.12
		0.25	1.00	0.94	0.92	0.88	0.84	0.81	0.76	0.72	0.68	0.64	0.59	0.55	0.50	0.46	0.41	0.37	0.32	0.27	0.23	0.18	0.13
		0.20	1.00	0.94	0.92	0.89	0.85	0.81	0.77	0.73	0.69	0.65	0.60	0.56	0.51	0.47	0.42	0.37	0.33	0.28	0.24	0.19	0.14
		0.15	1.00	0.95	0.93	0.90	0.86	0.82	0.78	0.74	0.69	0.65	0.61	0.56	0.52	0.47	0.43	0.38	0.33	0.29	0.25	0.20	0.15
		0.10	1.00	0.95	0.93	0.90	0.86	0.82	0.79	0.74	0.70	0.66	0.61	0.57	0.52	0.48	0.43	0.39	0.35	0.30	0.25	0.20	0.16
		0.05	1.00	0.95	0.93	0.90	0.87	0.83	0.79	0.75	0.71	0.66	0.62	0.58	0.53	0.48	0.44	0.39	0.35	0.30	0.25	0.21	0.16
	low	0.00	1.00	0.95	0.94	0.91	0.87	0.83	0.79	0.75	0.71	0.66	0.62	0.58	0.53	0.49	0.44	0.40	0.35	0.30	0.26	0.21	0.16
			1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
			0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
			High																				Low
			POTENTIAL (1 – POTENTIAL shown in red)																				

How Were Watershed-Level Impacts Assessed?

Within each Type 3 watershed, the stream reach scores were combined to form a *watershed score*. Each stream reach score was weighted according to the area (length times width) of its corresponding reach. In this manner, larger reaches were given more credence than smaller ones. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

Equation G-4. Channel Width as a Function of Basin Size

$$channel\ width\ (feet) = 3.28083 * 4.6957 * \left(\frac{basin\ size\ (acres)}{247.1044}\right)^{0.41111}$$

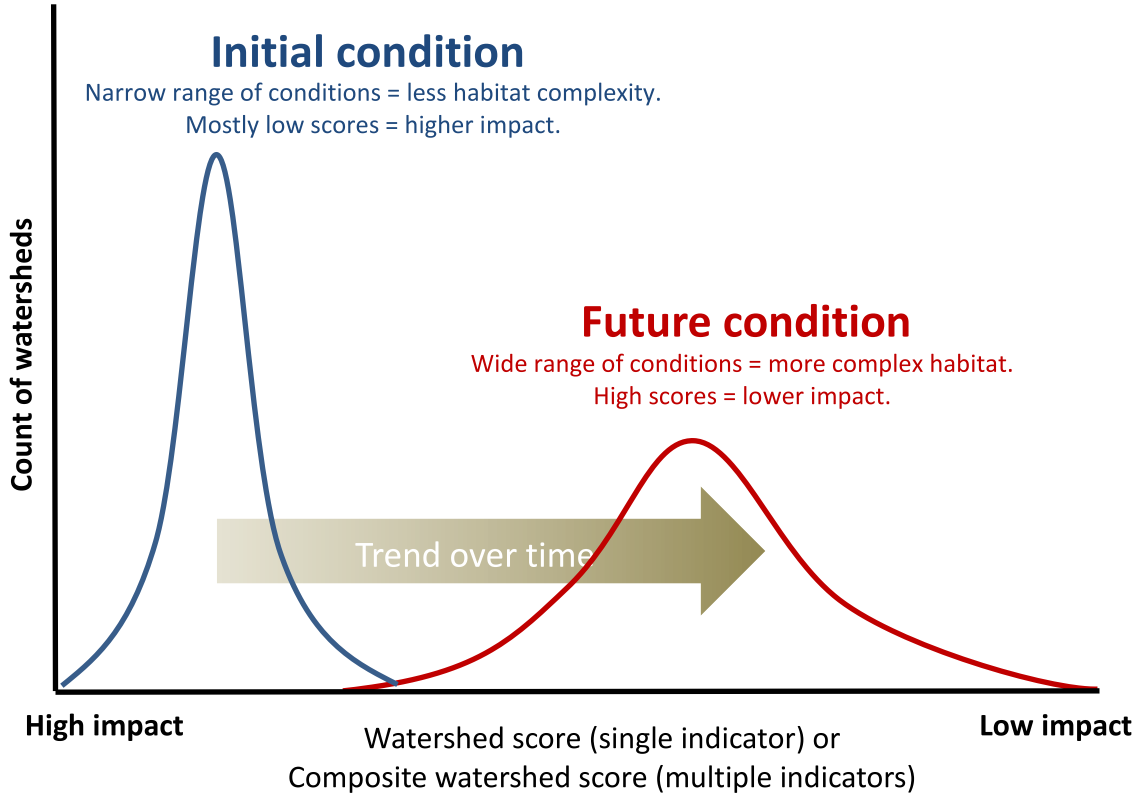
A separate *watershed score* was calculated for each riparian indicator. That is, one score was calculated for large woody debris, another score for leaf and needle litter, and so on. DNR used a hierarchical computer model to combine each of the watershed scores for the individual indicators to form a single *composite watershed score*. This composite score was used as the eighth indicator, and is described in detail in a subsequent section.

■ How Were Impacts Assessed Across the Entire OESF?

Impacts to the entire OESF were evaluated by considering the set, or distribution, of scores for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). Both the watershed scores for individual indicators and the composite watershed score were considered. By analyzing how the distribution of either score changes over time, it is possible to assess how effective the management alternatives are at maintaining riparian health and vitality for the entire OESF. Ideally, the set of scores should move toward an improved condition (represented by a higher watershed score, which indicates a lower impact) over time. However, it is important to note that a range of conditions is also desirable, and may indicate habitat variety or complexity.

Figure G-9 illustrates the hypothesized change in the distribution of scores over time. For a landscape that has been highly altered by human activity or severe environmental disturbance, initial conditions are likely to possess a strongly skewed distribution reflecting a large number of watersheds where the abundance of particular habitat elements has changed in response to a variety of anthropogenic and natural factors (Bisson and Wondzell 2009). Fully recovering the natural range of states of the habitat elements in an altered landscape requires management strategies that facilitate restoration of both the median and environmental extremes; otherwise, habitat diversity will be lost (Poole and others 2004 as cited in Bisson and Wondzell 2009).

Figure G-9. Hypothetical Change in the Distribution of Watershed Scores Over Time
Applies to both the individual riparian indicators (the watershed score) and the composite watershed score (all indicators combined).



DNR assigned a qualitative rating of the level of impact based on the observed changes in the distribution of scores (Table G-2). A qualitative rating was reported using the watershed scores for each riparian indicator (indicators 1 through 7) as well as the composite watershed score (indicator 8).

Table G-2. Qualitative Assessment of Impact Level
Applies to both the individual riparian indicators (the watershed score) and the composite watershed score (all indicators combined).

Qualitative impact level	Description
Low	Most watersheds are in a low impact condition. Watershed scores generally remain stable or increase over time, indicating maintenance or restoration of riparian function. Less than 10 percent of watersheds are in a high impact condition, or the number of watersheds in a high impact condition steadily decreases over time.
Medium	Most watersheds are in a medium impact condition. Watersheds scores generally remain stable or increase over time, indicating maintenance or restoration of riparian function. Less than 10 percent of watersheds are in a high impact condition, or the number of watersheds in a high impact condition steadily decreases over time.
High	More than 10 percent of watersheds are in a high impact condition and the number of watersheds in a high impact condition does not steadily decrease over time indicating failure to restore riparian function in these watersheds.

(1) Large Woody Debris Recruitment

What is Large Woody Debris and why is it Important?

The term *large woody debris* refers to logs, pieces of logs, root wads, or large chunks of wood that fall on the ground or into stream channels. While the definition of "large" can vary according to context (a log may provide a certain level of ecological function when it falls into a small stream; the same size log may not provide as much benefit in a large river), many biologists define large woody debris as having a minimum diameter of four inches and measuring six feet in length (Schuett-Hames and others 1999).

Numerous studies have shown that large woody debris is an important habitat component for fish and other aquatic organisms (Swanson and others 1976; Harmon and others 1986; Bisson and others 1987; Maser and others 1988; Naiman and others 1992; Samuelsson and others 1994). Trees and other large pieces of wood that fall into streams provide critical physical and biological functions such as sediment retention (Keller and Swanson 1979; Sedell and others 1988), gradient modification, channel structural diversity (Ralph and others 1994), nutrient production and retention (Cummins 1974), and protective cover from predators (Bisson and others 1987; Bilby and Ward 1989).

A variety of processes and mechanisms serve to transport large woody debris from both riparian and upland forests to the stream channel. Naiman and others (2005) provide a concise review of these processes; a summary follows. Mortality in woody riparian vegetation generally occurs as a result of disease, senescence, herbivory or catastrophic disturbances. Although relatively rare, severe disturbances such as windstorms, fires, or floods can contribute to episodic, widespread mortality (Harmon and others 1986 as cited in Naiman and others 2005). Avalanches, landslides, and debris torrents can remove vegetation from hillslopes and headwater riparian zones and deposit large woody debris and associated sediment in downstream channels.

The relative importance of mortality mechanisms varies by stream size and watershed characteristics. In gentle terrain, where landslides or avalanches are rare, trees growing along the stream channel generally die from disease, senescence, or herbivory (Johnston and Naiman 1990; Johnston and others 1993; as cited in Naiman and others 2005). In alluvial valleys, the undermining of riparian trees by the meandering stream is an important source of sediment and large woody debris to river channels (Naiman and others 2005). In unstable landscapes, such as portions of the OESF, landslides and debris torrents are significant factors. Wood recruited to the channels from landslides can constitute a significant portion of the wood load in the stream network (May and Gresswell 2003 as cited in Bisson and Wondzell 2009) and redistribution of hillslope derived wood through fluvial transport is an important process in habitat formation downstream (Benda and others 2003 as cited in Bisson and Wondzell 2009).

The relative importance of mortality factors also varies with valley form. Windthrow is the primary mechanism of mortality in tightly constrained channels with erosion resistant banks (Swanson and others 1982 as cited in Naiman and others 2005). In a study of forest buffers along small, non-fish bearing streams in northwest Washington, Grizzel and Wolff (1998) found that windthrow is likely the most significant mechanism by which large woody debris is recruited to those stream channels.

For this analysis, only large woody debris from riparian forests was considered. Large woody debris transported from upland forests via landslides and debris flows was not analyzed. An assumption of this analysis is that neither management alternative being examined here is likely to cause potential impacts to this mechanism of large woody debris delivery. As management activities are implemented, unstable slopes are identified through field reconnaissance or the use of geomorphology models and verified by qualified staff. Neither the frequency or severity of slope failure, nor the associated input of large woody debris, sediment, and nutrients is expected to change from naturally-occurring levels. This site-specific assessment of conditions is expected to identify and avoid or minimize potential impacts within the OESF. Nor was the fluvial transport of large woody debris considered. As described in Riparian, hydrologic maturity under both alternatives is sufficient to prevent or mitigate changes in peak flow. Therefore, the mechanism of fluvial transport of large woody debris was assumed to remain unaffected.

How was the Stream Reach Score for Large Woody Debris Calculated?

The stream reach score for large woody debris was calculated by combining the reach-level large woody debris channel recruitment potential and the reach-level large woody debris sensitivity rating using Equations G-1 and G-3. The score is intended to quantify not only the condition of large woody debris along the given reach, but also the expected channel response to large woody debris input. The stream reach score is directly proportional to the `POTENTIAL` and inversely proportional to the `SENSITIVITY`. That is, the score is lowest (indicating a high impact) along highly sensitive reaches with low potential (likelihood) for large woody debris recruitment. The score increases as conditions improve.

Which Streams Were Included in the Analysis?

All streams located on DNR-managed lands (regardless of type) and any streams (regardless of type or ownership) whose large woody debris area of influence extended onto DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

What was the Configuration of the Large Woody Debris Area of Influence?

For the FEIS analysis, DNR modeled the area of influence for large woody debris as the 100-year floodplain plus an additional distance equivalent to one site potential tree height (Table G-3). DNR defined the width of the 100-year floodplain by stream type, measured outward horizontally from the center of the stream channel along both sides of the stream.

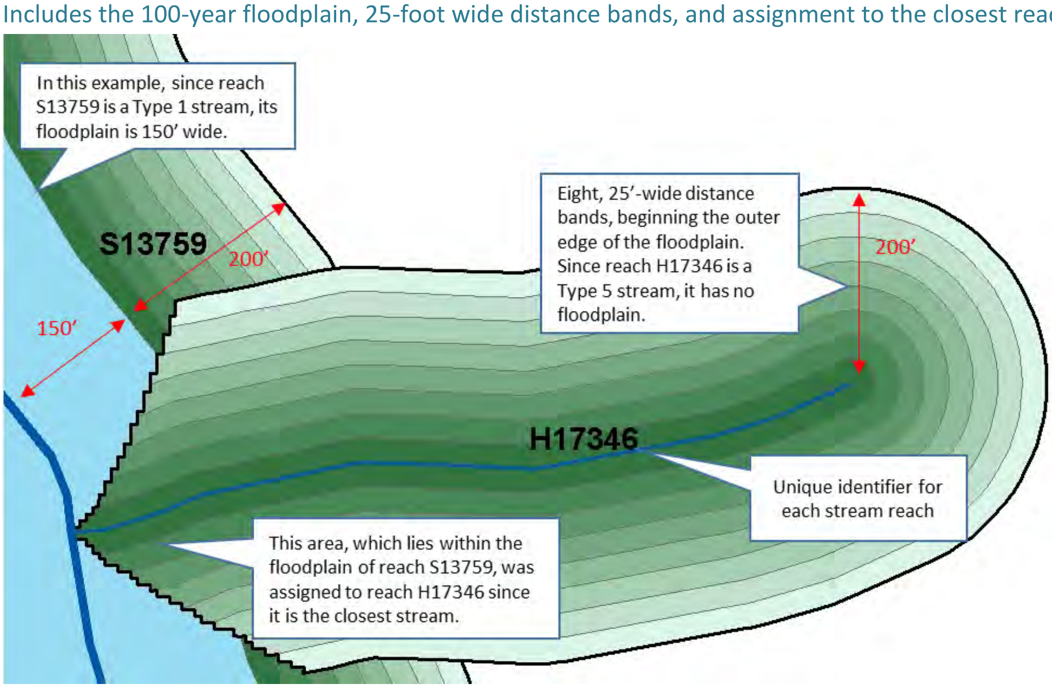
For the FEIS analysis, DNR approximated the site potential tree height as 200 feet. Conifer stands reach the old-growth stage at about 200 years (Spies and Franklin 1988, 1991 as cited in DNR 1997b, p. IV.71), which DNR assumed to represent the point at which a given stand achieves its maximum tree height. Using the tree height tables cited in the HCP (Wiley 1978) and the site index (height at 50 years breast height age) described in the HCP, the estimated site potential tree heights for a 200-year growing period are 204 feet (62 meters) for Type 1 and 2 streams, and 200 feet (61 meters) for Type 3 through 5 streams. DNR approximated these values by assuming a 200 foot site potential tree height at 200 years for all stream types in the OESF.

Table G-3. Width of Area Analyzed for Large Woody Debris Contribution
All Distances Measured Horizontally, Along Each Side of the Stream Channel.

Stream type (modified State Trust Lands water type)	100-year floodplain along each side of the stream (feet)	Site-potential tree height (feet)	Total width of analysis area along each side of the stream (feet)
1	150	200	350
2	30	200	230
3	15	200	215
4	3.75	200	203.75
5	0	200	200
9	0	200	200

Beginning at the outer edge of the 100-year floodplain, the area of influence was divided into eight 25-foot-wide distance bands (measured horizontally) (Figure G-10). The area that contributes to any specific stream reach was determined using the ArcGIS Euclidean allocation function, as previously described (Figures G-3 and G-4). Each reach-level area of influence was further subdivided by the individual REMSOFTID polygons used to represent the records in the spatial data set for the forest estate model[4]. The number of REMSOFTID polygons within each reach-level area of influence varied, ranging from a few to dozens. The average size of a riparian REMSOFTID polygon was 1.30 acres, with a standard deviation of 2.42 acres. The forest conditions within each REMSOFTID polygon were projected at decadal intervals for each management alternative in the forest estate model[4] as stands grow and develop, either in the presence or absence of management activities. Hereafter, DNR refers to each individual polygon within the area of influence (constructed by overalying the floodplain, distance bands, and REMSOFTID polygons) as "analysis polygons".

Figure G-10. Configuration of the Large Woody Debris Area of Influence
Includes the 100-year floodplain, 25-foot wide distance bands, and assignment to the closest reach.



How was Large Woody Debris Recruitment Potential Measured?

DNR assessed the ability of the riparian zone to supply functional large woody debris to the stream channel by examining riparian forest composition and structure within the area of influence. DNR considered three factors, described below: the recruitment potential rating (Q), the recruitment probability (Pr), and an area weight (Aw).

DNR performed the calculation using decadal (0-9) projections of forest conditions for each alternative (No Action, Landscape) and using the minimum thresholds of DNR's Desired Riparian Future Condition (RDFC), as specified in Table 2 (p.9) of DNR's Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006).

The recruitment potential for each alternative at each decade was then converted to a percentage of the recruitment provided by stands meeting RDFC, and normalized to a scale of 0 to 1 using a fuzzy curve.

Recruitment Potential Rating (Q)

DNR characterized the riparian overstory vegetation of each analysis polygon within the area of influence following the methodology outlined in DNR's Watershed Analysis Manual (DNR 1997a). DNR assigned a "riparian condition code" to each analysis polygon based on vegetation type (hardwood, conifer, mixed), size (quadratic mean diameter), and density, The riparian condition code was constructed from a concatenation of the three vegetative characteristics listed in Tables G-4, G-5, and G-6. For example, a stand classified as hardwood, small, sparse received a riparian condition code of HSS.

Table G-4. Dominant Vegetation Types

Forest type	Riparian condition code 1 (vegetation type)
DF, DFRC, DFSS, DFWH, RC, SFWH, SSDF, SSWH, WH, WHDF, WHRC, WHSF, WHSS	C
RADF, RASS, RAWH	H
DFRA, SSMA, WHRA	M

DF = Douglas-fir, RC = red cedar, SS = Sitka spruce, WH = western hemlock, SF = silver fir, RA = red alder, MA = big-leaf maple

Table G-5. Average Tree Size Classes

Quadratic mean diameter (QMD) of stand using trees 4" dbh and larger (YQMD3D5I from SOF)	Riparian condition code 2 (size)
YQMD3D5I < 12	S
12 ≤ YQMD3D5I < 20	M
YQMD3D5I ≥ 20	L

Table G-6. Stand Density Classes

Curtis' relative density of stand using trees 4" dbh and larger (YRD3D5I from SOF)	Riparian condition code 3 (density)

YRD3D5I < 42	S
YRD3D5I ≥ 42	D

Each riparian condition code was assigned a numerical score, normalized on a scale ranging from 0 (low) to 1 (high), adapted from Haggerty and North Olympic Land Trust (2011), The score is a relative ranking of each stand's potential to contribute functional large woody debris to the stream channel (Table G-7).

Table G-7. Large Woody Debris Recruitment Potential Rating

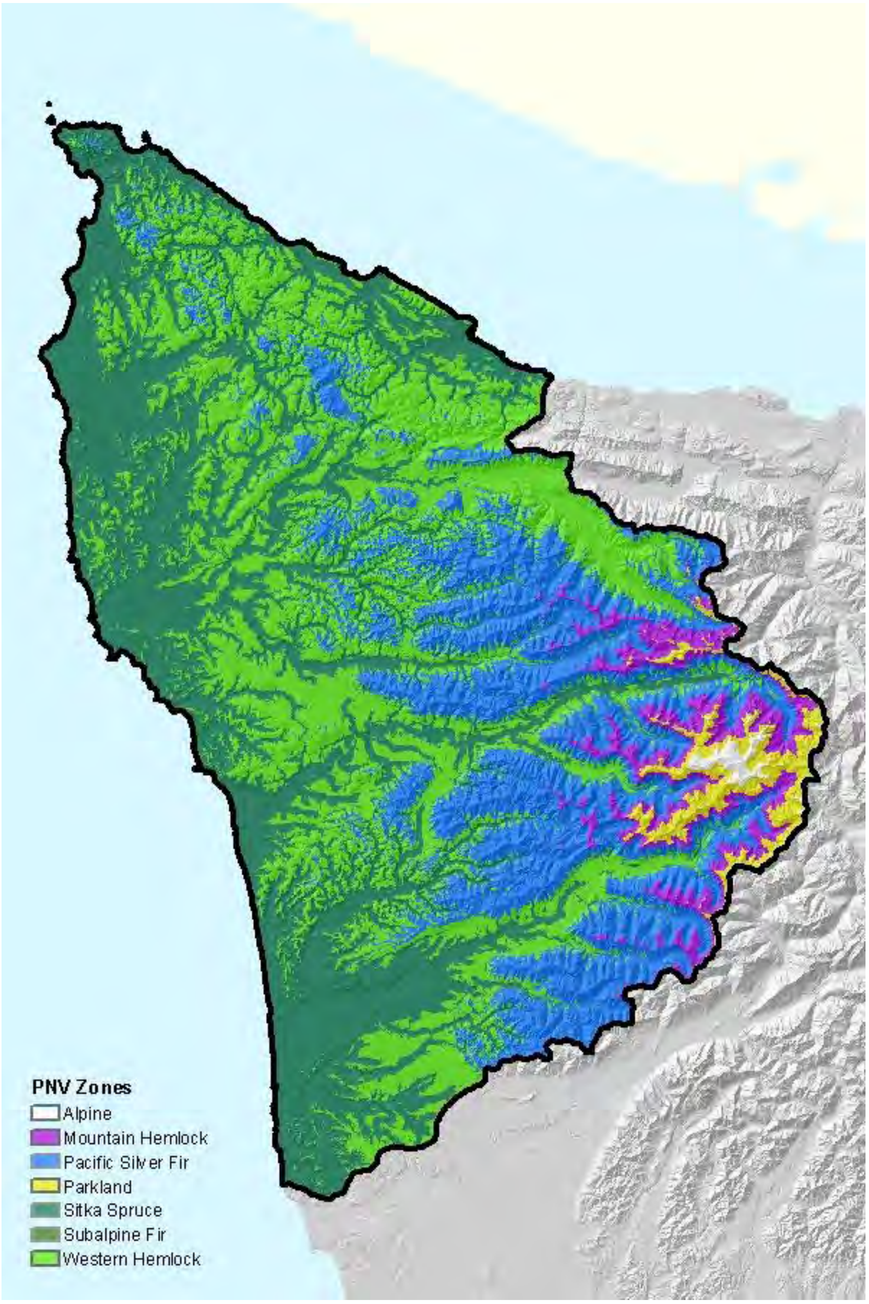
Adapted from Haggerty and North Olympic Land Trust (2011).

Riparian condition code	LWD recruitment potential score
CLD	1.0
MLD	0.9
CLS, HLD	0.8
CMD, MLS	0.7
HLS, MMD	0.6
CMD, HMD	0.5
MMS	0.4
CSD, CSS, HMS	0.3
MSD	0.2
HSD, HSS, MSS	0.1
Non-forest	0.0

A riparian condition code of "CLD" was used to represent the minimum specifications of RDFC. The dominant vegetation type (C) was based on the modeled potential natural vegetation for the given location (Henderson and others 2011) (Map G-1). Potential natural vegetation was represented using a raster gridded at 90 meter cell resolution. The value assigned to each analysis polygon within the large woody debris area of influence was calculated as the zonal majority (the most common value within the given polygon). Seven values occurred within the boundaries of the OESF HCP planning unit (Sitka spruce, western hemlock, Pacific silver fir, mountain hemlock, subalpine fir, parkland, and alpine), all of which were classificed as conifer (C).

Map G-1. Potential Natural Vegetation Zones Within the Olympic Experimental State Forest

Source: Henderson and others (2011)



The second character in the riparian condition code represents the average tree size class. For RDFC, all polygons within the large woody debris area of influence were assigned an average tree size class of L (large) by applying the classification of Table G-8 to the RDFC threshold target of a QMD of 21 inches.

The third charcter represents the stand density class. For RDFC, all polygons within the large woody debris area of influence were assigned a stand density class of D (dense) by applying the classification of table G-7 to an RD of 65, calculated from the RDFC thresholds for basal area (300 feet^2 per acre) and QMD of 21 inches.

Table G-8. Riparian Desired Future Condition (RDFC) Threshold Targets
Adapted from Table 2, p. 9, of DNR's Ripaian Forest Restoration Strategy (Bigley and Deisenhofer. 2006).

Parameter	RDFC value used for FEIS analysis	Source
Basal area	≥ 300 $feet^2$ per acre	Table 2, p. 9, of Bigley and Deisenhofer (2006)
QMD (trees > 7 inches DBH)	≥ 21 inches	Table 2, p. 9, of Bigley and Deisenhofer (2006)
RD	65	Derived: $RD = \frac{basal\ area}{\sqrt{QMD}}$
Species	Varies by location.	Derived from Potential Natural Vegation model (Hederson and others 2011), based on the most commonly occurring value (zonal majority) within each polygon. Possible values include: Sitka spruce, western hemlock, Pacific silver fir, mountain hemlock subalpine fir, parkland, or alpine.
Height	Varies by species.	Derived using species-specifc diameter to height growth relationships constructed from DNR's forest inventory.

The tree height for a stand meeting the minimum specifications of RDFC was estimated using the potential natural vegetation zone (Map G-1) and species-specific height-diameter equations constructed from DNR's forest inventory (Equation G-5). The coefficients for each species are shown in Table G-9. The height calculation used the RDFC threshold target of 21 inch QMD.

Equation G-5. Height-diameter Equation Ued to Estimate Tree Height for Stands Meeting the Minimum Specifications of RDFC

$$height = 4.5 + a * e^{(b*dbh^c)}$$

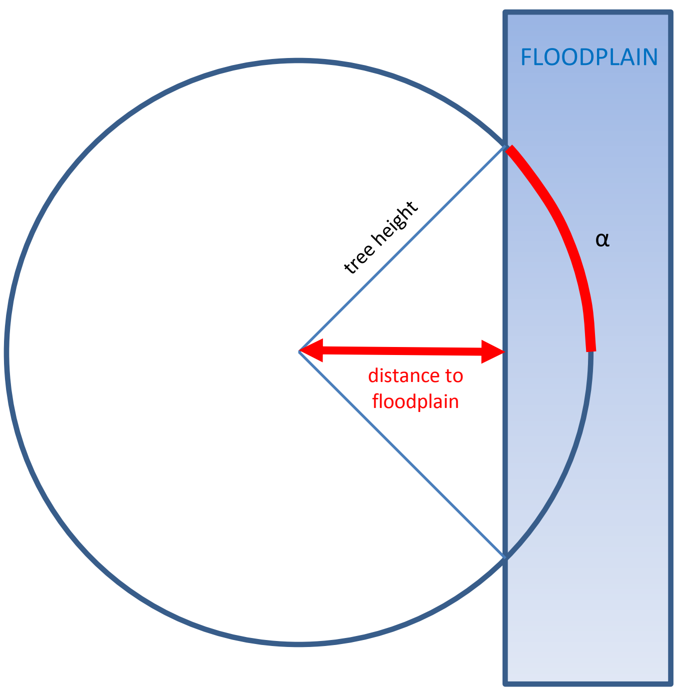
Table G-9. Height-Diameter Coefficients, by Species
Source: Gould, P., personal communication, Nov. 18, 2015.

Species	a	b	c	Calcualted height (feet) of a 21 inch dbh tree
Sitka spruce	603.3242486	-6.606812613	-0.406674661	93.4 feet
Western hemlock	253.7475471	-6.444705602	-0.663082515	112.3 feet
Pacific silver fir	595.6981211	-6.367406422	-0.414891475	102.9 feet
Mountain hemlock	218.7009196	-8.635226179	-0.704681108	84.1 feet
Subalpine fir, parkland, alpine	283.7018341	-6.185077363	-0.515858462	82.9 feet

Recruitment Probability (Pr)

DNR used a simple trigonometric model based on the assumptions of uniform tree height, random direction of tree fall, and uniform stocking density to represent the theoretical source distances for recruitment of large woody debris to the floodplain (McDade and others 1990). The model provided a general representation of the relationship between source distance and tree height. Assuming random fall direction, the recruitment probability of a falling tree was calculated as the proportion of fall directions that intersect the floodplain (Figure G-11).

Figure G-11. Modeling Large Woody Debris Contribution as a Function of Source Distance
Adapted from McDade and others (1990).



Floodplain-intersecting fall directions can be represented by 2α, the angle formed by the intersection of two tree length radii extending from the location of the tree to the floodplain. The probability of a falling tree entering the floodplain is calculated as the ratio of the floodplain-intersecting angle (2α) to all angles (360° or 2π radians).

Equation G-6

$$probability = \frac{2\alpha}{2\pi}$$

From figure G-7, it follows that

Equation G-7

$$\cos(\alpha) = \frac{distance\ to\ floodplain}{tree\ height}$$

Equation G-8

$$\alpha = cos^{-1}\left(\frac{distance\ to\ floodplain}{tree\ height}\right)$$

Substituting this value for α in Eq. G-3 yields:

Equation G-9

$$probability = \frac{cos^{-1}\left(\frac{distance\ to\ floodplain}{tree\ height}\right)}{\pi}$$

As shown in Figure G-10, The large woody debris area of influence was divided into nine intervals: the 100-year floodplain; and eight 25-foot-wide distance bands. Forest stands located within the floodplain were assigned a recruitment probability of 1, indicating they are always capable of recruiting wood to the floodplain. Forest stands located in the eight 25-foot wide distance bands were assignd a recruitment probability based on tree height and distance to the floodplain, using Equation G-9. Forest stands whose tree height is less than their distance to the floodplain were assigned a recruitment probability of 0.

The distance to the floodplain was set as the midpoint of each band. For example, stands in 0-25 foot band were treated as if they were located 12.5 feet from the floodplain. Tree height was based on the forest estate model[4] projections of the average height of the 40 largest diameter trees in the stand (known as TOP40 height).

Area Weighting (Aw)

Each analysis polygon within the area of influence was assigned an area-weight, which represented it's area as a proportion of the total area within the area of influence for the given reach (Figure G-12f).

Equation G-10. Area Weight

$$Aw_i = \frac{Area_i}{\sum_{i=1}^{n} Area_i}$$

Reach-level Recruitment Potential

For each analysis polygon in the area of influence, DNR calculated the product of the recruitment potential ratings (Q), the recruitment probability (Pr), and the area weight (Aw). The products were summed for all analysis polygons in the area of influence. This calculation was performed for each alternative at each decade.

The process was repeated using the minimum thresholds of DNR's RDFC, as specified in Table 2 (p.9) of DNR's Riparian Forest Restoration Strategy (Bigley and Deisenhofer 2006). The value was then reported as a percentage of the recruitment provided by stands meeting RDFC (Equation G-11).

Equation G-11

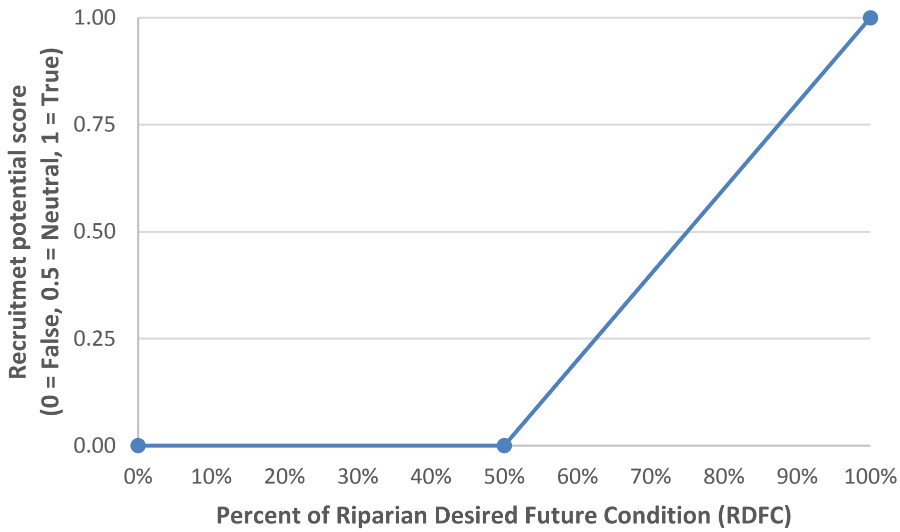
$$\frac{\sum_{i=1}^{n}(Q(alternative, decade)_i * Pr(alternative, decade)_i * Aw_i)}{\sum_{i=1}^{n}(Q(RDFC)_i * Pr(RDFC)_i * Aw_i)}$$

The percentage of RDFC was then normalized to a value of 0 (low) to 1 (high) using a fuzzy curve based on the professional judgment of DNR's scientific staff (Table G-10, Chart G-2).

Table G-10. Large Woody Debris Recruitment Potential Fuzzy Curve

Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
Large woody debris recruitment potential	Percentage of LWD recruitment provided by a stand meeting RDFC	<50% 75% ≥100%	0.0 false 0.5 neutral 1.0 true	Professional judgment of DNR scientific staff

Chart G-2. Large Woody Debris Recruitment Potential Fuzzy Curve



A summary of the workflow used to calculate the reach-level large woody debris recruitment potential is shown graphically in Figure G-12.

Figure G-12. Workflow Used to Calculate Large Woody Debris Recruitment Potential

a) The large woody debris area of influence for each stream reach was defined as the 100-year floodplain plus an additional distance equal to one site potential tree height (approximated as 200 feet). Using a GIS process known as Euclidean Allocation, this area was assigned to the closest stream reach. The area outside of the 100-year floodplain was divided into 25-foot wide distance bands.

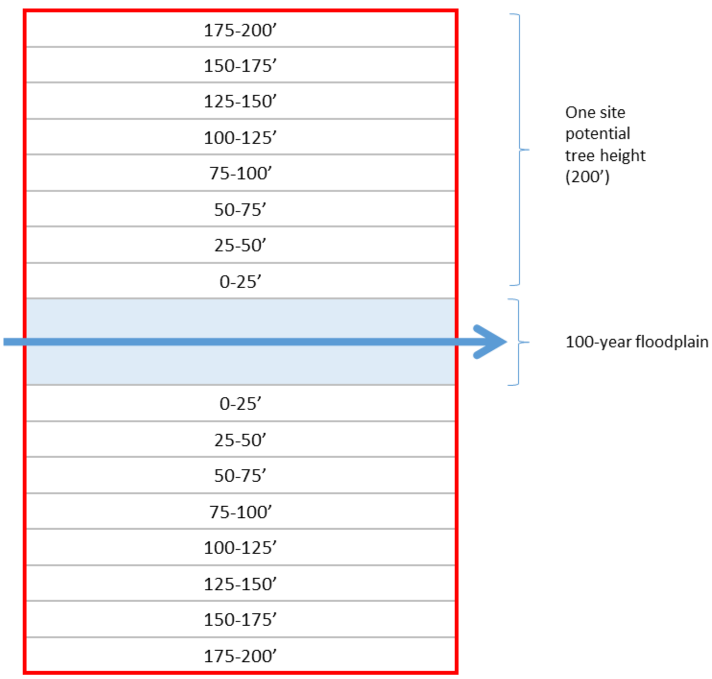
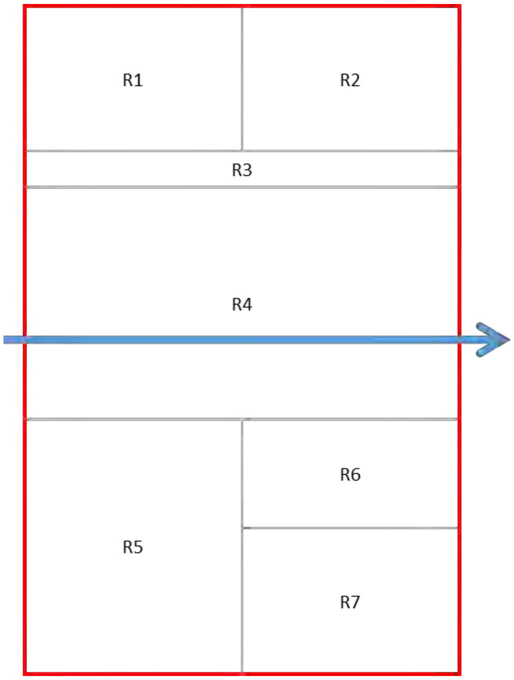


Figure G-12. (continued)

b) Stand-level projections of forest conditions within the area of influence were represented using a forest estate model[4]. Each record within the forest estate model[4] was assigned a unique identifier, known as the REMSOFT ID.



c) A GIS overlay of the floodplain/distance bands and REMSOFT polygons was used to create individual analysis polygons within the area of influence. Each analysis polygon was assigned a unique identifier (known as the OBJECTID).

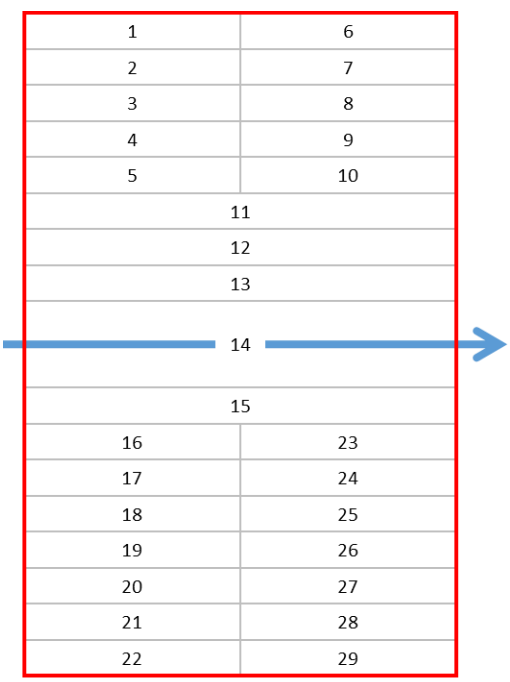


Figure G-12. (continued)

d) A large woody debris recruitment potential rating (Q) was calculated for each analysis polygon, based on its riparian condition code as described in tables G-5 through G-8. The recruitment potential rating ranged from 0 (low) to 1 (high).

1: Q(CMS) = 0.5	6: Q(CSD) = 0.3
2: Q(CMS) = 0.5	7: Q(CSD) = 0.3
3: Q(CMS) = 0.5	8: Q(CSD) = 0.3
4: Q(CMS) = 0.5	9: Q(CSD) = 0.3
5: Q(CMS) = 0.5	10: Q(CSD) = 0.3
11:Q(n/a) = 0	
12: Q(MMD) = 0.6	
13: Q(MMD) = 0.6	
14: Q(MMD) = 0.6	
15: Q(MMD) = 0.6	
16: Q(CSD) = 0.3	23: Q(CLD) = 1.0
17: Q(CSD) = 0.3	24: Q(CLD) = 1.0
18: Q(CSD) = 0.3	25: Q(CLD) = 1.0
19: Q(CSD) = 0.3	26: Q(CLD) = 1.0
20: Q(CSD) = 0.3	27: Q(CLD) = 1.0
21: Q(CSD) = 0.3	28: Q(CLD) = 1.0
22: Q(CSD) = 0.3	29: Q(CLD) = 1.0

e) The recruitment probability (Pr) for each analysis polygon was calculated as a function of tree height and distance to the floodplain [Pr = f(tree height, distance to floodplain)] using Equation G-6. Recruitment probability was 1 for analysis polygons located within the floodplain and 0 for any whose distance from the floodplain exceeds the tree height.

1: Pr(107, 187.5) = 0	6: Pr(107, 187.5) = 0
2: Pr(107, 162.5) = 0	7: Pr(107, 162.5) = 0
3: Pr(107, 137.5) = 0	8: Pr(107, 137.5) = 0
4: Pr(107, 112.5) = 0	9: Pr(107, 112.5) = 0
5: Pr(107, 87.5) = 0.20	10: Pr(107, 87.5) = 0.20
11: Pr(0, 62.5) = 0	
12: Pr(139, 37.5) = 0.41	
13: Pr(139, 12.5) = 0.47	
14: Pr(139, 0) = 1	
15: Pr(139, 12.5) = 0.47	
16: Pr(110, 37.5) = 0.39	23: Pr(160, 37.5) = 0.42
17: Pr(110, 62.5) = 0.31	24: Pr(160, 62.5) = 0.37
18: Pr(110, 87.5) = 0.21	25: Pr(160, 87.5) = 0.32
19: Pr(110, 112.5) = 0	26: Pr(137, 112.5) = 0.19
20: Pr(110, 137.5) = 0	27: Pr(137,137.5) = 0
21: Pr(110, 162.5) = 0	28: Pr(137, 162.5) = 0
22: Pr(110, 187.5) = 0	29: Pr(137, 187.5) = 0

Figure G-12. (continued)

f) Each analysis polygon was assigned a weighting factor (Aw) based on its area as a proportion of the total area of the area of influence for the given reach. In this example, the area of influence for this reach measured 3.17 acres.

1: Aw = 0.09/3.17 = 0.03	6: Aw = 0.09/3.17 = 0.03
2: Aw = 0.09/3.17 = 0.03	7: Aw = 0.09/3.17 = 0.03
3: Aw = 0.09/3.17 = 0.03	8: Aw = 0.09/3.17 = 0.03
4: Aw = 0.09/3.17 = 0.03	9: Aw = 0.09/3.17 = 0.03
5: Aw = 0.09/3.17 = 0.03	10:Aw = 0.09/3.17 = 0.03
11: Aw = 0.17/3.17 = 0.05	
12: Aw = 0.17/3.17 = 0.05	
13: Aw = 0.17/3.17 = 0.05	
14: Aw = 0.41/3.17 = 0.13	
15: Aw = 0.17/2.17 = 0.05	
16: Aw = 0.09/3.17 = 0.03	23: Aw = 0.09/3.17 = 0.03
17: Aw = 0.09/3.17 = 0.03	24: Aw = 0.09/3.17 = 0.03
18: Aw = 0.09/3.17 = 0.03	25: Aw = 0.09/3.17 = 0.03
19: Aw = 0.09/3.17 = 0.03	26: Aw = 0.09/3.17 = 0.03
20: Aw = 0.09/3.17 = 0.03	27: Aw = 0.09/3.17 = 0.03
21: Aw = 0.09/3.17 = 0.03	28: Aw = 0.09/3.17 = 0.03
22: Aw = 0.09/3.17 = 0.03	29: Aw = 0.09/3.17 = 0.03

g) For each analysis polygon, the recruitment rating (Q), recruitment probability (Pr), and area weight (Aw) were multiplied together. This product was summed for all analysis polygons in the area of influence for the given reach.

1: Q x Pr x Aw = 0	6: Q x Pr x Aw = 0
2: Q x Pr x Aw = 0	7: Q x Pr x Aw = 0
3: Q x Pr x Aw = 0	8: Q x Pr x Aw = 0
4: Q x Pr x Aw = 0	9: Q x Pr x Aw = 0
5: Q x Pr x Aw = 0.0027	10: Q x Pr x Aw = 0.0016
11: Q x Pr x Aw = 0	
12: Q x Pr x Aw = 0.0135	
13: Q x Pr x Aw = 0.0154	
14:. Q x Pr x Aw = 0.0783	
15: Q x Pr x Aw = 0.0154	
16: Q x Pr x Aw = 0.0032	23: Q x Pr x Aw = 0.0115
17: Q x Pr x Aw = 0.0025	24: Q x Pr x Aw = 0.0101
18: Q x Pr x Aw = 0.0017	25: Q x Pr x Aw = 0.0086
19: Q x Pr x Aw = 0	26: Q x Pr x Aw = 0.0053
20: Q x Pr x Aw = 0	27: Q x Pr x Aw = 0
21: Q x Pr x Aw = 0	28: Q x Pr x Aw = 0
22: Q x Pr x Aw = 0	29: Q x Pr x Aw = 0

$$\sum Q * \mathrm{Pr} * Aw = 0.1696$$

Figure G-12. (continued)

h) The process was repeated using forest conditions that meet the minimum specifications of the Riparian Desired Future Condition (RDFC) as described in Table 2 (p.9) of DNR's Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006). The recruitment potential rating and the recruitment probability will be different when using RDFC conditions, but the area weight is the same.

1: Q(CLD) = 1.0	6: Q(CLD) = 1.0
2: Q(CLD) = 1.0	7: Q(CLD) = 1.0
3: Q(CLD) = 1.0	8: Q(CLD) = 1.0
4: Q(CLD) = 1.0	9: Q(CLD) = 1.0
5: Q(LD) = 1.0	10: Q(CLD) = 1.0
11:Q(CLD) = 1.0	
12: Q(CLD) = 1.0	
13: Q(CLD) = 1.0	
14: Q(CLD) = 1.0	
15: Q(CLD) = 1.0	
16: Q(CLD) = 1.0	23: Q(CLD) = 1.0
17: Q(CLD) = 1.0	24: Q(CLD) = 1.0
18: Q(CLD) = 1.0	25: Q(CLD) = 1.0
19: Q(CLD) = 1.0	26: Q(CLD) = 1.0
20: Q(CLD) = 1.0	27: Q(CLD) = 1.0
21: Q(CLD) = 1.0	28: Q(CLD) = 1.0
22: Q(CLD) = 1.0	29: Q(CLD) = 1.0

X

1: Pr(112, 187.5) = 0	6: Pr(112, 187.5) = 0
2: Pr(112, 162.5) = 0	7: Pr(112, 162.5) = 0
3: Pr(112, 137.5) = 0	8: Pr(112, 137.5) = 0
4: Pr(112, 112.5) = 0	9: Pr(112, 112.5) = 0
5: Pr(112, 87.5) = 0.22	10: Pr(112, 87.5) = 0.22
11: Pr(112, 62.5) = 0.31	
12: Pr(112, 37.5) = 0.39	
13: Pr(112, 12.5) = 0.46	
14: Pr(112, 0) = 1	
15: Pr(112, 12.5) = 0.46	
16: Pr(112, 37.5) = 0.39	23: Pr(112, 37.5) = 0.39
17: Pr(112, 62.5) = 0.31	24: Pr(112, 62.5) = 0.31
18: Pr(112, 87.5) = 0.22	25: Pr(112, 87.5) = 0.22
19: Pr(112, 112.5) = 0	26: Pr(112, 112.5) = 0
20: Pr(112, 137.5) = 0	27: Pr(112,137.5) = 0
21: Pr(112, 162.5) = 0	28: Pr(112, 162.5) = 0
22: Pr(112, 187.5) = 0	29: Pr(112, 187.5) = 0

X

1: Aw = 0.09/3.17 = 0.03	6: Aw = 0.09/3.17 = 0.03
2: Aw = 0.09/3.17 = 0.03	7: Aw = 0.09/3.17 = 0.03
3: Aw = 0.09/3.17 = 0.03	8: Aw = 0.09/3.17 = 0.03
4: Aw = 0.09/3.17 = 0.03	9: Aw = 0.09/3.17 = 0.03
5: Aw = 0.09/3.17 = 0.03	10:Aw = 0.09/3.17 = 0.03
11: Aw = 0.17/3.17 = 0.05	
12: Aw = 0.17/3.17 = 0.05	
13: Aw = 0.17/3.17 = 0.05	
14: Aw = 0.41/3.17 = 0.13	
15: Aw = 0.17/2.17 = 0.05	
16: Aw = 0.09/3.17 = 0.03	23: Aw = 0.09/3.17 = 0.03
17: Aw = 0.09/3.17 = 0.03	24: Aw = 0.09/3.17 = 0.03
18: Aw = 0.09/3.17 = 0.03	25: Aw = 0.09/3.17 = 0.03
19: Aw = 0.09/3.17 = 0.03	26: Aw = 0.09/3.17 = 0.03
20: Aw = 0.09/3.17 = 0.03	27: Aw = 0.09/3.17 = 0.03
21: Aw = 0.09/3.17 = 0.03	28: Aw = 0.09/3.17 = 0.03
22: Aw = 0.09/3.17 = 0.03	29: Aw = 0.09/3.17 = 0.03

=

1: Q x Pr x Aw = 0	6: Q x Pr x Aw = 0
2: Q x Pr x Aw = 0	7: Q x Pr x Aw = 0
3: Q x Pr x Aw = 0	8: Q x Pr x Aw = 0
4: Q x Pr x Aw = 0	9: Q x Pr x Aw = 0
5: Q x Pr x Aw = 0.0059	10: Q x Pr x Aw = 0.0059
11: Q x Pr x Aw = 0.0170	
12: Q x Pr x Aw = 0.0213	
13: Q x Pr x Aw = 0.0252	
14: . Q x Pr x Aw = 0.1304	
15: Q x Pr x Aw = 0.0252	
16: Q x Pr x Aw = 0.0106	23: Q x Pr x Aw = 0.0106
17: Q x Pr x Aw = 0.0085	24: Q x Pr x Aw = 0.0085
18: Q x Pr x Aw = 0.0059	25: Q x Pr x Aw = 0.0059
19: Q x Pr x Aw = 0	26: Q x Pr x Aw = 0
20: Q x Pr x Aw = 0	27: Q x Pr x Aw = 0
21: Q x Pr x Aw = 0	28: Q x Pr x Aw = 0
22: Q x Pr x Aw = 0	29: Q x Pr x Aw = 0

$$\sum Q * \mathrm{Pr} * Aw = 0.2809$$

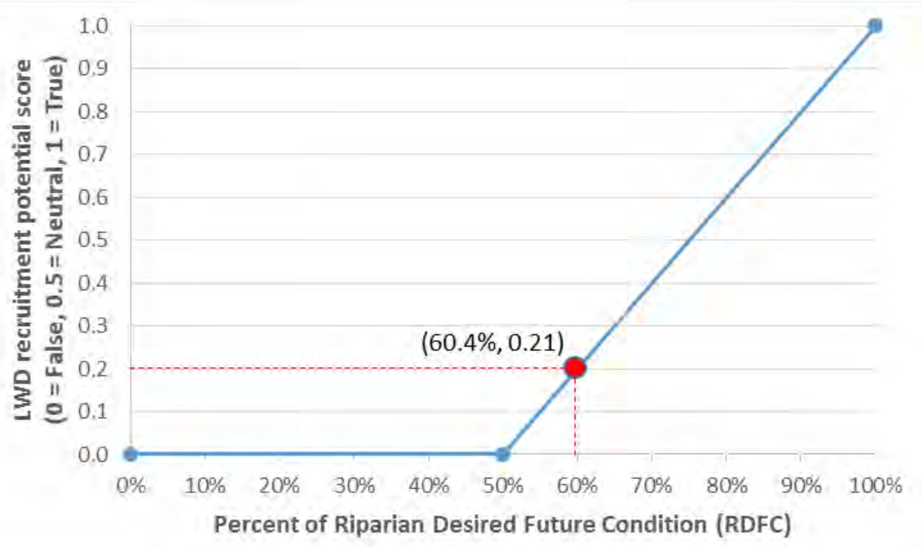
Figure G-12. (continued)

i) The sum was reported as a percentage of RDFC

$$\frac{projected\ conditions\ for\ each\ alternative\ at\ each\ decade}{Riparian\ Desired\ Future\ Condition\ (RDFC)}$$

$$= \frac{\sum(Q * \mathrm{Pr}* Aw)_{\ alternative,decade}}{\sum(Q * \mathrm{Pr}* Aw)_{RDFC}} = \frac{0.1696}{0.2809} = 60.4\ \%\ of\ RDFC$$

j) The percentage of RDFC was converted to a recruitment POTENTIAL score ranging from 0 (low) to 1 (high) using the fuzzy curve shown in Chart G-2. In this example, 60.4% of RDFC corresponds to a recruitment POTENTIAL score of 0.21.



How was the Large Woody Debris Channel Sensitivity Rating Assigned?

Each stream reach was assigned a large woody debris channel sensitivity rating representing the expected channel response to changes in the input of large woody debris. The sensitivity rating was qualitative or categorical in nature (“low”, “medium”, “high”), taken from watershed analyses that were performed (either initiated or completed and approved) in the OESF per Forest Practices rules. For stream reaches for which watershed analyses were not available, DNR based the sensitivity rating on gradient and confinement (Table G-12).

Gradient is the steepness of the stream grade, and confinement is based on the ratio of the stream width to the floodplain width. Since response types are determined by valley conditions, their location and morphology tend to remain constant over time frames important to forest management. Response types are assumed to remain static under all alternatives for the duration of the 100-year model simulation.

Gradient was used as a surrogate for stream energy, the dominant control on channel morphology. Confinement controls aspects of the response and reflects the long-term history of a valley where past events, such as glaciation, leave an imprint. For instance, a wide shallow channel will have a different response to large woody debris input than would a deep narrow channel. Gradient and confinement also are general indicators of transport capacity. Lacking more detailed information about specific channels, we may expect those with similar gradient and confinement to respond similarly to changes regarding input variables.

The degree to which large woody debris influences channel form and function determines the channel sensitivity rating. While almost all channels respond to woody debris to a certain degree (and could therefore be considered "sensitive"), the approach used here is to characterize stream channels based on their relative sensitivity, that is, their sensitivity compared to one another regarding the specific input. Descriptions of the large woody debris channel sensitivity ratings are provided in Table G-11.

Table G-11. Large Woody Debris Channel Sensitivity Ratings

Adapted from OWEB (1999).

Sensitivity Rating (Qualitative)	Sensitivity Rating (Numerical)	Description
Low	0.0	Large woody debris is not considered a roughness element. Woody often found only along channel margins.
Medium	0.5	Large woody debris is one of a number of roughness elements present, and contributes to pool formation and gravel sorting.
High	1.0	Large woody debris is critical in the maintenance of channel form and pool formation, gravel trapping and sorting, and bank protection.

The ratings shown in Table G-12 were developed from a review of the available watershed analyses. Reach-level gradient and confinement classifications were approximated from either topographic maps, remotely-sensed data, or digital elevation models. All streams (Type 1 through 9 waters) were assigned a large woody debris sensitivity rating. Reaches lacking gradient or confinement data, namely smaller headwater Type 4 and 5 channels not previously assigned a SSHIAP identifier, were assigned a medium sensitivity to large woody debris.

Table G-12. Large Woody Debris Sensitivity Ratings Based on Channel Gradient and Confinement

	Gradient (percent)					
Confinement	**< 1.0**	**1.0 – 2.0**	**2.0 – 4.0**	**4.0 – 8.0**	**8.0 – 20.0**	**> 20.0**
Unconfined	Low	Medium	High	High	High	*
Moderately confined	Medium	High	High	High	Medium	Medium
Confined	Medium	High	High	High	Medium	Medium

How was the Watershed Score for Large Woody Debris Calculated?

Within each Type 3 watershed, the watershed score for large woody debris was calculated as an area-weighted sum of each stream reach score for large woody debris using Equation G-12.

Equation G-12. Watershed Score

Where the Variable i Is Used to Index the n Reaches Within Each Type 3 Watershed

$$\frac{\sum_{i=1}^{n} stream\ reach\ score_i\ x\ length_i\ x\ width_i}{\sum_{i=1}^{n} length_i\ \ x\ width_i}$$

The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for large woody debris was assigned a qualitative rating of high impact (0 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Impacts to Large Woody Debris Assessed Across the Entire OESF?

Impacts to large woody debris across the entire OESF were assessed by examining the set or distribution of watershed scores for large woody debris for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of scores (Table G-2).

(2) Leaf and Needle Litter Recruitment

What is Leaf and Needle Litter and why is it Important?

The term *leaf and needle litter* refers to fine organic material such as leaves and tree needles that grow in the forest canopy and fall to the ground or into stream channels. In aquatic systems, some vegetative organic materials (such as algae) originate within the stream while others (such as leaf and needle litter) originate from sources outside the stream. Stream benthic communities are highly dependent on materials from both sources; leaf and needle litter can provide up to 60 percent of the total metabolic energy of the stream community (Richardson 1992). The abundance and diversity of aquatic species can vary significantly, depending upon the total and relative amounts of algae, leaf, and litter inputs to a stream. The health of the small aquatic insect community is important because it is a primary food source for fish (Reiser and Bjornn 1979).

The source and level of organic debris input can change over time in a riparian forest stand. For example, as a riparian forest stand ages, the amount of litter-fall increases (IMST 1999). Another important consideration is the relative contribution of conifer and hardwood litter to the aquatic ecosystem. Although the majority of forest practice regulations pertaining to forest management and wood in streams stress the importance of conifers for their longevity, resistance to breakage, and contribution to physical habitat, many hardwoods provide litter inputs that have higher nutrient value and are more readily broken down than conifer litter (Bisson and Wondzell 2009).

How was the Stream Reach Score for Leaf and Needle Litter Calculated?

The stream reach score for leaf and needle litter was calculated by combining the reach-level leaf and needle litter recruitment potential and the reach-level leaf and needle litter channel sensitivity rating using Equations G-1 and G-3. The stream reach score was intended to quantify not only the condition of leaf and needle litter recruitment along the given reach, but also the relative importance of leaf and needle litter input as a source of nutrient input to that reach. The stream reach score is directly proportional to the `POTENTIAL` and inversely proportional to the `SENSITIVITY`. That is, the score is lowest (indicating a high impact) along highly sensitive reaches with low potential (likelihood) for large woody debris recruitment, and increases as conditions improve.

Which Streams were Included in the Analysis?

All streams located on DNR-managed lands (regardless of type) and any streams (regardless of type or ownership) whose leaf and needle litter area of influence extended onto DNR-managed lands were included in the reach-level analysis. Watershed scores, however, were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

What was the Configuration of the Leaf and Needle Litter Area of Influence?

The area of influence for leaf and needle litter was identical to that used for the large woody debris. It included the 100-year floodplain plus an additional distance equivalent to one site potential tree height (200 ft) (Table G-13). The area of influence was divided into eight 25-foot-wide distance bands (measured horizontally). The area that contributes to any specific stream reach was determined using the ArcGIS Euclidean allocation function. Each reach-level area of influence was further subdivided by the individual REMSOFTID polygons used to represent the records in the spatial data set for the forest estate model[4].

Table G-13. Width of Area Analyzed for Leaf and Needle Litter Contribution
All Distances Measured Horizontally, Along Each Side of the Stream Channel

Stream type (modified State Trust Lands water type)	100-year floodplain along each side of the stream (feet)	Site-potential tree height (feet)	Total width of analysis area along each side of the stream (feet)
1	150	200	350
2	30	200	230
3	15	200	215
4	3.75	200	203.75
5	0	200	200
9	0	200	200

How was Leaf and Needle Litter Recruitment Potential Measured?

DNR assessed the ability of the riparian zone to supply leaf and needle litter to the floodplain by examining riparian forest composition and structure within the area of influence. DNR considered three factors, described below: litterfall production (Q), recruitment probability (Pr), and the area of the analysis polygon (A).

DNR performed the calculation using decadal (0-9) projections of forest conditions for each alternative (No Action, Landscape) and using the minimum thresholds of DNR's RDFC, as specified in Table 2 (p.9) of DNR's Riparian Forest Restoration Strategy (Bigley and Deisenhofer 2006).

The recruitment potential for each alternative at each decade was then converted to a percentage of the recruitment provided by stands meeting RDFC, and normalized to a scale of 0 to 1 using a fuzzy curve.

Litterfall Production (Q)

DNR estimated litterfall production for each analysis polygon within the leaf and needle litter area of influence based on methods developed by O'Keefe and Naiman (2006). Their studies of litter inputs at sites along the Queets River, in Olympic National Park determined that basal area of individual tree species is a significant predictor of leaf and needle litter production. O'Keefe and Naiman developed separate models for various components of litterfall (e.g., leaf litter vs. needle litter). DNR calculated the overall rate of leaf and needle litter production for each analysis polygon as the sum of leaf litter (Equation G-13) and needle litter (Equation G-14). Values were reported as an annual rate of litterfall per unit area (Mg ha^{-1} yr^{-1}) .

Equation G-13. Leaf litter production (Mg ha^{-1} yr^{-1}), as a function of tree species and basal area
Values for basal area in units of m^2 ha^{-1}. O'Keefe and Naiman (2006).

$$Leaf\ litter = 0.3485 + 0.1255 * red\ alder\ basal\ area$$

Equation G-14. Needle litter production (Mg ha^{-1} yr^{-1}), as a function of tree species and basal area. Values for basal area in units of m^2 ha^{-1}. O'Keefe and Naiman (2006).

$$Needle\ litter = 0.2219 + 0.05018 * Sitka\ spruce\ basal\ area + 0.03107 * Western\ hemlock\ basal\ area$$

Equations G-13 and G-14 require basal area by species as input. However, the forest estate model[4] only reports total basal area and forest composition (the proportion of the stand basal area classified as conifer, on a scale of 0 to 1). To determine the conifer basal area, DNR multiplied the total basal area by the forest composition. For the litter analysis, conifer basal area was assumed to consist entirely of Western hemlock; Sitka spruce basal area was set to zero for all analysis polygons. Hardwood basal area was calculated as basal area times (1 – forest composition), assumed to consist entirely of red alder.

The forest estate model[4] reports basal area for all trees greater than or equal to 3.5 inches dbh in units of ft^2 ac^{-1}, which DNR converted to m^2 ha^{-1} using Equation G-15.

Equation G-15. Conversion of basal area from ft^2 ac^{-1} to m^2 ha^{-1}

$$basal\ area\left(\frac{m^2}{ha}\right) = basal\ area\left(\frac{ft^2}{ac}\right) * \frac{1\ m^2}{10.76391042\ ft^2} * \frac{2.471053815\ ac}{1\ ha}$$

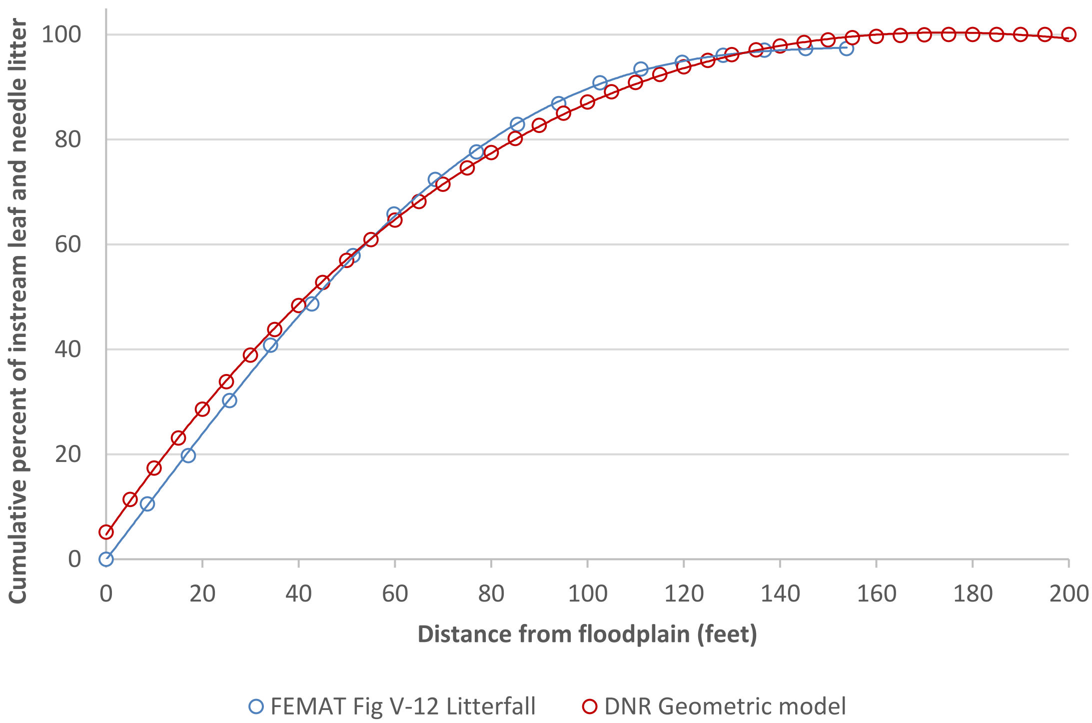
RDFC litterfall production was calculated using Equation G-14, using a western hemlock basal area of 300 ft^2 ac^{-1}.

Recruitment Probability (Pr)

Data on the diminishing contribution of leaf and needle litter with increasing source distance is limited. DNR based its analysis on source distance relationships presented in Figure V-12 of FEMAT (1993). Leaf and needle litter recruitment is generally thought to occur within one tree height of the stream channel, but declines sharply at distances greater than one-half a tree height. For this analysis, DNR assumed a site potential tree height of 200 feet.

DNR manually interpreted a series of coordinates along the curve shown in Figure V-12 of FEMAT (1993), then developed a geometric model to estimate the probability of litterfall contribution to the floodplain designed to fit the interpreted FEMAT coordinates. DNR's geometric model estimated the recruitment probability as a function of litterfall dispersal distance (itself a function of tree height) and distance from the floodplain. The FEMAT litterfall curve and the corresponding DNR geometric model are shown in Chart G-3.

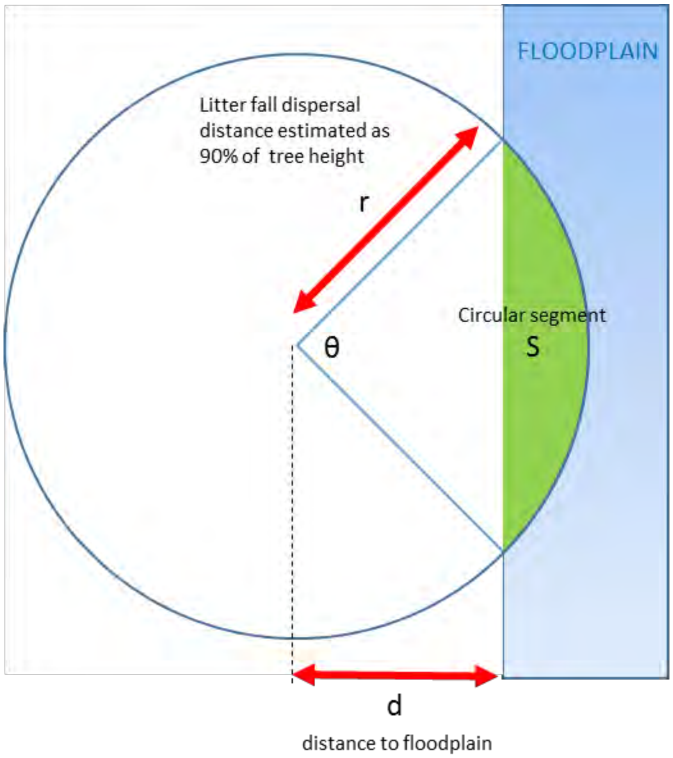
Chart G-3. Generalized Curves of Litterfall Recruitment as a Function of Distance from the Stream Channel
Assumes 200 foot site potential tree height. Blue line: litterfall curve adapted from Figure V-12, FEMAT (1993). Red line: litterfall geometic model developed by DNR, parameterized to approximate FEMAT (1993).



For its geometic model, DNR represented litterfall dispersal as a circle centered on the source tree, whose radius varied with tree height. The probability of leaf and needle litter entering the floodplain was calculated as the percentage of the dispersal circle that intersects the floodplain. That is, the recruitment probability was calculated as the ratio of the area of the cicular segment, s, to the area of a circle with a radius equal to the litterfall dispersal distance, r (Figure G-13). DNR modeled the litterfall dispersal distance as 90 percent of tree height. This value was selected because it resulted in a high correlation (r^2 = 0.99) with the curve shown in Fig V-12 of FEMAT (1993).

For Type 5 and 9 streams, which were modeled as lacking a floodplain, DNR estimated the probability of litterfall recruitment to the stream channel itself, assumed to be 2 feet wide.

Figure G-13. Modeling Leaf and Needle Litter Contribution as a Function of Source Distance



Equation G-16.

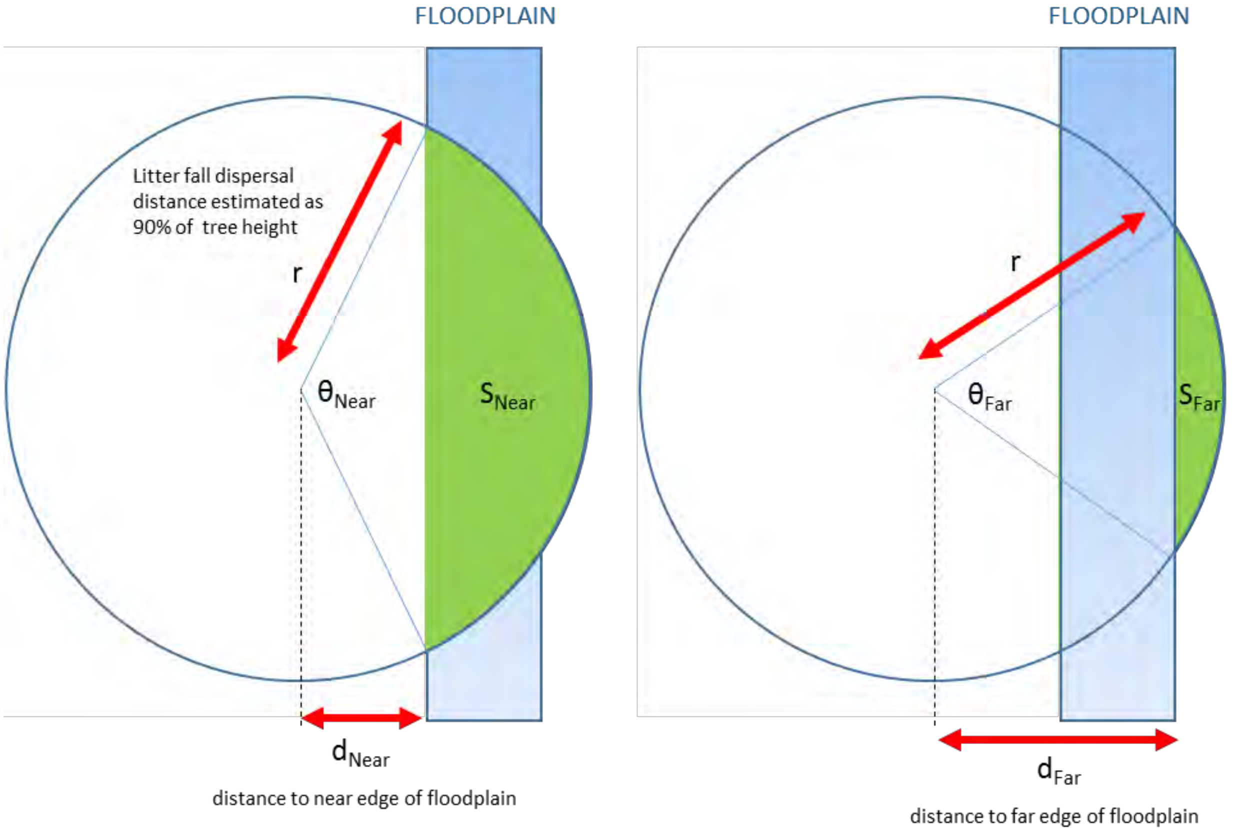
$$\theta = cos^{-1}\left(\frac{distance\ to\ floodplain}{litterfall\ dispersal\ distance}\right) = cos^{-1}\left(\frac{d}{r}\right)$$

Equation G-17.

$$\mathrm{Pr} = \frac{area\ of\ cicular\ segment}{area\ of\ circle} = \frac{\frac{r^2(\theta - \sin\theta)}{2}}{\pi r^2}$$

The recruitment probability was calculated separately for each analysis polygon in the leaf and needle litter area of influence. The methodology varied depending on whether the analysis polygon was inside or outside of the floodplain. For analysis polygons located outside of the floodplain, three configurations are possible: 1) the dispersal circle may not intersect the floodplain, in which case, the recruitment probability is zero; 2) it may intersect the floodplain as shown in Figure G-13; or 3) it may span the entire floodplain and emerge on the far side as shown in Figure G-14. In such case, the probability of recruitment to the floodplain was calculated as the probability of recruitment to the near circular segment, S_{Near}, minus the probability of recruitment to the far circular segment, S_{Far}.

Figure G-14. Modeling Leaf and Needle Litter Contribution as a Function of Source Distance



Equation G-18.

$$Pr(Floodplain) = Pr(S_{Near}) - Pr(S_{Far})$$

Equation G-19.

$$\theta_{Near} = cos^{-1}\left(\frac{d_{Near}}{r}\right), \qquad \theta_{Far} = cos^{-1}\left(\frac{d_{Far}}{r}\right)$$

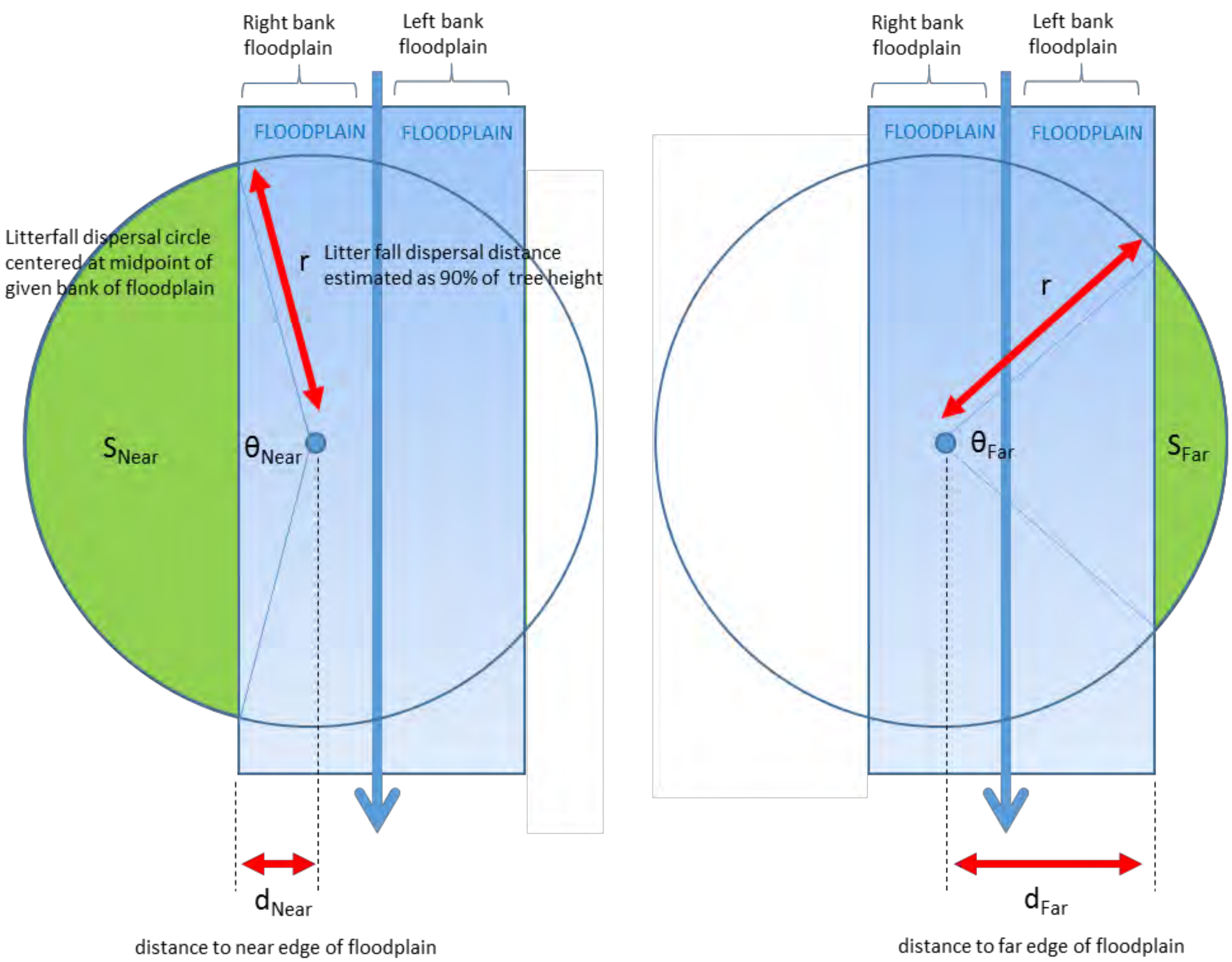
Equation G-20.

$$Pr(S_{Near}) = = \frac{\frac{r^2(\theta_{Near} - sin\ \theta_{Near})}{2}}{\pi r^2}, \quad Pr(S_{Far}) = = \frac{\frac{r^2(\theta_{Far} - sin\ \theta_{Far})}{2}}{\pi r^2}$$

For analysis polygons located within the floodplain, DNR calculated the recruitment probability as if the dispersal circle were centered on the midpoint of the given bank of the floodplain. For example, DNR modeled the floodplain of Type 1 streams as 150 feet wide along each side (bank) of the stream channel (300 feet total). The dispersal circle for an analysis polygon located on the right bank would be located 75 feet from the near edge of the floodplain, 75 feet from the stream channel, and 225 feet (75 + 150) from the far edge of the floodplain.

Depending on the width of the floodplain and the height of the source tree, the dispersal circle may be located entirely within the floodplain, in which case the recruitment probability is 1; or it may extend beyond either or both sides of the floodplain. In which case, the recruitment probability was calculated as 1 minus the probability of recruiting to the near circular segment, SNear, minus the probability of recruiting to the far circular segment, SFar (Equation G-21).

Figure G-15. Modeling Leaf and Needle Litter Contribution as a Function of Source Distance



Equation G-21.

$$Pr(Floodplain) = 1 - Pr(S_{Near}) - Pr(S_{Far})$$

RDFC recruitment probability was calculated assuming a tree height of 112.3 feet, which is the estimated height of a 21 inch dbh western hemlock tree (Equation G-5, Table G-9).

Area (A)

As with large woody debris, the leaf and needle litter recruitment potential was calculated separately for each analysis polygon in the area of influence. Litter production, as calculated using Equations G-13 and

G-14. was reported in Mg ha^{-1} yr^{-1}, which DNR coverted to Mg yr^{-1} by multiplying by the area of each analysis polygon (A) (see discussion below).

Reach-level Recruitment Potential

For each analysis polygon in the area of influence, DNR calculated the product of the litter production (Q), the recruitment probability (Pr), and the area (A). The products were summed for all analysis polygons in the area of influence. This calculation was performed for each alternative at each decade.

The process was repeated using the minimum thresholds of DNR's RDFC, as specified in Table 2 (p.9) of DNR's Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006). The value was then reported as a percentage of the recruitment provided by stands meeting RDFC (Equation G-22).

Equation G-22.

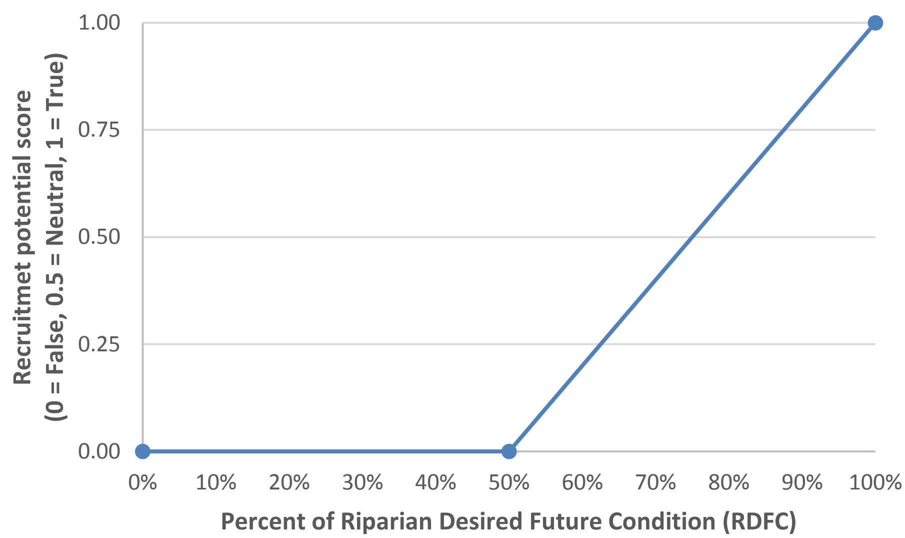
$$\frac{\sum_{i=1}^{n}(Q(alternative, decade)_i * Pr(alternative, decade)_i * A_i)}{\sum_{i=1}^{n}(Q(RDFC)_i * Pr(RDFC)_i * A_i)}$$

The reach-level recruitment `POTENTIAL`, as a percentage of RDFC, was then normalized to a value of 0 (low) to 1 (high) using a fuzzy curve based on the professional judgment of DNR's scientific staff (Table G-14, Chart G-4).

Table G-14. Leaf and Needle Litter Recruitment Potential Fuzzy Curve

Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
Leaf and needle litter recruitment potential	Percentage of leaf and needle litter recruitment provided by a stand meeting RDFC	<50% 75% ≥100%	0.0 false 0.5 neutral 1.0 true	Professional judgment of DNR scientific staff

Chart G-4. Leaf and Needle Litter Recruitment Potential Fuzzy Curve



How was the Leaf and Needle Litter Channel Sensitivity Rating Assigned?

Each stream reach was assigned a leaf and needle litter channel sensitivity rating based on stream type. Leaf and needle litter recruitment is especially important in small, headwater streams where it can provide the majority of the total metabolic energy for the stream community (Richardson 1992), and the sensitivity rating takes this into account. Type 1 and 2 streams were assigned a low sensitivity rating, Type 3 streams a medium sensitivity rating, and Type 4, 5, and 9 (unclassified) streams a high sensitivity rating.

Table G-15. Leaf and Needle Litter Channel Sensitivity Ratings

Stream type (modified State Trust Lands water type)	Leaf and needle litter channel sensitivity rating (qualitative)	Leaf and needle litter channel sensitivity rating (numerical)
1, 2	Low	0.0
3	Medium	0.5
4, 5, 9	High	1.0

How was the Watershed Score for Leaf and Needle Litter Calculated?

Within each Type 3 watershed, the watershed score for leaf and needle litter was calculated as an area-weighted sum of the stream reach scores for leaf and needle litter using Equation G-12.

The area of each reach was calculated as its length times its width. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for leaf and needle litter recruitment was assigned a qualitative rating of high impact (0.00 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Impacts to Leaf and Needle Litter Assessed Across the Entire OESF?

Impacts to leaf and needle litter across the entire OESF were assessed by examining the set or distribution of watershed scores for leaf and needle litter for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of scores (Table G-2).

(3) Coarse Sediment Delivery

Note: Additional analyses of coarse sediment delivery may also be found in the FEIS Soils section (refer to the indicators Landslide Potential and Road Failure). The analysis of coarse sediment delivery described in this appendix was conducted so that the indicator may be incorporated into the composite watershed score. For compatibility with the watershed composite score, this analysis was performed at finer scales (the stream reach and Type 3 watershed) than the analyses performed in Soils (the Watershed Administrative Unit and the Landscape Planning Unit).

This analysis is unique among the riparian indicators in that it does not change over time; all input data were held static. As part of the assumptions used to create the forest estate model[4], the location of unstable slopes and the extent of the stream and road networks were held constant. Nor did the input data vary by proposed management alternative. As a result of these assumptions, the coarse sediment delivery potential for each Type 3 watershed was calculated using the current condition of each of the input data set. The resulting calculated value for each watershed was used for both alternatives and all time periods when incorporated into the composite watershed score.

What is Coarse Sediment and why is it Important?

Sediment is typically described according to the size of its constituent particles. While descriptions of particle size can be somewhat subjective, the term coarse sediment usually describes material ranging in size from small rocks and gravel to boulders.

Coarse sediment is primarily delivered to the riparian system by landslides. Landslides, either naturally occurring or influenced by management activities (such as timber harvests or the construction and operation of logging roads), can have a dramatic effect on salmon and their habitat. These events can add great quantities of material (including large woody debris and both coarse and fine sediments) to the stream network. Material transported or deposited by landslides can bury and suffocate fish (including eggs, juveniles, and adults) or flush them downstream. On a larger scale, sediment delivered by landslides may entirely block stream channels and prevent fish passage (Meehan and Swanston 1977). Landslides can also reshape stream channels and affect the movement, distribution, and composition of spawning gravels, thereby reducing the quantity of or restricting access to suitable habitat (Swanston 1980, Cederholm and others 1979). In some cases, landslides completely scour stream channels and riparian zones, leaving streams in a highly unproductive state, at least for the near future (IMST 1999).

It is important to note, however, that not all landslides result in the transport of material to streams, and when they do, the consequences vary. Landslides are an important source of spawning material and can significantly enhance fish habitat by adding structural complexity (IMST 1999).

How was the Stream Reach Score for Coarse Sediment Delivery Calculated?

The stream reach score for coarse sediment delivery was calculated by combining the Type 3 watershed-level coarse sediment delivery `POTENTIAL` and the reach-level coarse sediment delivery channel `SENSITIVITY` using Equations G-1 and G-3.

The stream reach score is intended to quantify not only the likelihood for coarse sediment delivery within the watershed, but also the expected channel response to that delivery. The score is inversely proportional to likelihood of sediment delivery and the channel sensitivity. That is, the stream reach score is lowest (indicating a high impact) along highly sensitive reaches within watersheds with a high likelihood of sediment delivery (low `POTENTIAL`[3]). The stream reach score increases (indicating lower impact) as conditions improve.

Which Streams Were Included in the Analysis?

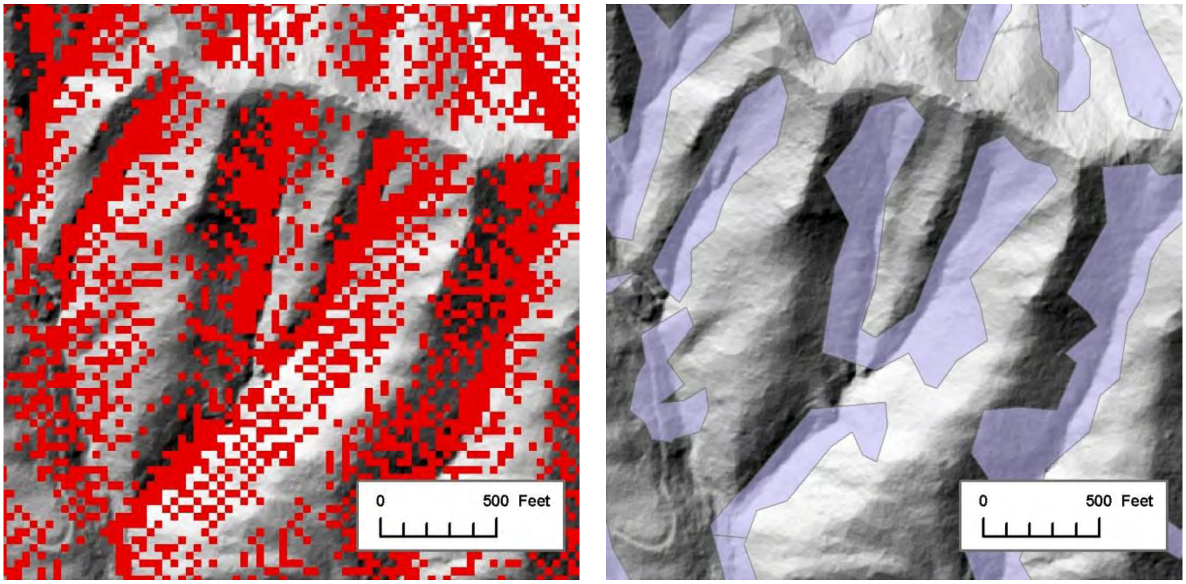
All streams, regardless of type or ownership, located within Type 3 watersheds containing DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

How was the Coarse Sediment Delivery Potential Measured?

Since the area of influence for coarse sediment delivery was considered “hydrologically-based” (versus “proximity-based”), coarse sediment delivery `POTENTIAL` was calculated at the watershed-level (versus reach-level) for each Type 3 watershed. The potential (likelihood) for coarse sediment delivery within each Type 3 watershed was assessed using an index of three factors considered indicative of the potential for road-related slope failure: 1) the percent of each Type 3 watershed classified as unstable, 2) the density of road-stream crossings, and 3) the extent of roads on unstable slopes. The selection of these parameters was patterned after a similar analysis recommended by Gallo and others (2005).

A proprietary DNR data set known as “TRISMORPH” was used to assess the percent of each Type 3 watershed classified as unstable. TRISMORPH applies an iterative, three-pass averaging algorithm (3 x 3 focal mean) to DNR’s slope stability model, known as SLPSTAB. SLPSTAB is a predictive data layer of shallow-rapid slope stability, itself constructed from multiple GIS-based terrain analyses using 10 meter digital elevation models (SMORPH and SHALSTAB), and coupled with additional information such as landslide inventories, soil properties, geology, and precipitation. TRISMORPH was initially calculated as a 10 meter raster, from which a smoothed (simplified) vector layer was produced.

Figure G-16. Comparison of Data Sources Used to Identify Unstable Slopes
SLPSTAB (Left) and TRISMORPH (Right). The same area is shown in each panel.



The percent of each Type 3 watershed classified as unstable was calculated using Equation G-23. All area within each watershed was evaluated, regardless of ownership. The value was reported on a unitless scale of 0 to 100.

Equation G-23. Percent of Waterhsed Unstable

$$percent\ watershed\ unstable = \frac{acres\ of\ unstable\ slopes\ within\ each\ watershed}{watershed\ area\ in\ acres}\ x\ 100$$

The density of road-stream crossings was reported as a count of crossings per stream mile, calculated from an intersection of DNR’s transportation data layer (ROPA.ROAD) with DNR’s hydrography (SHARED_LM.OESF_HYDRO), divided by the stream length within the Type 3 watershed in question (Equation G-24). The hydro data layer was first queried to remove non-stream arcs. All road-stream crossings within each watershed were evaluated, regardless of ownership. The value was reported as a count of crossings per stream mile.

Equation G-24. Road-Stream Crossing Density

$$density\ of\ road\ stream\ crossings = \frac{number\ of\ road\ stream\ crossings}{stream\ miles\ within\ watershed}$$

Road density on unstable slopes was calculating using the intersection of DNR’s transportation data layer with the slope stability data layer, TRISMORPH. For each Type 3 watershed, road density was reported as miles of road located on unstable slopes per square mile of watershed. All roads on unstable slopes were evaluated, regardless of ownership. The value was reported as miles of road per square mile of watershed.

Equation G-25. Road Density on Unstable Slopes

$$road\ density\ on\ unstable\ slopes = \frac{miles\ of\ roads\ on\ unstable\ slopes}{watershed\ area\ in\ square\ miles}$$

A fuzzy curve was applied to each parameter based on a review of the literature (Gallo and others 2005) or consultation with DNR scientific staff (Hanel, personal communication 2011) (Table G-16, Charts G-5 through G-7).

Table G-16. Coarse Sediment Delivery Potential Fuzzy Curves

Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
Percent of each Type 3 watershed classified as unstable	Percent	0 ≥20	1 true 0 false	Professional judgment of DNR scientific staff (Hanel, personal communication 2011)
Road-stream crossing density	Number of crossings per stream mile	0 ≥4	1 true 0 false	Gallo and others (2005)
Road density on unstable slopes	Miles of road per square mile of watershed	0 ≥0.5	1 true 0 false	Modified from Gallo and others (2005)

Chart G-5. Coarse Sediment Delivery Potential Fuzzy Curve: Percent of Watershed Unstable

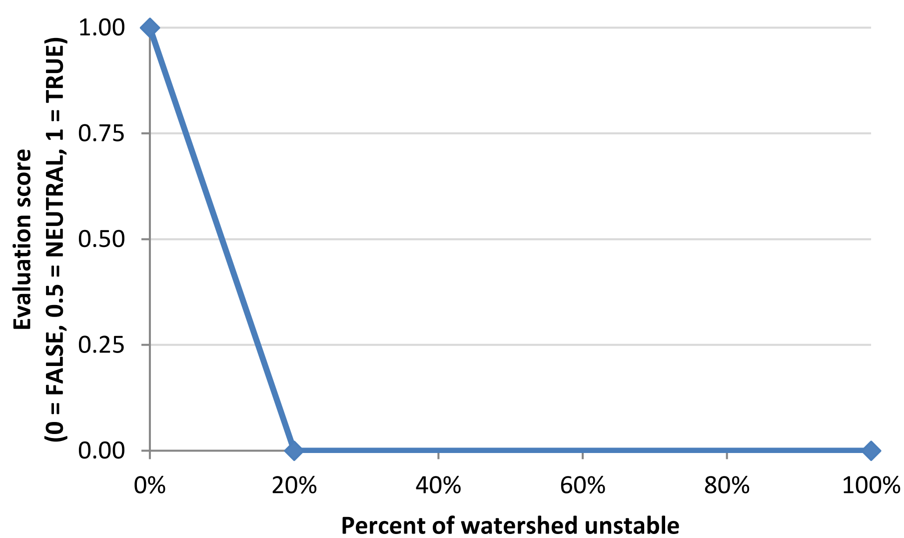


Chart G-6. Coarse Sediment Delivery Potential Fuzzy Curve: Road-Stream Crossing Density

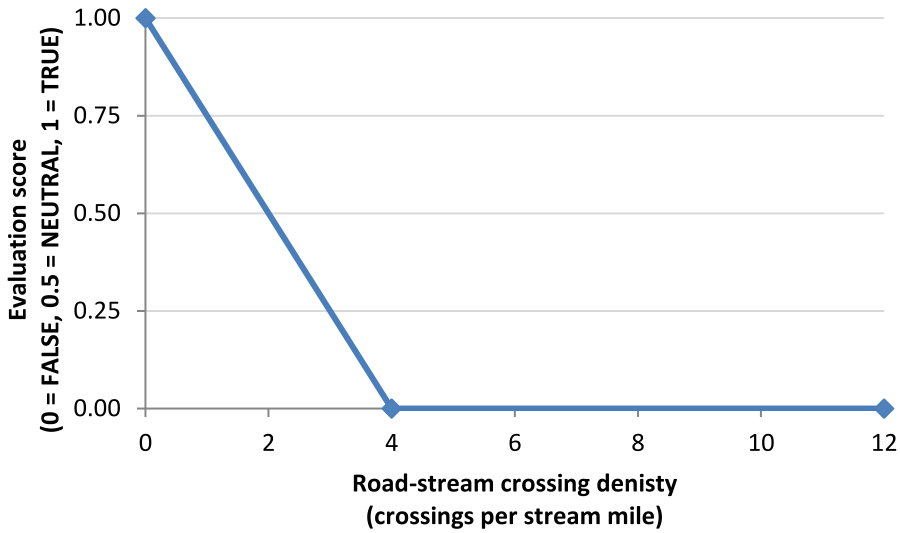
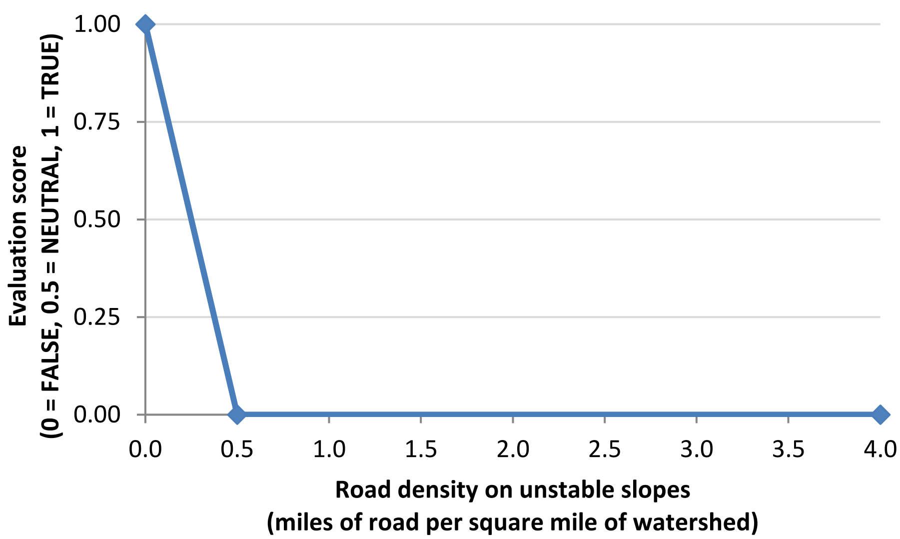


Chart G-7. Coarse Sediment Delivery Potential Fuzzy Curve: Road Density on Unstable Slopes



An aggregated coarse sediment delivery `POTENTIAL` rating was calculated for each Type 3 watershed by combining the three input parameters using the fuzzy AND logical operator (Equation G-26). The fuzzy AND operator will evaluate to 0 if any of the input parameters are 0, and will evaluate to 1 only if all input parameters are 1. For all other cases, fuzzy AND evaluates to an intermediate value designed to produce a conservative estimate in the presence of missing or partial negative evidence, and is strongly weighted toward the minimum value. Each parameter was normalized using its corresponding fuzzy curve prior to applying the AND operator.

Equation G-26. Fuzzy AND operator
Source: NetWeaver, Rules of Thumb, Inc. http://help.netweaver.rules-of-thumb.com/

$$AND\ (x_1, x_2, \dots\ x_n) = \left(\overline{x} - min(x_1, x_2, \dots\ x_n)\right) * min(x_1, x_2, \dots\ x_n)$$

All input data were held static. As part of the assumptions used to create the forest estate model[4], the location of unstable slopes and the extent of the stream and road networks were held constant. Nor did the input data vary by proposed management alternative. As a result of these assumptions, the coarse sediment delivery `POTENTIAL` for each Type 3 watershed was calculated using the current condition of each of the input data set; the resulting value for each watershed was used for both alternatives and all time periods.

How was the Coarse Sediment Delivery Channel Sensitivity Rating Assigned?

Each stream reach was assigned a coarse sediment delivery channel sensitivity rating. The sensitivity rating was used to represent the expected channel response to changes in the input of coarse sediment. The sensitivity rating provides an assessment of the degree to which coarse sediment delivery influences channel form and function and the relative ability of the given stream reach to either transport or store coarse sediment. The sensitivity rating was qualitative or categorical in nature ("low", "medium", "high"), taken from watershed analyses that were performed (either initiated or completed and approved) in the OESF per Forest Practices rules. Descriptions of the coarse sediment delivery channel sensitivity ratings are provided in Table G-17.

Table G-17. Coarse Sediment Delivery Channel Sensitivity Ratings
Adapted From (OWEB 1999)

Sensitivity Rating (Qualitative)	Sensitivity Rating (Numerical)	Description
Low	0.0	Coarse sediment is only temporarily stored. Most coarse sediment is transported through with little impact.
Medium	0.5	Coarse sediment delivery results in a slight change in overall morphology, such as localized widening and shallowing.
High	1.0	Bedload deposition is the dominant active channel process. Coarse sediment delivery results in a general decrease in substrate size, channel widening, or a conversion to plane-bed morphology.

For stream reaches for which watershed analyses were not available, DNR based the sensitivity rating on physical channel and floodplain characteristics as identified by gradient and confinement (Table G-18). These ratings were developed from a review of available watershed analyses. Reach-level gradient and confinement classifications were approximated from either topographic maps, remotely-sensed data, or digital elevation models .

Table G-18. Coarse Sediment Delivery Sensitivity Ratings Based on Channel Gradient and Confinement

	Gradient (percent)					
Confinement	**< 1.0**	**1.0 – 2.0**	**2.0 – 4.0**	**4.0 – 8.0**	**8.0 – 20.0**	**> 20.0**
Unconfined	Medium	High	High	High	Medium	*
Moderately confined	Medium	High	High	High	Medium	Medium
Confined	Low	Medium	High	Medium	Medium	Medium

* Shaded cells represent non-existent conditions.

Reaches lacking gradient or confinement data, namely smaller headwater Type 4 and 5 channels not previously assigned a SSHIAP identifier, were assigned a medium sensitivity to coarse sediment delivery. These channels are usually transport reaches for coarse sediment, although lower-energy sections can retain sediment and adjust channel dimensions. When the supply of coarse sediment surpasses the transport capabilities of the stream, pools are filled and the influence of large boulders, wood, and bedrock control structures is lessened. Minor channel widening or scour can occur (OWEB 1999).

How was the Watershed Score for Coarse Sediment Delivery Calculated?

Within each Type 3 watershed, the watershed score for coarse sediment delivery was calculated as an area-weighted sum of the stream reach scores for coarse sediment delivery using Equation G-12.

The area of each reach was calculated as its length x width. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for coarse sediment delivery was assigned a qualitative rating of high impact (0.00 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Impacts From Coarse Sediment Delivery Assessed Across the Entire OESF?

Since the modeling assumptions for coarse sediment delivery held the input parameters (location of unstable slopes and the extent of the stream and road networks) static, the method used to assess coarse sediment delivery impacts across the OESF only considered the current distribution of watershed scores. for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). No change in the distribution occured over time.

(4) Fine Sediment Delivery

What is Fine Sediment and why is it Important?

The term *fine sediment* refers to small soil particles, such as sand, silt or clay, generally less than two millimeters (approximately 1/16th of an inch) in diameter. Fine sediment is generated from the interaction of water and exposed soil (such as harvest units, skid trails and roads). There are several ways that fine sediment can be delivered to the riparian system, including erosion of stream banks (Megahan 1982, Scrivener 1988 as cited in DNR 1996); landslides (Cederholm and Reid 1987); water flowing across the land surface (a process called overland flow) (Comerford and others 1992 as cited in DNR 1997a); or from road-associated features such as ditches and culverts that drain near the stream channel (DNR 1997a). Studies in the OESF found roads to be a major source of management-related stream sediment (Cederholm and Reid 1987).

Increased levels of fine sediment can have detrimental effects to both water quality and aquatic habitat. Increased fine sediment can result in filling of pools and a loss of overall habitat complexity. As particles of silt, clay, and other organic materials settle to the streambed, they can suffocate newly hatched fish larvae (Cederholm and Reid 1987) and fill in spaces between rocks which could have been used by aquatic organisms as habitat (Cederholm and Reid 1987, Cederholm and others 1979). Fine particulate material also can clog or damage sensitive gill structures, decrease fish resistance to disease, prevent proper egg and larval development, and potentially interfere with feeding activities.

Increased levels of fine sediment can also reduce the populations of small aquatic insects, an important food source for salmon (Cederholm and Reid 1987). For an addition discussion of fine sediment and its effects on fish, refer to "Fish."

How was the Stream Reach Score for Fine Sediment Delivery Calculated?

The stream reach score for fine sediment delivery was calculated by combining the fine sediment delivery `POTENTIAL` (calculated at the Type 3 watershed level) and the fine sediment delivery channel `SENSITIVITY` (calculated at the reach level). The `POTENTIAL` and `SENSITIVITY` were combined using Equations G-1 and G-3.

The stream reach score was intended to quantify not only the likelihood for fine sediment delivery within the watershed, but also the expected channel response to that delivery. The score is inversely proportional to the likelihood of sediment delivery and the channel sensitivity. That is, the stream reach score is lowest (indicating a high impact) along highly sensitive reaches with a high likelihood for sediment delivery (low `POTENTIAL`[3]). The stream reach score increases as conditions improve.

Which Streams were Included in the Analysis?

All streams, regardless of type or ownership, located within Type 3 watersheds containing DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

How was Fine Sediment Delivery Potential Measured?

Since the area of influence for fine sediment delivery was considered "hydrologically-based" (versus "proximity-based"), fine sediment delivery `POTENTIAL` was calculated at the watershed-level (versus reach-level). Within each Type 3 watershed, the likelihood for fine sediment delivery was estimated based on an analysis of characteristics of the road network (such as surface type and proximity to streams or water bodies) and projected traffic levels. The analysis is identical to that used to calculate the "traffic impact score" described in Appendix C, Water Quality, with the exception that it is calculated and reported at the Type 3 watershed level instead of the Landscape Planning Unit.

The analysis of projected traffic levels is based on the location, extent, and intensity of proposed harvests under each alternative. As such, it is an analysis of future conditions. No comparable data exists on current traffic levels across all ownerships for all road segments on the OESF. To compensate for the lack of current data, decade 1 results were also used to represent current conditions for the purpose of calculating the composite watershed score. That is, decade 1 results were used twice: first, to represent current conditions (decade 0) and second, to represent decade 1 conditions.

How was the Fine Sediment Delivery Channel Sensitivity Rating Assigned?

Each stream reach was assigned a fine sediment delivery channel sensitivity rating. The sensitivity rating was used to represent the expected channel response to changes in the input of fine sediment. The sensitivity rating provides an assessment of the degree to which fine sediment delivery influences channel form and function and the relative ability of the given stream reach to either transport or store fine sediment. The sensitivity rating was qualitative or categorical in nature (low, medium, high), taken from watershed analyses that were performed (either initiated or completed and approved) in the OESF per Forest Practices rules. Descriptions of the fine sediment delivery channel sensitivity ratings are provided in Table G-19.

Table G-19. Fine Sediment Delivery Channel Sensitivity Ratings
Adapted From (OWEB 1999)

Rating (Qualitative)	Rating (Numerical)	Description
Low	0.0	Fine sediment is only temporarily stored. Most fine sediment is transported through with little impact.
Medium	0.5	Increased fine sediment delivery results in minor pool filling and bed fining.
High	1.0	Fine sediment is readily stored. Increased fine sediment results in widespread pool filling and loss of overall bed form complexity.

For stream reaches for which watershed analyses were not available, DNR based the sensitivity ratings on physical channel and floodplain characteristics as identified by gradient and confinement (Table G-20). These ratings were developed from a review of available watershed analyses. Reach-level gradient and confinement classifications were approximated from either topographic maps, remotely-sensed data, or digital elevation models .

Table G-20. Fine Sediment Delivery Sensitivity Ratings Based on Channel Gradient and Confinement

	Gradient (percent)					
Confinement	**< 1.0**	**1.0 – 2.0**	**2.0 – 4.0**	**4.0 – 8.0**	**8.0 – 20.0**	**> 20.0**
Unconfined	High	High	High	Medium	Low	
Moderately confined	High	High	High	Medium	Low	Low
Confined	Medium	High	Medium	Low	Low	Low

* Shaded cells represent non-existent conditions.

Reaches lacking gradient or confinement data, namely smaller headwater Type 4 and 5 channels not previously assigned a SSHIAP identifier, were assigned a low sensitivity to fine sediment delivery. Stream confinement and higher gradients combine to produce enough stream energy to route most introduced fine sediment downstream (OWEB 1999).

How was the Watershed Score for Fine Sediment Delivery Calculated?

Within each Type 3 watershed, the watershed score for fine sediment delivery was calculated as an area-weighted sum of the stream reach scores for fine sediment delivery using Equation G-12.

The area of each reach was calculated as its length times its width. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for fine sediment delivery was assigned a qualitative rating of high impact (0.00 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Impacts From Fine Sediment Delivery Assessed Across the Entire OESF?

Impacts from fine sediment delivery across the entire OESF were assessed by examining the set or distribution of watershed scores for fine sediment delivery for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of scores (Table G-2).

(5) Water Quantity (Peak Flow)

What is Peak Flow and Why is it Important?

The term *peak flow* refers to periods of high stream flow or maximum discharge, usually associated with storm events. In the Pacific Northwest, peak flows often coincide with humid, winter storms where rain falls on top of an existing snowpack (commonly known as “rain-on-snow” events) (Pentec Environmental, Inc. 1997)

While there are many aspects to how water flows through the riparian area that are relevant to land managers, such as low flow or total water yield, peak flows are of particular concern because of the effects they can have on stream channels and in-stream habitat. Excessive peak flows can produce dramatic changes in the shape and function of the stream channel. Significant changes in either the magnitude or frequency of peak flow events can lead to long-term damage to riparian ecosystems and the loss of salmon habitat. Peak flow events can destabilize and transport large woody debris, fill pools with sediment, and destroy the nests (known as "redds") where salmon lay their eggs. Peak flows can transform complex stream channels containing large woody debris and composed of pools, riffles, and side channels into simple, more uniform channels with limited salmon habitat value (DNR 1997b). For additional discussion of the nature of such impacts, refer to the "Fish" section of the FEIS.

In general, land use practices that reduce vegetative cover or increase soil compaction, such as timber harvest and road building, can alter hydrologic processes and increase peak flow. Removal or thinning of the forest canopy affects snow accumulation and melt processes. A closed canopy intercepts a large portion of snowfall, and much of the snow caught in the canopy evaporates or sublimates back to the atmosphere before ever reaching the ground. Constant long-wave radiation from trees, absent in clearings, also melts the snowpack under a forest canopy on a daily basis. Therefore, snow packs tend to be deeper and hold more water in clearings than they do under forest canopies (Troendle 1983; Coffin and Harr 1992).

During humid, windy rainstorms occurring above an existing snowpack, snow melts faster in clearings than it does under a forest canopy. Surprisingly, most snowmelt is not a result of the rain falling on the snow, but instead occurs as energy is transferred into the snowpack from warm, humid winds (Pentec Environmental, Inc. 1997). A forest canopy protects the forest floor from wind and this inhibits snowmelt during a rain-on-snow event.

As a result of these differences in snow accumulation and melt, the snowpack in a clearing tends to hold more water and melt faster during a rain-on-snow event than does a snowpack under forest cover. The total of rainfall and snowmelt is referred to as "water available for runoff." Canopy thinning or removal tends to increase the water available for runoff during rain-on-snow events.

Logging roads can affect a watershed's hydrologic response due to the low permeability of the road surface; rain falling on the road surface does not infiltrate but rather flows over the top of the road surface. This surface flow may run off into ditches and flow directly to channels. This can hasten the delivery of some rain water to channels and can result in storm flows from early fall storms or late spring storms that would not have produced storm flows without the presence of roads. The effect of direct road runoff depends on the density of road coverage, the size of the watershed, and the implementation and effectiveness of mitigating road management practices.

How was the Stream Reach Score for Peak Flow Calculated?

The stream reach score for peak flow was calculated by combining the peak flow `POTENTIAL` (calculated at the Type 3 watershed-level) and the peak flow channel `SENSITIVITY` (calculated at the reach-level).The `POTENTIAL` and `SENSITIVITY` were combined using Equations G-1 and G-3.

The stream reach score is intended to quantify not only the likelihood for elevated peak flows within the watershed, but also the expected channel response to those elevated peak flows. The score is inversely proportional to the likelihood of elevated flows and the channel sensitivity. That is, the stream reach score is lowest (indicating a high impact) along highly sensitive reaches with a high likelihood for elevated flows (low POTENTIAL[3]). The stream reach score increases as conditions improve.

Which Streams Were Included in the Analysis?

All Type 1 through 4 streams, along with any streams with a SSHIAP identifier, located within Type 3 watersheds containing DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

Reach-level impacts for Type 5 and 9 waters lacking a SSHIAP identifier were not analyzed. The contributing basins for Type 5 and 9 waters are smaller than those upon which the modeling equations were based (see discussion below). An assumption of this analysis is that adverse impacts associated with changes in peak flow as a result of harvest will not be manifested at the scale of Type 5 and 9 watersheds. These small, headwater channels have limited floodplains and are capable of passing most high flows without adjustments of the channel (OWEB 1999).

How was Peak Flow Potential Measured?

Since the area of influence for peak flow was considered “hydrologically-based” (versus “proximity-based”), peak flow POTENTIAL was calculated at the watershed-level.

The assessment of hydrologic conditions within each watershed was based on a method developed by Grant and others (2008) to predict the change in peak flow resulting from harvest. Hydrologic effects were evaluated at the Type 3 watershed level. Grant uses the percent of harvest within a watershed to calculate a percent change in peak flow for a given hydrologic zone. A hydrologic zone is a spatial classification that groups the portions of the landscape that share common hydrologic processes such as precipitation type and seasonality, hydraulic conductivity and residence times, and partitioning of surface and subsurface flow (Winter 2001 as cited in Grant and others 2008).

Three hydrologic zones were examined: lowland, rain-dominated, and rain-on-snow (transient snow) zone. The lowland and rain-dominated zones were grouped. The transient snow zone is of particular interest because it represents the geographic region where rain-on-snow events are particularly common during winter months, and such events are potentially affected by timber harvest (Berris and Harr 1987; Christner and Harr 1982; Harr 1986; Jones and Grant 1996; as cited in Grant and others 2008). Hydrologic change as a result of precipitation in the snow-dominated zone was ignored, as precipitation falls primarily as snow and is unlikely to be affected by rain-on-snow events.

Grant and others (2008) found the relationship between percent harvest and percent change in peak flow varies by hydrologic zone (Chart G-8). Linear regressions were developed for each hydrologic zone, using data manually interpreted from Figures 9 and 10 of Grant and others (2008). A minimum bound of zero was used for Equation G-27. Following the recommendations of Grant and others (2008), the mean response line was used for each zone in order to account for variation in harvest intensities.

Equation G-27. Peak Flow Response within the Rain-Dominated Hydrologic Zone

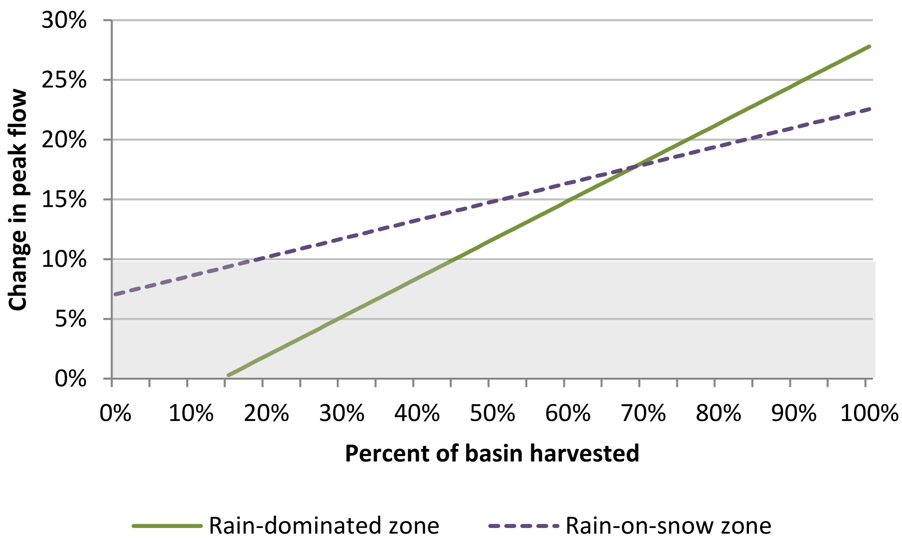
$$\Delta Peak\ Flow_{Rain-dominated\ zone} = 0.3236 * \%\ harvested - 4.5636$$

Equation G-28. Peak Flow Response within the Rain-On-Snow Hydrologic Zone

$$\Delta Peak\ Flow_{Rain-on-Snow\ zone} = 0.1549 * \%\ harvested + 7.0562$$

Chart G-8. Peak Flow Response to Harvest in the Rain-Dominated and Rain-On-Snow Zones

Adapted from Grant and others 2008. Grey shading indicates limit of detection.



Hydrologic immaturity was used as a surrogate for the extent of harvest, with the following areas considered hydrologically immature: 1) stands less than 25 years of age, 2) stands with a Curtis' relative density less than 25, 3) roads.

For DNR-managed lands, hydrologic immaturity was assessed based on projections of forest conditions within each record in the forest estate model[4] (REMSOFTID polygon). Forest conditions were projected at decadal intervals for each management alternative in the forest estate model[4] as stands grow and develop, either in the presence or absence of management activities. Curtis' relative density was calculated using all trees greater than or equal to four inches diameter at breast height (dbh).

The width of the road right-of-way (and therefore the roaded area considered hydrologically immature) varied according to the road classification. Primary and secondary roads were modeled with a 50 foot wide right-of-way; other paved roads, unpaved roads, and mistyped roads were modeled with a 30 foot wide right-of-way.

Hydrologic immaturity for non-DNR managed lands was assessed using remotely-sensed data on forest conditions as compiled in the Gradient Nearest Neighbor (GNN) data set. The GNN is a tool for characterizing vegetation structure and species composition in forested landscapes across large regions by integrating vegetation measurements from regional grids of field plots, mapped environmental data, and Landsat Thematic Mapper (TM) imagery (Ohman and Gregory 2002). The GNN is a product of the Landscape Ecology, Modeling, Mapping, and Analysis team at the USDA Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory. GNN is gridded at a 30 meter resolution.

Curtis' relative density was calculated from GNN attributes BAA_GE_3 and QMDA_GE_3. However, data collection protocols for the GNN are different than those used in the forest estate model[4]. Both GNN parameters used to calculate Curtis' relative density examined all trees greater than or equal to three centimeters dbh, while the forest estate model[4] uses a four inch diameter threshold. No attempt was made to correct for this difference in diameter threshold.

A scalar factor is incorporated into Equation G-29 , to convert BAA_GE_3 from square meters per hectare to square feet per acre, and QMD_GE_3 from centimeters to inches in order to calculate Curtis' relative density.

Equation G-29. Calculation of Curtis' Relative Density for the GNN Data Set

$$Curtis' relative\ density = \frac{basal\ area\ (ft^2 ac^{-1})}{\sqrt{quadratic\ mean\ diameter\ (in)}} = \frac{BAA\_GE\_3(m^2 ha^{-1})}{\sqrt{QMDA\_GE\_3(cm)}} * 11.06424$$

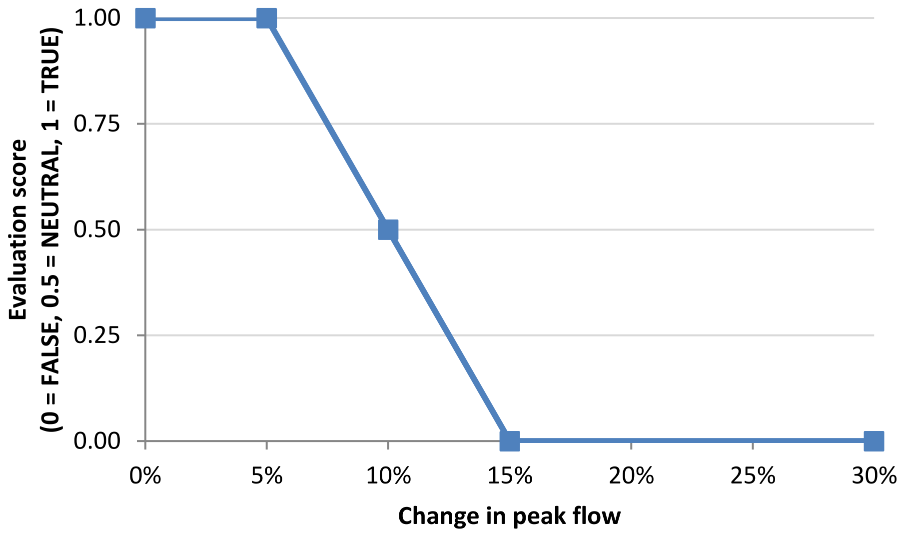
Within each Type 3 watershed, the percent of each hydrologic zone classified as immature was calculated using the sum of immature DNR-managed lands (from the forest estate model[4]) and immature lands for all other ownerships (from the GNN data set). Hydrologic immaturity within DNR-managed lands changed according to projections in the forest estate model[4]. Hydrologic immaturity on all other ownerships was held static, using the values in the GNN as derived from 2006 satellite imagery. The percent of each hydrologic zone classified as immature was converted to a projected percent change in peak flow using Equations G-27 and G-28. An area-weighted sum (based on the proportion of the Type 3 watershed in each hydrologic zone) was used to aggregate the values to the Type 3 watershed. The process was repeated for each management alternative and each time period (decades zero through nine).

A fuzzy curve based on the professional judgment of DNR scientific staff was applied to the calculated percent change in peak flow (Table G-21, Chart G-9). A ten percent change in peak flow was considered the detection limit (Grant and others 2008).

Table G-21. Peak Flow Potential Fuzzy Curves

Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
Percent change in peak flow	Percent	<5 10 ≥15	1 true 0 neutral 1 false	Professional judgment of DNR scientific staff

Chart G-9. Peak Flow Potential Fuzzy Curve



How was the Peak Flow Sensitivity Rating Assigned?

Each stream reach was assigned a peak flow channel sensitivity rating. The sensitivity rating was used to represent the expected channel response to elevated peak flows. The sensitivity rating was qualitative or categorical in nature ("low", "medium", "high"), taken from watershed analyses that were performed (either initiated or completed and approved) in the OESF per Forest Practices rules. Descriptions of the peak flow channel sensitivity ratings are provided in Table G-22.

Table G-22. Peak Flow Channel Sensitivity Ratings
Adapted From OWEB (1999)

Rating (Qualitative)	Rating (Numerical)	Description
Low	0.0	Minimal change in physical channel characteristics. Some scour and fill.
Medium	0.5	Detectable changes in channel form. Minor widening and scour expected.
High	1.0	Nearly all bed material is mobilized. Significant widening or deepening of the channel.

For stream reaches for which watershed analyses were not available, DNR based the sensitivity ratings on physical channel and floodplain characteristics as identified by gradient and confinement (Table G-23). These ratings were developed from a review of available watershed analyses. Reach-level gradient and confinement classifications were approximated from either topographic maps, remotely-sensed data, or digital elevation models .

Table G-23. Peak Flow Delivery Sensitivity Ratings Based on Channel Gradient and Confinement

	Gradient (percent)					
Confinement	**< 1.0**	**1.0 – 2.0**	**2.0 – 4.0**	**4.0 – 8.0**	**8.0 – 20.0**	**> 20.0**
Unconfined	Low	Medium	High	High	Medium	
Moderately confined	Medium	High	High	High	Medium	Low
Confined	Medium	High	High	Medium	Low	Low

* Shaded cells represent non-existent conditions.

How was the Watershed Score for Peak Flow Calculated?

Within each Type 3 watershed, the watershed score for peak flow was calculated as an area-weighted sum of the stream reach scores for peak flow using Equation G-12.

The area of each reach was calculated as its length x width. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for peak flow was assigned a qualitative rating of high impact (0.00 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Peak Flow Impacts Assessed Across the Entire OESF?

Peak flow impacts across the entire OESF were assessed by examining the set or distribution of watershed scores for peak flow for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of watershed scores (Table G-2).

(6) Stream Shade

What is Stream Shade and Why is it Important?

Stream shade refers to the extent to which incoming sunlight is blocked on its way to the stream channel. Stream shade can be provided by either the surrounding vegetation or terrain. Stream shade is one of the primary factors influencing stream temperature (Brown 1969). All aquatic organisms have a temperature range outside of which they cannot exist. Stream temperature also influences water chemistry, which can affect the amount of oxygen present to support aquatic life. Factors that affect shading include stream size, stream orientation, local topography, tree species, stand age, and stand density (DNR 2004).

A variety of thermal process control stream temperature. As a parcel of water flows through a stream reach, its temperature changes as a function of energy and water exchange across the water surface, streambed, and streambank. Factors that influence stream temperature include: long wave radiation exchanges between the forested canopy, atmosphere and water; incident and reflected solar radiation; transfers of sensible and latent heat through turbulent exchange; tributary inflow and mixing; upstream and downstream temperature discharge; bed heat conduction; groundwater inflow; and hyporheic exchange. Moore and others (2005) present an excellent review; a thorough discussion is beyond the scope of this appendix.

As Moore and others (2005) describe, despite decades of research on stream temperature response to forest harvesting, there are still vigorous debates in the Pacific Northwest about the thermal impacts of forestry and how to manage them (Larson and Larson 1996, Beschta 1997, Ice and others 2004, Johnson 2004; as cited in Moore and others 2005). The conventional approach is to retain a forested buffer strip along the stream in an effort to shield streams from an increase in solar radiation, which is one factor driving summertime stream warming (Moore and others 2005).

How was the Stream Reach Score for Stream Shade Calculated?

Unlike the other riparian indicators, the stream reach score for stream shade does not incorporate a sensitivity component. Instead, the stream reach score was based solely on the shade potential. The score is intended to quantify 1) the amount of shade provided to the given reach, 2) whether that shade is adequate to maintain water temperature within the desired range, and, if not, 3) the resulting temperature exceedance and 4) how the exceedance affects fish species associated with the reach in question.

Which Streams Were Included in the Analysis?

All streams located on DNR-managed lands (regardless of type) and any streams (regardless of type or ownership) whose floodplain was located within 200 feet of DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

How was Stream Shade Potential Measured?

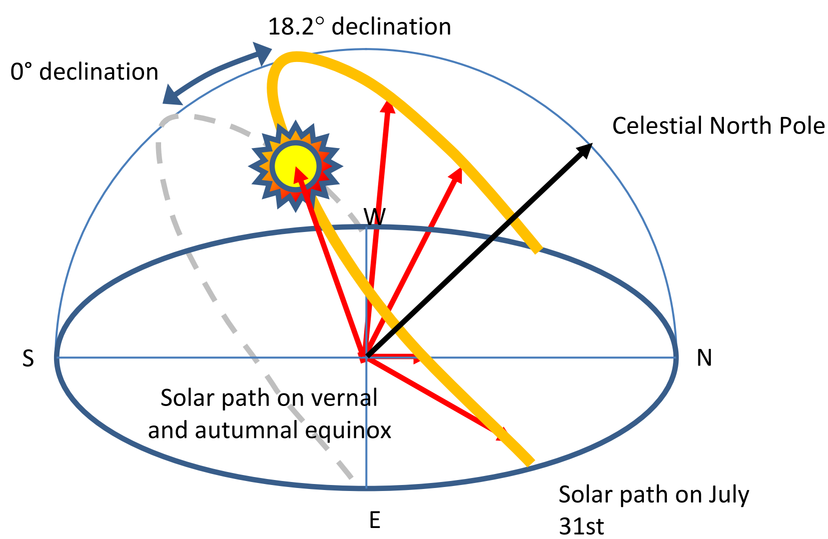
For this analysis, DNR developed a model to assess the level of shading at the stream channel. The shade model determines the degree to which the canopy of the riparian forest and the surrounding topography shield the stream channel from incoming solar radiation using a three-dimensional analysis of the geometry of the surrounding topography and the riparian forest in relation to the channel, the channel orientation and view to sky, and vegetation characteristics such as tree height and canopy density. Chen and others (1998), Welty and others (2002), Comnick and others (2006), and Benda and others (2007) used similar concepts to estimate shade, although none employed a technique that was explicitly informed by local topography.

The total solar radiation that strikes an object has two components: direct-beam radiation and diffuse-beam radiation. Direct-beam radiation is the radiation incident in a direct line from the sun. For sunny days with clear skies, most of the solar radiation is direct-beam. Diffuse radiation consists of direct-beam radiation scattered by matter in the air column such as clouds (water vapor), particulates, or aerosols. Brown (1969), as cited in Welty and others (2002) attributes direct-beam radiation as the primary heat source for streams.

The shade model calculates the total direct-beam solar radiation for each stream reach. Only direct beam radiation was analyzed; diffuse beam radiation was not considered. Solar radiation was calculated at hourly intervals using the sun position on July 31, 2011 for Seattle, Washington. While the longest day of the year occurs on the summer solstice (typically on or around June 21), July 31st was selected for this analysis. Based on a review of approximately 30 years of daily average temperature records for the Clearwater, Quinault, and Forks weather stations archived by the NOAA Western Regional Climate Center, July 31st is the hottest day of the year and therefore the one in which thermal loading to the stream is expected to be at a maximum. Hourly sun elevation and azimuth values were derived from the NOAA Earth Systems Research Laboratory Solar Position Calculator (Figure G-17). Azimuth values were transformed to degrees up from the x-axis; elevation was transformed to degrees up from the horizon (xy-plane). Sunrise at Seattle, WA occurred at 4:45 am, sunset at 7:45 pm Pacific Standard Time on July 31, 2001. The sun was above the horizon during fifteen hourly sun positions from 5:00 am through 7:00 pm (PST).

Figure G-17. Solar Position on July 31, 2011

Hourly position represented by red vectors. Not all intervals shown.



Direct-beam radiation was calculated at "stream sample points" located at 75 foot intervals along each stream reach (n = 270,616 stream sample points) (Figure G-18). Reaches were defined by their SSHIAP segment identifier. Segments lacking a SSHIAP segment identifier were processed by their HYDRO_UID.

The shade model calculated both topographic and vegetative shading. Topographic blocking at each stream sample point was determined by analyzing each of the 15 hourly sun position vectors. Each sun vector was sampled at five meter intervals, beginning at the stream reach and moving outward along the vector to a maximum distance of 250 meters. Each point along the vector was known as a "vector sample point". The height of each vector sample point, was compared to the height of the ground surface directly below. Topographic blocking occurred if any vector sample point along a given vector was below the ground surface. (Figure G-19). A USGS 10 meter digital elevation model was used to represent the ground surface. The elevation of a given point on the digital elevation model was sampled using bilinear interpolation (Gibson and Bailey 2004). Sampling along each sun position vector continued until it was determined to be blocked, or the end of the vector (250 m) was reached.

Figure G-18. Shade Model Sampling Design

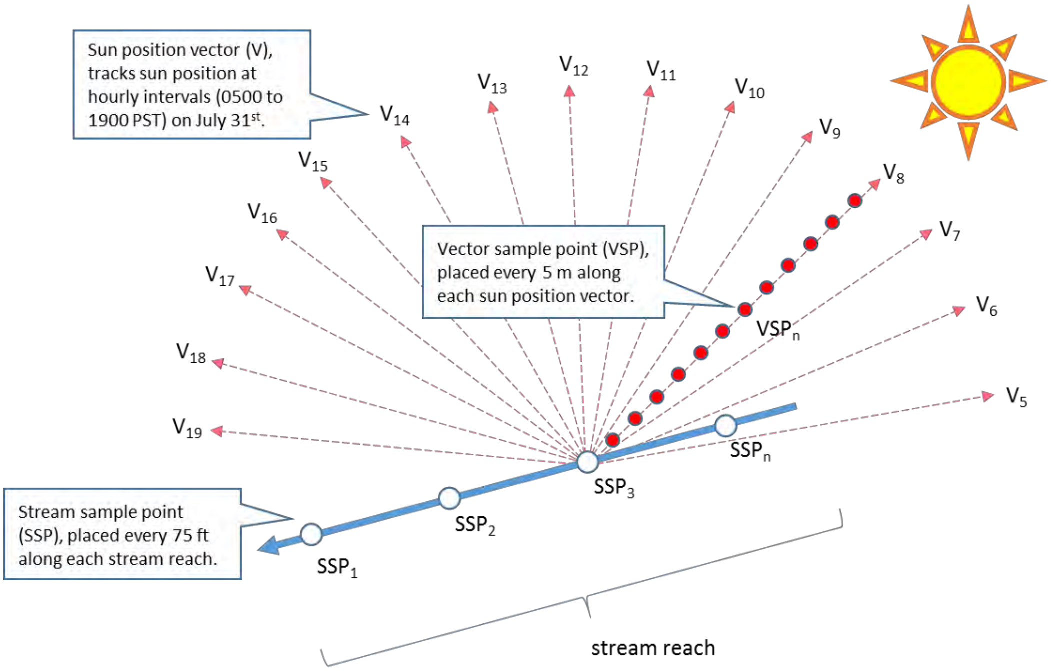


Figure G-19. Topographic Blocking

Hourly sun position vectors shown in orange. Stream sample points shown in red. Topographic blocking occurs at 5 am (PST) for this stream segment (arrow).

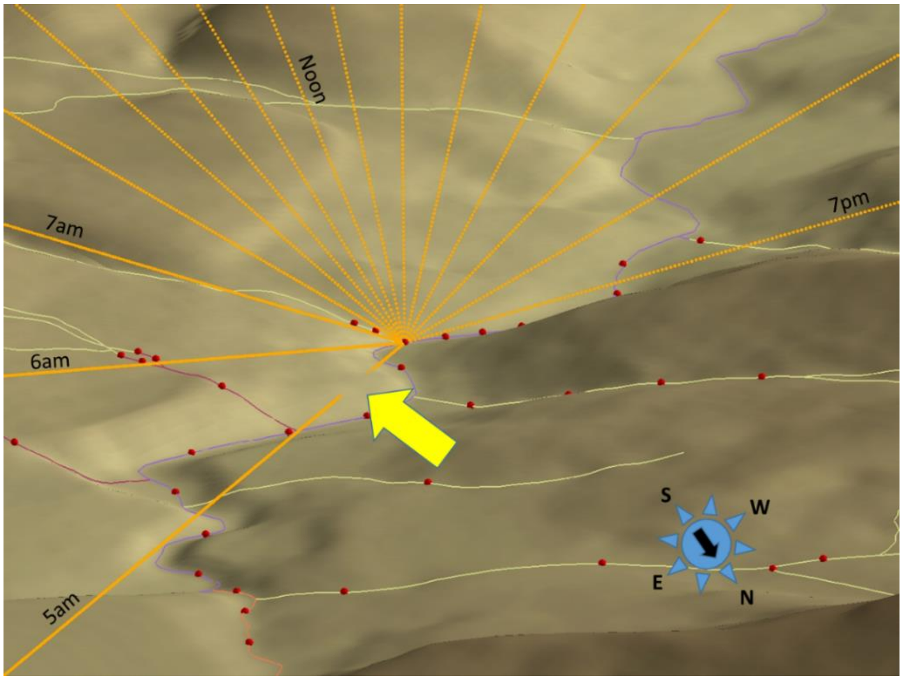
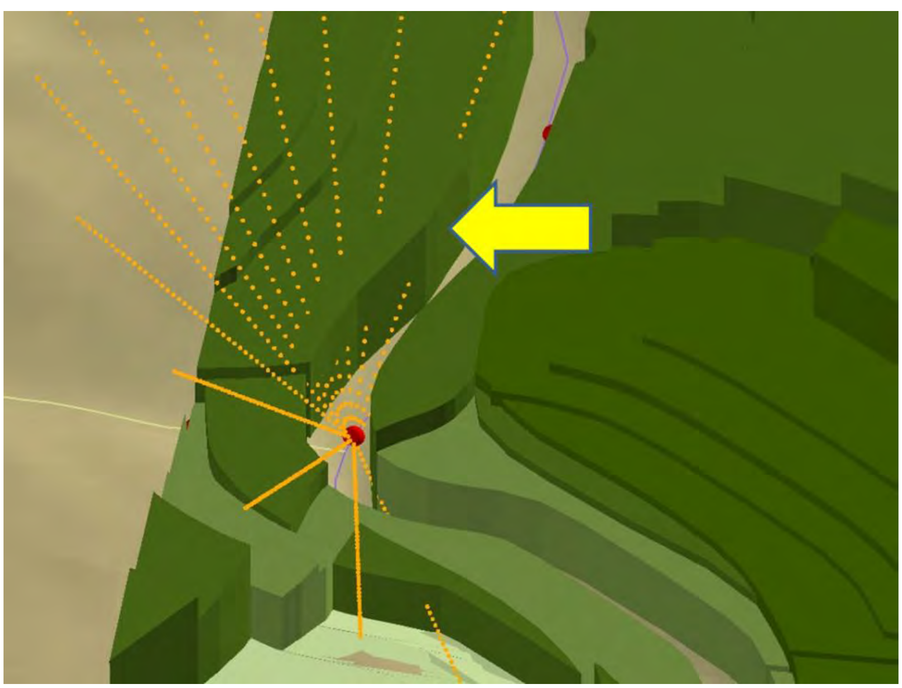


Figure G-20. Vegetative Shading

Forest stands shown as extruded polygons. Green hue indicates canopy density; darker hues indicate more dense canopies. Stream shading occurs where incident sunlight passes through the forest canopy (arrow).



For sun position vectors not blocked by topography, vegetation in the surrounding riparian buffer, if present, provides the only obstruction to incoming direct-beam radiation. The characteristics of the vegetative buffer, the distance of vegetation through which radiation passes, and the energy level of the incoming radiation determine how much energy reaches the stream surface.

Only overstory vegetation was considered; shading by overhanging or understory vegetation was not evaluated. Vegetation was represented by a vertical wall adjacent to the stream channel which follows the terrain (Figure G-20). For DNR-managed lands, stand-level forest conditions were represented at decadal intervals (0-9) for each alternative (No Action and Landscape alternatives) using the top height of the 40 largest diameter trees (TOPHT, reported in feet) and canopy cover (CANCOV, reported on a scale of 0 to 100). DNR-managed road right-of-ways were considered non-forested.

Non-DNR managed lands were assessed using remotely-sensed data on forest conditions as compiled in the Gradient Nearest Neighbor (GNN) data set (parameters CANCOV and STNDHGT). The GNN is a tool for characterizing vegetation structure and species composition in forested landscapes across large regions by integrating vegetation measurements from regional grids of field plots, mapped environmental data, and Landsat Thematic Mapper (TM) imagery (Ohman and Gregory 2002). The GNN is a product of the Landscape Ecology, Modeling, Mapping, and Analysis team at the USDA Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory. GNN is gridded at a 30 meter resolution.

The area immediately adjacent to the stream channel was treated as non-vegetated; its width was based on a regression analysis using data from DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

Vegetative shading was calculated using Equation G-30, known as the Beer-Lambert law, which provides a means of estimating energy attenuation through a substance. Where $\boldsymbol{I}$ is the transmitted light intensity; $\boldsymbol{I_0}$ is the incident light intensity; $\boldsymbol{\lambda}$ is the transmission coefficient, giving the amount of light intensity remaining after one unit of travel through a medium; and $\boldsymbol{L}$ is the path length through the medium.

Equation G-30. Beer-Lambert Law
Source: Gehringer (2010)

$$I = I_0\lambda^L$$

Gehringer (2010) estimated the transmission coefficient, λ, through a forest canopy as 0.95 per foot. The equivalent value in meters was calculated by raising the value to the number of feet in a meter (Equation G-31), yielding a coefficient of 0.845 per meter – which is the same estimate used by Welty and others (2002) for transmission through Douglas-fir, based on data from the Oregon Transect Ecosystem Research Projects (Ustin 1990, Angelici and others 1991).

Equation G-31. Transmission Coefficient, Meters

$$\lambda_m = {\lambda_{ft}}^{3.280839895}$$

Light transmission was assumed to be directly proportional to canopy density. Canopy cover (coverted to a proportional value from 0 to 1) was used as a surrogate for density. Light transmission at each vector sample point was calculated using Equation G-32, using a path length (L) of 5 meters, corresponding to the spacing between each vector sample point.

Equation G-32. Light Transmission at Each Vector Sample Point

$$transmission_{vsp} = (1 - ((1 - \lambda_m) * canopy\ cover_{vsp})^L$$

For a given sun position vector (v), the light attenuation occurring at each vector sample point is cumulative. That is, the total light transmitted along the vector is the product of the transmission of each vector sample point. Furthermore, the intensity of the direct-beam radiation along a given sun position vector varies with its orientation. The heating effect is greatest for high angle incident solar radiation, and decreases toward the horizon. This effect was modeled by weighing the transmission for each sun position vector in proportion to sine of the angle (α) up from the horizon, following Welty and others (2002). Total light transmission along each sun position vector was calculated using Equation G-33.

Equation G-33. Light Transmission along Each Sun Position Vector (v)

$$transmission_v = \sin(\alpha_{vector}) \prod_{vsp=1}^{n} transmission_{vsp}$$

The energy transmitted to each stream sample point (ssp) is the sum of the energy transmitted along each sun position vector (vector) (Equation G-34).

Equation G-34. Light Transmission to Each Stream Sample Point (ssp)

$$transmission_{ssp} = \sum_{v=5}^{19} transmission_v$$

The shade level at each stream sample was calculated as the ratio of the transmitted energy to the unobstructed energy (Equation G-35). The unobstructed energy is the total energy transmitted to the stream with no topographic or vegetative shading for the 15 hourly sun position vectors on the day analyzed. To calculate the unobstructed energy, each sun position vector was assigned an initial value of 1 (a proportional value, indicating all energy was transmitted), which was then weighted by the sine of the incident angle (α) for the given sun position vector, and summed for all sun position vectors (v = 5 .. 19) (Equation G-36).

Equation G-35. Shade at Each Stream Sample Point (ssp)

$$shade_{ssp} = 1 - \frac{transmission_{ssp}}{unobstructed\ transmission_{ssp}}$$

Equation G-36. Unobstructed Transmission

$$unobstructed\ transmission = \sum_{v=5}^{19} \sin \alpha_v$$

Each stream sample point was assigned a water temperature target in accordance with the “aquatic life temperature criteria” specified in WAC 173-201A Water Quality Standards for Surface Waters of the State of Washington (Table G-24), These criteria describe the maximum allowable 7-day average of the daily maximum temperature (7-DADMax), by aquatic use categories.

For this analysis, DNR used a dataset containing the spatial and attribute information of the Surface Water Quality Standards for the State of Washington stewarded by the Washington Dept. of Ecology (available for download: http://www.ecy.wa.gov/services/gis/data/data.htm). The dataset contained four views of the water quality standards: Freshwater Beneficial Uses, Seasonal Supplemental Spawning and Egg Incubation Temperature Standards, rules designated in Table 602, and exceptions to Table 602 listed in the footnotes. The version used for this analysis was last updated in April 2016.

DNR supplemented these temperature criteria using an overlay with 2010 NOAA Fisheries Bull Trout Critical Habitat Designations. Where it imposed a stricter temperature standard, 2010 NOAA Fisheries Bull Trout Critical Habitat Designations supplemented WAC 173-201A by assigning a 7-DADMax criteria of 12°C.

Reach-level attributes from both data sets (Surface Water Quality Standards for the State of Washington, Bull Trout Critical Habitat Designations) were transferred or conflated onto the stream sample points in an automated processes (Spatial Join). A default temperature criterion of 16°C was used for any stream sample points derived from stream reaches in DNR’s hydrography not shown in the Surface Water Quality Standards data set or the Bull Trout Critital Habitat data set.

Table G-24. Temperature Criteria, by Aquatic Life Use Category
Adapted from Table 200(1)(c) of WAC 173-201A.

Aquatic life use category	Highest 7-DADMax
Char spawning	9°C (48.2°F)
Char spawning and rearing	12°C (53.6°F)
Salmon and trout spawning	13°C (55.4°F)
Core summer salmonid habitat	16°C (60.8°F)
Salmonid spawning, rearing, and migration	17.5°C (63.5°F)
Salmonid rearing and migration only	17.5°C (63.5°F)
Non-anadromous interior redband trout	18°C (64.4°F)
Indigenous warm water species	20°C (68°F)

For each stream sample point, the level of shade necessary to meet the temperature criteria (hereafter, the “shade target”) was calculated using Equation G-37, which was developed from temperature nomographs shown in Figure 1.2 of the Forest Practices Board Manual (WFPB 2000), *Method for Determination of Adequate Shade Requirements on Streams*. The shade target was intended solely for the purpose of conducting this EIS; it was not intended for regulatory purposes.

Equation G-37. Minimum Shade Level (Shade Target) Necessery to Meet Temperature Critierion
Where the *shade target* is reported as a percent (from 0 to 100), *temp* is the temperature criterion in °C for the given reach, and *elev* is the elevation of the stream sample point in feet. Minimum and maximum bounds for the shade target were set to 0 and 100 percent, respectively.

$$shade\ target = 180 - 5 * temp + 0.073014 * elev - 0.00623 * temp * elev$$

Charts G-10 through G-13 show Equation G-37 applied to the four temperature criteria (12° C, 13° C, 16° C, and 17.5° C) occurring in streams included in this analysis.

Chart G-10. Minimum Shade Level (Shade Target) Necessary to Meet 12° C Temperature Criterion, by Elevation
Applied to “char spawning and rearing” aquatic life use category and bull trout critical habitat.

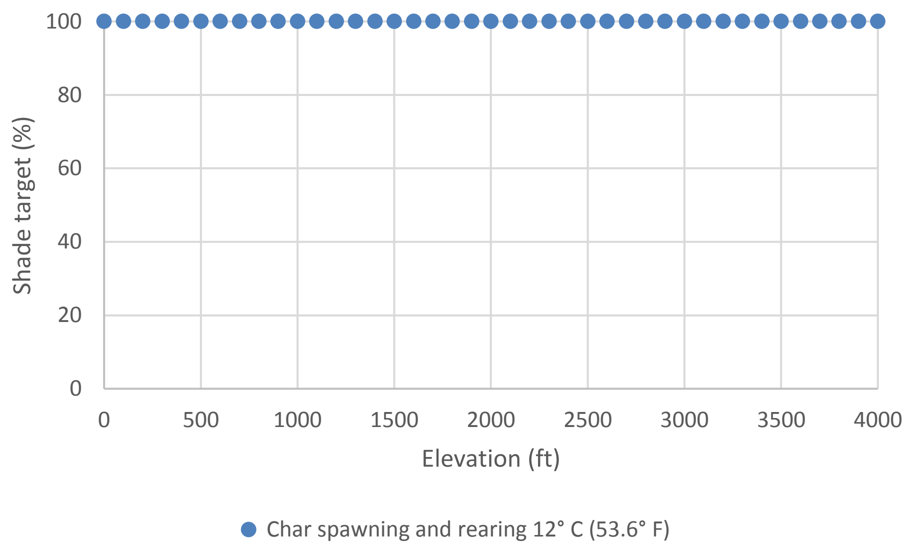


Chart G-11. Minimum Shade Level (Shade Target) Necessary to Meet 13° C Temperature Criterion, by Elevation
Applied to char salmon and trout spawning aquatic life use category.

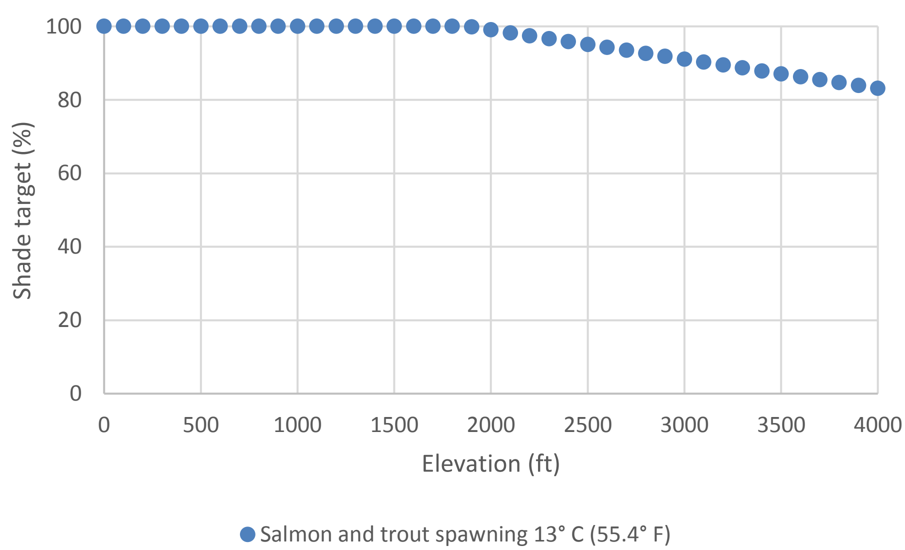


Chart G-12. Minimum Shade Level (Shade Target) Necessary to Meet 16° C Temperature Criterion, by Elevation
Applied to "core summer salmonid habitat" aquatic life use category.

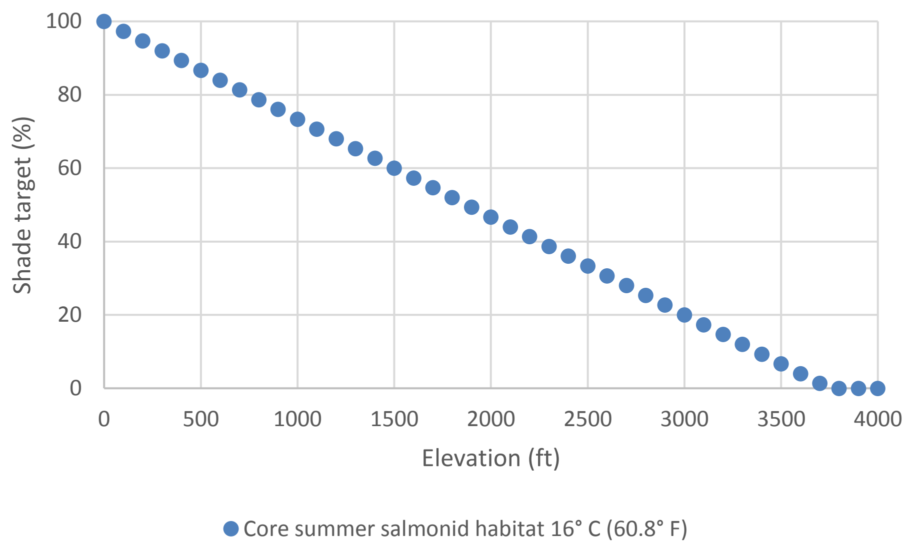
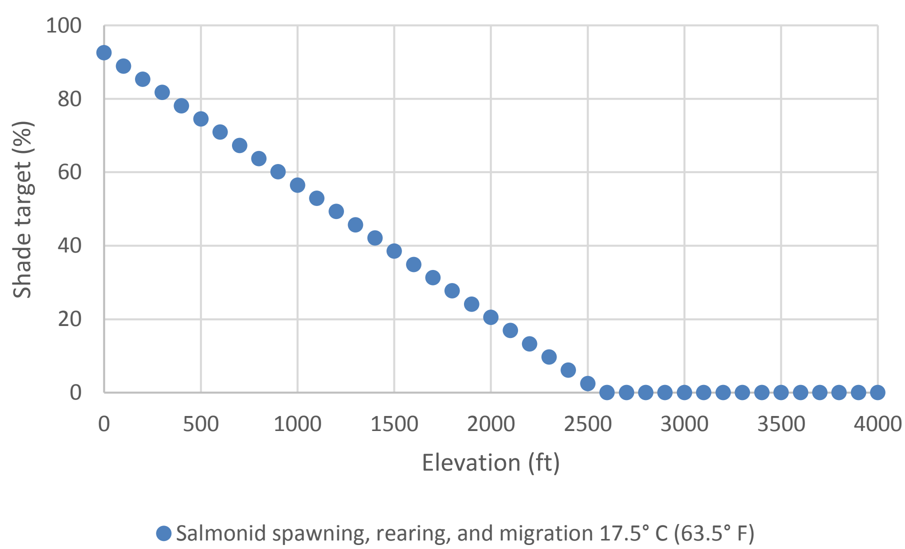


Chart G-13. Minimum Shade Level (Shade Target) Necessary to Meet 17.5° C Temperature Criterion, by Elevation
Applied to "salmonid spawning, rearing, and migration" and "salmonid rearing and migration only" aquatic life use categories.



Some stream sample points are naturally shade limited. That is, due to the geometry of the surrounding topography and the riparian forest in relation to the channel, the channel orientation and view to sky, the shade target cannot be met, even if the riparian forest has reached its site potential tree height.

For these stream sample points, DNR assigned an "adjusted water temperature target" and "adjusted shade target" based on an analysis of maximum achievable shade. The maximum shade for each stream sample point was determined using the shade model with the canopy density set to 0.85 and top height set to 60 meters (an approximation of site-potential tree height for the OESF). The adjusted shade target was the lesser of the original shade target and the maximum achievable shade. The adjusted temperature target was then calculated using Equation G-38, which is Equation G-37 solved for temperature.

Equation G-38. Temperature (°C) as a Function of Elevation (Feet) and Shade (Percent, Reported on a Scale of 0 to 100).

$$temp = \frac{180 + 0.073014 * elev - shade}{5 + 0.00623 * elev}$$

DNR calculated the shade level for each stream sample point for each alternative (No Action, Landcape) at each decade (0-9). The shade level was then converted to a corresponding temperature using Equation G-38. The resulting temperature was then evaluated using a set of fuzzy curves (Table G-25, Charts G-14 through G-17) based on the professional judgment of DNR scientific staff (Martens, K., personal communication, Feb. 23, 2016) from a review of scientific literature (Selong and others 2001, Dunham and others 2003, Pisano 2012, Carter 2005). A separate fuzzy curve was developed for each aquatic use category[5].

Table G-25. Stream Temperature Fuzzy Curves

Temp. criteria	Aquatic life use category	Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
12°C	Char spawning and rearing; Bull trout critical habitat	Predicted temp.	°C	<12 17.5 ≥22	1.0 true 0.5 neutral 0.0 false	Professional judgment of DNR scientific staff
13°C	Salmon and trout spawning	Predicted temp.	°C	<13 14.5 ≥16	1.0 true 0.5 neutral 0.0 false	Professional judgment of DNR scientific staff
16°C	Core summer salmonid habitat	Predicted temp.	°C	<16 18.5 ≥24	1.0 true 0.5 neutral 0.0 false	Professional judgment of DNR scientific staff
17.5°C	Salmonid spawning, rearing, and migration; Salmonid rearing and migration only	Predicted temp.	°C	<17.5 21.5 ≥24	1.0 true 0.5 neutral 0.0 false	Professional judgment of DNR scientific staff

Chart G-14. Stream Temperature Fuzzy Curve, Char Spawning and Rearing

Also applies to Bull Trout Critical Habitat

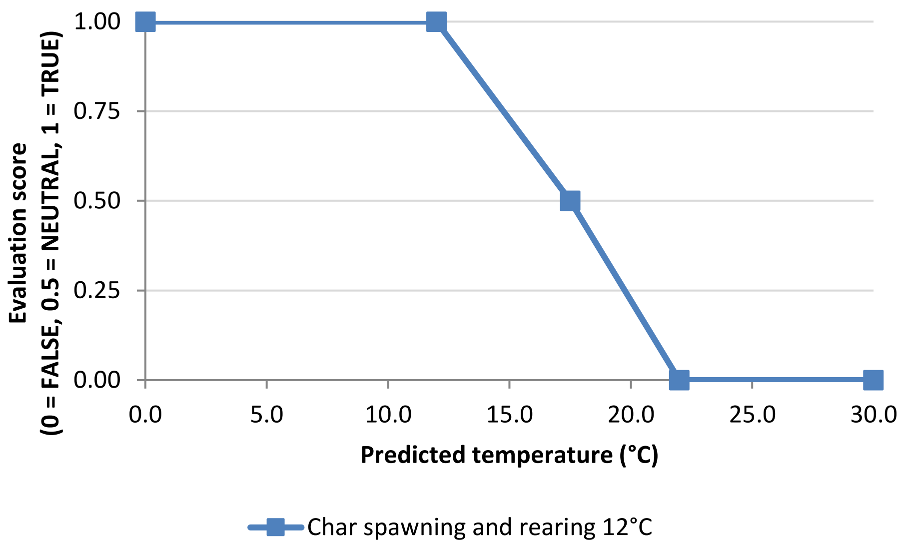


Chart G-15. Stream Temperature Fuzzy Curve, Salmon and Trout Spawning

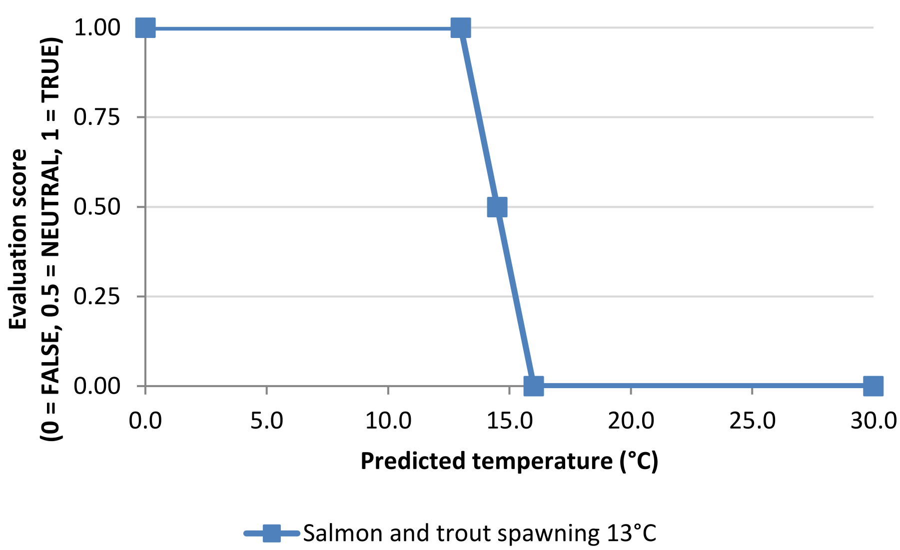


Chart G-16. Stream Temperature Fuzzy Curve, Core Salmonid Habitat

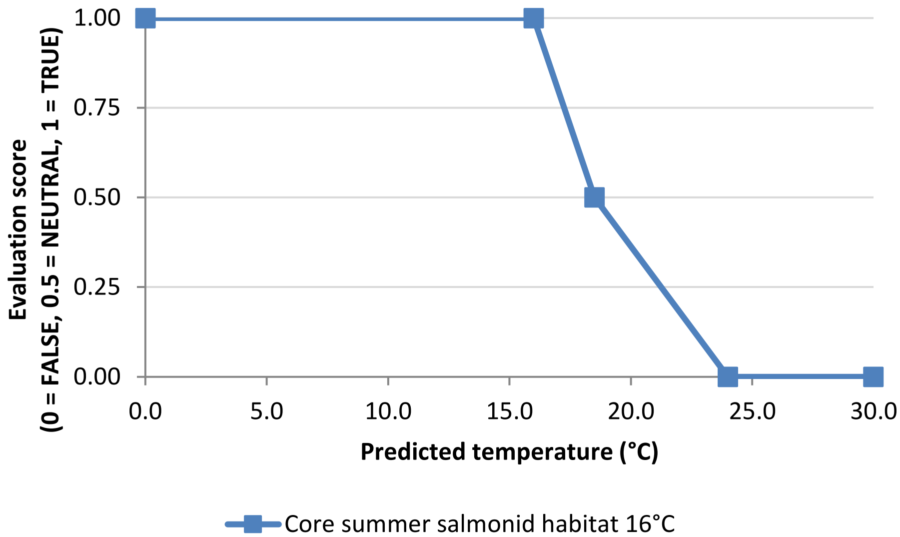
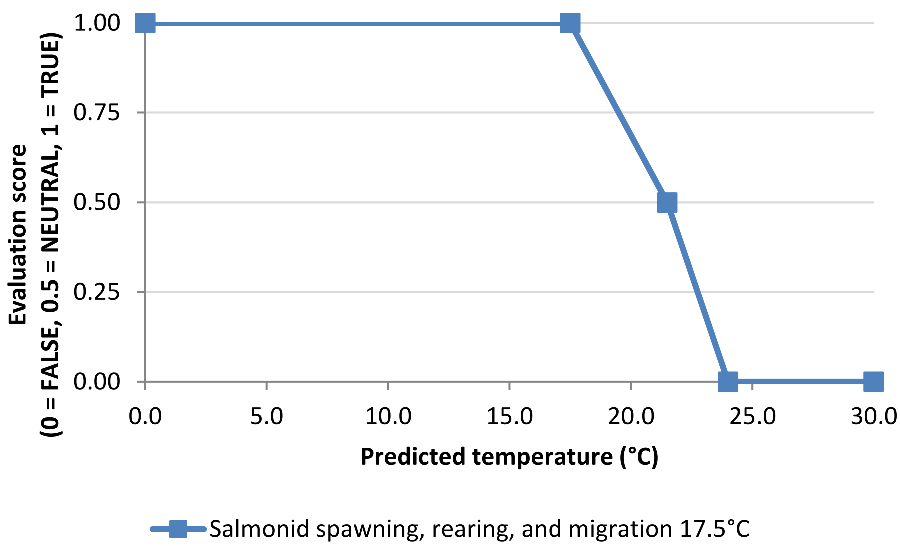


Chart G-17. Stream Temperature Fuzzy Curve, Salmond Spawning, Rearing, and Migration

Also applies to "Salmonid Rearing and Migration Only".



The stream reach score for a given stream reach is the average of the evaluations scores of each of its constituent stream sample points (Equation G-39).

Equation G-39. Stream Reach Score, Shade

$$stream\ reach\ score_{reach}(alternative, decade) = \frac{\sum_{1}^{n} evaluations\ score_{ssp_n}}{n}$$

How was the Watershed Score for Stream Shade Calculated?

Within each Type 3 watershed, the watershed score for stream shade was calculated as an area-weighted sum of the stream reach scores for stream shade using Equation G-12.

The area of each reach was calculated as its length times its width. The width of each reach was estimated using a regression analysis developed from data on DNR-managed streams in the Olympic Experimental State Forest relating contributing basin size to channel width (Equation G-4, Jaross 2009).

For any single Type 3 watershed, the watershed score for stream shade was assigned a qualitative rating of high impact (0.00 to 0.33), medium impact (0.33 to 0.67), or low impact (0.67 to 1.00).

How Were Stream Shade Impacts Assessed Across the Entire OESF?

Stream shade impacts across the entire OESF were assessed by examining the set or distribution of watershed scores for stream shade for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of watershed scores (Table G-2).

(7) Riparian Microclimate

What is Microclimate and why is it Important?

The term microclimate refers to extremely localized atmospheric zones (on the scale of tens to a few hundred feet) where the climate differs from the surrounding area. Removing streamside vegetation can result in changes to microclimatic conditions within the riparian zone, subsequently influencing a variety of ecological processes that may affect the long-term integrity of riparian ecosystems and associated aquatic habitat (Spence and others 1996).

Many riparian-associated plant and animal species require cool, moist, relatively stable conditions for survival and reproduction. Because of their close association with riparian habitat, changes in riparian microclimate caused by adjacent harvesting can decrease both quality and abundance of habitat, reduce landscape connectivity, and effectively fragment the landscape for species unable to cope with the altered conditions (Brosofske and others 1997).

How was the Stream Reach Score for Riparian Microclimate Calculated?

Unlike the other riparian indicators, the stream reach score for riparian microclimate does not incorporate a sensitivity component. Instead, the stream reach score was based solely on the riparian microclimate potential. The stream reach score is intended to quantify the integrity of the riparian microclimate along the given reach.

Which Streams Were Included in the Analysis?

All streams located on DNR-managed lands (regardless of type) and any streams (regardless of type or ownership) whose riparian microclimate gradient extended onto DNR-managed lands were included in the reach-level analysis. However, watershed scores were only reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

How was the Reach-Level Riparian Microclimate Potential Calculated?

The ability of the riparian zone to supply a functional riparian microclimate was assessed through an examination of riparian forest composition and structure, as affected by the competing influences of harvest edge effects. Riparian microclimate consists of both daytime and nighttime gradients for a suite of climatic variables including air temperature, soil temperature, relative humidity, wind speed, and short-wave solar radiation.

A graphic representation of the method used to model microclimate gradients is provided in Figure G-21. DNR considered the riparian microclimate gradient to extend across the 100-year floodplain (defined by stream type, Table G-3) and into the surrounding forest up to the point where climate conditions were indistinguishable from interior forest conditions (Figure G-21a). This distance varied by the climate parameter in question (air temperature, soil temperature, relative humidity). The riparian microclimate gradient was modeled as full strength within the floodplain itself, and thereafter declining in strength with increasing distance. For Type 5 and 9 streams, which DNR modeled as lacking a floodplain, the riparian microcliamte gradient was modeled as beginning at the edge of the stream channel.

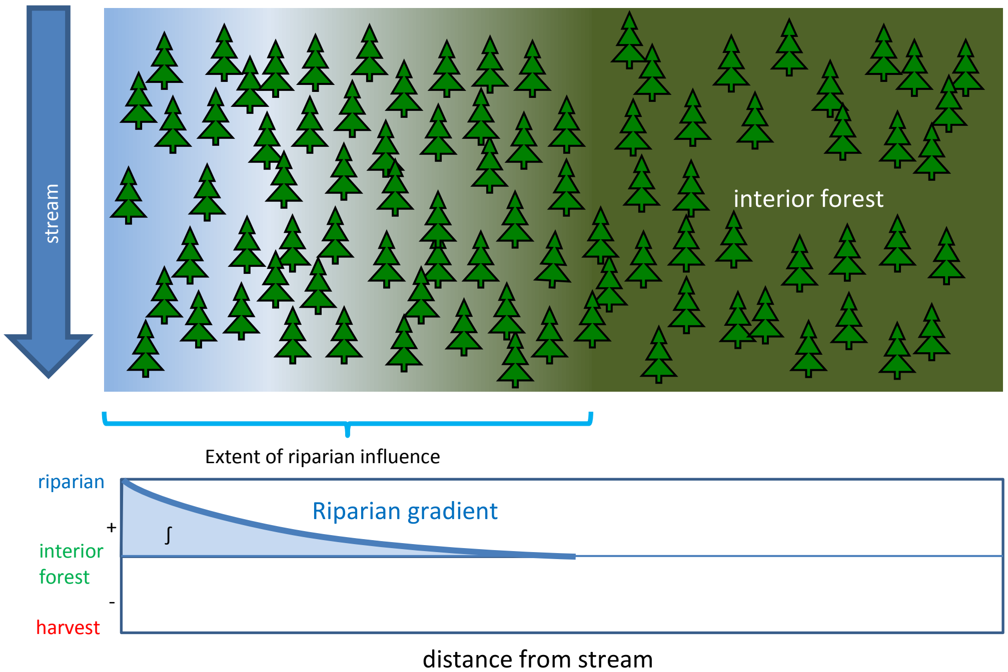
A fully intact riparian microclimate was quantified as the integral of the curve defining the gradient for each microclimate parameter. A competing harvest microclimate gradient exists along harvest edge (Figure G-21b). The resulting interaction was calculated as the sum of the riparian and harvest edge gradients.

Data on the extent and magnitude of riparian microclimatic gradients is limited. Brosofske and others (1997) studied of riparian microclimate gradients along small streams (two to four meters wide) in western Washington. They found daytime pre-harvest riparian microclimate gradients for air temperature, soil temperature, and relative humidity generally approached interior forest conditions within 47 meters from the stream. Gradient plots of relative solar radiation at pre-harvest sites showed no statistical differences at various distances from the stream along transects during the day. Wind-patterns varied widely at individual sites, and were possibly more sensitive to topographic or vegetative differences between sites than other variables (Brosofske and others 1997).

Only daytime gradients were modeled for this analysis, since the maximum amplitude of microclimate gradient is generally observed during the day. Polynomial regressions were developed from data manually interpreted from Figures 2, 3 and 6 in Brosofske and others (1997) showing riparian microclimate gradients for daytime air temperature, soil temperature, and relative humidity. Equations are presented in Table G-26; graphs are presented in Charts G-18, G-19, and G-20.

Figure G-21. Microclimate Gradients

a) Pre-harvest riparian microclimate gradient



b) Post-harvest riparian and harvest edge microclimate gradients

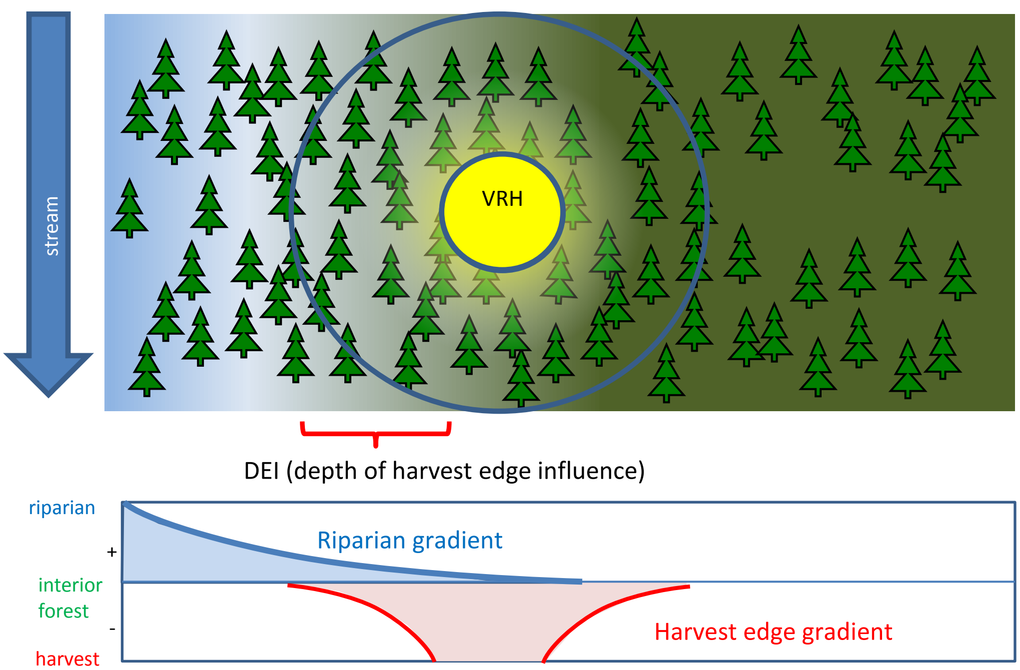


Table G-26. Equations for Microclimate Gradients for Selected Variables

Parameter	Maximum extent of gradient (feet)	Equation (x measured from the edge of the floodplain for Type 1-4 streams, or the edge of the stream channel for Type 5 and 9 streams)	Units		Source
			X	Y	
Daytime air temperature	Floodplain + 164 feet	$y = 0.000000553141472013225x^3 - 0.000254873390545266x^2 + 0.0452130262626149x - 2.99999999999999$	Feet	°C	Brosofske and others (1997)
Daytime soil temperature	Floodplain + 164 feet	$y = 0.0000091158085003185x^2 + 0.00616189357086708x - 1.2447561460419$	Feet	°C	Brosofske and others (1997)
Daytime relative humidity	Floodplain + 122 feet	$y = 0.000521626779968096x^2 - 0.145659074960127x + 9.99999999999998$	Feet	Percent (partial pressure / saturated vapor pressure)	Brosofske and others (1997)
Harvest-edge daytime air temperature (0 to 10 years from harvest)	418 feet	$y = 0.00000000000000052294204195x^6 - 0.00000000000059188283954701x^5 + 0.000000000214176225131555x^4 - 0.0000000221164868660292x^3 + 0.0000214816397332562x^2 - 0.0243238241318835x + 4.8808147928371$	Feet	°C	Interpreted from FEMAT (1993), Chen (1991), and Chen and others (1995)
Harvest edge daytime air temperature (attenuated, 10 – 20 years from harvest)	296 feet	$y = 0.00000000000000295820691517x^6 - 0.00000000000236753136084030x^5 + 0.000000000605781845527758x^4 - 0.0000000442329738763875x^3 + 0.000030379626376198x^2 - 0.0243238241395183x + 3.45125723816118$	Feet	°C	Interpreted and modified from FEMAT (1993), Chen (1991), and Chen and others (1995)
Harvest edge daytime soil temperature (0 to 10 years of harvest)	261 feet	$y = -0.00000000000005901845885713x^6 + 0.00000000004988210335434\text{54}x^5 - 0.0000000158757294155167x^4 + 0.0000022385429911064\text{8}x^3 - 0.000942809923592858x^2 - 0.0949935454213033x + 10.3956074986478$	Feet	°C	Interpreted from FEMAT (1993), Chen (1991), and Chen and others (1995)

Parameter	Maximum extent of gradient (feet)	Equation (x measured from the edge of the floodplain for Type 1-4 streams, or the edge of the stream channel for Type 5 and 9 streams)	Units		Source
			X	Y	
Harvest edge daytime soil temperature (attenuated, 10 to 20 years from harvest)	185 feet	$y = -0.0000000000033385882201958x^6 + 0.0000000019952841467048 2x^5 - 0.000000449033439681168x^4 + 0.0000447708600790908x^3 - 0.00133333459194951x^2 - 0.0949935452435966x + 7.35080455647197$	Feet	°C	Interpreted and modified from FEMAT (1993), Chen (1991), and Chen and others (1995)
Harvest edge daytime relative humidity (0 to 10 years from harvest)	545 feet	$y = -0.000000000000000033142546817x^6 + 0.0000000000044037764960245x^5 - 0.0000000022181535531962 1x^4 + 0.00000052493439523307 3x^3 - 0.000057625723398846 4x^2 + 0.0483763379590982x - 23.4487968414528$	Feet	Percent (partial pressure / saturated vapor pressure)	Interpreted from FEMAT (1993), Chen (1991), and Chen and others (1995)
Harvest edge daytime relative humidity (attenuated, 10 to 20 years from harvest)	385 feet	$y = -0.0000000000000187482557116x^6 + 0.000000000017615106022108 4x^5 - 0.000000006273885693732 98x^4 + 0.0000010498687936927 3x^3 - 0.000081495079619742 2x^2 + 0.0483763379109234x - 16.5808032547911$	Feet	Percent (partial pressure / saturated vapor pressure)	Interpreted and modified from FEMAT (1993), Chen (1991), and Chen and others (1995)

Chart G-18. Daytime Air Temperature Riparian and Harvest Edge Microclimate Gradients

Modified from Brosofske and others (1997), FEMAT (1993), Chen (1991), and Chen and others (1995). Distance measured from the outer edge of the floodplain (Type 1-4 streams) or the edge of the stream channel (Type 5 and 9 streams) for riparian microclimate gradient, and from the harvest unit boundary for harvest microclimate gradients.

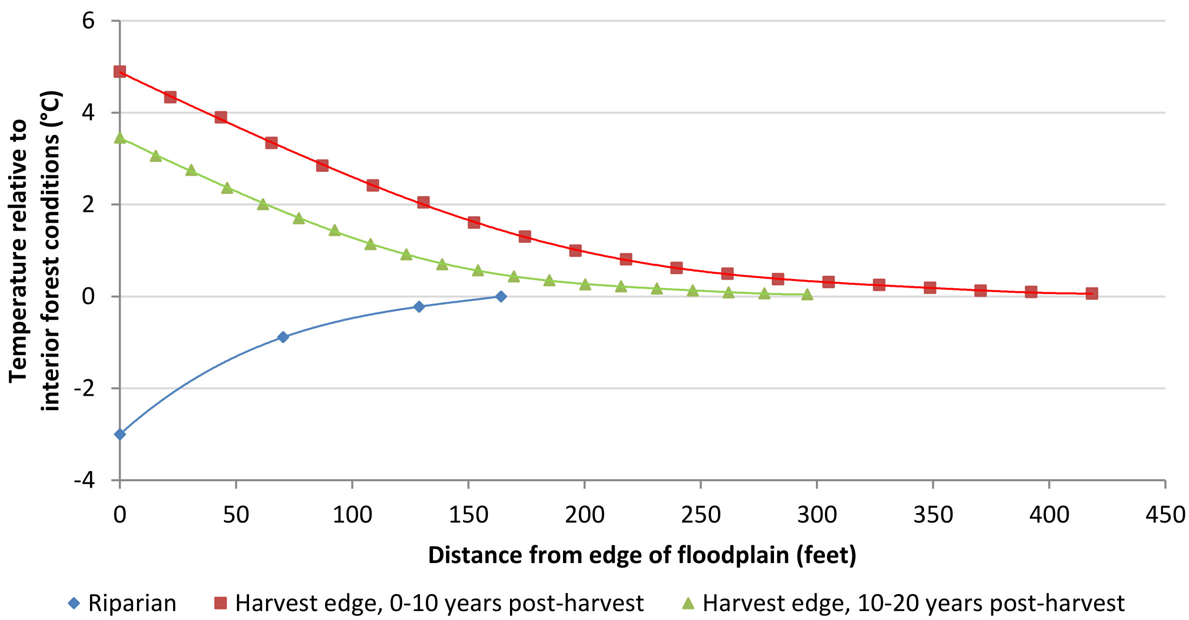


Chart G-19. Daytime Soil Temperature Riparian and Harvest Edge Microclimate Gradients

Modified from Brosofske and others (1997), FEMAT (1993), Chen (1991), and Chen and others (1995). Distance measured from the outer edge of the floodplain (Type 1-4 streams) or the edge of the stream channel (Type 5 and 9 streams) for riparian microclimate gradient, and from the harvest unit boundary for harvest microclimate gradients.

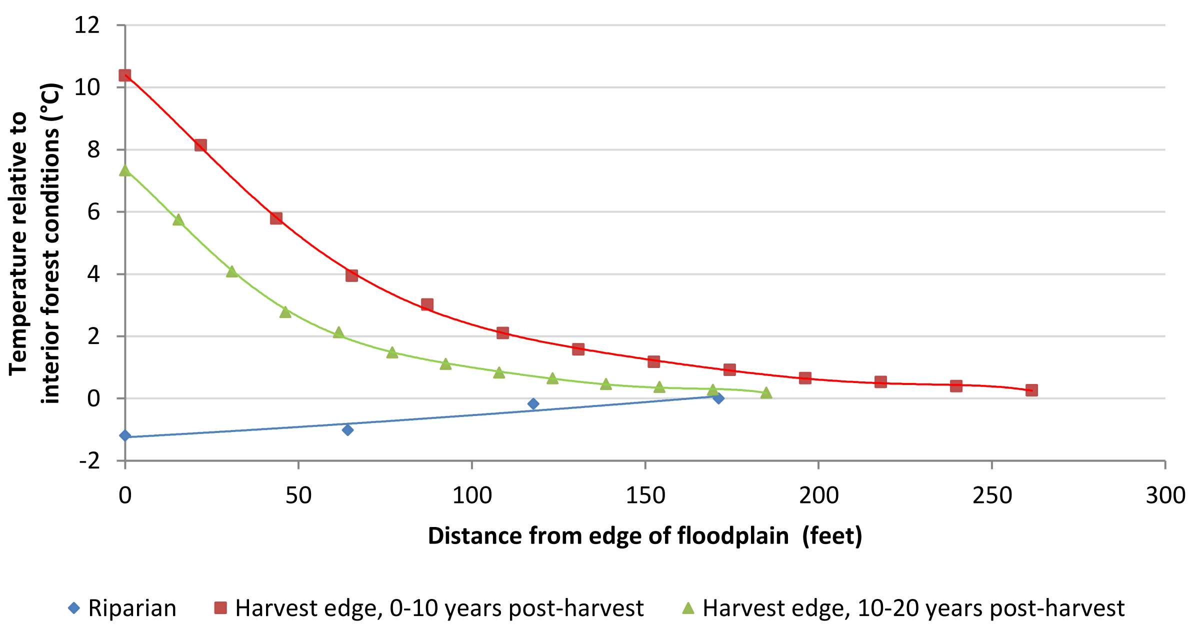
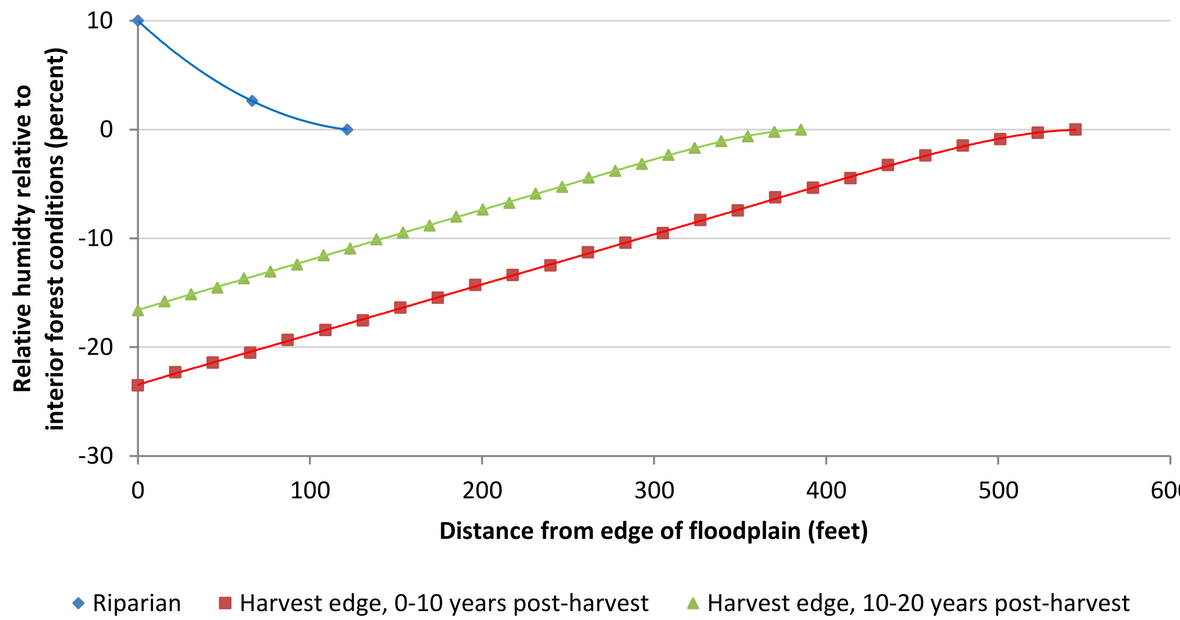


Chart G-20. Daytime Relative Humidity Riparian and Harvest Edge Microclimate Gradients

Modified from Brosofske and others (1997), FEMAT (1993), Chen (1991), and Chen and others (1995). Distance measured from the outer edge of the floodplain (Type 1-4 streams) or the edge of the stream channel (Type 5 and 9 streams)for riparian microclimate gradient, and from the harvest unit boundary for harvest microclimate gradients.



Data on the effects of harvest on microclimate gradients is also limited. Chen (1991) and Chen and others (1995) examined microclimatic gradients from clearcut edges into old-growth Douglas-fir forests west of the Cascade Range in the Pacific Northwest. Data were collected for air temperature, soil temperature, relative humidity, short-wave radiation, and wind speed over the course of the day for a variety of edge orientations. Chen and others (1995) summarized both the magnitude of edge influence (what they refer to as the significance of edge influence, or SEI) and the extent of edge influence (referred to as the depth of edge influence, or DEI). Depending on the microclimate parameter, edge orientation, and time of day, the extent of harvest edge effects varied from 100 to 800 feet into the forest. Results from Chen (1991) were summarized across all edge orientations and time of day in FEMAT (1993). An average of the magnitude of edge influence (SEI) was used for this analysis (4.9 °C for daytime air temperature, 10.8 °C for daytime soil temperature, and -23.5 percent daytime relative humidity relative to interior forest conditions) (Chen and others 1995). Polynomial regressions for harvest edge microclimate gradients were developed from a manual interpretation of data from Figure V-12 in FEMAT (1993) (Table G-26; Charts G-18, G-19, and G-20).

Changes in microclimate gradients along thinning harvest edges were not analyzed. Data on thinning effects on microclimate are limited. Olson and Chan (2005) examined the effects of upland thinning harvests on summer air temperature, soil temperature, and relative humidity gradients along headwater streams in western Oregon. Thinning did not affect soil temperature within the riparian forests. Changes in gradients were observed for air temperature (mean 4° C higher in the thinned areas vs. the control) and relative humidity (15 percent lower in the thinned areas vs. the control), but riparian buffers as narrow as 56 feet wide mitigated the microclimate changes associated with thinning harvests (Olson and Chan 2005).

Data on the recovery of microclimate gradients over time following harvest is also limited. Hibbs and Bower (2001) examined the structure and composition of forested buffer strips in the central and northern Oregon Coast Range and found that concerns about microclimate changes due to edge effects appeared unfounded with regards to the plant community. They describe edges as often temporary. In the Oregon Coast Range, where plant growth is rapid, the vegetation in a clear cut can often grow as high as the base of tree crowns in the buffer in 10 years. Side light and air movement quickly became limited and microclimate conditions more like those of a continuous forest are reestablished (Hibbs and Bower 2001). Summers (1982) found that shade recovered to old-growth levels in about 10 years in the Sitka spruce forest zone, within 14 years in the Oregon Coast Range western hemlock zone, and about 20 years in the Cascade Mountain western hemlock zone. However, shade recovery was slower in higher elevation Pacific silver fir forests in the Cascades, and was only 50 percent complete after 20 years (Brown and Krygier, 1970; Harris 1977; Feller 1981; Harr and Fredriksen 1988; as cited in Moore and others 2005). Recovery took longer in some cases or was not detected in others. Based on a classification of forest zones by Henderson and others (2011), the western hemlock vegetation zone accounts for the largest proportion of DNR-managed lands within the OESF (43%), followed by the Sitka spruce zone (33%) and the Pacific silver fir zone (24%).

Based on review of the available literature, the duration of harvest edge effects on microclimate gradients were modeled over a 20 year period. Edge effects were considered to be attenuated by 50 percent after ten years. The attenuation was modeled by reducing the integral (area under the curve) of the harvest edge effect gradient by half, accomplished by multiplying both the magnitude and extent of each harvest edge microclimate gradient by 0.7071 ($\sqrt{2}$) (Table G-26; Charts G-18, G-19, and G-20). A full harvest edge gradient was applied to all variable retention harvests for the first decade post-harvest; an attenuated harvest edge gradient was applied to all variable retention harvests during the second decade post-harvest. No attempt was made to distinguish variable retention harvests according to their edge density; all variable retention harvests were treated equally.

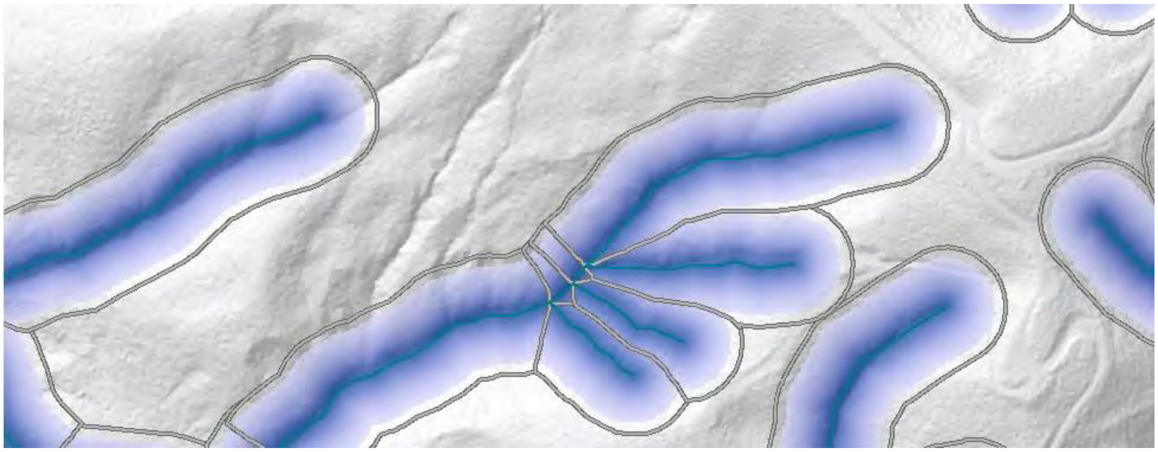
A riparian microclimate gradient was assigned to a given stream reach based on a proximity analysis using the ArcGIS Euclidean allocation function. Microclimate gradients for each stream reach were modeled at a two meter grid cell resolution (Figure G-22a). A fully-intact microclimate gradient was quantified as the sum of all cells within the assigned area for the given reach. Gradients were calculated for daytime air, soil, and relative humidity.

Harvest edge effects and their interactions with each reach-level riparian microclimate gradient were examined for each management alternative at decadal intervals. A full strength harvest edge gradient was applied to all variable retention harvests for the given decade (0 to 10 years post-harvest); an attenuated harvest edge effect gradient was applied to all variable retention harvests from the previous decade (10 to 20 years post-harvest) (Figure G-22b).

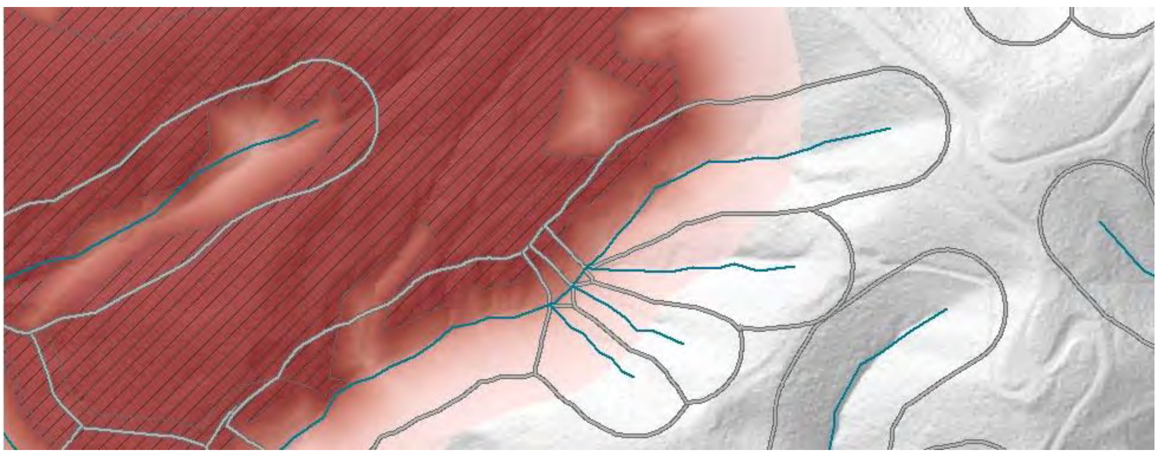
The net effect was quantified as the sum of the riparian and harvest edge microclimate gradients (Figure G-22c). Daytime air temperature, soil temperature, and relative humidity were tallied separately. The net riparian microclimate gradient for each parameter was normalized using fuzzy curves calculated separately for each stream reach (Table G-27).

Figure G-22. Riparian Microclimate Analysis

a) Riparian Microclimate Gradient. Modeled at full amplitude within the floodplain, and attenuating with increasing distance (Table G-28, Charts G-18, G-19, G-20).



b) Harvest Edge Microclimate Gradient. Modeled at full amplitude within the current decade's variable rention harvests, partially attenuated within previous decade's variable retention harvests. Attenuates with increasing distance from harvest edge into the surrounding forest (Table G-28, Charts G-18, G-19, G-20).



c) Net Microclimate Gradient. Represents the riparian microclimate gradient, as affected by the harvest microclimate gradient. Modeled as the sum of a) and b).

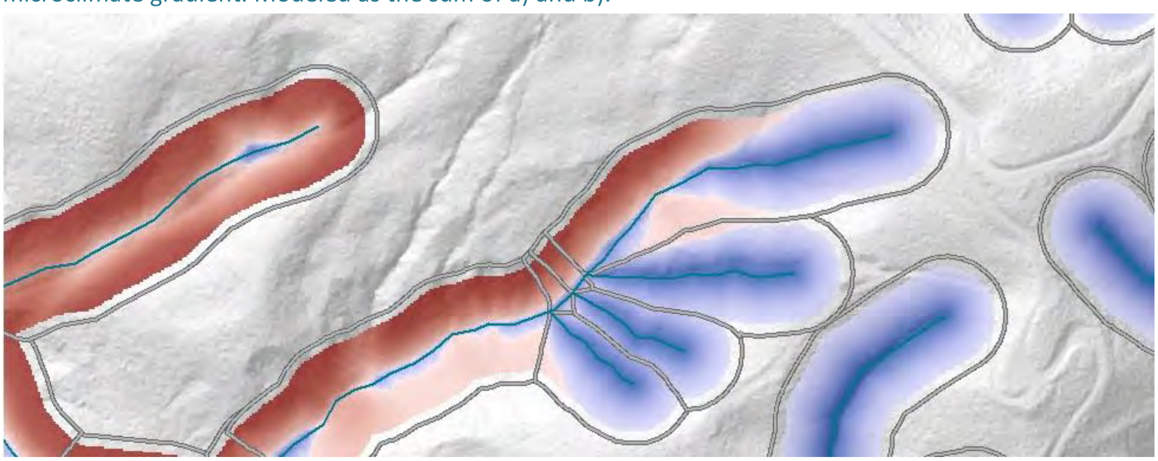


Table G-27. Riparian Microclimate Fuzzy Curves

Attribute	Units	Data value (x-value)	Evaluation score (y-value)	Source
Net daytime air temperature riparian microclimate (riparian + harvest edge)	°C	Σ fully clearcut condition 0 interior forest condition Σ fully riparian condition	0.0 false 0.5 neutral 1.0 true	Professional judgment of DNR scientific staff
Net daytime soil temperature riparian microclimate (riparian + harvest edge)	°C	Σ fully clearcut condition 0 interior forest condition Σ fully riparian condition	0.0 false 0.5 neutral 1.0 true	Professional judgment of DNR scientific staff
Net daytime relative humidity riparian microclimate (riparian + harvest edge)	Percent (partial pressure/ saturated vapor pressure)	Σ fully clearcut condition 0 interior forest condition Σ fully riparian condition	0.0 false 0.5 neutral 1.0 true	Professional judgment of DNR scientific staff

How was the Watershed Score for Riparian Microclimate Calculated?

For each Type 3 watershed, a watershed score for riparian microclimate was calculated by using a weighted sum of the reach-level microclimate condition. Since the riparian microclimate gradients were considered terrestrial features, the stream reach analysis scores were weighted by the area of the riparian microclimate gradient, not by the area of the reach. Each parameter was tallied separately to the watershed-level. A watershed-level index of the microclimate potential was calculated as an average of the watershed-level daytime air, daytime soil, and daytime relative humidity gradients (Equation G-40).

Equation G-40. Watershed Score, Riparian Microclimate

Where the variable *i* is used to index the *n* reaches within each Type 3 watershed, and the variable *j* is used to index each of the three microclimate analyses performed for each reach (air temperature, soil temperature, relative humidity).

$$\frac{\sum_{j=(air\ temp, soil\ temp, RH)} \frac{\sum_{i=1}^{n} microclimate\ evaluations\ core_{i,j}\ x\ area_{i,j}}{\sum_{i=1}^{n} area_{i,j}}}{3}$$

How Were Impacts to Riparian Microclimate Assessed Across the Entire OESF?

Impacts to riparian microclimate across the entire OESF were assessed by examining the set or distribution of watershed scores for riparian microclimate for all Type 3 watersheds in which DNR manages at least 20 percent of the land area (n = 427 Type 3 watersheds). A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of watershed scores (Table G-2).

(8) Composite Watershed Score

What is the Composite Watershed Score and why is it Important?

The composite watershed score is a measure of the overall condition of riparian ecosystem within each Type 3 watershed.

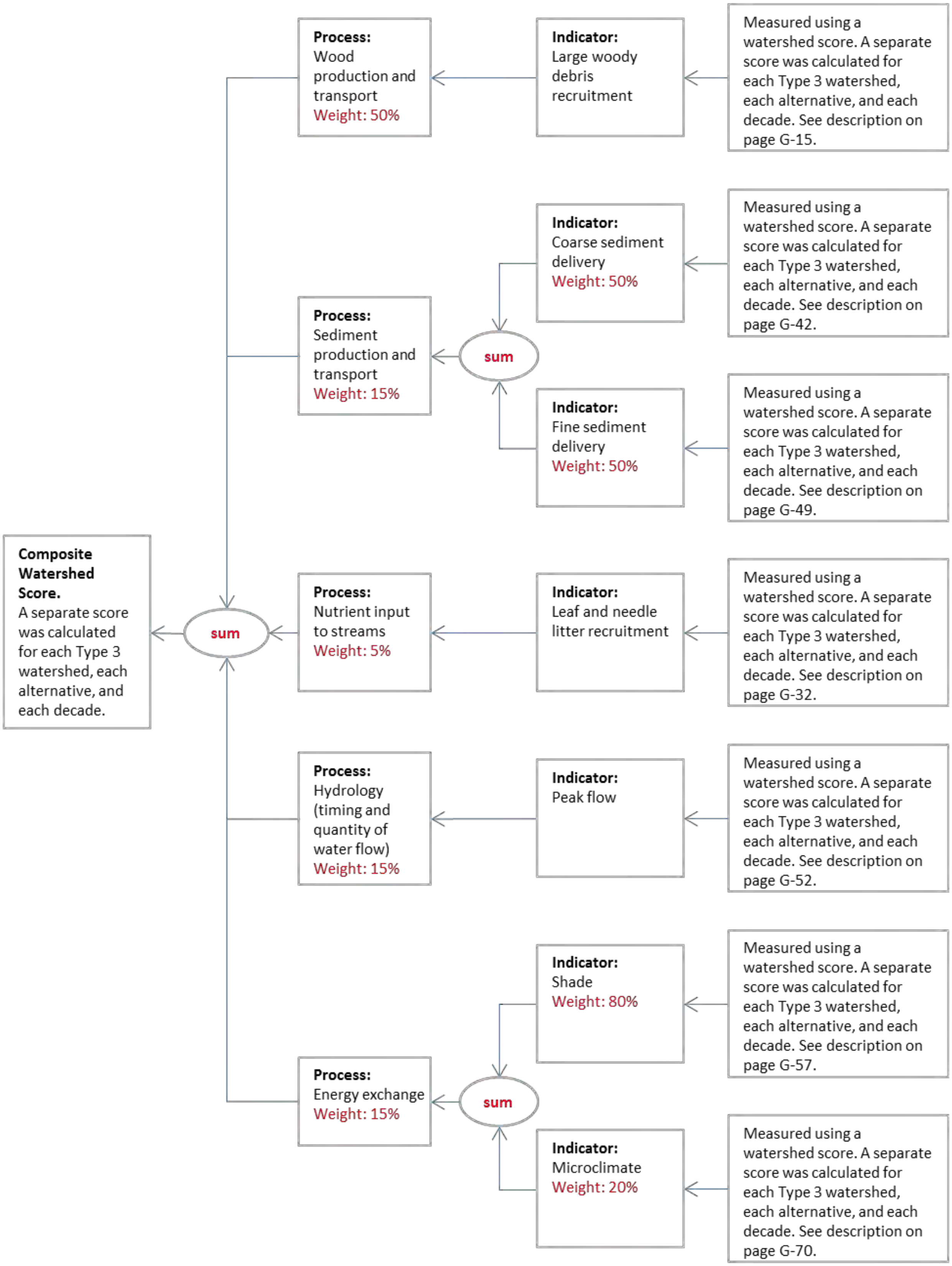
How was the Composite Watershed Score Calculated?

As described in preceding sections, DNR calculated a watershed score for each of the seven riparian indicators (large woody debris recruitment, leaf and needle litter recruitment, coarse sediment delivery, fine sediment delivery, peak flow, stream shade, riparian microclimate).

The *composite watershed score* combines the individual watershed scores for each indicator using a hierarchical model (Figure G-23). The framework for the hierarchical model was based on a review of available literature (Reeves and others 2004, Gallo and others 2005, Mathews 2007), as adapted to work with the available data, and the professional judgment of DNR scientific staff.

Figure G-23. Framework of the Model Used to Calculate the Composite Watershed Score

Weighting factors and the operators used to combine variables are shown in red.



DNR assigned weighting factors to various parameters in the model based on the professional judgment of scientific staff of each parameter's contribution to overall watershed health. Large woody debris was given the most weight, in accordance with the key role it plays in riparian ecosystems and its ability to influence or mitigate other riparian parameters. For example, large woody debris can be an important roughness element in some stream channels, effectively reducing stream energy during high flow events. Large woody debris also plays an important role in establishing and maintaining interactions between surface and subsurface flow (known as "hyporheic exchange"), helping to cool stream water even in areas lacking shade (Pollock and others 2009).

A separate composite watersheds score was calculated for each Type 3 watershed, each alternative, and each decade.

Which Watersheds Were Included in the Analysis?

The composite watershed score was reported for those Type 3 watersheds in which DNR manages at least 20 percent of the watershed area (n = 427 watersheds).

How Were Impacts to the Watershed Composite Score Assessed Across the Entire OESF?

A qualitative rating of the level of impact (low, medium, high) was assigned based on the observed changes in the distribution of composite watershed scores (Table G-2).

■ Summary of Changes in Analysis Methodology Implemented for the FEIS

The following table summarizes the changes in the analysis methodology DNR implemented for the FEIS. The changes were implemented either in reponse to public comments received or as iterative improvements in analysis techniques.

Table G-28. Summary of Changes in Analysis Methodology Implemented for the FEIS

No.	Indicator(s)	Parameter	Change	Impetus
1	Large woody debris, leaf and needle litter, coarse sediment, fine sediment, peak flow, shade, microclimate	Type 3 watershed in which each stream reach is located	Each stream reach is located within a Type 3 watershed. For the RDEIS, the assignment of Type 3 watershed to a given stream reach was based on a GIS overlay of DNR's stream layer with DNR's Type 3 watershed layer. For the FEIS, DNR made corrections to the watershed assignment, to adjust for hydrologic inaccuracies in the watershed boundaries. Approximately 2,000 stream reaches were reassigned to different watersheds. In addition, stream reaches which formed the boundary between adjacent watersheds (such as a mainstem stream with a different watershed delineated along the right and left banks) were assigned as members of both watersheds. In this manner, the condition of these reaches is incorporated into the watershed score for both watersheds.	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff
2	Large woody debris, coarse sediment, fine sediment, peak flow	Channel sensitivity	For the RDEIS, DNR assigned a sensitivity rating to each stream reach based on its expected response to changes in the indicator. These ratings were assigned to each indicator using a generalized matrix of gradient x confinement, based on a review of watershed analyses and professional judgment of DNR scientific staff. For the FEIS, DNR developed a reach-level spatial data set by compiling the channel sensitivity ratings from watershed analyses approved or initiated under forest practices. Where such data were not available, DNR relied upon the generalized matrix of gradient x confinement used in the RDEIS.	In response to comments 196, 197, 198

No.	Indicator(s)	Parameter	Change	Impetus
3	Large woody debris, leaf and needle litter, coarse sediment, fine sediment, peak flow, shade	Method for weighting the reach-level scores when calculating a watershed-level score	For the RDEIS, DNR calculated the watershed-level score as a length-weighted sum of reach-level scores. For the FEIS, DNR calculated the watershed-level score as an area-weighted sum of the reach-level scores. The area-weight assigned to each stream reach was based on its surface area (length x width) as a proportion of the total surface area analyzed in the watershed. The width was estimated using a regression of bankfull width as a function of contributing basin size (Equation G-4, Jaross 2009). Note, the microclimate analysis continues to use the area-weighting method used in the RDEIS, based on the area of the riparian microclimate area of influence.	In response to comment 186.
4	All: large woody debris, leaf and needle litter, coarse sediment, fine sediment, peak flow, shade, microclimate	Scaling of stream reach score	For the RDEIS, the stream reach score was a measure of impact, reported on a scale of 0 (low impact) to 100 (high impact). For the FEIS, DNR modified the stream reach score to be a meaure of condition reported on a scale of 0 (impaired or degraded condition, high impact) to 1 (properly functioning condition, low impact) for consistency with other published decision support models (such as Reeves and others 2004, Gallo and others 2005, Mathews 2007).	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff

No.	Indicator(s)	Parameter	Change	Impetus
5	Large woody debris, leaf and needle litter, coarse sediment, fine sediment, peak flow	Methodology for combining potential and sensitivity ratings	For the RDEIS, DNR reported an impact score based on a percentile ranking of sensitivity divided by potential. Using this method, highly sensitive channels cannot be assigned a low impact score, and low sensitivity channels cannot be assigned a high impact. DNR addressed this issue for the FEIS by updating its methodology for combining sensitivity and potential. For the FEIS, DNR calculated an impact score (in an intermediate step) as: $impact = \sqrt{(1 - potential)^2 + w * sensitivity^2}$ Where the weighting factor: $w = (1 - potential)$ And potential and sensitivity are reported on a scale of 0 (low) to 1 (high). In a final step, DNR calculated a stream reach score as 1 minus the percentile ranking of the impact score. The updated methodology was adapted from InVest, (Sharp and others 2016), and represents the modified Cartesian distance in 2d space where the axes are sensitivity and potential. The weighting factor is used to negate the effect of channel sensitivity when potential is high.	In response to comment 201

No.	Indicator(s)	Parameter	Change	Impetus
6	Large woody debris	Methodology for assessing recruitment potential	Each forest stand was assigned a riparian condition code, based on forest type, quadratic mean diameter, and relative density. The RDEIS assigned a score of 1, 2, or 3 to each stand (low, medium, high recruitment potential, respectively) following the standard methodology for conducting watershed analysis (DNR 1997a). For the FEIS, DNR modified the recruitment potential score assigned to each riparian condition code to allow more categories and finer gradation of categories, adapted from Haggerty and North Olympic Land Trust (2011). For the FEIS, DNR reported the recruitment potential score on a scale of 0 to 1, in 11 categories of 0.1 increments. CLD = 1.0, MLD= 0.9, CLS = 0.8, HLD = 0.8, CMD = 0.7, MLS = 0.7, HLS = 0.6, MMD = 0.6, CMS = 0.5, HMD = 0.5, MMS = 0.4, CSD = 0.3, CSS = 0.3, HMS = 0.3, MSD = 0.2, HSD = 0.1, HSS = 0.1, MSS = 0.1, Non-forest = 0.0	In response to comment 193.
7	Large woody debris, leaf and needle litter	Area of influence	DNR expanded the area in which it assessed large woody debris recruitment and leaf and needle litter recruitment. For the RDEIS, DNR analyzed all areas within 150 feet of and including the 100-year floodplain of Type 1-5 streams. For the FEIS, DNR analyzed all areas within 200 feet of and including the 100-year floodplain of Type 1-5 streams. DNR used 200 feet as an approximation of the 200-year site-potential-tree-height for the OESF. Conifer stands reach the old-growth stage at about 200 years (Spies and Franklin 1988, 1991 as cited in DNR 1997b, p. IV.71), which DNR assumes to represent the point at which a given stand achieves its maximum tree height. Using the tree height tables cited in the HCP (Wiley 1978) and the site index (height at 50 years breast height age) described in the HCP, the estimated site potential tree heights for a 200-year growing period are 204 feet (62 meters) for Type 1 and 2 streams, and 200 feet (61 meters) for Type 3 through 5 streams. For the FEIS, DNR approximated these values by assuming a 200 foot site potential tree height at 200 years for all stream types in the OESF.	In response to comment 200.

No.	Indicator(s)	Parameter	Change	Impetus
8	Large woody debris	Distance weighting / probability of recruiting woody debris	For the RDEIS, DNR had divided the large woody debris area of influence into 3 bands (floodplain + 0-75 ft, 75-100 ft, 100-150 ft), and assigned a "distance weighting factor" to each band based on its expected proportional contribution of large woody debris, assuming a 170 foot tall tree height. This method did not consider the tree height of the stand and allowed for large woody debris contribution from stands whose distance from the floodplain exceeded the tree height. For the FEIS, DNR addressed this issue by dividing the large woody debris area of influence into smaller increments (25 foot wide distance bands) and calculating the explicit probability of large woody debris recruitment given the tree height and distance from the floodplain for each stand in each distance band.	In response to comment 195.
9	Large woody debris	Recruitment potential score	For the RDEIS, DNR reported the large woody debris recruitment potential score on a scale of 1 (low) to 3 (high) following the standard methodology for watershed analyses (DNR 1997a). For the FEIS, DNR reported the large woody debris recruitment potential score on a scale of 0 (low, impaired) to 1 (high, properly functioning) using a fuzzy curve based on recruitment potential as a percentage of the recruitment potential of a stand that meets the Riparian Desired Future Condition, as specified in the Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006).	In response to comments 134, 180, 194.

No.	Indicator(s)	Parameter	Change	Impetus
10	Leaf and needle litter	Leaf and needle litter recruitment potential	Each forest stand within the leaf and needle litter area of influence was assigned a riparian condition code, based on forest type, quadratic mean diameter, and relative density. For the RDEIS, DNR reported leaf and needle litter recruitment in a scale of 1 (low) to 3 (high), using a qualitative ranking of the riparian condition code based on the professional judgment of DNR scientific staff. For the FEIS, DNR estimated leaf and needle litter production in Mg per ha per yr, following the methods of O'Keefe and Naiman (2006). For the FEIS, DNR assigned a leaf and needle litter recruitment potential score on a scale of 0 (low, impaired) to 1 (high, properly functioning) using a fuzzy curve based on recruitment potential as a percentage of the recruitment potential of a stand that meets the Riparian Desired Future Condition, as specified in the Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006)	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff

No.	Indicator(s)	Parameter	Change	Impetus
11	Leaf and needle litter	Distance weighting / probability of recruiting leaf and needle litter	For the RDEIS, DNR had divided the leaf and needle litter area of influence into 3 bands (floodplain + 0-75 ft, 75-100 ft, 100-150 ft), and assigned a “distance weighting factor” to each band based on its expected proportional contribution of leaf and needle litter following source distance relationship of Figure V-12 (FEMAT 1993), assuming a 170 foot tall tree height. This method did not consider the tree height of the stand and allowed for leaf and needle litter contribution from stands whose distance from the floodplain exceeded the tree height. For the FEIS, DNR addressed this issue by dividing the leaf and needle litter area of influence into smaller increments (25 foot wide distance bands) and calculating the explicit probability of leaf and needle litter recruitment given the tree height and distance from the floodplain for each stand in each distance band. Based on Figure V-12 of FEMAT (1993), DNR estimated that leaf and needle litter dispersal is limited to a circle whose radius is 90 percent of tree height. DNR estimated the probability of leaf and needle litter recruitment to the floodplain as the proportion of that circle that intersects the floodplain. DNR estimated the quantity of leaf and needle litter recruitment to the floodplain of a given reach (in Mg per yr) as the production of each analysis polygon (in Mg per ha per yr) times its probability of recruitment times its area.	In response to comment 195, and iterative improvement in analysis techniques based on professional judgment of DNR scientific staff
12	Leaf and needle litter recruitment	Recruitment potential score	For the RDEIS, DNR reported the leaf and needle litter recruitment potential score on a scale of 1 (low) to 3 (high). For the FEIS, DNR reported the leaf and needle litter recruitment potential score on a scale of 0 (low, impaired) to 1 (high, properly functioning) using a fuzzy curve based on recruitment potential as a percentage of the recruitment potential of a stand that meets the Riparian Desired Future Condition, as specified in the Riparian Forest Restoration Strategy (Bigley and Deisenhofer. 2006).	In response to comments 134, 180, 194.

No.	Indicator(s)	Parameter	Change	Impetus
13	Peak flow	Fuzzy curve	For the FEIS, DNR updated the fuzzy curves it used to convert the projected change in peak flow to a scale of 0 (impaired condition) to 1 (properly functioning condition). DNR developed its fuzzy curves based on the professional judgement of its scientific staff and a reading of the scientific literature. As recommended by Grant and others (2008), a 10 percent increase in peak flow is considered the minimum detectable change. Changes in peak flow below this level are within the experimental and analytical error of flow measurement and cannot be ascribed as a treatment effect (Grant and others 2008). DNR modified the fuzzy curve used in the FEIS to be rather conservative. Changes in peak flow less than 5 percent were assigned a score of 1 (the highest score, indicating a properly functioning condition); a change in peak flow at the detection limit of 10 percent was assigned a score of 0.5 (a neutral score); and changes in peak flow greater than or equal to 15 percent were assigned a score of 0 (the lowest score, indicating an impaired condition).	In response to comment 192
14	Microclimate	Riparian microclimate gradient within 100-year floodplain	For the RDEIS, DNR modeled attenuation of riparian microclimate gradients as a function of distance from the center of the stream channel. For the FEIS, DNR modeled the riparian microclimate gradient as full amplitude within the 100-year floodplain, attenuating outward from the outer edge of the floodplain. Data on the extent of riparian microclimate gradients is limited, and the equations used to represent their extent in the RDEIS were based on studies along small streams. DNR modified its methodology for the FEIS to better represent variation in the extent of riparian microclimate gradients as a function of stream size. Large streams have larger floodplains, and therefore larger riparian microclimate gradients.	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff
15	Microclimate	Raster resolution	For the FEIS, DNR updated its methodology for calculating distances in the microclimate analysis to use a raster resolution of 2 meters instead 5 meters as used in the RDEIS.	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff

No.	Indicator(s)	Parameter	Change	Impetus
16	Shade	Transmission	For the FEIS, DNR updated the methodology for calculating transmission of sunlight through the forest canopy. DNR updated the attenuation coefficient (λ) to 0.95 per foot, following the method of Gehringer (2010). DNR updated its application of Beer's law of energy transmission to: $$transmission = (1-(1-\lambda) * \ canopy\ cover/100)^{path\ length}$$ following the methods of Welty and others (2002).	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff
17	Shade	Reach-level shade target	For the FEIS, DNR updated its methodology for assigning a target shade level to each stream reach. The updated methodology calculates the level of shade necessary to meet the temperature threshold set by Washington State Surface Water Quality Standards (WAC 173-201A). The updated analysis also assigns a 12° C temperature threshold for all stream reaches designated by NOAA Fisheries as 2010 Bull Trout Critical Habitat. DNR calculated the level of shade necessary to meet these thresholds using published shade/temperature relationships known as nomographs (Sullivan and others 1990).	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff
18	Shade	Method of assessing impacts from temperature exceedances by species	For the FEIS, DNR developed fuzzy curves to assess the level of impact that would result from temperature exceedances. Based on the professional judgment of DNR scientific staff, DNR developed fuzzy curves to assess the level of impact for each of the freshwater designated uses and criteria listed in WAC 173-201A that occur on DNR-managed stream reaches in the OESF, and for Bull Trout.	Iterative improvement in analysis techniques based on professional judgment of DNR scientific staff

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[1] Additional analyses of coarse sediment delivery may also be found in Soils (refer to the indicators *Landslide Potential* and *Road Failure*). The analyses of coarse and fine sediment delivery described in this appendix were conducted so that these indicators may be incorporated into the composite watershed score (described below). For compatibility with the watershed composite score, these analysis of coarse and fine sediment delivery were performed at finer scales (the stream reach and Type 3 watershed) than the analyses performed in Soils (the Watershed Administrative Unit) or Water Quality (the Landscape Planning Unit).

[2] Sensitivity was not incorporated into the analysis of stream shade or microclimate. For a discussion, refer to p. G-57 (shade) and p G-70 (microclimate).

[3] All of the riparian indicators incorporate a variable which DNR calls the `POTENTIAL`, which is scaled from 0 (detrimental) to 1 (beneficial). The reader is cautioned not to confuse the variable `POTENTIAL` with the term "potential", which in common usage is synonymous with "likelihood" or "ability". For some indicators, (e.g., coarse sediment delivery, fine sediment delivery, and peak flow) an increase in the indicator is considered detrimental. For example, an increase in the potential for fine sediment delivery (here, meaning an increase in the likelihood of fine sediment delivery) translates into a decrease in the fine sediment delivery `POTENTIAL` (here, referring to the variable `POTENTIAL`). To avoid confusion, this appendix adopts the convention of using the `Courier` font for the variable `POTENTIAL`, to distinguish it from the term "potential". The variable `SENSITIVITY` is also shown in the `Courier` font. DNR developed computer programs to implement much of the riparian analysis; the use of a standardized scale from 0 (detrimental) to 1 (beneficial) permitted the re-use of the computer code across multiple indicators.

[4] DNR used a forest estate model to conduct the environmental analysis for the FEIS as well as the DEIS and RDEIS. DNR refers to this model as the "analysis model." The forest estate model DNR will use to conduct planning from a landscape perspective after the plan is adopted is referred to as the "tactical model." Both models (analysis and tactical) are based on current policies and laws. Refer to Chapter 3 of the FEIS for a description of the analysis model.

[5] DNR did not develop separate fuzzy curves for the adjusted temperature criteria it applied to shade-limited stream sample points. Instead, for these stream sample points, DNR calculated the temperature exceedance relative to the adjusted temperature target. The temperature exceedance was then added to the original temperature target, and a fuzzy curve was applied to the resulting sum. For example, a given stream sample point may have a temperature target of 13°C, based on an aquatic life use category of "salmon and trout spawning". However, DNR's analysis may indicate the maximum level of shade possible at that location (assuming a 60 meter tree height and a canopy density of 0.85) will result in a temperature of 14.5°C. This value is then assigned as the adjusted temperature target for the stream sample point. Subsequent analysis may indicate that the shade provided under a given alternative and decade would result in a temperature of 15.5°C. The temperature exceedeance is 1°C, calculated relative to the adjusted temperature target. That is, the resulting temperature (15.5°C) is 1°C above the adjusted temperature target (14.5°C). However, the evaluation score is calculated as if the temperature exceedance (1°C) occurred relative to the original temperature target (13°C). That is, DNR then applies the 13°C fuzzy curve to a temperature of 14°C.