SMALL FOREST LANDOWNER ALTERNATE PLAN TEMPLATE REVIEW

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TABLE OF CONTENTS

List of Figures

List of Tables

Executive Summary

This review was conducted following recommendations by Timber, Fish and Wildlife Policy Committee (Policy) to determine whether an alternate plan template for riparian management zones (RMZ) submitted by Washington Farm Forestry Association (WFFA) is supported by best available science (BAS) and to discern the scientific strength of WFFA's findings. In doing so, the review also considered whether the alternate template provides protection of riparian function at least equal in effectiveness to those in existing Forest Practices rules.

This review used scientific studies screened from literatures sources representing the science influencing the latest riparian forest practices rules determinations in the U.S. Pacific Northwest. 279 references were identified and reviewed, carrying forward 63 on the effects of forest practices in the western Pacific Northwest on the five riparian functions of concern to Policy (large woody debris (LWD) recruitment, stream shade, leaf and litterfall, sediment filtration, and streambank stability). Where possible, peer-reviewed studies which tested the effects of forest practices on riparian function using statistically sound experimental design were carried forward as the primary basis for review of the WFFA proposal. However, this was not always possible and lesser quality information may have been carried forward where better information was not available. An independent function evaluation was then conducted using this science and compared to WFFA's, providing the basis for BAS determinations.

Field study in the western Pacific Northwest is robust about effects of wide no-harvest buffers on riparian function, but it is generally lacking about the effectiveness of 25-ft buffers and it is generally lacking about the effects of thinning within RMZ buffers. Overall, WFFA's use of, and agreement with, science varies function to function, affecting the strength of their findings:

- WFFA used much of the information identified by the independent function evaluation that characterizes short-term LWD recruitment in young stands without windthrow and WFFA's source-distance relationship for this narrow set of conditions comports with this science. However, WFFA limited their consideration of the science about windthrow effects along cut-block edges and about long-term LWD availability under management. Predictions in Table 3 of their report likely underrepresent LWD recruitment loss.
- WFFA relied on unvalidated models to characterize effects of forest management on shade loss and WFFA's predictions using the DOE shade model underrepresent shade loss reported in westside field studies that test effects of fixed-width no-harvest buffers.
- WFFA did not use relevant science for their leaf and litterfall function evaluation and, instead, relied on professional judgement to characterize a source-distance response. Though WFFA's assertions generally agree with the independent function evaluation, they arrived at their conclusions without any explicit consideration of the science.

- WFFA cited key relevant science regarding the effects of RMZ prescriptions on sediment filtration, generally finding that sediment filtration increases with increasing buffer width and sediment delivery decreases with increasing buffer width. However, trends identified in the independent function evaluation suggest that WFFA's criteria are less protective than suggested by science, especially the effectiveness of a 25-ft buffer.
- Table 3 in WFFA's report does not consider streambank stability as a separate function. Though the retention of streambank vegetation would occur through most WFFA prescriptions, we are concerned about the effectiveness of a 25-ft buffer.

The deficiencies in use and application of science in the WFFA analysis affected their function evaluation of all prescriptions equally—both those proposed by WFFA and those promulgated in the Forest Practices Rules (FPR)—and, based on findings of the independent function evaluation, we find that all prescriptions—both WFFA and FPR—would provide less function than depicted in Table 3 of the WFFA analysis. Most importantly, we find that none would provide maximum function. The Synthesis section summarizes, using the independent function analysis, differences in function that each WFFA prescription would provide relative to analog FPR prescriptions. This is intended as a reference for Policy as they consider WFFA's proposal.

INTRODUCTION

Background

Attachment B of PSC-93-096940 outlines the following background:

> At the February 10, 2015 Forest Practices Board meeting, Washington Farm Forestry Association (WFFA) presented a proposal for consideration as a small forest landowner alternate plan template to conduct harvest activities within the western Washington forest practices riparian management zones (RMZs). WFFA requested the Forest Practices Board (Board) accept and forward the proposal to the Adaptive Management Program (AMP) for consideration as specified in Board Manual, Section 22. The Board accepted their request for review, and directed the Adaptive Management Program Administrator to, per direction in Board Manual, Section 22, present proposed tracks for Timber, Fish and Wildlife Policy Committee (Policy) concurrence and bring a recommended timeline and strategy for evaluation of the template back to the Board.
>
> Policy recommended implementing a three step strategy following the guidance in WAC 222-12-0403 and Board Manual Section 22 with components of both a "policy track" and a "science track". The steps forward were:
>
> - A review from Policy to determine whether the alternate plan template proposal meets the criteria outlined in WAC 222-12-0403 for "alternate plans". Policy will also consider different strategies for moving forward, if appropriate.
> - A literature synthesis conducted through the AMP's Cooperative Monitoring, Evaluation, and Research Committee (CMER) to evaluate the five forest practices functions of the riparian zone (sediment filtration, shade, large woody debris recruitment, leaf and litterfall, and bank stability). This literature review would not explicitly address the WFFA proposal, but it would provide important context for the review as well as future proposals. In addition, it will provide CMER with a best available science [(BAS)] document on riparian functions.
> - A written response with recommendations will be provided to the Board that succinctly describes the results of both the "science" and "policy tracks". This response would include addressing subsection (5) of WAC 222-12-0403.
>
> This contract will be addressing the "policy track" found in the first bullet above. WFFA developed an Alternative Plan Template in consultation with Dr. Douglas Martin that is designed to provide protection of RMZ functions at least equal in effectiveness to those in existing Forest Practices rules, meet current performance standards, and support economic viability of small forest landowners (WAC 222-12-040 through -0404 and

> Section 21 of the Board Manual). The Contractor will review this template, the Proposal Initiation Document, the Scientific Justification document, and background documents provided to develop a report that answers the following questions [see Purpose below] utilizing information gathered during literature review.

Inherent in such a review is the core criterion articulated by WAC 222-12-0401 (6): *Approval standard. An alternate plan must provide protection for public resources at least equal in overall effectiveness to the protection provided in the act and rules*. This is the core principle about which WFFA organized their scientific justification and about which our review was focused. Therefore, this review determined not only whether Best Available Science (BAS) was used, but also whether the proposal meets this criterion and, if not, the extent to which it deviates.

Purpose

Attachment B of PSC-93-096940 continues, articulating the following purpose:

> The Contractor will review this template, the Proposal Initiation Document, the Scientific Justification document, and background documents provided to develop a report that answers the following questions utilizing information gathered during literature review. The Contractor will evaluate the quantitative estimates of the relative effectiveness (risk) of the proposed prescriptions as depicted in Table 3 in the Background information: "WFFA Template Proposal – Scientific Justification". The Contractor will determine:
>
> 1. If the function analysis is supported by Best Available Science (BAS), and
> 2. If the function analysis followed credible scientific/statistical protocols, and
> 3. The scientific strength of the findings.
>
> The Contractor will provide the basis for their assessments and position along with supporting literature citations.

APPROACH

Review of WFFA's function evaluation consisted of: 1) identifying and reviewing the best available science (BAS), **independent** of WFFA's analysis, on the effects of forest practices on riparian function in the Pacific Northwest, 2) compiling a function evaluation, **independent** of WFFA's analysis, based on BAS compiled by the contractor, and 3) through comparison of the independent analysis to WFFA's proposal, answering Policy's three questions about the strength of WFFA's proposal. In the process, findings were synthesized to evaluate whether the proposal provides protection at least equal in overall effectiveness to the protection provided in the act and rules and, if not, the extent to which it may deviate from the act and rules.

Literature Review

Literature Sources

The following literature sources were surveyed to identify the science influencing the latest riparian forest practices rule determinations in the U.S. Pacific Northwest:

- CMER study plans and reports (the studies and references cited within):
    - Westside Type F Riparian Effectiveness Monitoring
    - Westside Type N Riparian Effectiveness Monitoring
    - Hardwood Conversion Study
- Olympic Experimental State Forest HCP research and monitoring:
    - Catalog of Research and Monitoring
    - LWD and Shade Literature Reviews
- Idaho Forest Practices Act Advisory Committee rule revision:
    - Contractor technical reports and memoranda
    - EPA comments on proposed rule revisions
- Oregon Riparian Rulemaking Advisory Committee documentation:
    - Private Forests Riparian Function and Stream Temperature study
    - Systematic review of effectiveness of riparian buffers
- California State Board of Forestry riparian rule administration:
    - Anadromous Salmon Protection Rule Section V Technical Advisory Committee
    - Forest Practices Implementation and Effectiveness Monitoring report
- Alaska Forest Resources and Practices Act effectiveness monitoring
    - Relevant Literature for an Evaluation of the Effectiveness of the Alaska Forest Resources and Practices Act: An Annotated Bibliography
    - Riparian status and trends and effectiveness monitoring reports

Practically, many of these sources also include Canadian studies that address the effects of forest practices on riparian function in British Columbia where stand conditions may reflect those in western Washington. Overall, because these literatures sources were developed independent of our review, they not only reflect input of scientists and managers throughout the Pacific Northwest but also avoid any appearance of undue influence by the contractor.

In addition to the literature sources listed above, the bibliography provided by Northwest Management, Inc. under contract SC 93-095549 was reviewed at the direction of the DNR Project Manager and the references cited by WFFA in their function evaluation for Alternative Plan Template were reviewed in order to understand their proposal. Otherwise, all literature identified by the contractor was done so **independent** of the WFFA analysis.

As these literature sources were surveyed, references were pre-screened for those that are directly relevant to AMP's interest in five riparian functions: sediment filtration, stream shade, LWD recruitment, leaf and litterfall, and streambank stability. This was necessary in order to contain the scope within contract parameters. In total, 279 references were identified and cataloged in an Excel spreadsheet that was delivered along with this review.

Screening

References identified from these literature sources were reviewed and screened to determine how they provide insight into the response of riparian function to forest practices. In reviewing them, we answered the following questions with either a yes/no or a categorical response:

- Which Board Manual 21 parameters are addressed?
- Is the study published in a peer-reviewed science journal?
- Does the study address natural stands, managed stands, or both?
- Is the study a literature review, field study, or modeling exercise?
- Does the study follow an experimental design or is it a synoptic survey?
- What states or provinces and what broad regions are covered?

Most often, this review was based on information in abstracts, however, when necessary, the entire reference was scanned to answer these questions. Answers to these questions, along with a short description of the study, were cataloged in the Excel spreadsheet.

Information gathered in review was then used to screen references that would be carried forward in this report. References were first screened to select those that addressed one or more of the riparian functions stipulated in Board Manual 21—large woody debris recruitment, shade, leaf and litterfall, sediment delivery, and streambank stability. As noted above, this was necessary in order to contain the scope within contract parameters.

The screening then considered geographic coverage. Overall, the applicable references identified from the literature sources provide a rich understanding of the effects of forest practices on riparian function not only in the Pacific Northwest, but also throughout North America. However, subsequent review was limited to westside Pacific Northwest studies. The WFFA proposal is specific to westside Pacific Northwest forests and there is robust enough study within this region without going beyond.

Next, information quality was considered. All literature reviews cited in the literature sources that are relevant to the effects of forest practices on riparian function in westside Pacific Northwest forests were carried forward in order to gain a comprehensive understanding of the strength of science on the topic. Then, individual studies of the effects of forest practices on riparian function in the Pacific Northwest were assessed, using the following principles to gage their relative value for use in our independent function evaluation:

- Peer-reviewed literature generally receives more unbiased scrutiny and wider acceptance from the scientific community than "gray literature;"
- Field studies generally reflect on-the-ground conditions and management, whereas unvalidated models are untested and may not be representative; and,
- Experimental studies testing the effects of forest practices on riparian function generally enable discernment of cause-effect relationships that may not be possible through synoptic surveys that typically only infer correlations, not causation.

Under these guidelines, literature was considered to be of most value, for instance, if it was from a peer-reviewed study testing the effects of forest practices on riparian function using a statistically sound experimental design, comparing treatment effects to those in unmanaged controls. Where possible, such studies were carried forward in this report as the primary basis for review of the WFFA proposal. However, this was not always possible and lesser quality information may have been carried forward when better information was not available.

Finally, the contractor focused on results that covered the range of prescriptions evaluated in Table 3 in the Background information: "WFFA Template Proposal – Scientific Justification." Specifically, the review used studies that offered insight on source-distance relationships for buffer widths 0 ft to 100 ft and on general thinning density relationships. Many studies fall outside WFFA's prescription range, or analog rules prescriptions, or they are non-specific; however, several such studies provided valuable context in the independent evaluation.

Function Evaluation

The standard for evaluation of alternative plans is provided in Board Manual 21:

> Because of the complexity of riparian areas, any given riparian area may not provide the ideal characteristics for each function. To be approved, alternate plans must be designed to provide for riparian function **at least equal in overall effectiveness** to the protection provided by the Forest Practices Act and rules [author emphasis added].

Strategies in Board Manual 21 for achieving functional goals are generally based on source-distance relationships for the five riparian functions.

Therefore, the objective of the independent function analysis was to derive source-distance relationships and density relationships from the information identified by the contractor. Key findings are first summarized in bullet form in a manner directly relevant to the prescriptions considered in Table 3 in WFFA's science justification. Then, these findings are synthesized into source-distance relationships presented in narrative form and, where possible, density relationships. Typically, these are expressed as quantitative estimates of riparian function loss, relative to maximum potential, for unharvested riparian buffers 0 to 100 ft wide and, where possible and meaningful, for mixed no-harvest inner/thinned outer buffers.

Best Available Science Determination

The contractor's process yielded references selected objectively and reflecting the highest value studies relevant to the effects of forest practices on riparian function in westside forests. Literature sources reflect science accepted by neighboring states in riparian rule-making and the criteria employed by the contractor emphasize use of peer-reviewed science, where possible, especially those employing hypothesis testing. Further, the selection was focused topically and geographically. In these ways, the literature used not only reflects Best Available Science per WAC 365-195-905, but also incorporates that directly relevant to the proposal.

Policy's three study questions were answered for each riparian function, using information compiled in the contractor's independent function evaluation, based on the level of corroboration between WFFA's function evaluation and the independent function evaluation:

- *Is the function analysis supported by Best Available Science (BAS)?* The question of "support" was answered in terms of use and agreement. For each riparian function, information used by WFFA to develop their source-distance relationships was compared to the information used in the independent function evaluation. Then trends reported in Table 3 of the WFFA report were compared to trends found in the independent function evaluation. BAS determinations considered both comparisons.
- *Does the function analysis follow credible scientific/statistical protocols?* Per WAC 365-195-905, peer-reviewed information is considered to follow credible methods. Per screening criteria described above, information quality can improve and degrade from this standard. The contractor did not see it as their charge to judge the credibility of gray-literature—such determinations are the role of refereed panels. Instead, the type and quality of gray literature used to support source-distance relationships are presented for the reader's own independent judgement of credibility.
- *What is the scientific strength of the [WFFA] findings?* The answer is, in part, provided by the answers to the previous two questions. That is, does the WFFA analysis use and/or comport with the most reliable, generally accepted information relevant to the effects of forest practices on the five riparian functions in western Washington? And, does this information provide information quality expected in peer-reviewed field experiments? If the answer to these two questions is "yes," then scientific strength is very high. When they deviate, discussion is provided for the reader's consideration.

Synthesis

The independent review of the literature was synthesized by preparing an alternate to Table 3 in the Background information: "WFFA Template Proposal – Scientific Justification" which uses the findings of the independent function evaluation to summarize riparian function potential of WFFA Template proposals and analog Forest Practices prescriptions. The function potential of WFFA Template proposals were then compared to those from corresponding Forest Practice rules, prescription-by-prescription, and findings were then characterized by stream type.

In answering Policy's three questions and synthesizing findings, the following additional questions posed by the TFW Policy Committee was used as guidance and, where appropriate, was used to further clarify the relative effectiveness of the proposed prescriptions:

- Does the proposal initiation report provide a complete and accurate presentation of the relevant scientific literature?
- Does the proposal take into consideration the strength of the underlying research studies referenced in the proposal (e.g. research framework, replicates, and method of analysis) when using them in support of the recommendations and conclusions?
- Based on the shade and temperature models' design and use in the proposal, what level of confidence should be applied to the prescription response estimates for shade and temperature? Compare to results of well conducted field studies.
- Compare the extent to which the template prescriptions provide protection for public resources at least equal in overall effectiveness to the protection provided by the standard forest practices rules that they would be used to replace.
- What are the tradeoffs in wood recruitment to the stream, both site-specifically and basin-wide, in using site-class (with site potential tree height) and stream size vs. stream size alone, for determining RMZ width? Do both methods provide equivalent wood recruitment to the stream (site-specifically and basin-wide)?
- Are the proposed RMZ prescription buffer widths (especially 25 ft) more prone to windthrow than the current rule potentially changing protection to riparian function?
- Has the shade model been validated for the purpose and range of buffer configurations for which it is used in the proposal? If not, what are the implications?

We did not develop FEMAT-like curves for the five functions from the review of BAS, a request among Policy's questions, because the contract is focused on the range of prescriptions evaluated in WFFA's Table 3. Therefore, the independent function evaluation should not be extrapolated or interpreted beyond this specific purpose (i.e., not for other prescriptions).

We also did not address performance goals and targets in FFR Schedule L1. Rather, the evaluation was focused on the criterion provided by WAC 222-12-0401 (6), the standard by which alternate prescriptions are to be judged under forest practices rules.

Finally, per our contract, our review was focused on Table 3 of the WFFA report. In doing so, the contractor may not have considered other aspects of WFFA's proposal which may avoid or mitigate impacts to riparian function. However, WFFA did not qualify their function evaluation underlying Table 3 in their report for such considerations and they were not addressed here. Therefore, this review should be considered with other information presented by WFFA.

REVIEW

Large Woody Debris Recruitment

Board Manual 21 Background

Board Manual 21 offers the following considerations for developing and analyzing alternate plan prescriptions, helping landowners and foresters determine current riparian conditions and how management strategies can result in properly functioning LWD recruitment:

> Ecological functions associated with large woody debris (LWD) are an important part of productive in-stream habitat. LWD provides important habitat diversity by providing structure for stabilizing streambeds, building floodplains, storing sediment, retaining spawning gravels, maintaining flow complexity, storing nutrients, and providing habitat for fish and/or stream-associated amphibians. LWD should be of a size (length and width) and species to remain intact and stable for many years. See Board Manual Section 26 Guidelines for Large Woody Debris Placement Strategies, under "The criteria for wood placement" for more information.
>
> Wood naturally enters streams from:
>
> - Fallen dead trees.
> - Trees undercut by stream flows.
> - Disturbance events such as debris torrents, landslides, fire, insects, disease, and wind storms.
>
> LWD from large trees forms pools and cascades in streams. However, many riparian areas no longer have large diameter trees available to fall into the streams. Small diameter wood may be available but is not necessarily adequate to provide optimum riparian woody debris function. Therefore, both short-term and long-term woody debris

recruitment is desirable. Woody debris comes from the riparian forest adjacent to the stream and by water transport from areas upstream.

Any tree that has the potential to contribute wood to the stream is within the LWD area of influence. Trees closest to the stream have the highest potential to fall into the stream. To determine the width of the area influencing woody debris input and availability consider the potential tree height of the tallest (dominant) trees on the site. The area of influence for LWD recruitment may be estimated as the distance equal to 75 percent of the 100-year site-potential tree height of the dominant trees within the riparian area, measured from the outer edge of BFW or CMZ. When evaluating the areas of influence for woody debris recruitment consider:

- Trees leaning towards the stream. The most likely candidate trees for entering a stream are those leaning towards the stream, and trees located on steep slopes, on the edge of the first terrace, and in inner gorges.
- Hardwood contribution for short-term benefit. Woody debris from hardwood forests decomposes faster than woody debris from conifer forests.
- Placing large wood to enhance the near-term function. This will allow the development of long-term woody debris recruitment opportunities within the riparian forest. For technical guidance on in-channel woody debris placement, see Board Manual Section 26.
- The extent and conditions of existing in-stream woody debris adjacent to the proposed area of harvest.
- The productivity of the soil. Higher soil productivity will grow taller trees for future supply of woody debris to the stream. More productive soils will have larger areas of influence.
- Promoting growth of existing understory conifer by releasing it from competing brush and hardwood vegetation. This may be preferable to relying on seedling growth.
- Extending the area of influence where there is the potential for channel migration. For guidance on the potential for channel migration, see Board Manual Section 2.

The best strategy for woody debris availability is to manage for the potential recruitment of LWD for the short- and long-term [author emphasis added].

WFFA Function Evaluation

WFFA's function evaluation for large woody debris recruitment states:

The primary factors controlling large wood (LW) recruitment to streams are tree height and stand mortality processes. In general the distances to sources of stream wood increase with increasing tree height. For example, the source distances for tall old growth Douglas fir or coastal redwoods of California may extend out to 200 ft., but recruitment of shorter Sitka spruce in Southeast Alaska may only extend to 125 ft. (Benda & Bigelow 2014, Martin & Grotefendt 2007, McDade et al. 1990). Similarly, smaller trees in second-growth stands will have shorter source distances than trees from old-growth stands. However, the tree height source distance relationship is modified by site-specific factors (i.e., valley morphology, stream width, and wind exposure) that can have a strong influence on stand mortality. For example, LW recruitment by bank erosion is the dominant wood input process for low- to moderate-gradient channels in unconfined valleys and bank erosion recruitment increases with increasing stream width (Benda & Bigelow 2014, Johnston 2011, Martin & Benda 2001). Most of the LW in erosion prone channels is derived from the stream banks (e.g., 86% to 98% may be recruited from within 25 ft.; Table A-3, Figure A-3). Recruitment by stand mortality (e.g., stem suppression) is generally dominant where bank erosion is limited, such as in riparian stands adjacent to smaller streams and streams of any width that are confined by bedrock or hillslopes. Also, there is a strong tendency for dead trees to fall towards the channel on steeper hillslopes (i.e., >40%) that may increase recruitment by 1.5 to 2.4 times over levels from lower-gradient landforms (Sobota et al. 2006). In areas where stand mortality dominates, the source distance distribution shifts away from the stream bank and most recruits are derived from within 50 to 75 ft. (Table A-3, Figure A-3). Note, the far right shift of source distances for the McDade et al. (1990) data (Figure A-3) are due, in part, to significant recruitment from trees and tree pieces that slid down steep side slopes (50% of study sites were located on slopes > 40%). Windthrow can extend the source distance by increasing recruitment from trees along the outer edge of buffer strips (Rollerson et al. 2009, Martin & Grotefendt 2007, Liquori 2006). Local landslides can extend the source distances even farther from the channel up the hillslopes (Benda & Bigelow 2014). The rank ordering of source distances for all mortality processes are bank erosion < tree mortality < windthrow < local landslides.

Windthrow can increase the probability of LW recruitment from buffer strips over the short-term and can influence the long-term supply at locations prone to wind damage. At the landscape scale, windthrow mortality is highly variable; having a skewed mortality distribution (i.e., most sites have low mortality and a few have high mortality (Grizzel and Wolff 1998, Martin and Grotefendt 2007, Rollerson et al. 2009). Wind damage is strongly associated with buffer orientation relative to the predominant storm direction (i.e., southeast, south, southwest in the Pacific Northwest) and local conditions including wind fetch length resulting from the size of clearcut units (Kramer et al. 2001,

> Mitchell et al. 2001, Rollerson et al. 2009). At the scale of individual trees, windthrow mortality is associated with low percent live crowns (< 40%) and high height-diameter ratios (>60%) (Scott 2005). Reductions in windthrow mortality are feasible when site and landscape factors are considered in harvest unit plans (Kramer et al. 2001; Mitchell et al. 2001).

This leads to evaluation criteria that state:

> Effectiveness for LW supply is based on the widths of the no-cut buffer and the thinned buffer. Large wood source-distance curves based on empirical data from the Northwest and Southeast AK (Appendix Figure A-3) are used to evaluate LW supply potential. The LW supply potential for the thinned zone is reduced by tree harvest. Therefore the post-thinning LW supply potential is adjusted as follows. First the LW supply potential for the no-cut width and the width at the outer edge of the thinning zone (i.e., outer edge of "inner zone" for FPR rules) are derived from the source distance curves (Appendix A). Second, the difference in LW supply between the no-cut and thinned zone widths, is adjusted based on the predicted loss in dead tree production due to thinning as shown in modeling by Pollock and Beechie (2014). The reduction in dead tree production for trees > 20" (i.e., 50 cm dbh) at 50 years post-treatment for thinning levels of 57 tpa and 100 tpa (i.e., 150 tph and 250 tph, respectively) are based on results presented in Figure 5b of Pollock and Beechie (2014). Using these results, the relative production of dead trees for thinning treatments of 57 (heavy thin) and 100 tpa (moderate thin) are 45% and 73%, respectively, of the potential production for an un-thinned stand at 50 years. For example, LW supply potential after heavy thinning (retain 57 tpa) in Situation 8 (50/nc, 75/hth) is > 93%. This estimate is based on LW supply potential of 91% and 96%, respectively for the no-cut buffer distance at 50 ft and thinning distance at 75 ft respectively; with difference of 5% and relative dead tree production of 45%; results in LW potential of 93% (i.e., 0.91 + (0.05 x 0.45) = 0.93).

Dr. Martin further explains in an email to the contractor:

> Because prescriptions in the SFLO proposal are based on Stream Type and BFW categories, I used the latter to guide selection of the dominant LW input process. For streams >15 ft, I assumed that LW input is dominated by bank erosion. Thus, I used the most conservative value for the given RMZ width. For example, for Rx No 1 with 75 ft RMZ I used the least wood recruit value (96%) from the two rows of data (Martin & Grotefendt 2007 or Johnston 2011). For the 5-15 ft and <5 ft categories I assumed the dominant input process is "mixed". Thus, I used the most conservative values from the three listed sources for a given width RMZ.

Interpreting Table 3 of WFFA's science justification, their application of these assumptions led to estimated percent reductions in LWD recruitment, relative to unmanaged reference stands, that would range between 2 percent and 25 percent for 100-ft and 25-ft fixed width no-harvest buffers, respectively (**Table 1**). According to their analysis, most (about 75 percent) LWD recruitment would occur within 25 feet of the stream channel. Clearcut harvest to the streambank would eliminate all LWD recruitment, except slash. Thinning would further decrease LWD recruitment, the extent depending on whether a stream-adjacent no-harvest buffer was prescribed (**Table 2**). When using an "inner" 25-ft no-harvest buffer, LWD recruitment potential would be greater than when thinning throughout the buffer.

Table 1: Percent reduction in LWD recruitment from fixed-width no-harvest buffers, relative to unmanaged reference stands, under the WFFA function evaluation.

Buffer Width (ft)	Percent Reduction
0	All but slash
25	25%
50	9%
75	4%
100	2%

Table 2: Percent reduction in LWD recruitment from thinned riparian buffers, relative to unmanaged reference stands, under the WFFA function evaluation.

Buffer Width	Thinning Prescription	Percent Reduction
25	Thin entire buffer from above	81%
50	Moderate thinning in the outer 25 ft	13%
75	Heavy thinning in the outer 25 ft	7%
100	Heavy thinning in the outer 50 ft	6%

Independent Function Evaluation

One peer-reviewed study was identified that tested the effect of riparian buffers on LWD source-distance relationships in western PNW forests:

- Martin et al. (1998) found that, in streams along unlogged stands in southeast Alaska, where streambank erosion was the major agent for LWD recruitment, 100 percent of LWD (pieces) in the channel was derived from within 20 m of the stream, 95 percent of which was delivered from within 10 m of the stream. Using standard buffers, a lower proportion was derived from within 10 m of the stream (75 percent) and more came from the 10-20 m zone (21 percent). Median tree heights were about 17 m (56 ft) ranging to the tallest trees at about 45 m (147 ft). Buffers were 5 to 10 years old.

Two studies were identified in gray literature that tested the effect of riparian buffers on LWD source-distance relationships in western PNW forests:

- In un-reentered coastal northern California redwood and Douglas-fir forests, Reid and Hilton (1998) found 80 percent of the LWD delivery (pieces) were sourced from within 25 m of the stream channel. When buffer strips were employed, 80 percent of LWD was delivered from within about 33 m. Average canopy height of about 175 ft was assumed.
- In southeast Alaska, Martin and Grotefendt (2007) found that 80 percent of LWD recruitment (pieces) occurred within about 5 m (16 ft) of the stream along unmanaged reference sites. They found that logging caused an increase in the proportion of tree recruitment from the outer zone of buffers. The mean tree height was 21.8 m (71.5 ft) in treatment units and were 1.7 m taller (77 ft) in reference units. Buffer strip age ranged between 3 and 15 years, post-harvest.

Several synoptic surveys were identified, both peer-reviewed and gray literature, monitoring LWD recruitment source-distances along westside managed and unmanaged streams:

- Lienkaemper and Swanson (1987) surveyed LWD delivery from unmanaged old-growth conifer stands in the H.J. Andrews Experimental Forest, finding that 66 percent of LWD (pieces) were delivered from trees growing in areas not subject to bank erosion; source distances are not reported. The remaining 34 percent were delivered from stream-adjacent trees. Tree heights are not reported in this study.
- McDade et al. (1990) found that, in surveys of streams along unmanaged mature and old-growth stands in Oregon and Washington, 11 percent of LWD (pieces) were recruited within 1 m of the stream channel and over 70 percent originate within 20 m. Stands with taller trees (old-growth conifers) contributed LWD to streams from greater distances (80 percent within about 27.5 m) than did stands with shorter (mature) trees (80 percent within 20 m). Stand heights are not reported.
- McKinley (1997) found that, along unmanaged reference streams in western Washington, about 83 percent of LWD recruitment (pieces) occurred within 25 to 30 ft of the stream and that more recruitment occurred along tributaries than along mainstems. Stands surveyed ranged in age from 50 to 80 years-old.
- In studying LWD recruitment from unmanaged forests in northern coastal California, Benda et al. (2002) found that approximately 80 percent of LWD (volume) was recruited

within 12.5 m from 50-year old second-growth stands, compared to about 80 percent recruited within 35 m of the stream from old-growth stands.

- May and Gresswell (2003) surveyed LWD recruitment in old-growth forests along the southern Oregon coast, finding that 80 percent of LWD recruitment (pieces) was sourced from trees within 30 m of the stream channel. Stand height was not measured.
- In a synoptic survey of LWD recruitment along unmanaged and old-growth and mature forests in southwest British Columbia, Johnston et al. (2011) found that 90 percent of the LWD (pieces or volume) entering the channels originated within 18 m of the stream in 90 percent of all cases. 80 percent of competition-induced LWD recruitment came from within 20 m. Where streambank erosion was the predominant agent, a greater proportion of LWD was sourced near-stream. Where windthrow and landslides were more prevalent, the proportion sourced beyond 20 m was greater. Stand heights are not reported in this study; however, stands were classified “old-growth.”
- Benda and Bigelow (2014) compiled a comprehensive report of synoptic surveys of LWD recruitment throughout northern California, showing the effects that recruitment process and tree heights had on source-distance curves in unmanaged forests:
    - Where bank erosion dominated LWD recruitment, 80 percent of LWD recruitment occurred within 5 to 10 m of the stream;
    - In second-growth stands where competition-induced mortality was the most prevalent agent and where trees were relatively shorter, 80 percent of LWD recruitment occurred within about 10 to 15 m of the stream; and,
    - In managed coastal Douglas-fir-redwood forests, 80 percent of LWD recruitment occurred within about 15 m of the stream.

One peer-reviewed, field-validated model was identified for western PNW streams that predicts LWD recruitment based on tree heights and distance to stream:

- Murphy and Koski (1989) found that in southeast Alaska streams, nearly all LWD (pieces) was derived from within 30 m of the stream. Along unmanaged reference streams in southeast Alaska, about 80 percent of LWD recruitment occurred within 10 m of the stream. Stand age is not reported; however, they were considered “old-growth.”

These studies observed the consistent influence of tree height on source-distance relationships, a dynamic otherwise shown theoretically by several unvalidated LWD recruitment models (e.g., Robison and Beschta 1990, Welty et al. 2002, and Teply et al. 2007).

Of the studies cited above, six informed the source-distance relationships used by WFFA: one experimental study found in gray literature (Martin and Grotefendt 2007), three peer-reviewed synoptic surveys (McDade et al. 1990, Johnston et al. 2011, and Benda and Bigelow 2014), one gray literature synoptic survey (McKinley 1997), and one peer-reviewed field-validated model

(Murphy and Koski 1989). Therefore, there is overlap in the literature the contractor **independently** found relevant to LWD recruitment in westside forests and that which WFFA found relevant; however, it should be emphasized that we found additional relevant studies, as listed above). WFFA used these six studies to construct the source-distance curves in **Figure 1** which depicts a range of outcomes predominantly driven by delivery process (mostly reflecting bank erosion or competition-induced mortality) and tree height (predominantly shorter trees due to forest type and/or stand age). Generally, these curves show that, under these conditions, most LWD is recruited near-stream. With the exception of McDade et al. (1990), these curves show that 80 percent of instream LWD was recruited within 25 ft of the stream.

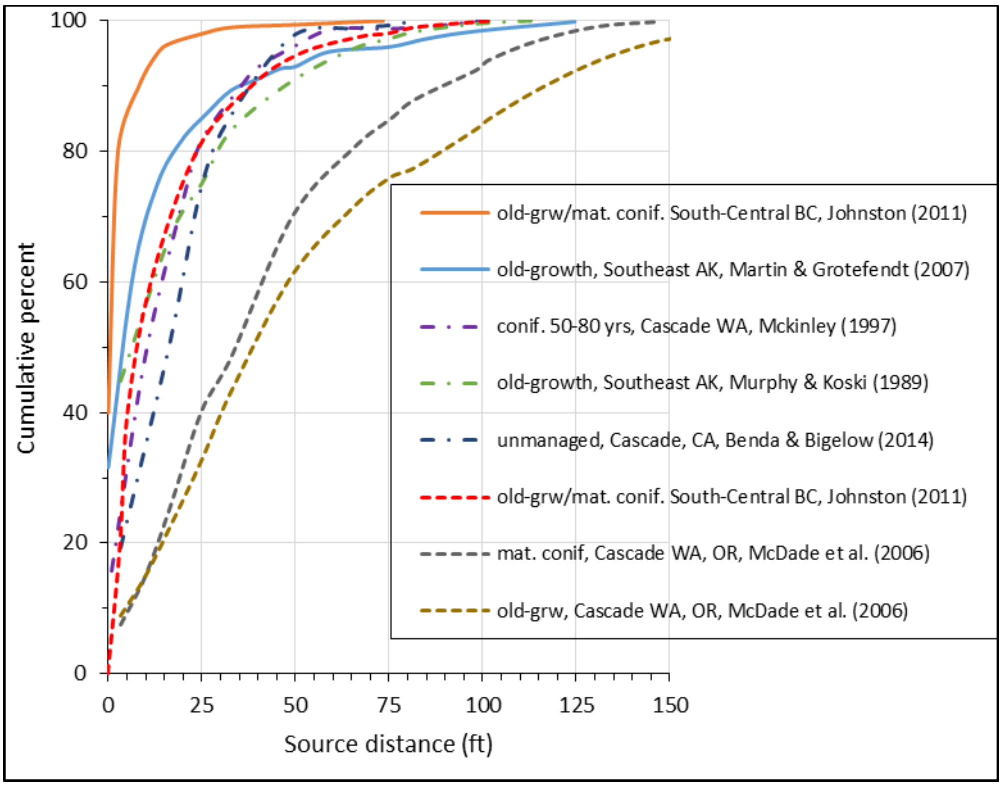

Figure A-3. Large wood source distance curves for riparian forests similar to stands typical of western Washington. Dominant recruit processes are bank erosion (solid line), stand mortality (dashed line), mixed (dash-dot line). Note, the far right shift of source distances for the McDade et al. (1990) data are due, in part, to significant recruitment from trees and tree pieces that slid down steep side slopes (50% of study sites were located on slopes > 40%).

Figure 1: LWD source-distance recruitment curves synthesized in the WFFA proposal. (Note that the citation for McDade et al. 2006 is mislabeled; the correct citation is McDade et al. 1990.)

We are concerned with two aspects of LWD recruitment that are not adequately addressed by the WFFA analysis, however. First, we find that the average heights of the stands in most studies referenced by WFFA are short (about 20 m tall) compared to the potential heights of trees that could be found in mature Douglas-fir-hemlock forests that would develop over time in western Washington. Spies and Franklin (1991) characterize that the mean dbh of mature conifer stands in the Pacific Northwest range between 30 and 39 inches—this translates to average tree heights (about 40 m) much greater than those assumed in **Table 1** and **Table 2**. Where tree heights are shortest (e.g., in Alaska forests studied by Martin et al. 1998 and Murphy and Koski 1989) most trees are delivered near-stream (within about 10 m of the stream channel). However, the proportional delivery distance increases as tree heights increase (e.g., in mature forests in Washington and Oregon studied by McKinley 1997 and McDade et al. 1990) to 10 to 20 m, ultimately reaching maximum in old-growth forests (e.g., those studied by Johnston et al. 2011 and May and Gresswell 2003) to about 20 to 30 m and greater. This would have the effect of shifting LWD recruitment source-distance recruitment curves to the right (as with the McDade et al. 1990 curves in **Figure 1**). Consequently, levels of LWD recruitment loss in **Table 1** and **Table 2** would likely be greater than shown. Instead of 80 percent of LWD recruited within 25 ft of the stream, this zone of delivery could be as great as 75 ft or more.

Second, we find that WFFA's selection of studies predominantly reflect one delivery process—streambank erosion. The importance of streambank erosion is acknowledged as documented by Martin et al. (1998) and by other researchers (e.g., Benda and Bigelow 2014). However, several studies from western Washington (e.g., McKinley 1997, Schuett-Hames et al. 2012, and CMER 2018a) do not observe the prevailing effects of streambank erosion on LWD recruitment. Instead, most western Washington studies found that windthrow was a dominant post-harvest process and it is possible that the effects of streambank erosion are masked. Such concerns are further confounded when McKinley (1997) observed similar relationships where streambank erosion was not a predominant process. Nonetheless, we found considerable study about the effects of windthrow on LWD delivery in the western Pacific Northwest not addressed by WFFA:

- In assessing the effects of logging on winter salmonid habitat, Heifetz et al. (1986) observed greater pool habitat along buffered reaches, compared to that along unmanaged reaches, due to greater LWD recruitment from blowdown.
- Murphy et al. (1986) found that, along southeast Alaska streams with riparian buffers that ranged 15 m to 130 m wide, windthrow resulted in instream LWD loads post-harvest that were nearly twice those along unmanaged reference reaches.
- Lisle and Napolitano (1998) found substantial windthrow following timber harvest along buffers in second-growth coastal redwood forests. Their evaluation of stream habitat conditions suggests that improved habitat following blowdown will be followed in future decades by less favorable conditions as LWD decays and as input rates from windthrow-depleted riparian sources in buffer zones decline and recover.
- Reid and Hilton (1998) further investigated the windthrow observed by Lisle and Napolitano (1998), finding that about 30 percent of tree-falls within one tree length of the stream were triggered by trees falling upslope of the contributing tree. This process nearly doubled the buffer width within which the windthrow acted in LWD recruitment.

- Martin et al. (1998) found in the evaluation of riparian buffer effectiveness in southeast Alaska that exposing the outer buffer zone trees to windthrow increased the percentage of trees falling toward the stream and that the percentage of trees affected by windthrow (which they interpreted to be 10 m to 30 m from the stream) that hit the stream was about 5 percent to 13 percent greater than at unlogged sites.
- In a report on the effectiveness of Washington watershed analysis prescriptions on LWD recruitment, Grizzel et al. (2000) found that buffers 20 to 30 m wide contributed, on average, about 19 percent of LWD outside 20 m from the stream and that 30-m buffers contributed 28 percent of LWD from outside 20 m from the stream.
- Liquori (2006) monitored riparian buffers in the Cascade Mountains of western Washington, finding that post-harvest wind-derived tree fall rates up to three years post-harvest were nearly 26 times greater than competition-induced mortality rates. He also found treefall direction was strongly biased towards the stream. Interpreting his results, findings suggest that creating a clearcut edge can effectively increase the source-distance curve for second-growth Douglas-fir forests to over 50 m.
- Jackson et al. (2007) report on monitoring LWD recruitment following harvest under forest practices rules in Washington's Coast Range finding that blowdown rates ranged from 33 percent to 64 percent of buffer trees within 2 years after harvest.
- From monitoring LWD recruitment in southeast Alaska, Martin and Grotefendt (2007) found about 46 percent more downed trees in 20-m riparian buffers compared to recruitment within the same zone along reference reaches and higher levels of recruitment from the outer buffer than from the inner buffer, flattening the source-distance recruitment curve seen at the unmanaged reference sites.
- In a study of windthrow in riparian buffers in western British Columbia, Bahuguna et al. (2010) found that windthrow was higher in 10-m buffers, compared to unmanaged stands, while competition-induced mortality was higher in reference unmanaged conditions. Within two years, 11 percent of standing trees were blown down in the 10-m buffer compared to 4 percent in 30-m buffers and 1 percent in unharvested controls.
- Schuett-Hames et al. (2012) found in investigating LWD recruitment along western Washington streams that LWD recruitment from 50-ft no-harvest buffers was 3 times greater than that from unmanaged stands along reference reaches, the difference mostly due to increased windthrow along the buffered reaches.
- The Type N Hardrock Study in western Washington (CMER 2018a) found that windthrow contributed to LWD recruitment within 2 years of harvest along 50-ft no-harvest buffers at about twice the rate as that from unharvested reference sites and that LWD recruitment along buffers under the Forest Practices rules was nearly three times reference rates. In managed stands, LWD contribution from the outer half of buffers was substantially greater than from beyond the same distances at reference sites.

Generally, though these studies reflect a range of information quality for PNW forests, they collectively indicate that windthrow can increase short-term LWD recruitment to streams, extend the effective source-distance of LWD recruitment, increase the proportion of LWD recruited from the outer portions of riparian buffers, and defer recovery of LWD availability for decades (see **Table 3** for the contractor's synthesis of the literature findings). These effects intensify as riparian buffers narrow, as trees are thinned from buffers, and as stands develop over time. Though we agree with WFFA's assessment that windthrow does not occur in every harvest situation and that buffers can be designed to mitigate windthrow effects, we do not agree that windthrow processes can be dismissed. The studies listed above validate our concerns, but it is difficult to precisely quantify the impact—windthrow will vary depending upon a range of site and management factors. Overall, we can only state that levels of LWD recruitment loss in **Table 1** and **Table 2** would likely be greater than shown.

Table 3: Influence of windthrow on short-term, near-term, and long-term LWD recruitment.

Scenario	Short-term (Immediately post-harvest)	Near-term (After post-harvest windthrow pulse)	Long-term (At maturation of the residual buffer)
Unmanaged stands	• All available trees are retained	• Availability of trees decreases as windthrow occurs at natural levels	• Availability of trees decreases as windthrow occurs at natural levels
Wide buffer (greater than or equal to the average height of mature trees)	• All available trees are retained	• Availability of trees decreases due to windthrow at levels greater than in unmanaged stands	• Availability of trees decreased due to windthrow at levels greater than in unmanaged stands • Windthrow "thinning" reduces competition-induced mortality leading to lower recruitment
Narrow buffer (less than the average height of mature trees) **Young stands** (average height of the buffered stand is less than the buffer width)	• All available trees are retained	• Availability of trees decreases due to windthrow at levels greater than in unmanaged stands	• Availability of trees decreased due to windthrow at levels greater than in unmanaged stands • Windthrow "thinning" reduces competition-induced mortality leading to lower recruitment

			• Narrow buffer removes trees that would otherwise be available beyond the buffer's edge
Narrow buffer (less than the average height of mature trees) **Mature stand** (average height of the buffered stand greater than the buffer width)	• Loss of all available trees beyond buffer	• Availability of trees decreases due to windthrow at levels greater than in unmanaged stands	• Availability of trees decreased due to windthrow at levels greater than in unmanaged stands • Windthrow "thinning" reduces competition-induced mortality leading to lower recruitment • Narrow buffer removes trees that would otherwise be available beyond the buffer's edge
Incremental effect of buffer thinning	• Loss of available trees through thinning	• Potentially higher windthrow from greater exposure	• Availability of trees decreased even more than unthinned buffers due to windthrow at levels greater than in unmanaged stands • Greater windthrow "thinning" reduced competition-induced mortality even more leading to even lower recruitment

In considering thinning effects, field evaluation of the effects of thinning riparian buffers on LWD recruitment was absent and were more widely addressed in unvalidated models:

- In simulations of forest management alternatives within riparian buffers in Oregon forests, Benda et al. (2016) found that single and double entry thinning on one side of a stream, without a buffer, reduced cumulative instream wood volume 33 percent and 44 percent, respectively, after 100 years. Deficits can be offset through tree-tipping.

- In interpreting the impacts of blowdown on LWD recruitment, Liquori (2006) found that post-harvest wind effects reduced the standing density of trees enough to reduce or eliminate competition-induced mortality, resulting in different long-term LWD recruitment dynamics from buffers compared to that in unmanaged forests.
- Schuett-Hames et al. (2012) found in investigating LWD recruitment along western Washington streams that increased mortality in 50-ft no-harvest buffers, mostly due to increased windthrow which decreases the number of stems, would also likely lead to lower mortality as stands develop. Lower density and lower levels of competition-induced mortality were projected to lead to lower LWD recruitment.
- Spies et al. (2013) made several general observations about the effects of thinning on LWD recruitment through simulation in Oregon Douglas-fir forests:
    - Conventional thinning (i.e., thinning that removes all or most dead wood from the stand) generally produces fewer large dead trees;
    - Conventional thinning can accelerate development of very large trees; and,
    - Nonconventional thinning (i.e., thinning from below, retaining both poor- and high-quality large trees with sufficient residual stocking to induce mortality) can accelerate dead wood production.
- Pollock and Beechie (2014) modeled thinning in riparian stands, projecting decreased levels of competition-induced mortality as thinning intensity increases.

Generally, the theme found throughout these studies was that thinning may further limit LWD availability, both short-term and long-term. Short-term losses could occur through removal of trees; long-term losses could occur through fewer residual trees and lower mortality. However, we found no field study of thinning effects, only of windthrow serving as a surrogate.

Best Available Science Determination

The science used by WFFA in their function evaluation overlaps with the science used to conduct the independent function evaluation of short-term, post-harvest effects of forest practices in westside young stands not subject to windthrow and their curves agree with the independent function evaluation in finding that, in these instances, about 80 percent of instream LWD is recruited within 25 ft of the stream. Information used by WFFA to derive the source-distance relationship includes field experiments, synoptic surveys, and field-validated models from peer-reviewed and gray literature. The independent function evaluation used more field experiments and synoptic surveys, but findings show similar general trends.

We are concerned, however, that WFFA's analysis did not incorporate science about long-term LWD availability and recruitment (i.e., from taller stands) and, in this regard, their analysis is deficient. Though most information about long-term LWD recruitment in the westside is found in peer-reviewed synoptic surveys, not field experiments, these studies nonetheless show that average heights of the stands reflected in most studies referenced by WFFA are short compared to the potential heights of trees that could be found in mature Douglas-fir-hemlock forests that would develop over time in western Washington. Therefore, estimates of LWD recruitment loss in Table 3 of the WFFA report likely underrepresent the distance from which full potential LWD could occur and underrepresent LWD recruitment loss.

We are also concerned that WFFA's analysis did not incorporate science about the effects of windthrow in all stand types and, in this regard, their analysis is deficient. Windthrow effects on LWD recruitment have been addressed by westside field experiments, as well as westside synoptic surveys, and these studies show that windthrow can increase short-term LWD recruitment to streams, extend the effective source-distance of LWD recruitment, increase the proportion of LWD recruited from the outer portions of riparian buffers, and defer recovery of LWD availability for decades. Such dynamics are not represented in Table 3 of the WFFA report and, therefore, LWD recruitment loss is likely underrepresented by the WFFA analysis.

Finally, field study of the effects of thinning on LWD recruitment is lacking in the literature and this, we assume, led to WFFA's use of models. In our professional opinion, we found the modeling results in Pollock and Beechie (2014), which were used by WFFA to estimate thinning effects on stand stocking and available LWD, to be consistent with the findings reported in the other listed models and we found the study authors to be transparent about their modeling assumptions and applicability to westside forests. WFFA's interpretation of the Pollock and Beechie (2014) was sound. Nonetheless, it is unvalidated and, consequently, it is difficult to ascertain whether rates in Table 3 of the WFFA report are under- or over-represented.

Stream Shade

Board Manual 21 Background

Board Manual 21 offers the following considerations for developing and analyzing alternate plan prescriptions, helping landowners and foresters determine current riparian conditions and how management strategies can result in properly functioning stream shade:

> The most significant influence on stream temperature, under the control of forest managers, is shade from the canopy of the adjacent riparian area vegetation. An important function of canopy cover in the riparian area is to provide shade to maintain cool stream temperatures. This is a particularly vital function for fish and amphibians.
>
> To determine the area of influence of the shade function, consider the guidance provided in Board Manual Section 1, Method for Determination of Adequate Shade Requirements on Streams. Following the steps of this manual can help the landowner to establish the minimum width of the riparian area needed to meet the water quality

standards for stream temperature. For streams within channel migration zones, additional guidance may be obtained from Board Manual Section 2, Standard Methods for Identifying Bankfull Channel Features and Channel Migration Zones. The trees closest to the stream are the most important for shade. The area of influence of shade from trees usually extends for a distance of 75 feet measured from the outer edge of bankfull width (BFW) or the edge of the channel migration zone (CMZ).

To understand the overall impact of management activities on the shade function, consider all of the forest characteristics in the riparian areas within the stream reach to be included in the alternate plan. The level of influence the overstory riparian canopy has on water temperature depends on a variety of factors, including:

- Stream size. Streams less than 30 feet wide are greatly influenced by riparian shading in the summer months. In larger streams, the influence of shade on water temperature will be site-specific.
- Topography. Local topography, such as steep hill slopes or cliffs may provide shading to the stream.
- Channel orientation. On east-west oriented channel segments, the shade from riparian vegetation on the south side of the stream has a greater and more direct influence on the stream than vegetation on the north side of the stream.
- Understory vegetation. Thick understory vegetation can contribute to stream shading, especially in entrenched or narrow stream channels.
- Canopy openings. Canopy openings naturally occur from bank erosion, vegetation succession, or stream bank disturbances such as flooding, debris flow, fire, or wind.

The best strategy for providing shade to protect stream temperature is to retain or develop a multi-storied riparian forest that is wide enough to minimize the impacts of solar radiation on the stream environment [author emphasis added].

WFFA Function Evaluation

WFFA's function evaluation for shade states:

> Predictions of effective shade (i.e., percentage of potential daily solar radiation blocked by vegetation and topography) were simulated with the Ecology shade model (http://www.ecy.wa.gov/programs/eap/models.html) to demonstrate how stand height, composition, buffer width, and stream aspect influence shade. Effective shade was simulated for a hypothetical low-gradient (2 - 3%) stream, with no topographic shading, located in Olympia vicinity, and having conifer/deciduous riparian stands that are typical of western Washington (Table 2). The simulation results are consistent with

the findings described by others and show that effective shade is mostly provided by trees within 15-25 ft. of the stream regardless of stand height, composition, and aspect (Figure A-1, Appendix B). Trees beyond 25 ft. only contribute a small amount of shade. Shade is correlated with tree height as high shade levels (i.e., exceeding 75%) are provided by small trees along 5-ft. streams, and by medium to large size trees along streams up to 25 ft. wide. Shade potential declines with increasing stream width and is lowest for the wider streams with a N-S aspect. Note, the mixed-medium and mixed-large stands provide slightly more shade than the conifer stands of similar size (Appendix B). The latter is partly due to the greater overhang which blocks direct beam radiation. Similarly, high shade levels can be maintained along E-W streams (aspects 270º and 225º) with dense stands on the south side and sparse stands on the north side because most radiation is blocked by the south side stand (Figure A-2).

Interpreting Table 3 of WFFA's science justification, estimated percent reductions in shade, relative to presumed maximums in unmanaged reference stands, range between 0 and 6 percent for 100-ft and 25-ft fixed-width no-harvest buffers, respectively (**Table 4**). Only slight differences exist between narrow and wide streams. Based on WFFA's predictions using the DOE shade model, nearly all shade would be provided within the first 25 feet of the stream channel. Clearcut harvest to the streambank would remove all shade, except that from brush and streambank. Thinning would have negligible effect on shade loss when an "inner" 25-ft no-harvest buffer is used (**Table 5**). Predictions from the DOE shade model show that thinning throughout a 25-ft buffer, however, would result in much greater shade loss.

Table 4: Percent reduction in stream shade from fixed-width no-harvest buffers, relative to unmanaged reference stands, under the WFFA function evaluation.

Buffer Width	Less than 5-ft BFW	5 to 15-ft BFW	Greater than 15-ft BFW
0	All but brush, streambank	All but brush, streambank	All but brush, streambank
25	5%	6%	6%
50	4%	6%	6%
75	0%	0%	0%
100	0%	0%	0%

Table 5: Percent reduction in shade from thinned riparian buffers, relative to unmanaged reference stands, under the WFFA function evaluation.

Buffer Width	Thinning Prescription	Percent Reduction
25	Thin entire buffer from above	57%
50	Moderate thinning in the outer 25 ft (5 to 15-ft BFW)	5%
75	Heavy thinning in the outer 25 ft (greater than 15-ft BFW)	6%
100	Heavy thinning in the outer 50 ft	6%

Independent Function Evaluation

The contractor has conducted several investigations employing Shade.xls, the shade model used by WFFA to conduct their function evaluation. In the course of their work, insight was provided by the EPA (shown in Teply and Ceder 2012) which asserted that predictions from Shade.xls do not comport with field observation. The contractor did not dismiss the EPA assertions and conducted analyses informed by shade monitoring across the region, concluding that Shade.xls *is* prone to bias, both across ecoregions and within ecoregions. The nature and extent of this bias is extracted from Teply et al. (2014) (**Figure 2**). The contractor conducted a similar analysis for western Oregon for the Oregon Forest Industry Council which is proprietary but nonetheless showed similar trends. From this experience, it is the contractor's practiced judgement that field observation is superior to unvalidated modeling results from Shade.xls. We **do not** advise the use of Shade.xls without field-verification. For these reasons, we have chosen to focus on field observations from the western PNW for their independent evaluation.

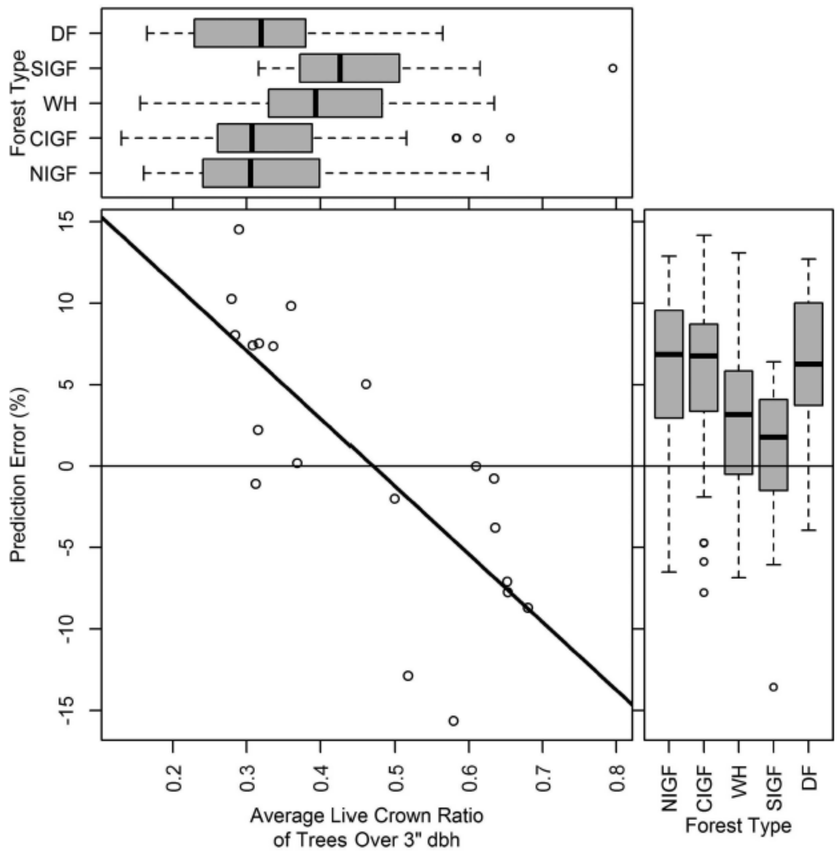

Figure 2. Plot of prediction errors versus average live crown ratio of trees >3 in. dbh and their comparison to boxplots of the data distribution of average live crown ratios in IDL CFI plots from uncut stands in north, central, and southwest Idaho. NIGF, north Idaho grand fir-western redcedar; CIGF, central Idaho grand fir-western redcedar; SIGF, southwest Idaho grand fir-western redcedar; WH, Western hemlock-subalpine fir; DF, Douglas-fir.

Figure 2: Shade.xls prediction errors as a function of average live crown ratio, developed using paired shade and riparian vegetation monitoring data from Oregon, Washington, Idaho, and Montana.

Several field studies were identified that quantify shade along streams with fixed-width no-harvest buffers in stand conditions which the WFFA template would apply (**Table 6**). Six are experimental studies, testing the difference in shade provided by different levels of buffer protection. Two of these are peer-reviewed (Brazier and Brown 1973, Janisch et al. 2012) and the other four are state-led effectiveness monitoring efforts in Washington and Oregon. The seventh study tabulated, Steinblums et al. (1984), is a synoptic survey across western Oregon, measuring shade along a range of riparian buffers, including those in unharvested stands.

When the average shade levels reported by these studies are plotted for the different buffer widths encountered, several general trends emerged (**Figure 3**). First, measurable decreases in shade occurred over the range of fixed-width no-harvest buffer widths considered in the WFFA proposal. Second, there appears to be a meaningful difference between shade loss based on angular canopy density (ACD) and those from overhead metrics (i.e., spherical densiometer or fish-eyed photography). Because the Forest Practices rules employ overhead metrics, only these results were carried forward in this review. However, the effects on ACD are noted, and acknowledged greater, because Shade.xls *does* measure effective shade which represents the blocking of solar rays that travel through the riparian forest canopy at an angle.

In order to compare findings of this independent function evaluation to those from the WFFA analysis and summarized in **Table 4**, we calculated the difference of the averages depicted in **Figure 3**, standardizing them to represent shade loss on a per foot buffer loss basis, and compared them to rates calculated from **Table 4**. Calculated this way, from paired experimental studies, the rate represents shade loss observed from dependent samples, **not** average shade calculated from independent samples. The rates of shade loss over the range of buffer widths considered by the WFFA proposal were remarkably similar across fish-bearing and non-fish-bearing streams, averaging about 0.2 percent for each foot of buffer width lost. Translated to buffer widths shown in **Table 4**, a 75-ft buffer would lose about 5 percent shade; a 50-ft buffer would lose 10 percent; and a 25-ft buffer 15 percent. These rates are about 30 percent to 100 percent greater than effective shade loss reported by WFFA using the DOE model.

It is important to note that the overhead shade metric predicted by Shade.xls, effective shade, is different from view-to-sky metrics used in these calculations. However, CMER (2018b) shows that effective shade loss would be greater than that estimated view-to-sky. Thus, the rate calculated by the contractor likely underrepresents the shade loss in effective shade terms. Further, because these rates are calculated from averages, they do not incorporate variability that does exist in the rate of shade loss *within each study*. There *is* variability in shade loss, stand to stand, as affected by such factors as species composition, stocking density, stand height, stream orientation, latitude, season, and time of day (see Teply et al. 2014). But the consistent average trends, *study to study*, are powerful indicators of a general rate of shade loss. Overall, these rates are presented to provide a basis of comparison to the WFFA proposal. The contractor does not warrant them for rule-making targets or management; they are simply provided to demonstrate the potential bias of the results reported by WFFA using Shade.xls.

Table 6: Stream shade from fixed-width no-harvest buffers compared to shade along unmanaged reference stands, from selected field studies in the Pacific Northwest (N/A=Not Applicable; NM=Not Measured).

Citation	Landscape	Stream Width (ft)	Metric	25 ft	50 ft	75 ft	Reference
Brazier and Brown (1973)	Western Oregon	N/A	ACD	50	70	78	80
CMER (2018b)	Western Washington	6	CTD	NM	88	NM	95
Janisch et al. (2012)	Western Washington	2	CTD	86		NM	93
Morman (1993)	Southern Oregon	28	SD	67	NM	NM	81
Morman (1993)	Northwest Oregon	40	SD	62		NM	77
Schuett-Hames et al. (2012)	Western Washington	6	SD	NM	76	NM	89
Steinblums et al. (1984)	Western Oregon	N/A	ACD	NM	45	60	75

Notes:
Brazier and Brown (1973) – Angular canopy density (ACD) interpreted from Figure 5, within the range of buffer strips monitored, including 100-ft "reference" conditions
CMER (2018b) – Canopy and topographic density (CTD) averaged for 50-ft WA Forest Practices Rules buffer and for unharvested reference sites
Janisch et al. (2012) – Canopy and topographic density (CTD) averaged for 10-15 m continuous buffers and for unharvested reference sites
Morman (1993) – Spherical densiometer (SD) averaged for 24-ft average riparian buffers and for pre-harvest conditions.
Schuett-Hames et al. (2012) – Spherical densiometer (SD) averaged for a 50-ft WA Forest Practices Rules buffer and for unharvested reference sites
Steinblums et al. (1984) - Angular canopy density (ACD) interpreted from Figure 2, within the range of buffer strips monitored, including 100-ft "reference" conditions

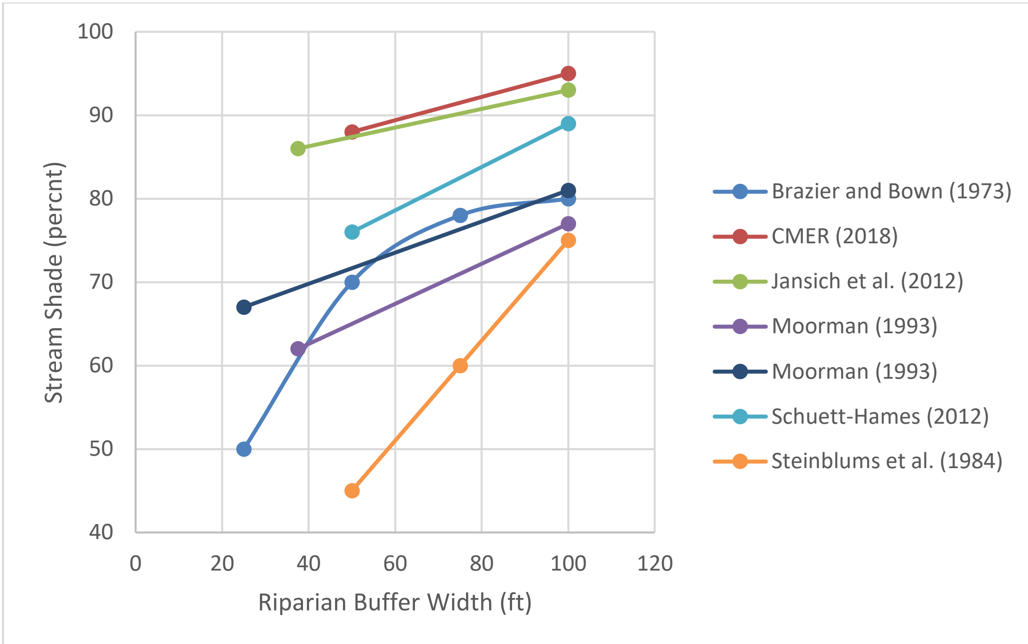

Figure 3: Stream shade from fixed-width no-harvest buffers and along unmanaged reference stands from selected field studies in the Pacific Northwest.

Five field experiments were identified that that test the effects of inner near-stream no-harvest buffers and outer thinned buffers on shade, prescriptions similar to those proposed by WFFA (**Table 7**). All cover studies conducted in western Oregon, three of which are peer-reviewed and two are gray literature reporting state-led forest practices effectiveness monitoring. These studies also found measurable decreases in shade, compared to reference conditions, over the range of buffer widths considered in the WFFA function evaluation. Yet, because of variability in the extant and widths of interior no-harvest buffers, overall buffer width extent, and variability in the intensity of outer buffer thinning, it is difficult to organize these studies into a clean plot similar to the one produced above. Yet, on average, levels of shade loss along narrow streams with stands harvested according to Oregon's forest practices rules were comparable to those along fixed-width no-harvest buffers summarized in **Table 6** (about 0.2 percent per foot of overall buffer width loss). Along wider streams, rates of shade loss were double no-harvest buffer rates (about 0.4 percent per foot of buffer width loss). This result implies that a stream-adjacent no-harvest buffer has little to no effect on mitigating shade loss. We find this result counter-intuitive and inconsistent with modeling results (e.g., Teply et al. 2014).

Overall, because these field studies occurred in landscapes where windthrow occurs, and where other tree fall agents are a factor, it is presumed that a portion of this shade loss was due to such a loss of trees; however, the proportion has not been quantified.

Table 7: Stream shade from inner near-stream no-harvest buffers and outer thinned buffers compared to shade along unmanaged reference stands, from selected field studies in the Pacific Northwest.

Citation	Landscape	Stream Width	Metric	25 ft	50 ft	75 ft	Reference
Allen and Dent (2001)	Western Oregon	7-10	1-GSF	NM	72	NM	89
Allen and Dent (2001)	Western Oregon	19-20	1-GSF	NM	NM	77	89
Anderson et al. (2007)	Western Oregon	4	1-GSF	91		NM	97
Groom et al. (2011)	Western Oregon	13	1-GSF	NM	78		85
Zwieniecki and Newton (1999)	Western Oregon	11	SD	NM	NM	78	83

Notes:
Allen and Dent (2001) - One minus global site factor (1-GSF) averaged for 50- and 75-ft OR Forest Practices Rules buffers and for unharvested reference sites
Anderson et al. (2007) – Mean one minus global site factor (1-GSF) interpreted and approximated from Figure 3 for 5- to 14-m streamside retention buffers with adjacent thinning and unthinned reference sites
Groom et al. (2011) – One minus global site factor (1-GSF) averaged for 50- and 75-ft OR Forest Practices Rules buffers and for pre-harvest reference conditions
Zwieniecki and Newton (1999) – Spherical densiometer (SD) averaged for 21-m average buffers under OR Forest Practices Rules and for unharvested reference sites above and below harvest areas

Best Available Science Determination

WFFA relied on an unvalidated model to predict shade loss that would occur under RMZ management. Yet, substantial field experimentation, peer-reviewed and in gray literature, has been conducted in the western Pacific Northwest that indicates that shade loss from narrowed buffer widths would be greater than assumed by WFFA's predictions using the DOE shade model. Therefore, we not only find WFFA’s use of best available science deficient, but also that WFFA's predictions using the DOE shade model do not comport with field studies testing the effects of riparian management compared to that in unmanaged forests. Projections in Table 3 of the WFFA report likely underestimate the amount of shade loss that would occur.

Leaf and Litterfall

Board Manual 21 Background

Board Manual 21 offers the following considerations for developing and analyzing alternate plan prescriptions, helping landowners and foresters determine current riparian conditions and how management strategies can result in properly functioning leaf and litterfall:

> Riparian areas play a key role in determining the concentration of nutrients in stream water. Uptake and storage of various elements carried by overland flows and

groundwater are influenced by both the width of riparian buffers and the species of vegetation present.

Organic input from riparian vegetation influences water quality and provides an important food source for aquatic organisms. The size, composition, and age of the riparian forest will determine the amount of organic material available to be deposited into the stream.

The area influencing nutrient input from litter fall is the maximum distance that leaf litter could be expected to reach the stream. This distance depends on tree species composition, understory riparian vegetation, height of the canopy, topographic features and prevailing winds. When evaluating the areas of influence from nutrients and litter fall consider:

- The tree species composition of the riparian stands.
- The understory species composition of the riparian stands.
- Maintaining a portion of bank along the streams in hardwood forests.
- The long-term advantages of converting to conifer.

The best management strategy for nutrients and leaf litter fall is to ensure diverse vegetation composition within the area of influence [author emphasis added].

WFFA Function Evaluation

WFFA's function evaluation for leaf and litterfall states:

> Streambank erosion and flooding of the adjacent forest floor in flood plain areas is also known to be a significant source of litter and invertebrates (White and Harvey 2007). Therefore, by inference, stream adjacent trees and shrubs, especially overhanging vegetation, are considered the most important contributors of litter and terrestrial insect fallout. Riparian management for high quality litter and terrestrial macroinvertebrate inputs would be most effective by maintaining stream adjacent (e.g., one tree crown width or about 30 ft) deciduous overstory and understory vegetation, especially near streams with moderately confined or unconfined channels (i.e., locations susceptible to bank erosion and flooding).

Followed by the determination criteria that:

> Litter potential is ranked as High if riparian stand is at least 25-ft wide or Low if clearcut.

Independent Function Evaluation

Five field experiments were identified that test the effects of forest practices on leaf and litterfall in westside PNW riparian stands. Two studies were published after WFFA's submission of their proposal in 2015, but they are nonetheless included. Most are peer-reviewed studies. Two, Bisson et al. (2013) and Estrella et al. (2018), are gray literature reporting on outcomes of federal and state-led forest practices effectiveness monitoring. Collectively, they provide consistent insight into source-distance relationships for this riparian function:

- Bilby and Heffner (2016) determined that 95 percent of litterfall recruitment from mature Douglas-fir and red alder stands in western Washington (average stand height about 155 feet) came from between about 13 m and 20 m of the stream.
- Bisson et al. (2013) found that a 15- to 20-meter continuous width buffer in western Washington field trials in young, merchantable, second-growth provided significantly more litterfall recruitment than that occurring at unharvested reference sites.
- Estrella et al. (2018) found in the Type N Hardrock study—in young, merchantable, second-growth—that there was no significant difference in litterfall recruitment along a 50-ft fixed-width buffer compared to that along unharvested reference sites.
- Kiffney and Richardson (2010) found in study of southwestern British Columbia riparian zones—in mature, second-growth stands—that a 30-meter buffer had significantly more litterfall recruitment than that occurring at unharvested reference sites and that litterfall recruitment along sites with 10-meter buffers were comparable to that which occurred along unharvested reference sites.
- Various studies in the Pacific Northwest have found that litterfall recruitment along clearcut sites to be measurable, but less than that provided from buffers (e.g., Bisson et al. 2013, Estrella et al 2018, Hetrick et al. 1998, and Kiffney and Richardson 2010).

Synthesizing the foregoing, these studies suggest the following about source-distance relationships of riparian buffers in providing leaf and litterfall function:

- Clearcuts would have marked reductions in litterfall recruitment, compared to no-harvest buffers greater than 10 m, but leaf and litterfall recruitment would still occur.
- Reductions in total litterfall recruitment along clearcut streams or no-harvest buffers less than 10 m would be short-term, returning to unharvested levels within a decade.
- Partial harvest buffers greater than 10 m wide would have a reduction in litterfall recruitment directly proportional to the reduction in stem density of the riparian.
- No-harvest buffers between 10 and 30 m wide may experience a slight increase in litterfall recruitment, compared to unharvested stands, due to increased wind exposure.
- No-harvest buffers greater than 30 m wide would have no discernable difference in litterfall recruitment to streams compared to that from unharvested stands.

Overall, the science indicates that for no-harvest buffers 10 m and greater up to about 30 m leaf and litterfall may be greater than from unharvested stands and that for buffers less than 10 m wide leaf and litterfall would likely be less than along unharvested stands, but studies of the effectiveness of 25-ft buffers have not been done. Thinning would reduce leaf and litterfall recruitment below that provided by no-harvest buffers. These overall trends are consistent among the studies; however, there can be differences site-to-site depending on species composition, stand density, stand height, stand age, slope, and exposure to the wind.

Because these field experiments occurred in landscapes where windthrow occurs, and where other tree fall agents were a factor, it is presumed that a portion leaf and litterfall was lost due to loss of trees; however, the proportion loss has not been quantified.

Best Available Science Determination

The WFFA function evaluation was premised on a study by White and Harvey (2007) which did not measure litterfall into streams. Rather, it measured trout feeding under different streamflow and turbidity conditions. Though White and Harvey (2007) offer a plausible explanation for higher feeding success during high streamflows (which coincide with higher turbidity), they offered no evidence for the cause-effect relationship with litterfall. To be clear, the study measured stomach contents which yielded fauna, not litterfall. In this regard, we found the WFFA analysis deficient because it did not incorporate relevant science.

However, their source-distance relationship, based on professional judgement, tends to agree with the science. The independent function analysis identified and used several field experiments conducted in westside riparian stands, most peer-reviewed, that consistently indicate most leaf and litterfall occurs from the first 10 m along harvested buffers. Generally, this agrees with the WFFA determination that a 25-ft buffer provides “high” leaf and litterfall function, but the effectiveness of 25-ft buffers has not been studied in the field and, more importantly, they can’t claim that any science explicitly influenced their determination.

Sediment Filtration

Board Manual 21 Background

Board Manual 21 offers the following considerations for developing and analyzing alternate plan prescriptions, helping landowners and foresters determine current riparian conditions and how management strategies can result in properly functioning sediment filtration:

> Riparian vegetation helps to filter sediments, reduce the likelihood of landslide events, and regulate the natural erosion processes within riparian areas. Reducing the amount of fine sediment entering streams and other water bodies is a major function of the riparian area. Riparian vegetation can prevent sediment from entering the stream as a

result of ground disturbance or skid trails in upland areas, and roads or road cross drains.

The width of the riparian area and the amount of riparian vegetation needed to perform filtering varies according to stream size and channel type. Large streams that connect to a floodplain at high flows require greater distances for sediment filtering than small, incised channels that rarely experience overbank flows.

Areas influencing sediment filtering are usually within 30 feet of the outer edge of BFW or CMZ, or to the top of the first terrace beyond the outer edge of BFW or CMZ. This area of influence may extend to the top of the second terrace if the first terrace is susceptible to frequent flood emersion or stream erosion. When evaluating the areas of influence for sediment filtering consider that:

- Management activities on exposed soils in riparian areas have the potential to deliver to streams.
- Management activities on steeper ground have higher potential for sediment delivery to streams.

The best strategy to prevent sedimentation caused by management activities is to keep equipment from operating below the topographic break directly above a stream or within 30 feet of the stream [author emphasis added].

WFFA Function Evaluation

The WFFA function evaluation includes overall assessments for sediment filtration and a specific assessment for near-stream delivery:

Timber harvest in or adjacent to riparian management zones can influence surface erosion and sediment input to streams as a result of ground disturbances from yarding activities (e.g., skid trails, yarding ruts), or to increases in root-pit formation from windthrow. Sediment retention within a riparian forest is controlled by vegetative ground cover, hillslope gradient, and soil erodibility (WFPB 1997). Ground cover including roots, stems, and debris (logs, slash) bind soils and create roughness elements minimizes surface runoff and traps soil particles (Liquori et al. 2008, Litschert and MacDonald 2009). Sediment delivery potential increases with slope. Therefore, the sediment retention function of riparian ground cover is most important in steeper terrain.

Sediment filtering and biotic subsidies (i.e., litter, invertebrates) are influenced most by near-stream undisturbed soil and vegetation that are maintained by minimum 25-ft no-cut or thinned buffers for all prescriptions. Thinning of merchantable trees (i.e., thinning from above (tha)) is permitted where ground disturbance is controlled (i.e., subject to ELZ rules) and includes the removal of windthrow-prone trees (i.e., small crown ratio) within 10 ft. of the stream to minimize the potential for sediment delivery from windthrow-root-pits.

Research shows that current harvest procedures and BMPs are largely effective in reducing erosion and sediment delivery to streams. Post-harvest evaluations of erosion features across a wide range of sites indicates that buffers and the prevention of ground disturbances within 30-ft of streams effectively prevented sediment inputs in most cases (Rashin et al. 2006, Litschert and MacDonald 2009). For example, Schuett-Hames et al. (2012) found that implementation of a 30-ft equipment exclusion zone (ELZ) in clearcut units met the performance targets for sediment control at seven of eight clear-cut reaches. In a related study of buffer and ELZ effectiveness in headwater streams Stewart et al. (unpub.) reported the area of bank erosion (or lack thereof) was similar among reference and treatment sites suggesting the absence of a treatment effect. Root-pit formation is increased as result of post-harvest windthrow. However, the density of root-pits with sediment delivery were no different among reference and buffer treatment sites in two separate studies of BMP effectiveness (Schuett-Hames et al. [(2012)], Stewart et al. unpub). In both studies the mean distance to stream for root-pits that delivered sediment was less than 9 ft.

Determination of riparian function provided by riparian buffers is assessed qualitatively:

Sediment filtering is ranked as H (high), M (moderate), or L (low) based on following conditions: a minimum 25-ft RMZ with 25% stand density within a 30-ft. ELZ = H; a clearcut with 30-ft ELZ = M; and, a clearcut with no ELZ = L.

Independent Function Evaluation

Several literature reviews were identified (Castelle et al. 1994, Castelle and Johnson 2000, CH2MHill and Western Watershed Analysts 1999, Decker 2003, Gomi et al. 2005, Liquori et al. 2008, Sweeney and Newbold 2014) that had already compiled relevant study about sediment delivery associated with forest practices in westside forests and that had synthesized this information into source-distance curves for sediment buffer effectiveness. These syntheses show that sediment filtration generally increases with increasing buffer width, but they also found the relationship complex, varying by factors such as hillslope gradient (more buffer needed as slope increases), density of hillslope obstructions (less buffer needed as obstructions increase), total volume of material (more buffer needed as volume increases), occurrence of landslides (more buffer needed as landslides increase), and lithology (less buffer needed as lithology becomes more competent). Nonetheless, they elicit a general trend from a range of study that indicates that about 80 percent of sediment filtration occurs using 100 ft buffers.

Aside from these literature reviews, only one field experiment was identified from the gray literature that tested sediment delivery under forest management in the western PNW:

- Schuett-Hames et al. (2012) found, in evaluation of forest practices in western Washington, that disturbance-related sediment delivery was significantly higher in unbuffered treatments protected only by a 30-ft ELZ compared to buffered treatments. Soil disturbance in 50-ft fixed-width no-harvest buffers was relatively minor, less than 0.1 soil disturbance feature was found per 100 feet of stream.

Two synoptic surveys were also identified, one peer-reviewed and one gray literature, that investigated trends in sediment delivery associated with forest practices buffers:

- Lewis et al. (2001) validated modeling of sediment delivery in the Caspar Creek watershed study in northern California, finding that the most important explanatory variable was increased streamflow during storms after logging. However, field evidence suggested that unbuffered stream channels contributed more to sediment loads.
- Rashin et al. (2006) found that, of 22 sediment routing surveys conducted across five physiographic regions to assess Washington forest practices stream buffers, 19 showed zero delivery from harvest erosion features. The average buffer width monitored was 25 m. Clearcuts and partial cuts without buffers showed significantly lower channel condition scores, however, than reference stands and buffered treatments.

Studies specifically quantifying source-distance relationships for sediment filtration in western Washington forests were not found and such a relationship would likely be extremely difficult to sense confidently given the complexities underlying it. Yet, the studies cited above support the value of buffered treatments in reducing sediment compared to unbuffered treatments. The studies cited above suggest four data points for the independent function evaluation:

- Unbuffered treatments likely have significantly greater sediment delivery
- 50-ft fixed-width no-harvest buffers likely have very low soil disturbance
- 75-ft fixed width no-harvest buffers likely have zero sediment delivery
- 100-ft fixed-width no-harvest buffers generally provide 80 percent sediment filtration

Sediment delivery and filtration from 25-ft buffers has not been untested and is unknown. Overall, as noted earlier, these are general trends subject to site factors, but the overall trend of improved sediment filtration with increased buffer width is consistently reported as is the finding that there are effective widths at which delivery to the stream becomes negligible. Because these field studies occurred in landscapes where windthrow occurs, and where other tree fall agents were a factor, it is presumed that a portion sediment filtration was lost due to loss of trees; however, the proportion loss has not been quantified.

Several literature reviews (Gomi et al. 2005, Liquori et al. 2008, Schuett-Hames et al. 2015), however, indicate that increased windthrow from exposure of riparian buffers to clearcut edge can increase near-stream soil disturbance through windthrow-pits which subsequently deliver sediment to streams. Yet, two field experiments found in the gray literature specifically addressing western Washington forest practices contradict this:

- Schuett-Hames et al. (2012) found in evaluation of buffered treatments in western Washington that, though windthrow increased immediately post-harvest along streams with 50-ft continuous buffers, root-pit related sediment also increased along reference streams long-term, offsetting the treatment effect.
- Stewart et al. (2018) found in effectiveness monitoring of buffered treatments in western Washington that cumulative suspended sediment exports were heavily influenced by storm events and it is unlikely that windthrow is the primary source of treatment period or post-harvest spikes in suspended sediment exports.

Two peer-reviewed synoptic surveys addressing western Washington forest practices attempt to quantify the volume of sediment associated with windthrow:

- Grizzel and Wolff (1998) found that increased sediment delivery due to windthrow, in managed second-growth western Washington stands harvested with riparian buffers averaging 26 m wide, averaged about one-half cubic meter per 100 meters of stream channel. Most sediment came from within 3 meters of the stream channel edge.
- Rashin et al. (2006) found in sediment routing surveys conducted to evaluate Washington forest practices buffers in western Washington stands that, in spite of a high number of windthrow features at some sites, windthrow was a minor contributor to the total chronic sediment delivery from harvest-site erosion.

One field-validated modeling project also attempts to quantify this:

- Lewis et al. (2001) conducted modeling of sediment delivery in the Caspar Creek watershed study in northern California, a managed watershed employing riparian buffers averaging 20 m wide, finding that 68 percent of large failures were due to windthrow, contributing 18 percent of failure-related sediment volume.

Overall, for studies evaluating the effectiveness of buffers 50 ft and greater, results are mixed regarding contributions from windthrow-related root-pit sediment. The science is absent on the effectiveness of 25-ft buffers. Because windthrow may increase when creating cut block edges along riparian buffers, and because near-stream root-pits have been observed to contribute sediment delivery, we are concerned that 25-ft buffers may experience consistently greater near-stream windthrow than wider buffers and that, given their proximity to the stream, they would then deliver more sediment; however, this statement is presented only as a hypothesis.

Best Available Science Determination

The WFFA analysis incorporates findings from three key studies, one peer-reviewed and two in gray literature, that study effects of Washington forest practices on sediment delivery. The independent function analysis considers these studies as well as several literature reviews and two synoptic surveys, one peer-reviewed and one in gray literature, relevant to westside riparian conditions. Collectively, these studies and reviews generally support the riparian function criteria developed by WFFA for sediment filtration in that sediment filtration generally increases with increasing buffer width and sediment delivery decreases with increasing buffer width. However, the trends identified in the independent function evaluation suggest that WFFA's criteria are less protective than suggested by science. We are especially concerned with WFFA's conclusion that a 25-ft buffer provides "high" function. Field studies have not tested the effectiveness of 25-ft buffers and we are especially concerned about the potential for increased windthrow in such a narrow buffer that could increase sediment delivery and lower filtration.

Streambank Stability

Board Manual 21 Background

Board Manual 21 offers the following considerations for developing and analyzing alternate plan prescriptions, helping landowners and foresters determine current riparian conditions and how management strategies can result in properly functioning streambank stability:

> Maintaining stable stream banks will allow channel structure to develop naturally. Natural erosion of stream banks enhances channel function by:
>
> - Recruiting sand, gravel, and other stream bank material needed for various in-stream habitats.
> - Exposing tree root-wads on the stream bank that can provide cover for fish and eventually recruit large wood to the channel.
>
> Maintaining stream bank vegetation is vital to maintaining stable stream banks. The roots of vegetation hold soil together, slow water velocities and facilitate deposition of sediments during high stream-flow events. Loss of stream bank vegetation can accelerate stream bank erosion which can destroy fish spawning and rearing habitats.
>
> The area influencing stream bank stability usually extends a distance equal to ½ the average crown diameter of the dominant conifer trees closest to the outer edge of BFW or the CMZ, or to the top of the first terrace from the outer edge of BFW or the CMZ.

However, streams showing evidence of channel movement may require protecting more area to accommodate future channel migration. A good reference for determining potential channel movement is Board Manual Section 2. When evaluating the areas of influence for stream bank stability:

- Look for connected root masses along the management area.
- Look for deeply undercut banks which indicate the channel is migrating.
- Anticipate which streamside trees could fall from root rot, stream undercutting, heavy lean, or susceptibility to windthrow; then consider which adjacent trees should be retained to maintain long-term bank stability.

The best strategy is to maintain live trees and vegetation within the area of influence to provide the greatest stability to stream banks [author emphasis added].

WFFA Function Evaluation

The WFFA function evaluation did not compare streambank stability provided by the WFFA prescriptions to analog prescriptions under the forest practice rules.

Independent Function Evaluation

Several literature reviews were identified (Castelle and Johnson 2000, CH2MHill and Western Watershed Analysts 1999, Decker 2003, Liquori et al. 2008) that stress the importance of streambank vegetation for maintaining streambank stability in westside PNW riparian forest stands by reducing soil moisture through uptake and providing soil reinforcement and armoring through roots. These syntheses also stress the importance of avoiding direct disturbance to streambanks. Indirectly, these reviews synthesize several studies providing insight into source-distance relationship for streambank stability in westside PNW forests:

- Castelle and Johnson (2000) asserts that "perhaps one of the most important streambank stabilizing forces is the influence of roots." They cite several studies (Schlosser and Long 1974, Waldron 1977, and Zimmerman et al. 1967) that show how deep roots, from trees, penetrate the soil and become anchored, increasing streambank cohesiveness and strength, building tensile strength that resists shear stresses.
- CH2MHill and Western Watershed Analysts (1999) assert that "buffer distance to maintain the effectiveness of [tree] root strength for bank stability probably does not extend beyond 30-50 feet (10-15 m) (Newton 1993, Newton et al. 1996) or one-half tree crown diameter (Wu 1986). … Data quantifying the effective zone of influence relative to root strength is scarce (Spence et al. 1996)."

- Decker (2003) asserts that "remaining roots from cut trees decay within the thereby soil lowering soil stability potentially leading to mass movement of soil and/or erosion of stream banks during peak flows (Barden 2001, White and Krause 1993)."
- Liquori et al. (2008) assert that "increased streamflow from reduced post-harvest canopy interception and/or snowmelt processes (within harvest areas) [has been] implicated as one mechanism for increased bank erosion (Lewis 1998)."
- Liquori et al. (2008) also assert that "Direct disturbance can deliver sediment into the stream … can include direct yarding impacts, mechanical disturbance of banks, and introduction of debris into the stream (Jackson et al. 2001, Rashin et al. 2006)."

This general evidence supports the value of buffered treatments in protecting streambanks compared to unbuffered treatments and it suggests three data points for the independent function evaluation of source-distance relationships for streambank stability:

- Prohibition of direct disturbance to the streambank can prevent sediment delivery.
- Retention of live streambank vegetation can armor the stream against stream forces.
- Effectiveness of root armoring decreases significantly beyond about 30 to 50 feet.

However, there is no data specifically addressing the effectiveness of a 25-ft fixed-width no-harvest buffer. Zero-foot buffers likely provide no protection as deep-penetrating roots decay.

Because these field studies occurred in landscapes where windthrow occurs, and where other tree fall agents were a factor, it is presumed that a portion streambank stability was lost due to loss of trees; however, the proportion loss has not been quantified.

Best Available Science Determination

Table 3 in WFFA's report does not consider streambank stability as a separate function. In this regard, we find their analysis deficient. Though some aspects of their sediment analysis could be construed to have relevance, distinct evaluation of the effectiveness of their template prescriptions in protecting streambank stability was not performed. Literature reviews were found synthesizing westside studies that suggest that most protection occurs within 30 to 50 ft of the stream, but there is no data addressing the effectiveness of a 25-ft fixed-width no-harvest buffer. As with sediment delivery, we are concerned that increased windthrow could occur in such a narrow buffer that could compromise root armoring along the streambank.

SYNTHESIS

Using source-distance relationships developed in the independent function evaluations presented above, estimates of riparian function were compiled for each prescription listed in Table 3 in the "WFFA Template Proposal – Scientific Justification" along with those for their analog Forest Practices Rules (FPR) prescriptions (**Table 8**). Discussion of these results, and their comparison to WFFA's function evaluations (**Table 9**), are addressed below by stream type.

Briefly, the differences between estimates of riparian function in **Table 8** and **Table 9** reflect the following findings discussed in greater detail above in the independent function evaluations:

- The inequality operators for LWD function loss are flipped from ">" in **Table 9** to "<" in **Table 8** to reflect that the WFFA analysis likely under-represents LWD recruitment loss due to long-term losses from near-term windthrow along cut-block edges and lost opportunities, long-term, for recruitment of trees that would grow to heights that could be recruited but are otherwise harvested near-term through use of narrow buffers.
- The greater rates of shade loss reported in **Table 8** reflect an overall rate derived from field experimentation conducted in the western Pacific Northwest, peer-reviewed and in gray literature, that indicates shade loss due to forest management occurs at a greater rate than shown by the unvalidated model used to estimate shade loss in **Table 9**.
- The impacts of forest management on leaf and litterfall are generally the same in **Table 8** and **Table 9**; however, qualifiers in **Table 8** reflect uncertainty because the effectiveness of 25-ft buffers on leaf and litterfall has not been studied in the field.
- In regard to sediment filtration, **Table 8** shows continued contribution of riparian buffers beyond the 25 ft "high" function depicted in **Table 9** and it reflects uncertainty because the effectiveness of 25-ft buffers on sediment filtration has not been studied.
- **Table 8** reports estimated impacts on streambank stability omitted in **Table 9**.

Throughout the independent function evaluation, and implicit in WFFA's analysis, is the acknowledgment that riparian function can vary site-to-site under the same forest management regime. However, for the purposes of conducting an assessment per the core criterion articulated by WAC 222-12-0401 (6), the metric of interest is change—that is, does the WFFA prescription result in greater loss of function than the FPR analog. This is a pair-wise assessment—one reason why we consider experimental studies more valuable than synoptic surveys or models—for which, in the contractor's experience, the relative trajectory of change is reliable and the variability about change is inherently lower. Therefore, we have fair-to-high confidence that the comparisons derived from this assessment are meaningful.

Table 8: Comparison of riparian function potential predicted from WFFA template prescriptions to Forest Practices rule prescriptions based on findings of the independent function evaluations in the Review section. See "WFFA Template Proposal – Scientific Justification" for a complete explanation of WFFA and Forest Practices rules prescriptions.

Rx No.	Stream Type	WFFA Riparian Function					FPR Riparian Function				
		LWD	SHD	LIT[1]	SED[2]	SB[3]	LWD	SHD	LIT[1]	SED[2]	SB[3]
1	F	<96%	95%	a	b	a	<94% - <98%	90% - 100%	a	a - a/c	a
2	F	<91%	90%	a	c	a	<93% - <97%	90% - 98%	a	b - b/c	a
3	F	<75%	85%	b	d	b	<93% - <97%	90% - 98%	a	b - b/c	a
4	Np	<75% /<19%	85% / 85%	b	d	b	<91% / 0%	90% / 0%	a/c	c/e	a/c
5	Np	<19%	85%	b	d	b	<91% / 0%	90% / 0%	a/c	c/e	a/c
6	Ns	>0%	>0%	c	e	c	>0%	>0%	c	e	c
7	F	<93%	90% / 95%	a	b/c	a	<94%	90% / 100%	a	a/c	a
8	F	<87%	85% / 90%	a/b	c/d	a/b	<93%	90% / 98%	a	b/c	a

Notes:

1- Leaf and litterfall:
   a. would likely be greater than or equal to that from unharvested stands
   b. has not been observed for buffers smaller than 10 m
   c. would be measurable, but less than that from 10 m buffers

2- Sediment:
   a. filtration would generally be 80 percent and delivery would likely be zero
   b. filtration would generally be less than 80 percent and delivery would likely be zero
   c. filtration would be less than that from a 75-ft buffer and the buffer would likely have very low soil disturbance
   d. filtration or delivery effectiveness has not been observed for 25-ft buffers
   e. filtration would be less than that provided by a 25-ft buffer and delivery would be significantly greater than that from buffered treatments

3- Streambank stability:
   a. is likely protected with fixed-width buffers 50 feet and wider
   b. has not been observed with use of 25-ft fixed-width buffers
   c. would likely have no protection as deep-penetrating roots decay

Table 9: Table 3 in the "WFFA Template Proposal – Scientific Justification."

		Riparian function potential									Riparian function potential							
Prescription No.	Stream Type	BFW (ft)	RMZ (ft)	Prescript.	Shade	LW	Sed.	Litter	Invert	Long. Cont.	BFW (ft)	Prescript.	Shade	LW	Sed.	Litter	Invert	Long. Cont.
		Standard Prescription									FPR Prescriptions							
1	F	>15	75	75/nc	max	> 96%	H	H	L	Y	>10	105/nc[c]	max	> 98%	H	H	L	Y
											>10	50/nc, 105/hth	> 94%	> 94%	H	H	L	Y
2	F	5-15	50	50/nc	> 94%	> 91%	H	H	L	Y	<10	93/nc	max	> 97%	H	H	L	Y
											<10	50/nc, 93/hth	> 94%	> 93%	H	H	L	Y
3	F	<5	25	25/nc	> 95%	> 75%	H	H	L	Y	<10	93/nc	max	> 97%	H	H	L	Y
											<10	50/nc, 93/hth	> 96%	> 93%	H	H	L	Y
				25x300/nc	> 94%	> 75%	H	H	L	Y		50x50%/nc	> 94%	> 91%	H	H	L	Y
4	Np	>5 ft	25	25/tha	43%[a]	> 19%[b]	H	H	H	Y	NA	50%/cc	>0	slash	M	L	M	N
												50x50%/nc	> 96%	> 91%	H	H	L	Y
5	Np	<5 ft	25	25/tha	43%[a]	> 19%	H	H	H	Y	NA	50%/cc	59%[d]	slash	M	L	M	N
6	Ns	NA	0	30/elz	>0	slash	M	L	M	N	NA	30/elz	>0	slash	M	L	M	N
		Thinning Prescription									FPR Prescriptions							
7	F	>15	75	50/nc, 75/hth	> 94%	> 93%	H	H	L	Y	>10	50/nc, 105/hth	> 94%	> 94%	H	H	L	Y
8	F	5-15	50	25/nc, 50/mth	> 95%	> 87%	H	H	L	Y	<10	50/nc, 93/hth	> 94%	> 93%	H	H	L	Y

[a]Shade in upper portion of Np reach based on cms stands (i.e., 25% density)

[b]Assume 75% supply potential for a 25-ft buffer which is reduced by 25% stand density (i.e., 0.25 x 0.75 = 0.19)

[c]Top and bottom cell Rx's are no-inner-zone-harvest and thin-from-below, respectively

[d]Base on mean canopy cover for headwater streams with slash (see Appendix A).

Type F Streams

According to **Table 8**, all prescriptions for fish-bearing streams—WFFA and FPR analogs—would provide less than maximum riparian function. Function provided by WFFA prescriptions would most often be lower than that provided by their FPR analog, but to varying degree distinguished by whether the WFFA prescription uses a 25-ft fixed-width no-harvest buffer:

- WFFA Rx Nos. 1, 2, and 7 employ a 50-ft buffer or wider; LWD recruitment in young stands without the influence of windthrow would be 1 to 6 percent lower than FPR analogs for these WFFA prescriptions. Greater departure from function provided by FPR prescriptions would occur with WFFA Rx Nos. 3 and 8 (up to about 20 percent lower); these prescriptions use a 25-ft buffer. For all prescriptions—WFFA and FPR—LWD losses would be greater when trees are taller and/or with the occurrence of windthrow.
- Compared to FPR analogs, overhead shade loss would be 5 to 8 percent greater for WFFA prescriptions (Rx Nos. 1, 2, and 7). Departure from FPR shade loss using WFFA Rx Nos. 3 and 8, which employ a 25-ft buffer, would be even greater—up to 13 percent.
- Leaf and litterfall provided by WFFA Rx Nos. 1, 2, and 7 would likely be equal to that provided by the FPR analog and would likely be greater than or equal to that from

unharvested stands. WFFA Rx Nos. 3 and 8, however, employ 25-ft buffers for which leaf and litterfall function effectiveness has not been tested; the FPR analogs to these prescriptions employ 50-ft buffers or greater and would likely have leaf and litterfall comparable to unharvested stands.

- Each WFFA Type F prescription—Rx Nos. 1, 2, 3, 7, and 8—employ buffer widths smaller than their FPR analogs and, therefore, would have lower sediment filtering function. WFFA Rx Nos. 1, 2, and 7 employ 50-ft buffers for which sediment delivery would likely be very low, similar to their FPR analogs. Rx Nos. 3 and 8 employ 25-ft buffers for which their effectiveness in providing sediment function has not been tested; the FPR analogs to these prescriptions would likely have very low sediment delivery.
- Streambank stability provided by WFFA Rx Nos. 1, 2, and 7 would likely be protective, as would their FPR analogs. WFFA Rx Nos. 3 and 8, however, employ 25-ft buffers for which their effectiveness in providing streambank stability has not been tested; the FPR analogs to these prescriptions would likely be protective of streambank stability.

Using the findings of the independent function evaluations, differences between riparian WFFA and FPR prescriptions are greater than indicated in Table 3 of the WFFA analysis and differences are greatest when the WFFA prescription (Rx Nos. 3 and 8) use 25-ft no-harvest buffers.

Type Np Streams

According to **Table 8**, all prescriptions that apply to perennial non-fish-bearing streams—both the WFFA and the FPR analogs—would provide less than maximum riparian function. Comparisons between the sets of prescriptions are mixed depending on the use of fixed-width buffers: when buffers are employed by the FPR prescriptions, they provide greater function than the buffers proposed by WFFA, but when buffers are not employed by the FPR prescriptions, they provide near zero function while the WFFA prescriptions provides some.

- Under the WFFA prescriptions (Rx Nos. 4 and 5), LWD recruitment in young stands without the influence of windthrow would likely be about 15 percent lower than when FPR analogs use 50-ft no-harvest buffers; thinning within the WFFA riparian buffer would make the difference substantially greater (about 70 percent lower). However, when FPR prescriptions harvest to the stream, they would provide no LWD recruitment while the WFFA alternatives would provide about 20 percent of maximum LWD recruitment from use of continuous 25-ft no-harvest buffers.
- Shade loss under the WFFA prescriptions would be about 5 percent lower than when the FPR analogs use 50-ft no-harvest buffers. However, when FPR analogs harvest to the stream, they would provide no shade while WFFA prescriptions would provide substantially more shade—about 85 percent.

- Leaf and litterfall from the 25-ft buffers used in the WFFA prescriptions has not been observed in field study and it unknown whether it is lower than when the FPR analogs use a 50-ft no-harvest buffer (which likely provides greater leaf and litterfall than unharvested stands). However, when FPR prescriptions use no buffer, they would provide little leaf and litterfall while the WFFA prescriptions would provide some.
- Sediment filtration and delivery from the 25-ft buffers in the WFFA prescriptions has not been observed in the field and it is unknown whether it is lower than when the FPR analogs use a 50-ft no-harvest buffer (which would likely provide some sediment filtration and would likely have very low soil disturbance). However, when FPR prescriptions use no buffer, they likely would provide less sediment filtration and greater sediment delivery than WFFA's 25-ft buffered treatments.
- Streambank stability under the 25-ft buffers used in the WFFA prescriptions has not been observed in the field and it is unknown whether it is lower than when the FPR analogs use a 50-ft no-harvest buffer (which would likely provide protection). However, when the FPR analogs use no buffer, they would likely have little protection while the WFFA prescriptions would provide some protection of streambank stability.

Using the findings of the independent function evaluation, differences between WFFA and FPR prescriptions are greater than those indicated by Table 3 of the WFFA analysis. Both analyses, however, show similar directional trends, and both show the near lack of riparian function provided by FPR prescriptions when streams are harvested to the streambank.

Type Ns Streams

Riparian function provided by the WFFA prescription for Type Ns streams (Rx No. 6) would be comparable to that provided by the Forest Practices rules, but both prescriptions provide no LWD recruitment, very little shade, very little leaf and litterfall, very little sediment filtration, significantly greater sediment delivery than buffered treatments, and little protection of streambank stability. This overall finding does not differ from the WFFA function evaluation.

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