Review of current and proposed riparian management zone prescriptions in meeting westside Washington State anti-degradation temperature standards

DRAFT REPORT

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Forest Practices Adaptive Management Program

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Technical Type Np Prescription Workgroup

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EXECUTIVE SUMMARY

This report summarizes the findings of a technical workgroup formed by the Timber, Fish and Wildlife (TFW) Policy Committee, to develop and evaluate, for Policy's consideration, Riparian Management Zone (RMZ) buffer prescriptions for Type Np streams. This effort was initiated due to the finding by the CMER Type N Study (McIntyre et al. 2018) that the current rules do not always meet state water temperature criteria. The state water quality measurable change standards permit no temperature increase of 0.3 °C or greater (WAC 173-201A-200, -300-320). The workgroup was tasked with developing buffer options that address the temperature issue as well as additional natural resource, operational and economic considerations. These objectives include: meet the water temperatures rules; are repeatable and enforceable; are operationally feasible; provide wood to the stream over time; account for windthrow; consider options that allow for management (e.g., selective harvest) in the RMZ; and minimize additional economic impact. The workgroup was directed to use available and relevant information from CMER reports and outside literature and data to propose and evaluate RMZ buffer prescriptions.

The objectives were consolidated into three broad categories to facilitate evaluation of the effectiveness of buffer alternatives:

- Minimize probability of exceeding the temperature measurable change standards anywhere in Np streams at any time following harvest
- Minimize post-harvest windthrow to provide a future supply of large wood
- Avoid economic harm to landowners

Seven alternatives (including the current RMZ prescription) were developed and evaluated for performance against objectives. These alternatives fell into three broad groups of prescriptions: fixed-width buffers; shade-focused buffers; and buffers that vary by bankfull width. Using the evaluation criteria, we concluded that three alternatives have the best chance of succeeding at meeting the resource and economic objectives. These three buffer descriptions were:

<u>100% buffer, 75 feet, both banks</u>

The entire Np stream network is buffered with a fixed-width, 75-foot two-sided buffer. The first 50 feet remains a no-management zone, while the outer 25 feet beyond the no-management zone can include harvest of economically valuable trees.

<u>Site-specific buffer</u>

This alternative is based on the Headwater Stream Smart Buffer Design Project. The portion of the riparian buffer that will provide effective shade to the stream is retained.

<u>Aspect-based buffer</u>

East-west oriented portions of the Np stream system have a 75-foot south-sided buffer and a 25-foot north-sided buffer. North-south oriented portions of the Np system have 65-foot buffers on both banks.

The RMZ prescriptions proposed here were designed to programmatically address water quality change standards of no temperature increase of 0.3 °C or greater and may not assure a categorical compliance at

all sites. As part of a CMER study that initiated this review, even undisturbed or reference watersheds (of second growth forest) showed temperature changes among years of up to 1.0 °C. A programmatic evaluation is necessary due to the variability in stream temperatures both in the absence and presence of harvest. Estimating forest harvesting impacts to stream temperatures requires statistical modeling, modeling assumptions, and an acceptance of uncertainty in the results.

INTRODUCTION

The Technical Type Np Prescription Workgroup was formed by the Timber, Fish and Wildlife (TFW) Policy Committee (hereafter: Policy), to develop and evaluate, for Policy's consideration, Riparian Management Zone (RMZ) buffer prescriptions to achieve temperature protection criteria for Type Np streams in western Washington. The process was initiated by the TFW Policy Committee in response to findings in the study entitled *Effectiveness of Experimental Riparian Buffers on Perennial Non-fish-bearing Streams on Competent Lithologies in Western Washington (Hard Rock Study)* (McIntyre et al. 2018). This study reported temperature increases associated with the current RMZ prescription for Type Np streams. Mean 7-day maximum temperatures at streams with continuous 50-foot buffer (100% treatment) streams increased by 1.2 °C and FP buffer streams increased on average by 1.4 °C and 1.0 °C in the first- and second-year post-harvest, respectively. The no-buffer (0% treatment) streams increased on average by 3.4 and 3.0 °C in the first- and second-year post-harvest (Figure 7-9 and Appendix Table 7-B-7, McIntyre et al. 2018). Therefore, TFW Policy determined that the findings warranted action and proposed the following process components:

1. Formation of a technical workgroup, governed by a charter, to develop and deliver a set of proposed RMZ buffer prescriptions for perennial, non-fish bearing (Type Np) streams in western Washington that meet the current antidegradation requirement of no temperature increase of 0.3°C or greater, and also meet a suite of resource protection, feasibility, and economic objectives.

2. To utilize all relevant information to inform proposed RMZ buffer prescriptions for Np streams, including available literature and data, while adhering to the timeline established in the team charter. Relevant information developed through CMER incudes the Buffer Integrity – Shade Effectiveness (Amphibian) project; Westside Type N Buffer Characteristics, Integrity and Function (BCIF) study; Type N Experimental Buffer Treatment in Hard Rock Lithology - Phase II Extended Monitoring study; Extensive Riparian Status and Trends Temperature Monitoring – Type N/F (Westside and Eastside) study; and the Type N Experimental Buffer Treatment in Soft Rock Lithologies study. In addition, studies conducted in the Pacific Northwest that are relevant to the questions being addressed are also to be considered.

What is the problem?

The above referenced study (Hard Rock) on the Forest Practices rules for "sensitive site and RMZs protection along Type Np Waters" suggested that current rules protected many resource values relative to reference sites but did not categorically prevent an increase in mean 7-day maximum water temperatures of 0.3 °C or greater, higher rates of tree mortality due to windthrow, and changes to amphibian populations.

The Hard Rock study compared temperature response under the current Forest Practices (FP) rules, with 100% treatment, 0% treatment, and unharvested reference sites. Shading provided to stream channels by all the treatments, including both the FP and 100%, was decreased relative to reference sites. As described above, temperatures in the 100%, FP, and 0% treatments increased. These increases were detected using pre- and post-treatment regressions of concurrent stream temperature measurements in reference and treatment watersheds. The average temperature increases exceed the Washington measurable change standards (a change of > 0.3 °C; WAC 173-201A-200 and -320).

Tree mortality in buffers and Perennial Initiation Points (PIPs) was elevated in the FP treatments and less so, but still significantly, in the 100% treatments, relative to reference sites. Following harvest, wind damage was the dominant mortality agent, accounting for ≥70% of trees that died; other mortality agents including suppression, damage from insects and diseases, erosion and slope failure, and unidentified causes accounted for ~20% of mortality in the 100% treatments and references, while a fire of anthropogenic origin at one site contributed about 12% of the FP buffer mortality. Mortality of buffer trees from felling and yarding activity associated with the adjacent harvest was minimal.

There was a significant increase in the amount of slash in FP channels relative to reference sites, and appearance of more fine sediments associated with slash and wood accumulations. The same pattern was not observed in 100% buffer streams. Slash and windthrow inputs to small channels can increase storage of fine and coarse sediments.

For the first several years after logging, tailed frog densities increased in the FP and 100% buffer streams. Tailed-frog abundance declined in the extended sampling period (7- and 8-years post-treatment). There was some indication of lower numbers of coastal giant salamanders in the FP buffer streams. Torrent salamander abundance increased in areas with heavy slash accumulations immediately after the treatments. The causal factors of changes in amphibian abundance were unclear. Suggestions for such potential causes included the alterations to water temperatures possibly affecting productivity, growth rates and movement rates, but a causal agent was not identified.

Changes to Forest Practices rules can lead to economic impacts to landowners but can also contribute to greater protection of natural resources. The problem at hand is to propose revisions that address requirements for environmental protection while minimizing economic impacts to forest landowners.

Relevant Washington water quality standards

WAC 173-201A-200(1) defines freshwater aquatic life uses, including non-fish aquatic species (e.g., amphibians). Subsection (c) states that water temperatures are measured using the 7-day average of the daily maximum temperatures, lists temperature criteria for indigenous fish species, and in subsection (c)(1)(i) states that when water temperatures are naturally above the listed criteria that human actions may not raise water temperatures by more than 0.3 °C.

WAC 173-201A-300, the antidegradation policy, applies three levels of protection to surface waters. Tier II includes waters of higher quality (i.e., cooler) than the criteria issued in WAC 173-201A-200 and ensures that such water quality is not degraded. Streams on lands under forest management are managed in a way that assumes that waters qualify as Tier II.

WAC 173-201A-320 states that changes to Tier II waters are generally not allowed. In subsection (3) it states that the quality of such waters may not measurably change and defines such change for water temperature again as increases of 0.3 °C or greater.

To summarize, on forest land in Washington, stream temperatures may not experience human-caused increases greater than 0.3 °C, whether or not stream temperatures are naturally above the criteria stated in WAC 173-201A-200(1)(c). If stream temperatures are naturally above the criteria, WAC 173-201A-200(1)(c) prevents measurable change. If temperatures on forested streams (Tier II) fall below the criteria, then WAC 173-201A-3020 generally does not allow for measurable change. We refer to the two standards (WAC 173-201A-200(1), -320(3)) that define measurable change as an increase of 0.3 °C or more as the "measurable change standards" throughout.

Our examination of expected temperature outcomes for different alternatives only considers the effect of alternatives on the measurable change standards throughout a harvested reach or harvested basin. The workgroup did not consider examining the cumulative effects of stream temperature increase, either for multiple harvests within an Np basin or for temperatures below Type F junctions. We had little available information on which to base such an analysis. We did not know, at a landscape level, how frequently harvests would occur within basins, nor what the range and distribution of stream sizes were to calculate mixing equation outcomes. We note that, temporally, stream temperature increases are not permanent (undergrowth and canopy return over time; Johnson and Jones 2000, D'Souza et al. 2011), and that stream temperature increases do not persist downstream (Zwieniecki and Newton 1999, Studinski et al. 2012, Davis et al. 2015). A cumulative effects analysis would need to take these factors into account. Ultimately, if rule changes succeed in preventing stream warming, cumulative effects should not be an issue.

Perspective

Workgroup members agree that the current FPA Np rules are, barring California, the most protective in the United States and Canada. The current rules provide some temperature protection for these non-fish streams, along with large wood input. The current rules also appear effective at preventing harvest-related sediment intrusion into streams. The Hard Rock and Soft Rock studies identified temperature increases in some streams above the measurable change standards. In our process of examining alternative management prescriptions, we found that the current Np rules performed poorly for protecting stream temperatures relative to the other prescriptions and performed well at preventing economic harm to landowner. However, we wished to convey our perspective that the current rules do provide considerable resource protection and that within this document we have developed and evaluated the relative performance of alternatives designed to enhance temperature protection.

Overview of the workgroup's approach and the report structure

The workgroup made use of an approach called Structured Decision Making (SDM, Gregory et al. 2012) to develop and arrive at management recommendations. This process is more fully described in Appendix Section A1. To summarize, the workgroup developed and refined lists of objectives and management alternatives. We reviewed findings from CMER adaptive management studies, the scientific literature, and our own assessments of harvest units to arrive at estimates of effectiveness for different alternatives at meeting objectives.

We structured the report to focus on the outcomes of our work; the Appendix provides a detailed description of the process used to develop and evaluate buffer alternatives. The report defines the question, provides framing of the water quality regulations considered, outlines how our methods integrated with TFW Policy direction, and briefly summarizes how we developed alternatives and the sideboards used in that development.

The report includes an explicit description of the alternatives, our evaluation, and then offers our recommendation of alternatives to consider. It then discusses uncertainties associated with our recommendations, offers future research recommendations, and ends with conclusions.

Developing buffer prescription alternatives

The Technical Type Np Prescriptions Workgroup developed buffer designs that addressed multiple natural resource, operational and economic goals. Potential buffer designs were evaluated against the following objectives:

- Protect water temperatures to meet the rule (WAC 173-201A-200, -300-320);
- Are repeatable and enforceable;
- Are operationally feasible;
- Provide wood to the stream over time;
- Account for windthrow;
- Consider options that allow for management (e.g., selective harvest) in the RMZ; and
- Minimize additional economic impact.

The Technical Type Np Prescriptions Workgroup Charter suggested a process for the workgroup that was adopted into the Structured Decision Making (SDM) process described by Gregory et al. (2012) and utilized by the workgroup. The Technical Workgroup used this process to develop a set of possible buffer alternatives based on the available technical information. Each buffer option was then evaluated as to its effectiveness at addressing each objective.

The process included these steps:

- Review the completed Hard Rock Study and associated findings;
- Review and understand Forest Practice rules associated with Type Np streams and how Washington's water quality standards apply to forest practices;
- Identify information gaps and assess available information to assist Workgroup in deriving proposed RMZ buffer prescription for Type Np streams;
- Review newly completed Type N related studies and their associated findings; integrate relevant information into the decision-making process; consider field visits/practical field application time as needed;
- Develop a suite of possible alternatives and assess each against the temperature, environmental, feasibility, and economic objectives listed above;
- Develop associated language that articulates how/where to implement a given prescription;
- Aggregate proposed prescriptions and a description of the process pursued, additional resources utilized, and any other relevant information into a final proposal for Policy's consideration.

PROCESS FOR DEVELOPING RECOMMENDED ALTERNATIVES

The workgroup used aspects of SDM to craft a set of alternatives that we believe address the original objectives described above. The appendix provides details of the process, aspects of the decision considered, and the evolution of our thinking around alternative development.

During the SDM process we found that although we deemed all objectives important, many did not appear critical to include in decision making (i.e., estimates of effectiveness did not substantially differ among alternatives). For instance, two objectives, protection of stream-associated amphibians and ease of layout, were considered and were deemed to be either covered by meeting temperature requirements (amphibians) or did not represent a significant, incremental cost (layout) and the cost of laying out the alternative prescriptions would be adequately addressed under a more inclusive objective of avoiding economic harm to landowners. Thus, these two objectives were left out of the final assessment of possible alternative prescriptions.

Using our process we arrived at three key objectives:

- Minimize probability of exceeding the water quality temperature measurable change standards anywhere in Np stream at any time following harvest
- Minimize post-harvest windthrow to provide a future supply of large wood
- Avoid economic harm to landowners

When describing alternative prescriptions, we hold the following conditions as constant:

> The 30-foot Equipment Limitation Zone remains around all Np streams regardless of alternative selected.
>
> Yarding of timber from or across Type Np RMZs and sensitive sites will continue to be subject to WAC 222-30-021(2)(c)(iii) and WAC 222-30-060(4).
>
> As a minimum, the current protections for sensitive sites shall remain, unless specifically excluded in a proposed alternative:
>
> No timber harvest is permitted in an area within fifty feet of the outer perimeter of a soil zone perennially saturated from a headwall seep or side-slope seep.
>
> No timber harvest is permitted within a fifty-six-foot radius buffer patch centered on the point of intersection of two or more Type N waters.
>
> No timber harvest is permitted within a fifty-six-foot radius buffer patch centered on a headwater spring or, in the absence of a headwater spring, on a point at the upper most extent of a Type Np water.
>
> No timber harvest is permitted within an alluvial fan.

We also considered the ease of implementation for both small and large landowners for all alternatives.

We developed and considered seven prescription alternatives. These alternatives can be grouped into three general categories. The first group of alternatives require buffers of a pre-determined width and extent along both sides of the channel. A second group of alternatives retains trees in locations to maintain stream shading; for example, requiring a wider buffer on the side of the channel exposed to the sun. A third group was an option that varies the required buffer width based on channel width. This alternative assumes that resource values tend to be greater in larger Type Np channels, and therefore, these channels would receive a higher level of protection. Below we describe the alternatives, provide brief estimates of our assessment of their potential performance against the three key objectives, and describe the uncertainties associated with each. The effectiveness of each buffer alternative relative to the three key objectives was estimated using a combination of existing scientific literature, models, and professional judgement. We considered how alternatives would perform given programmatic assessments, not individual site assessments. The expectation is that the harvest rules will result in conditions that, on average, are met across the landscape to satisfactory levels (a "satisfactory level" is a value ultimately determined by decision makers). Details on the process used to evaluate the effectiveness of each option are provided in the appendix.

Group 1: Fixed-width buffers

Alternative A: Current Np buffer rules.

- Description: WAC 222-30-021*(2). Retain two-sided 50-foot buffers for at least 50% of an Np stream length. No-harvest 50-foot buffers are required for at least the first 300 to 500 feet of Type Np stream above the Type F/Np break, varying by the length of Type Np water.
- Estimates of outcomes:
    - Minimize exceedance of the temperature measurable change standards: This prescription on average, across the landscape, and immediately post-harvest, is very unlikely to meet measurable change standards. The portion of streams that are clear-cut are generally expected to warm. The portions within a 50-foot buffer are also expected to warm on average, although buffered sites are likely to display greater heterogeneity in response than unbuffered sites. We expect that after two years post-harvest the temperature increases in the buffered reaches will return towards baseline conditions while the clear-cut reach temperatures are more likely to remain above 0.3 °C for several years afterward. Regarding estimate uncertainty, this alternative was evaluated by the Type N Hard Rock and Soft Rock studies, reducing its level of uncertainty relative to untested alternatives listed below. Stream temperature responses were variable. Some sites warmed substantially following harvest while others cooled. However, according to stream temperature literature, clear-cut portions of stream channels generally warm following harvest, therefore this alternative would be expected to cause an increase in water temperature.
    - Minimize post-harvest windthrow: Current blowdown rates are highly variable. Due to the overriding effect of site features on blow down risk, uncertainty of the estimate is high.
    - Avoid economic harm to landowners: This prescription is the "no change" option, against which all other alternatives are compared. Each alternative was tested on nine randomly selected Type Np sites (within nine FPAs). Although each harvest unit was unique, there is little uncertainty about the general parameters of economic costs associated with this alternative. Alternative A is scored as "1" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners.

Alternative B: 100% buffer, 50 feet wide, both banks

- Description: The entire Np stream network is buffered with a fixed-width, 50-foot two-sided buffer. This is one of the alternatives tested in the Hard Rock study.
- Estimates of outcomes:
    - Minimize exceedance of temperature measurable change standards: On average, sites are expected to exhibit warming above the measurable change standards for approximately one to two years post-harvest but return to pre-harvest temperature ranges after two years. We are fairly certain that this prescription on average will not meet the measurable change standards, but we are not 100% certain. Stream temperature responses are variable. Some sites warm substantially following harvest while others show little response or cool. This alternative was tested at four Hard Rock study sites, where one site cooled while three sites warmed. In the Soft Rock study, four sites (T4 through T7) were buffered along at least 92% of their length by average buffer widths of 47 feet wide or wider. These sites may therefore approximate Alternative B. They exhibited different amounts of warming at their T1 thermistor locations. There were within-site differences as well, as a site's two post-harvest years may have different specific months and numbers of months with warming. All T1 or D100 thermistors showed some months with warming post-harvest (Table 4-6).
    - Minimize post-harvest windthrow: Improved wind firmness relative to current rules due to the buffer being continuous. However, as all trees are close to the channel, this option frequently could place trees on wetter soils. Uncertainty is high due to the influence of site conditions.
    - Avoid economic harm to landowners: No uncertainty in the comparison of Alternative B to Alternative A: the number of acres of leave trees for this alternative is essentially double the acres for Alternative A. Alternative B is scored as "3" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners.

Alternative C: 100% buffer, 75 feet, both banks

- Description: The entire Np stream network is buffered with a fixed-width, 75-foot two-sided buffer. The first 50 feet remains an unmanaged zone as in Alternative B above. The managed zone, which is the outer 25 feet beyond the unmanaged zone, can include harvest of economically valuable trees. Removal of 50% of the basal area within the managed zone, removing the largest trees first, will result in the retention of at least 50% of the trees in this zone. Tree retention will be evenly distributed.
- Estimates of outcomes:
    - Minimize exceedance of temperature measurable change standards: With a 75-foot no-cut buffer we would expect, on average across the landscape, that immediately following harvest sites will not warm beyond the measurable change standards amount (see figures 1 and 2). The inclusion of a 25-foot managed zone may reduce the efficacy of the buffer, but we do not know to what extent. The loss of 50% of the basal area in the outer 25 feet

may not translate into much effective shade loss (see references in Appendix Section A5) but we do not know to what extent. We are also uncertain about the extent to which landowners will take advantage of the limited entry option, as some may elect to take a few valuable exterior trees while others may opt to extract whatever basal area is permissible.

- Minimize post-harvest windthrow: Greater width than the earlier options may include more trees in upslope areas, which tend to be more stable. Harvest in the outer 25 feet may increase the risk of post-harvest blowdown of the outer and/or inner zones. Uncertainty is high due to the influence of site conditions.
- Avoid economic harm to landowners: Some level of uncertainty in the comparison of Alternative C to Alternative A. Site-specific conditions (cable logging versus ground-based logging, higher logging costs and layout expenses, landowner preference to limit leave stand damage, etc.) may preclude full removal of 50% of the basal area within the managed zone or limit the percentage of removal to something less than 50% basal area removal. The number of acres of leave trees for this alternative could be as high as three times as many acres as the number of acres for Alternative A (if no harvest occurs within the 25-foot managed zone) but could be as little as ~2.5 times the number of acres retained under Alternative A, with 50% basal area tree extraction in the 25-foot managed zone. Alternative C is scored as ranging from "3.5 to 4" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners.

Alternative D: 100% buffer, 100 feet, both banks

- Description: The entire Np stream network is buffered with a fixed-width, 100-foot no-entry two-sided buffer.
- Estimates of outcomes:
  - Minimize exceedance of temperature measurable change standards: We expect, with high certainty, that sites with buffers of this size will not on average warm beyond the measurable change standards amount for any given year post-harvest. Uncertainty is moderate since some individual sites will likely exhibit temperature warming above the measurable change standards as a result of factors related or unrelated to harvest. However, these sites are expected to fall strongly in the minority. It is our opinion that this alternative will provide greater temperature protection than alternative C above, although we believe both options have the potential to meet the current standards at most locations.
  - Minimize post-harvest windthrow: This option has the widest buffers and would often include more trees in upslope areas, which tend to be more stable. Uncertainty is high due to the influence of site conditions.
  - Avoid economic harm to landowners: No uncertainty in the comparison of this Alternative D to Alternative A: the number of acres of leave trees for this alternative is essentially four times as many acres as the number of acres for Alternative A. Alternative D is scored as "5" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners.

Group 2: Shade-focused buffers

Alternative E: Site-specific buffer.

- Description: This alternative is based on the Headwater Stream Smart Buffer Design Project (Martin and Romey 2020). The portion of the riparian buffer that will provide effective shade to the stream is retained. Effective shade is defined as the fraction of total possible potential solar radiation that is blocked by riparian vegetation and topographic features (Allen and Dent 2001). For a given Np stream, a "shadeshed", or the riparian area providing effective shade, is modeled using tree height, stream orientation, and solar altitude for 10:00 – 14:00 on August 1. The shadeshed may extend to only one or both sides of a stream depending on the aspect of the stream channel. The GIS-based NetMap Thermal Loading Tool (NTLT) will be used to predict changes in solar radiation between pre-harvest conditions and the buffer prescribed by the shadeshed model. Estimates of tree heights and vegetation density will be derived from LiDAR coverages or timber stand data. The adapted version of the shade model from Groom et al. (2018; see Appendix Section A5 and Figure 2) suggests that, on an absolute effective shade scale of 0-100%, minimizing shade reduction to 7% or less would be sufficient to limit temperature increases to 0.3°C, on average (Figures 1 and 2). At a minimum, for both stream banks, all streamside, merchantable trees (those within 10 feet of the bankfull width) will be retained. Operators are encouraged to leave non-merchantable trees within 30 feet.
- Expectations of outcomes:
    - Minimize exceedance of temperature measurable change standards: We expect this prescription to have a reasonable chance of meeting the measurable change standards for the first two years following harvest and for the measurable change standards to be met beyond two years post-harvest. Regarding uncertainty, the percent reduction in shade may not be sufficient to protect some sites from warming more than 0.3 °C. These sites may experience more blowdown closer to the stream as a consequence of wind direction relative to the layout design, which in turn could increase the number of streams exhibiting warming.
    - Minimize post-harvest windthrow: Increased width on the sun-exposed side of the channel may include more trees in upslope areas relative to current rules. This would confer a greater degree of stability to the trees in areas with wider buffers but no increase in wind firmness at locations where buffers are narrow. Uncertainty is high due to the overriding influence of site conditions on windthrow risk.
    - Avoid economic harm to landowners: Since this alternative is site-specific (dependent on stream orientation, tree heights, existing unstable slope set-asides, etc.) and the buffer area that would be required to achieve a shade loss of 7% or less will vary among sites, the number of acres of leave trees required cannot be estimated at this time; therefore, there is high uncertainty as to comparison with Alternative A. It is assumed that the number of acres of leave trees required to achieve no more than a 7% loss in available shade will likely fall between Alternatives A and B, but closer to Alternative B. Thus, Alternative E is scored as a "2.5" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners. Alternative E may represent a significant challenge to small landowners who may not have the required data or expertise to apply the shadeshed tool. Therefore, this option may disproportionately affect their unit layout costs (hiring consultants) or prevent them from using this option.

Alternative F: Aspect-based buffer.

- Description: East-west oriented portions of the Np stream system (azimuth between 45 - 135° and 225 - 315°) have a 75-foot south-sided buffer and a 25-foot north-sided buffer. North-south oriented portions of the Np system (315-45° and 135-225°) have 65-foot buffers on both banks. North-south / east-west categories are evaluated for sequential 200-foot sections of stream. The buffer system extends to the PIP.
- Estimates of outcomes:
  - Minimize exceedance of temperature measurable change standards: We expect this prescription to have a reasonable chance of meeting the measurable change standards for the first two years following harvest and a high probability of meeting the standard in subsequent years. As in Alternative E, uncertainty is high as the percent reduction in shade may or may not be sufficient to protect most sites from warming more than 0.3 °C. These sites may experience more blowdown closer to the stream as a consequence of wind direction relative to the layout design, which in turn could increase the number of streams exhibiting warming.
  - Minimize post-harvest windthrow: The 75 ft buffer on the sun-exposed side of the channel will have wind throw risk similar to the option with 75 ft buffers on both sides. Because prevailing winds in western Washington are predominantly from the south, the wider buffer will be on the wind-exposed side of the channel. The narrower buffer on the downwind (north) side of the channel will have some protection from prevailing winds. Uncertainty is high due to variation in site conditions.
  - Avoid economic harm to landowners: This alternative is site-specific (dependent upon stream orientation) but, as described, appears to be roughly equivalent to Alternative B for streams oriented east-west, and would likely cause more economic harm for north-south oriented streams. Alternative F is scored as a "3" on a 1 to 5 scale of incremental economic harm, where "1" best avoids economic harm to landowners.

Group 3: Buffers that vary by bankfull width

Alternative G: Variable-width two-sided buffer

- Description: The riparian zone buffer width is determined by the stream bankfull width, which itself is evaluated in 200-foot sections. Np streams < 1 foot wide receive a 25-foot two-sided buffer while 1 foot to 5-foot-wide streams receive 50-foot two-sided buffers. Np streams > 5 feet width have 50-foot no-management ("core") buffers, with an added 25-foot outer managed zone (see Alternative C above). Removal of 50% of the basal area within the managed zone of 25 feet, removing the largest trees first, will result in equal to, or greater than, 50% of the trees in this zone retained. Tree retention will be evenly distributed.
- Estimates of outcomes:
  - Minimize exceedance of temperature measurable change standards: Since most Np streams fall within the first two width categories (i.e., less than 5 ft wide), we expect this prescription on average to fail to meet the measurable change standards, with probabilities of success falling between Alternatives A and B. Uncertainty for this alternative is relatively low as we are fairly certain that this prescription on average will

not meet the measurable change standards but are not 100% certain. This prescription has not been tested anywhere that we are aware of.

- Minimize post-harvest windthrow: This option would have a high degree of blowdown risk on small channels, which receive the narrowest buffers. Wind firmness would be expected to increase as channel width and buffer width increases. However, harvest in the outer 25 feet may increase risk of post-harvest blowdown of the managed and/or unmanaged zone. Uncertainty is high due to the variable buffer width and site conditions.
- Avoid economic harm to landowners: This alternative is site-specific (depends on bankfull width by 200-foot segments), so uncertainty is higher than Alternatives A, B, D and F but, as described, Alternative G may pose the least economic harm except Alternative A, along with some opportunity for tree extraction in the managed zone for streams > 5 foot BFW, and so is scored as a “2” on a 1 to 5 scale of incremental economic harm, where “1” best avoids economic harm to landowners.

We found when we examined the estimated effects of the alternatives on the three objectives that a trade-off existed between retaining sufficient buffer to prevent temperature increase and avoiding economic harm by minimizing land encumbered as riparian buffer (Table A4).

Assessing the effectiveness of buffer alternatives

This section summarizes the information that was utilized in assessing buffer alternative effectiveness. We utilized a combination of information from peer-reviewed Washington CMER studies, relevant published literature, and professional judgement to estimate the effectiveness of any buffer alternative at addressing the three key objectives: meet the temperature measurable change standards, minimize windthrow risk and minimize economic impact.

Water Temperature

The Type N Hard Rock study (McIntyre et al. 2018) was designed as an intensive examination of the physical, chemical, and biological response of small streams to forest harvest with different buffer treatments. Because of the high level of sampling effort required at each of the study sites, only a relatively few sites were included in their study: 4 reference sites, 4 with 0% (no overstory vegetation left) buffers, 4 with 100% buffer and 3 with FP buffers. The Soft Rock study increased the sample size of FPA sites by 7 and incorporated sites on a different lithology. However, the sites were clustered in a small region of the state and made almost all treatment comparisons against a single control site. Therefore, the extent to which the responses observed at these sites can be extrapolated generally to Type Np streams in western Washington remains unclear. However, there have been several other studies of water temperature response to buffer design in the Pacific Northwest over the last two decades that are relevant to the objectives of the technical workgroup.

Several evaluations of the effectiveness of buffers for temperature control on small fish streams have been completed in Oregon in the last decade. Groom et al. (2011a, 2011b) conducted an evaluation of two buffer designs. This study used a before-after, control-impact experimental design to evaluate 18 sites on private forest land with buffers as narrow as 25 feet wide and 15 sites on state forest land with buffers widths that ranged between 157 and 170 feet. They found no significant change in the mean-7-day-maximum water temperature after harvest at sites with buffers 110 feet wide or greater. However, the narrower buffers on private sites were associated with an average increase of 0.7 °C. A predictive model generated from the data of the study's 33 streams (Groom et al. 2018) suggested that a 100-foot buffer would result in a temperature increase of 0.2 °C (95% Credible Interval, which is similar to a Confidence Interval, of 0.0 °C to 0.4 °C) within the first two years following harvest. It predicted a 0.5°C increase with a 75-foot buffer (0.3 °C, 0.8 °C) and an increase of 1.15 °C for a 50-foot buffer (0.85 °C, 1.5 °C). The buffer widths considered in the manuscript were slope distances, not horizontal distances; Washington forest practices rules use horizontal distances. The temperature metric was the average of daily maximum stream temperatures measured between July 13 and August 23.

Another evaluation of buffer effectiveness on small fish streams in Oregon was reported in Bladon et al. (2016). This study examined temperature response following harvest with 15-m buffers on Needle Branch, a small stream in the central Oregon Coast Range. Harvest resulted in a modest decrease in stream shade; from 96% prior to harvest to 89% after. There was a temperature response in the mean-7-day-maximum of 0.6 °C. However, the warmest temperature recorded during the post-harvest period was 14.7°C, within the thermal tolerance range of aquatic biota of conservation concern in the Pacific Northwest (McCullough 1999; Reiter et al. 2019).

Of more direct relevance to the task of the technical workgroup are several studies evaluating temperature response to harvest along non-fish streams that have been conducted recently. As would be expected, harvest without the retention of overstory trees results in water temperature increases. Bladon et al. (2018) included 18 non-fish streams in their study. Five of these sites were references that did not experience any harvest during the study. Buffer widths varied among the treated streams. Continuous buffers were retained at 4 of the sites, with width ranging from 11 m to 20 m. Discontinuous buffers were retained at two of the sites; an 8-m buffer along 60% of the channel length at one location and an 8-m buffer along 25% of the channel at the other. Removal of all overstory trees to the edge of the channel occurred at the remaining study sites. Increases in mean-7-day-maximum water temperature occurred at all the sites, with the largest increases at the locations with the least overstory retention. At sites without buffers or with partial buffers the increase in mean-7-day-maximum temperature ranged from 2.4 °C to 3.9 °C. Locations where continuous buffers were retained experienced increases in the mean-7-day-maximum temperature of less than 1.0 °C. This study also noted that temperature response at several sites was muted by the introduction of slash into the channel during logging. The slash provided enough shade to reduce temperature response. The influence of in-channel slash on water temperature has also been noted in several other studies (Jackson et al. 2001; Kibler et al. 2013).

Reiter et al. (2019) re-examined the data from a subset of the sites included in the Bladon et al. (2018) study. Rather than focusing on the regulatory metric mean-7-day-maximum temperature, this analysis examined the alteration in the frequency distribution of summer (1 July to 31 August) water temperatures for 6 years prior to harvest and for 4 years after harvest. Buffer treatments at the sites included harvest without retention of overstory trees, discontinuous buffers and continuous buffers ranging in width from 12 m to 15 m. Buffered sites exhibited a distribution of temperatures before and after harvest comparable to the distribution observed at the reference sites; the temperature metrics examined in this study were not affected by harvest with continuous buffers. The sites harvested without buffers or with discontinuous buffers experienced a post-harvest increase in temperatures. Median temperature increased about 2 °C.

In British Columbia, an assessment of temperature response to 3 buffer treatments on non-fish streams was conducted on 10 headwater streams (Gomi et al. 2006). Treatments included no buffer, 10-m buffers and 30-m buffers. Average daily maximum water temperature during summer increased consistently in streams harvested without buffers; increases ranged from 2 °C to 8 °C. In contrast, very little response was seen in average daily maximum temperature at the sites where buffers were retained, even at the site where the buffer was only 10-m wide. The effectiveness of the buffers at preventing water temperature response in this study may have been enhanced by the north-south orientation of the streams. This orientation might make the narrower buffers effective at intercepting sunlight during midday.

Results from the studies summarized above indicate that relatively narrow buffers along headwater streams can provide a significant amount of protection from temperature increases. Reiter et al. (2019) found that buffers of 12 m – 15 m wide prevented any change in the frequency distribution of summer temperatures. Bladon et al. (2018) reported that buffers ranging in width from 11 m – 20 m wide restricted temperature response to 1.0 °C or less and Gomi et al. (2006) found that even a 10-m wide buffer prevented temperature increases at their study sites. However, these studies also illustrate the high degree of variation in temperature responses to buffer configuration on small, headwater streams. Some of this spatial variation is due to factors other than shade from riparian vegetation, like underlying geology (Bladon et al. 2018), high contribution of groundwater inputs, or stream orientation (Gomi et al. 2006). In addition, some of the differences in temperature response among these studies is due to the temperature metrics used to characterize temperature response. For example, Bladon et al. (2018) and Reiter et al. (2019) examined the same data set but used different temperature metrics. Bladon et al. (2018) reported a small increase in the mean-7-day-mean-maximum temperature at buffered sites while Reiter et al. (2019) found no change in the frequency distribution of summer water temperatures using these same data.

The variability illustrated by these studies can be partially reduced by focusing on the effect of buffer design on shade. Groom et al. (2018) describes the results from a Bayesian analysis data that examined the changes in stream temperature relative to the intensity of the streamside harvest. The study included 33 sites and data were collected before and after treatment. The analysis linked a relationship between shade and riparian buffer characteristics to a relationship between shade and stream temperature (along with other variables). Because the riparian vegetation data collection utilized a 100% cruise before and after harvest, including tree distance to stream, the analysis could be used to simulate different harvests of the riparian stand, predict remaining shade levels, and predict how that change in shade would affect stream temperatures. As mentioned above, the paper reports findings and riparian buffers in slope distance. Figures 1 and 2 below present predicted changes in shade and temperature for harvests of different buffer widths. The temperature figure below (Figure 1) is similar to Figure 11 from the paper but uses horizontal distance and feet instead of slope distance and meters. The figure depicting the relationship between buffer width and shade represents a new display of predicted outcomes (Figure 2).

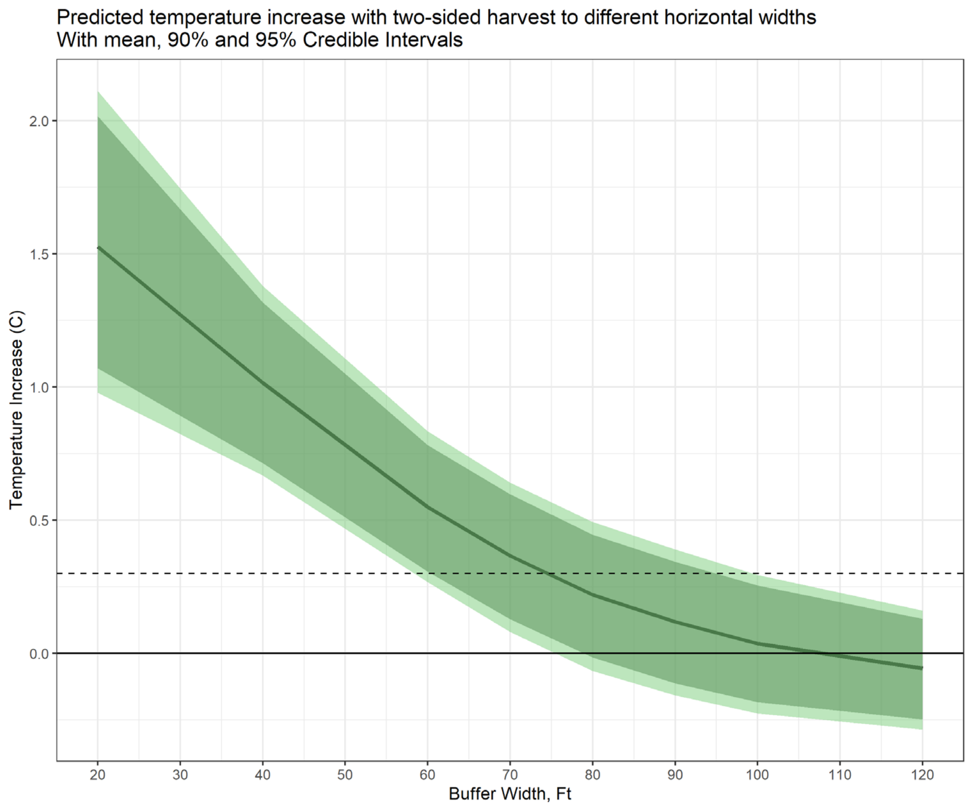

Figure 1: Predicted relationship between two-sided buffer width and stream temperature increase post-harvest. This prediction was based on the data and analysis approach of Groom et al. (2018).

These figures indicate that on average a buffer of about 75 feet is required to maintain post-harvest temperature increases to less than 0.3°C. Change in shade with a 75-foot buffer is approximately an absolute value of 7% (e.g., if pre-harvest shade was 87%, the post-harvest shade level would be on average 80%; Figure 2). Therefore, our analysis of buffer alternative effectiveness for meeting the temperature measurable change standards assumed that buffer alternatives that retained this level of shade protection would be effective at meeting the measurable change standards.

Two of our alternatives propose thinning in a portion of the buffer furthest from the channel. Studinski et al. (2012) found that riparian thinning of a stream to 50% of original basal area resulted in a 13% reduction in canopy coverage. Drever and Lertzman (2003) and Hale (2003) found, for non-riparian stand thinning on relatively flat ground, that a 50% reduction in basal area resulted in a 19% increase in full sun exposure and a 22% increase in solar transmittance, respectively. Sonohat et al. (2004) found that solar radiation transmittance relationships by basal area varied by species examined. In summary, a thinning regime of 50% of basal area will increase solar transmission, but because the relationship is nonlinear, it will proportionally allow less transmission than a 100% clear cut (Drever and Lertzman 2003, Hale 2003). Therefore, we assumed that thinning that resulted in removal of 50% or less of stand basal area in the zone beyond 50 feet from the channel would provide sufficient shade to meet the measurable change standards.

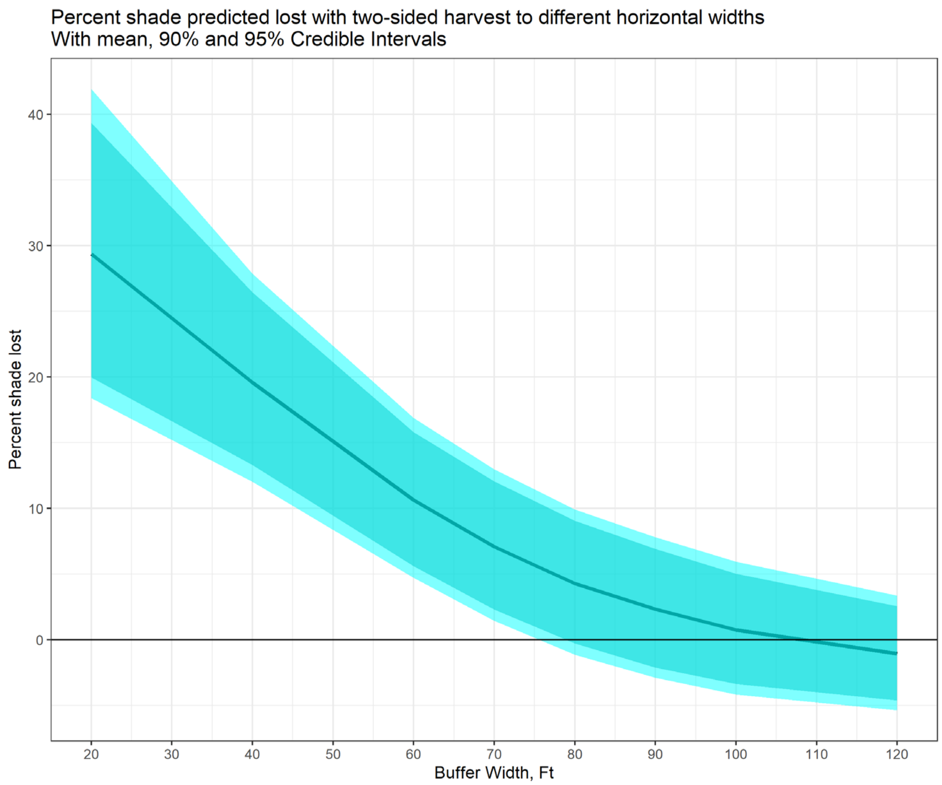

Figure 2: Predicted relationship between two-sided buffer width and percent shade lost post-harvest. This prediction was based on the data and analysis approach of Groom et al. (2018).

Windthrow

Windthrow of trees is a natural process and one of the primary mechanisms by which wood is delivered to stream channels (Bilby and Bisson 1998). One of the purposes of retaining buffers along stream channels is to ensure a continuous supply of this material for streams (Reeves et al. 2018). However, windthrow risk can increase dramatically following forest harvest. A study of windthrow in riparian buffers along 40 non-fish streams in northwestern WA reported that an average of 33% of the retained trees blew down within three years of timber harvest (Grizzel and Wolff 1998). Other studies report varying levels of post-harvest windthrow, but all indicate that some sites experienced a large increase in tree fall in buffers within the first decade following harvest (Table 1; Steinblums 1978, Hobbs and Halback 1981, Andrus and Froelich 1988, TFW 1994, Mobbs and Jones 1995).

Table 1: Average and range of blowdown rates in buffers in western WA and OR during the decade following logging.

Study	Location	# Sites	Mean Windthrow Frequency (%)	Range of Windthrow Frequency (%)
Grizzel and Wolff (1998)	WA	40	33	2 – 92
Mobbs and Jones (1995)	WA	90	5	0 – 100
TFW (1994)	WA	91	10	0 – 80
Andrus and Froelich (1988)	OR	30	22	0 – 72
Hobbs and Halbach (1981)	WA	37	5	0 – 17
Steinblums (1978)	OR	40	29	0 – 78

The physical characteristics of a site, stand-level features, soil characteristics and factors associated with individual trees all contribute to the blowdown risk in a buffer (Blackburn et al. 1988, Stathers et al. 1994). Physical site factors are related to stream orientation, size and shape of the cut unit and topography. Susceptibility of a buffer to windthrow is heavily influenced by the orientation of the buffer. In western Washington, most strong winds are from the south or southwest. As a result, buffers oriented in an east-west direction are more exposed to strong winds and typically experience higher windthrow rates than in buffers oriented north-south. Grizzel and Wolff (1998) found that 67% of all windthrown trees fell to the north, indicating they succumbed to a wind from the south. In contrast, only 3% of the fallen trees they surveyed at their 40 study sites fell to the south. Other site physical attributes that have been related to windthrow risk include distance from the buffer edge to uncut timber in the direction of the prevailing wind, change in elevation from the buffer to the uncut edge in the direction of the prevailing wind, distance from the buffer to the closest major ridge in the direction of the prevailing wind and elevation of the buffer (Steinblums et al. 1984). All these factors influence the strength of the wind experienced by trees retained in the buffer.

Stand characteristics also relate to the susceptibility to windthrow (Stathers et al. 1994). Tree density in a buffer can influence windthrow risk with denser stands tending to be more windfirm due to interlocking root systems and damping of tree swaying caused by the wind. High incidence of defects like root rot in a stand also is related to elevated windthrow risk (Hubert 1918). Thinning of trees in the buffer can elevate windthrow risk. Heavily thinned stands, in particular, experience high windthrow rates compared to unthinned stands (Stathers et al. 1994).

Soil characteristics influence rooting architecture and, as a result, influence risk of windthrow (Stathers et al. 1994). Trees on deep, well-drained soils develop large, deep root systems making these trees less prone to windthrow. In contrast, sites with shallow soils typically restrict rooting depth and enhance windthrow risk. Rooting depth can also be limited in wet soils. Trees on these soils often develop a shallow, plate-like rooting structure. Root depth is restricted to the soil zone above the saturation level. Root systems less than 50 cm deep are common on wet soils. In addition, wet soils have dramatically lower shear stress than dry soil, reducing soil cohesion to tree roots and greatly enhancing probability of windthrow. Because wet soils are most typically associated with flat ground, blowdown rates are related to riparian landform. Andrus and Froelich (1988) observed blowdown rates in buffers on terrace or floodplain landforms that were double those of buffers on sloping ground.

Individual tree characteristics are also related to windthrow risk. Windthrow risk varies by tree species. Grizzel and Wolff (1998) reported higher windthrow rates in conifers than in hardwoods. The species most susceptible to falling were western hemlock and Pacific silver fir; over 35% of these trees fell at the

40 sites in their study. Windthrow rates of Douglas-fir and western redcedar were about 20% while red alder and bigleaf maple suffered blowdown rates of 17% and 7%, respectively. Andrus and Froelich (1988) also found that hemlock suffered the highest post-harvest blow down rates in buffers on the Oregon coast.

Evaluating the buffer alternatives for windthrow was difficult due to the site-specific nature of risk of windthrow. However, review of the available literature on this topic did clearly indicate that continuous buffers tended to be more windfirm than buffers containing gaps. In addition, due to the enhanced risk of windthrow on wet soils, we assumed that wider buffers would locate more retained trees upslope from the stream where soil moisture was likely to be lower.

Economic Impact

Private forest land ownership is a long-term financial investment in the growth and harvest of trees, which includes carrying the accumulated financial cost (from original purchase cost, planting and other silvicultural costs, road construction and maintenance costs, annual ad valorem forestland taxes and other administrative costs) to the time of harvest (or sale of land and growing stock), when the landowner recovers their accumulated costs and hopefully makes a profit. Retaining buffers along stream channels (including Type Np waters) economically impacts private forest landowners by reducing harvestable and operable acres, harvestable timber volumes and thereby economic returns to landowners from timber harvest of their forestlands, annually or periodically, and over time. Reduced timber harvest volumes from private forestlands may reduce employment levels (both direct and indirect jobs) as well as severance (excise) tax revenues to counties and the state general fund.

In addition to reducing harvestable timber acres and volumes, retention of riparian trees affects harvest unit layout cost and timber harvesting costs, with these costs varying depending upon specific buffer alternatives / configurations and site-specific conditions. Several factors that affect harvesting costs include but are not limited to the following:

- Harvest method: ground-based (shovel, skidder, dozer, etc.) or cable system (leading end or full suspension); selection of a harvest method is generally based upon site-specific topography and limits of equipment operability
- Yarding distances
- Road construction costs
- Buffer widths, as well as availability and number of yarding corridors (ground-based or cable) allowed through buffers
- Availability and location of landings
- Worker safety issues, and
- Other site-specific factors

Some buffer alternatives on specific sites may create “orphan” harvestable timber patches / areas that necessitate higher costs, such as additional road building or expensive helicopter logging, for harvest of such areas to occur, or that preclude conventional timber harvest of all or portions of such areas due to environmental / public safety issues such as road construction across unstable slopes. Such orphan acres and timber will further reduce economic returns to landowners.

While most buffer alternatives evaluated by the Workgroup require common forest engineering techniques for harvest unit layout, several buffer alternatives may require more data, expertise and labor (and therefore more cost) to lay out such buffers compared to the other buffer alternatives. Small forest landowners that lack engineering expertise may face significantly greater challenges implementing more sophisticated buffer alternatives than large forest landowners with such expertise.

RECOMMENDATIONS – EVALUATION OF BUFFER OPTION EFFECTIVENESS

We found that Alternatives C, E, and F were the most likely buffer options to achieve the temperature measurable change standards while avoiding the most extreme costs to landowners (e.g., Alternative D, 100-foot buffers along 100% of the stream channel). We scored each buffer option for the likelihood of achieving each of the three objectives, presented in Figures 3 and 4. Figure 3 conveys a composite score for each alternative, with a higher score indicating objectives overall were better met. It shows that we judged the overall performance of the three alternatives to be overall approximately equivalent. Figure 4 provides a better comparison of each objective's score across the three buffer alternatives. The Np Workgroup estimated that the three alternatives would perform equivalently for protecting stream temperatures and preventing blowdown. There were slight differences in estimated avoidance of economic costs, with Alternative E performing better at minimizing landowner costs than C and F.

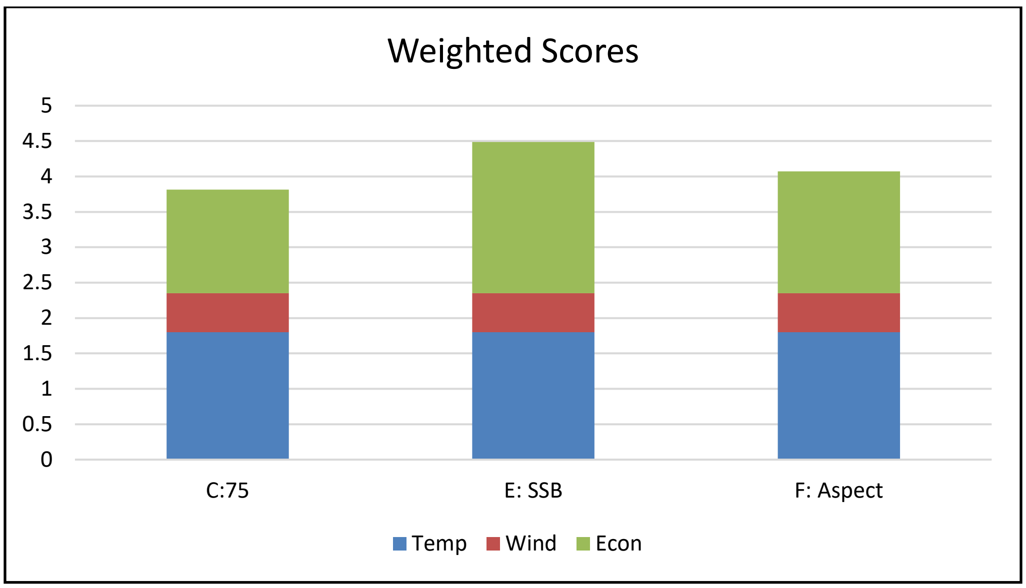

Figure 3: Stacked barplots of unequally weighted scores for Alternatives C, E, and F. SSB is an abbreviation for Site-Specific Buffer. Figure 3 reproduces information from Section A7.

There are many sources of uncertainty that affect our estimations and recommendations. We describe some uncertainties below and provide uncertainty estimates in Table A12, Appendix Section A6. Regarding Figures 3 and 4, note that the uncertainty for the Alternatives E and F economic impact values was considered to be larger than for Alternative C.

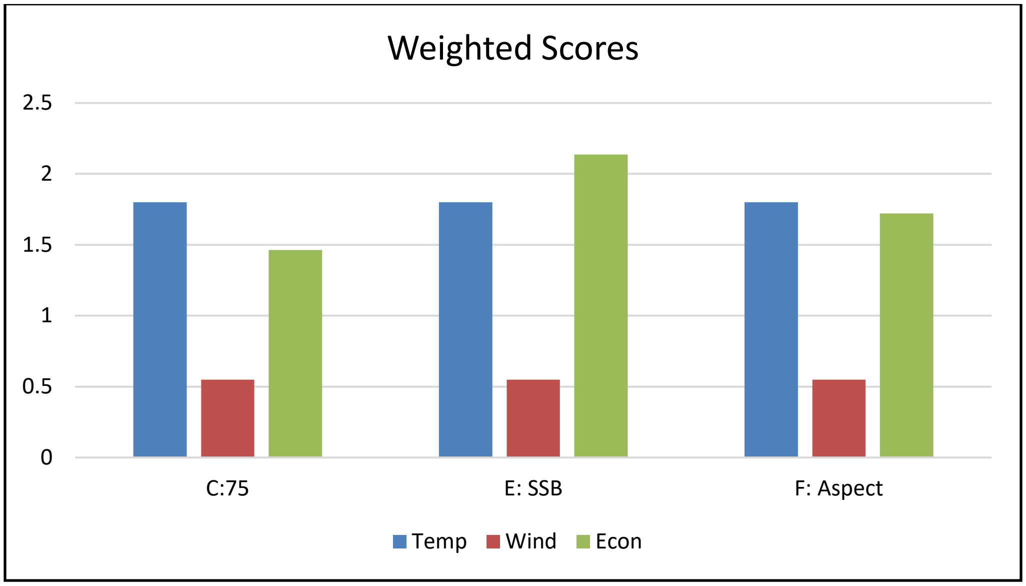

Figure 4: Side-by-side barplots of unequally weighted scores for Alternatives C, E, and F. SSB is an abbreviation for Site-Specific Buffer. Figure 4 reproduces information from Section A7.

We recommend and encourage the TFW Policy Committee to consider the adoption of a combination of the three alternatives. We believe that Alternatives E and F represent the best opportunity for meeting resource objectives with lower cost to landowners than Alternative C. However, E and F represent a fundamentally new approach to stream buffer design that will require careful assessment to determine effectiveness and practicality. Alternative E may be more difficult or burdensome for small landowners to enact than Alternative F, as determining harvest boundaries using Alternative E likely requires technical skill and access to specific computer programs.

The alternatives as proposed may be modified, with the caveat that modifications may affect outcomes for stream temperatures, windthrow, and economic impact. The level of thinning proposed for Alternative C could be set to different levels with consideration for minimizing economic impacts or minimizing the probability of temperature increase as a priority. The widths of Alternative E and F could be adjusted as well, and the channel orientation designations for Alternative F can be modified. However, our recommendations only apply to the alternatives as described in this report.

UNCERTAINTIES

Studies of timber harvesting practices on water and water resources have often been conducted on entire watersheds that were subject to harvest, including CMER's Hard Rock and Soft Rock studies. A treatment effect is easier to detect when a larger portion of the watershed area is treated, rather than a small portion. There is no doubt that this experimental design may create a study bias, but this approach is used to better identify and understand the altered watershed level processes. In practice, harvest units rarely encompass entire watersheds, and streams and RMZs often form a harvest boundary. We are uncertain about the extent of these study biases; future examinations of the effects of more representative harvest layouts on aquatic resources rather than experimental treatments of entire watersheds could reduce this uncertainty and allow us to better understand the magnitude of this source of bias. Future studies must also accommodate a changing environment. Global change models suggest that in the Pacific Northwest air temperature will increase and summer low flows decrease with concomitant stream temperature increases (Snover, et al., 2013). These changes will alter system response to forest management.

Alternatives E and F are untested, both by CMER and the broader forestry community. This is a limitation and an opportunity. To date there have been very few variations for streamside protection that have been tested empirically; most prescriptions are based on fixed-width buffers. Riparian protection could benefit from novel, innovative means of addressing resource protection concerns, and Washington has been a global leader in developing and implementing forest practices that enhance protections for aquatic ecosystems for decades.

As described in Appendix Section A5, although generally stream temperature increases post-harvest are lower when more riparian vegetation is retained, when we look across many studies, we see that this pattern is a noisy one. This variability may be driven by many different hydrological, geological, or geographical factors. Responses are additionally variable because researchers make use of different temperature metrics. Patterns of windthrow following harvests are even noisier.

The temperature metric of concern, the 0.3 °C increase of the measurable change standards, is difficult to assess. We argue, in Appendix Section A5, that the Hard Rock and Soft Rock studies do not directly assess it, but instead assess it by approximation. Because the standards are not directly assessed, we are uncertain about how well results from CMER studies, and other research on temperature response to buffers in the PNW, apply. To directly assess the standards and reduce this uncertainty, we would recommend that a larger sample of sites be obtained, that the study evaluate the proportion of sites that increased in temperature above the measurable change standards, and that the study additionally estimate the fraction of temperature increases that represent false positives.

Further, to the above point about the site-specific variations in temperature, the temperature target itself is based on technological ability to accurately measure temperature, and less about the environmental relevance of the standards. The intent of managing for no measurable change is an excellent target, in principle. The current technical limit of accuracy for most temperature recording devices is about 0.3 °C. In the future, that may become more refined, but we do not imagine reducing this margin of error. However, other elements of temperature responses may be equally important to consider beyond an instantaneous increase above an arbitrary threshold. Most organisms are tolerant to short-term increases in temperature within the natural range of variation, and duration of exposure can be a much more important factor on growth and survival. The Washington temperature standards for protection of aquatic life are progressive; however, most of the temperatures recorded in CMER studies to date have not exceeded those standards; rather, the concern has been the exceedance of the measurable change standards. In addition to duration, other considerations for thermal changes from an ecological aspect include flow conditions, life stages of the organisms considered, and connectivity. In western Washington, the warmest temperatures are associated with the lowest flows, which makes this a vulnerable period and these two physical properties might interact with each other additively or synergistically. Most species in Np streams of western Washington have evolved to cope with short-term (days) changes in their environments within a natural range of variation, so it may be worth considering the incorporation of exposure duration into temperature standards, rather than simple thresholds.

FUTURE DIRECTIONS

The motivation in our work has been towards meeting the anti-degradation measurable change standards. Questions about the biological relevance of the current measurable change standards suggest that there may be value in examining alternative methods of establishing thermal criteria that acknowledge the temporal and spatial variation in this variable. Studies could examine the persistence downstream and over time of stream temperature increases due to harvest watershed-wide to determine anticipated effects on biota. The traditional regulatory approach to protecting aquatic ecosystems in the Pacific Northwest has been to create a set of desired water quality or habitat conditions, often based on the requirements of salmonid fishes, and to develop management prescriptions that enable these standards to be achieved and maintained. This approach to management implicitly assumes that once desired conditions are achieved, they will remain static. However, this perspective fails to account for the dynamic nature of natural systems and does not acknowledge the critical role that periodic disturbance and subsequent recovery plays in supporting long–term habitat complexity, system productivity and species diversity (Bilby et al. 2003; Dunham et al. 2007, Bisson et al. 2009). For instance, future riparian forests will have gaps as trees fall from windthrow or other processes that create large wood in the channel and create heterogeneous light conditions for streams, which might be of value to stream-associated amphibians and other species as noted in MacCracken et al. (2018). Storms or wildfires may impact large areas regardless of history of forestry and other land use. For instance, in the Hard Rock study, a large storm in 2007 created large windthrow impacts that were unrelated to the study's treatments. Watersheds may have idiosyncratic responses depending on particulars of geology, soil depth, aspects (e.g., Richardson and Béraud 2014), and the variation among sites treated by similar harvest plans in many studies is a reminder that even the best practices may not always yield the desired outcomes at every site.

The natural spatial and temporal variability in aquatic habitat conditions means that at any point in time a proportion of stream reaches in a watershed will exhibit characteristics that differ from a fixed criterion. Management schemes that acknowledge this variation and attempt to incorporate this principle into prescriptions have been developed for some federal lands in the Pacific Northwest (Cissel et al. 1998) and have been proposed as a component of the recent revision of the Northwest Forest Plan (Reeves et al 2018). This dynamic perspective of aquatic ecosystem management does offer an alternative way to assess the relative effectiveness the Type Np buffer options being evaluated. Rather than the fixed numerical criterion that currently exists, the criterion could be based on a desired range of thermal conditions among all Type Np streams in a watershed. This approach would offer some flexibility in buffer design by allowing the application of prescriptions that cause some temperature increase as long as the increase was short-lived and impacted only a small proportion of stream reaches at any point in time. However, this management approach presents the challenge of determining the desired range of conditions, i.e., what proportion of sites should deviate from conditions considered to be optimum at any point in time?

Climate change may affect these stream systems in numerous ways, including an increase in fire frequency, tree pathogen outbreaks, precipitation variability within and across years, windstorm events, snowmelt timing, and shifts in peak flow and low flow rates and timing. These conditions may be causative of one another, and all can directly or indirectly affect riparian areas. Earlier snowmelt and later onsets of rainy seasons may lead to an increase in previously unusual low-flow events. Depending on streambed substrate, lower flow may lead to individual streams becoming warmer or cooler. Streams previously considered perennial may become more intermittent as portions of stream channels go subsurface for parts of the year and static assessments of streams as perennial and seasonal may become less useful. Intensive and extensive monitoring is needed to better understand how climate change will affect riparian areas across Washington. Evaluating the effectiveness of current or new riparian buffer rules may become more difficult as well, as variability in stream response may increase under an altered climate.

The Hard Rock study only reported stream temperatures proximate to the buffer treatment site, yet stream temperature data were collected at other locations above and below the buffer treatment as well. These latter data can be analyzed to further identify temperature variability in time and space, as well as thermal recovery. The Hard Rock Extended report provided mean-7-day-maximum temperatures for each year, but the text cautions against making direct comparisons of these values as differences need to be established based on predicted versus observed treatment values. It is suggested that these data be re-examined to determine a rate of measurable change standards exceedance.

We were unable to include an examination of cumulative effects in this report for a number of reasons, including the complexity of factors that influence this process. Stream temperatures fluctuate daily, under canopy cover and in exposed clearcuts. Groundwater intrusion and subsurface flow can mediate upstream temperature increases. When streams of different temperatures converge, their individual flow volumes determine the resulting stream temperature. Water residency time can affect the degree by which streams warm when exposed to sunlight and the distance a stream must travel under closed-canopy conditions for that temperature increase to decrease to background conditions. Research is needed to better quantify and predict expected thermal cumulative effects, and ideally would involve intensive, watershed scale studies and extensive stream junction-level analyses to provide landscape-level predictions.

We recommend that future Np stream temperature monitoring efforts consider extensive studies, where only a few variables are measured at more locations. We also encourage the studies to incorporate sites that harvest at sub-watershed scales to better improve study inference. The inference would be improved as more sites would be available for selection (e.g., not as geographically constrained as either the Hard or Soft Rock study) and the results would better represent harvest types conducted across Washington. An extensive study with more study and reference sites would also allow for a more thorough evaluation of the measurable change standards exceedance rate.

CONCLUSIONS

The current Forest Practices Np buffer prescription did not categorically protect against stream temperature increases. The causal mechanism for meeting or not meeting the stream temperature measurable change standards was indeterminate. In our process of considering alternative prescriptions and objectives we determined that a primary trade-off existed between preventing exceedances of the measurable change standards for stream temperatures and avoiding landowner economic impact. Our objective for ensuring wood delivery to streams was of lesser concern given the extreme variability of blowdown events post-harvest. We developed and evaluated seven alternate prescriptions and concluded that three alternatives could best balance the trade-off between stream temperature protections and economic impact. Two represent novel, progressive approaches to riparian buffer protections with great promise and uncertainty of success. We emphasize that our recommendations contain different sources of uncertainty, and that regardless of the direction chosen by TFW Policy, the Adaptive Management

Program will continue to be essential for validating the efficacy of the selected prescriptions and reducing uncertainty.

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APPENDIX: PROCESS FOR ARRIVING AT RECOMMENDED ALTERNATIVE(S)

Section A1: Overview of the alternative development and recommendation process

The workgroup made use of the Structured Decision Making (SDM) process described by Gregory et al. (2012) for the development of management recommendations. SDM is a facilitated process designed to assist diverse stakeholder groups in coming to an agreement about the dimensions of a complicated natural resources problem and developing management recommendations. The process stops short of making an actual decision; the purpose of SDM is to empower decision makers to make informed decisions.

Step 1 of SDM is to define the problem. The problem definition was in part provided by TFW Policy and in part fleshed out by the workgroup. The report's Introduction section provides the problem statement. Step 2 involves defining "what matters" regarding the problem statement. Appendix Section A2 includes a means-ends network diagram developed by the workgroup. The purpose of the means-ends network diagram is to ensure that, as we define objectives, we include all critical objectives in the process. Developing the means-ends network also allows for creative thinking about ways to achieve objectives.

Step 3, described in Section A3, describes how the workgroup developed objectives for the project. The process involved the group using the means-ends diagram to define early objectives and consider how they would be quantified or otherwise evaluated. The initial objectives list was whittled down and altered to ensure that the intent behind the broad list of early objectives was captured in fewer objectives. Then the workgroup members met to quantify objective performance against alternatives.

Step 4, the development of alternatives (Appendix Section A4), took place alongside Step 3. Pieces from the means-ends diagram were gathered and organized, and then used to construct the alternatives. At this point the alternatives existed in a draft stage and were not well fleshed out.

Step 5 represents the convergence of steps 3 and 4. The workgroup members endeavored to predict, to the best of their abilities, outcomes for each objective relative to each alternative. The predictions are summarized in "consequence tables" (an SDM term) which allow for performance comparisons among alternatives. The process of consequence table development was iterative, where alternatives and objectives lists were consolidated and improved. Table A4 represents the culmination of our efforts to estimate the efficacy of alternatives at meeting our objectives.

Appendix Section A6 is a continuation of Step 5. This section describes the research findings used by the group to inform their estimates as well as the methods and logic used to arrive at estimates. This section provides an overview of research considered and also describes sources of uncertainty with estimates for each metric. We included this section to provide the reader with a description of our understanding of the state of knowledge around each objective, focused strictly on addressing the problem statement.

Step 6 describes our thought process for developing recommendations, described in Appendix Section A7. The workgroup considered various ways of evaluating the information in Table A4, such as placing different importance weights on the three remaining objectives. The workgroup developed graphical means for displaying and considering the performance of each alternative, and the section describes our findings. The appendix culminates with our recommendation and considerations.

Section A2: Overview for development of objectives and alternatives

The Np Workgroup met and used a “means-ends network” process tool (Gregory et al. 2012) to define objectives and construct management alternatives. The Workgroup kept in mind the objectives that were included in the group’s charter. The exercise helped verify if any objectives were missing and identify what they were. The resulting Means-Ends diagram, Figure A1, is presented on the next page.

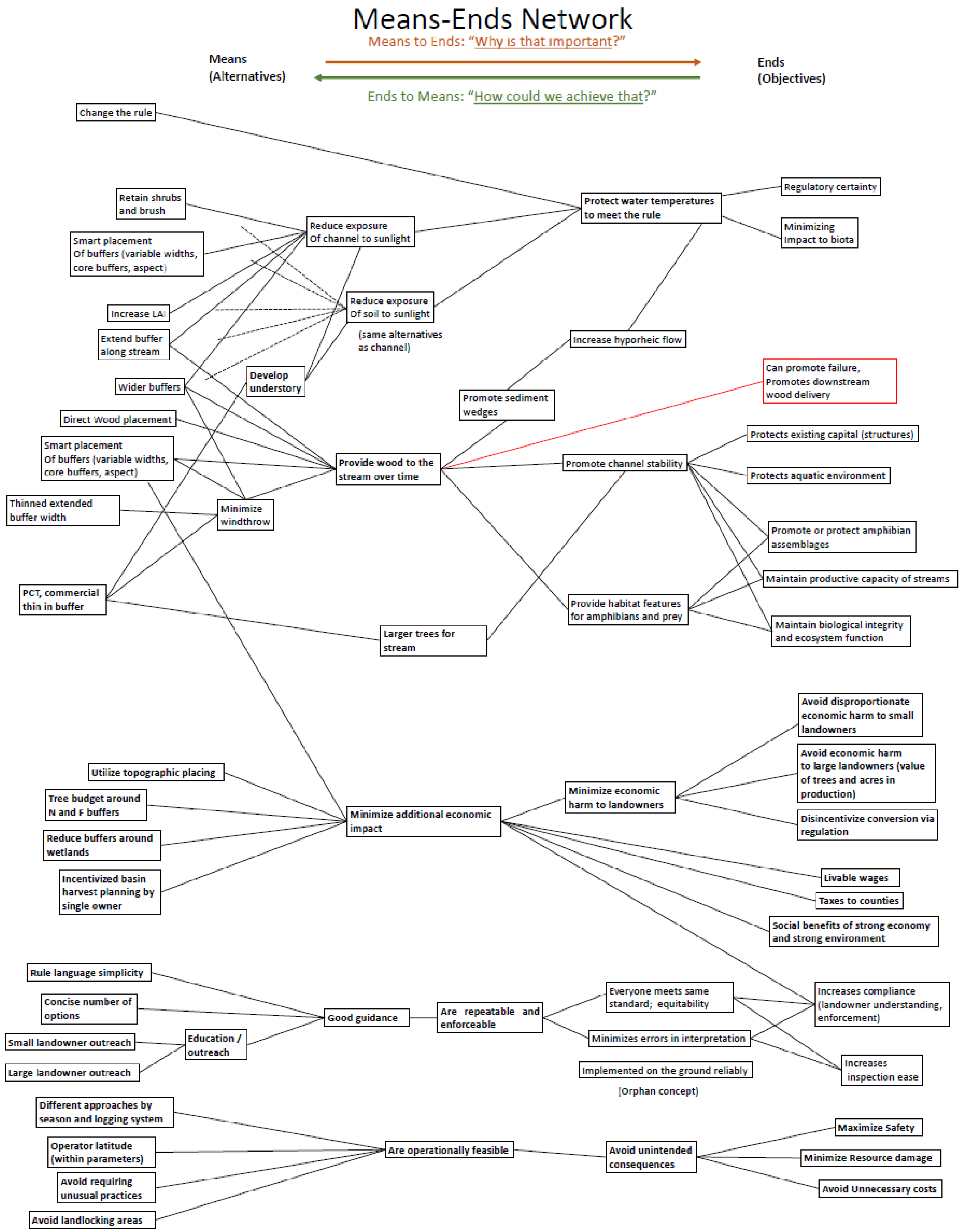

Figure A1: Means-ends network diagram.

Section A3: Development of objectives

The Workgroup distilled the objectives from the means-ends network (Table 1). An objective's purpose is to represent an aspect of the decision that matters without highlighting any particular strategy as a solution. A performance measure is selected that will be used to represent a given objective. Performance measures are used to assess the effect of each alternative on every objective, allowing for a direct comparison of the expected outcomes of the management alternatives.

Below is a table of the original drafted objectives and their associated performance measures. Broad objectives categories are underlined. Notes reflect our considerations at the time. Objectives that have a strike-through are ones that we considered dropping but did not wish to forget about.

We immediately saw that there was some strong overlap among objectives. Under "Avoid Economic Harm" we found the objectives "Avoid reducing timber harvest taxes to counties" and "Avoid reducing the social benefit of strong economy and environment" were well covered by other considerations for avoiding economic harm, minimizing impacts to stream temperature, and promoting or protecting amphibian assemblages.

Table A1. Initial list of Objectives and draft performance measures.

Objectives	Performance Measure	Notes
Stream temperature		
Minimize thermal impacts to biota		Only salmonids downstream, and stream-associated amphibians of concern. Probably drop this one
Minimize probability of exceeding measurable change standards	°C	
Promote or protect amphibian assemblages		
Maximize probability of channel stability		
Maintain the current light regime		
Provide habitat features for amphibians and prey		
Promote downstream wood delivery		Long-term process, separate from blowdown inputs
Minimize windthrow, especially catastrophic events - associated mortality of trees (blowdown)		

Maximize ease and success of rule implementation		
Facilitate inspection ease		
Facilitate high compliance rates		
Promote operational feasibility		
Maximize safety		
Minimize resource damage potential		
Minimize likelihood of unnecessary costs		
Avoid economic harm		
Avoid disproportionate economic harm to small landowners	Area (ac) of timber	Different species command different prices, and those change
Avoid economic harm to all landowners	Area (ac) of timber	Area is surrogate for # of trees. Variability of stands is a factor too. Some homogeneous. Others very heterogeneous or just dominated by stands of different species
Avoid reducing wages	Area (ac) of timber	
Avoid reducing timber harvest taxes to counties	Area (ac) of timber	
Disincentivize conversion as a result of (over) regulation		
Avoid reducing the social benefit of strong economy and environment		

The Workgroup then examined each objective more closely. Some were, again, recognized as important yet covered by other objectives.

Maintain the current light regime: This objective serves as a proxy for stream temperature and is the main feature that management can affect. The group believed that the temperature objectives would sufficiently capture this objective.

Provide habitat features for amphibians and prey: This objective appeared confounded with the channel stability objective, i.e., managing for channel complexity and stability would provide for amphibian habitat and prey productivity. We dropped this as a separate objective.

Maximize probability of channel stability: This objective was refined to make it easier to quantify and understand. It became "No increase in percentage fines or sediment movement and no decrease in residual depth in pools or the number of pools". This objective was subsequently broken into two distinct objectives, "Maximize probability of channel stability: no increase in percentage fines or sediment" and "Maximize probability of channel stability: no decrease in residual pool depth, number of pools, etc.". This was done so that each aspect could be examined separately.

Promote downstream wood delivery: The workgroup discussions brought to light that an objective regarding minimizing post-harvest windthrow better captured concerns about buffer blowdown affecting stream temperatures, and that the new objective should not fall under "Promote or protect amphibian assemblages". Except in the case of mass wasting, these stream systems are in general too small to move wood downstream. Therefore, this objective was modified and moved.

Facilitate inspection ease; Facilitate high compliance rates: The larger objective to "Maximize ease and success of rule implementation" was altered to "Promote operational feasibility". "Facilitate inspection ease" was changed to "Facilitate layout ease". The Workgroup thought that we should drop "Facilitate high compliance rates" as buffers that were straightforward to lay out would be more likely to comply with rules.

Minimize likelihood of unnecessary costs: The workgroup maintained this objective for a while as a placeholder in case there were costs not captured under "Avoid Economic Harm". It was later dropped as no additional costs were identified.

Avoid disproportionate economic harm to small landowners: As described elsewhere, the objective "Avoid economic harm to all landowners" is quantified using encumbrance increases relative to the current Np buffers. The team decided that the objective to avoid disproportionate economic harm to small landowners could be encompassed by one that related to all landowners. Following that decision, all discussions about rule implementation and costs considered both large and small landowners explicitly.

Avoid reducing wages; Avoid reducing timber harvest taxes to counties: These objectives are both serious concerns, but the Workgroup felt that rules which caused an additional encumbrance of forested land would also reduce jobs and taxes. Therefore, these two objectives were seen as being represented by the objective to "Avoid economic harm to all landowners".

Once the objectives list had been refined (Table A2) pairs of Workgroup members met to quantify the eight selected alternatives (Section A3) and compare the alternatives' scores for the objectives in consequence tables (Section A4).

Section A4: Development of alternatives

The Workgroup used the Means-Ends network (above) to collect ways of achieving each objective. We developed a list of alternative "pieces"; a given complete alternative will make use of several alternative pieces to address all objectives. We placed the alternative pieces under general headings (underlined) to facilitate the use of the list. Italicized items are repeated from higher up on the list. Strike-through items are alternative pieces we decided to drop.

Table A2: Updated objectives list with accompanying measures.

Objective Group	Objective	Measure
Stream Temperature	Minimize degradation of water quality below F/N mixing junction	Probability that F/N junction experiences > 0.3 °C increase (%)
	Minimize exceeding antideg anywhere in Np, any time	Probability that all Np stream channel < 0.3 °C increase (%)
	Avoid negative thermal impacts to stream biota across whole Np network, any time	Constructed scale (needs defined)
	Emulate natural range of shade and temperature conditions at basin scale	
Promote or Protect amphibian assemblages	Maximize probability of channel stability / no increase in percentage fines or sediment	Constructed scale, proportion of units with direct hydrologic connectivity and affecting amphibians.
	Maximize probability of channel stability / no decrease in residual pool depth, number of pools, etc.	Constructed scale, expected change in bank stability.
Windthrow	Minimize post-harvest windthrow to provide supply of LW distributed over time	Constructed scale of blowdown ranging from uncut stand amounts to complete loss
Maximize ease and success of rule implementation	Promote layout ease	Constructed scale, relative to technical expertise / time required for layout of alternative prescriptions, compared to current Np buffer rules
Promote operational feasibility	Maximize safety	Constructed scale, relative exposure of workers to working under or adjacent to standing timber
Minimize public resource damage	Minimize resource damage potential	
Avoid economic harm	Avoid economic harm to all landowners	Constructed scale, encumbered acreage for alternatives, compared to current Np buffer rules

Construction pieces for alternatives

Stream Temperature

Change the rule to consider different spatial and temporal scales of measurement

Retain shrubs and brush

Smart placement of buffer (variable widths, core buffers, aspect, utilize topographic placing)

Increase Leaf Area Index (LAI)

Extend buffer along stream

Buffer width

Promote or protect amphibian assemblages

Extend buffers along streams

Buffer width

Direct wood placement

Smart placement of buffer

Thinned extended buffer width

PCT, commercial thin in buffer

Maximize ease and success of rule implementation

Rule language simplicity

Concise number of options

Small landowner outreach

Large landowner outreach

Promote operational feasibility

Different approaches by logging system

Operator latitude (within parameters)

Avoid requiring unusual practices

Avoid landlocking areas

Avoid economic harm

Incentivize basin harvest planning by single landowner

Cognizant of requirement for more retention or increased operational cost

The group then constructed a set of eight alternative management actions from the above list. The alternatives developed and became better described over time. The Workgroup also developed a set of rule development criteria that would not appear within alternative descriptions but applied to all alternatives, provided in the Report section "Process for Developing Recommended Alternatives".

The early version of the alternatives fell into three broad categories:

1. Fixed-width buffers

Current Forest Practices Type Np rules: Alternative A

Buffer similar to Alternative A but with 75 foot no-cut buffer: Alternative A2 (later dismissed)

Buffers along 100% of Np length with widths varying by alternative:

Alternatives B, C, and D (50, 75, and 100 feet)

2. Shade-focused buffers

Site-specific buffers: Alternatives E and F

3. Stream size-specific buffers

Alternative G also has buffers along 100% of the streams but the buffer widths depend on stream bankfull width

Subsequent discussion removed Alternative A2 (below) because we found it too similar to Alternative A. It was predicted to cost landowners more than Alternative 1 while not providing incremental protection to streams to prevent warming.

The eight original rule alternatives:

Current Np buffer rules

A2. Like the current Np rules, at least 50% of stream lengths would be buffered, but to a width of 75 ft on both banks.

100% buffer of 50 feet along all Np streams within a harvest unit. This is the same alternative that was tested in the Hard Rock study and effectively tested at four Soft Rock study sites.

100% buffer of 75 feet along all Np streams within a harvest unit.

100% buffer of 100 feet along all Np streams within a harvest unit.

Site-specific buffer: Harvest applications would tailor buffers according to site conditions with a target of maintaining 95% shade along the Np streams. The applications would be developed using a model provided by WA DNR that relies on LiDAR and site topographic details including stream azimuth and topographic shading. The buffer can be moved around the stream to best ensure shade and minimize additional area encumbered. Shade requirements may be lessened where streams tend to go subsurface August – September. Management will be allowed in riparian zone to remove "sail" trees that could have greater odds of becoming blowdown in order to retain trees likely to remain standing. In the absence of considering stream aspect or topographical shading there will be a 75-foot horizontal buffer width assumed to influence stream shading.

A mixture of one-sided and two-sided buffers along the entire stream reach. The exposed bank would receive a 75-foot-wide buffer while the shaded side would retain all bank-rooted trees, using crown extent as proxy for roots. North-south oriented streams would receive a 65-foot buffer on both banks.

Buffer riparian zone by stream width. 25-foot buffer for streams <1 foot and 50-foot buffer for streams 1 foot to 5 feet [bankfull]. Np streams >5 feet width have 50-foot no-harvest ("core") buffers, with an added 25-foot equivalent to the Type F streams' "inner zone" in which partial harvest is allowed.

Section A5: Consequence table evolution

The objectives and alternatives from Sections A2 and A3 were combined into a consequence table (Table A3; Gregory et al. 2012). Pairs of workgroup members formed teams that examined assigned objectives. The teams reviewed relevant literature or randomly sampled harvest units and attempted to provide estimates for expected average outcomes and uncertainty for each alternative on the objective in question. Estimates could be quantified as actual responses (e.g., temperature) or along constructed scales (e.g., 1 through 5). The consequence table includes an indication of a preferred direction for each objective, both in the objective name and in the Scale column.

When the teams met to discuss and obtain estimates for their objectives it became apparent that certain objectives may not be useful.

Emulate natural range of shade and temperature conditions at basin scale: It became apparent that this objective, while desirable to quantify, would be difficult to quantify. Alternatives would need to be considered as applied across a large area. This was unrealistic, as discussions with foresters both within our Workgroup and from elsewhere led us to believe that basin-wide harvests occurred but occurred in a relatively low percentage of harvest units. Usually only portions of basins are harvested at a time, making predicting outcomes of harvest at a basin level difficult. The Hard Rock and Soft Rock studies found the number of available sites that met study criteria extremely limited due to the limitation that harvests needed to virtually encompass entire basins.

Minimize resource damage potential: As stated in Section A2, this objective was maintained as a placeholder. The team involved in investigating it concluded that it was not needed; they did not identify any resources of concern that were not already covered.

Alternatives E and F in Table A3 were not filled out for all objectives. At the time, the teams generally found that these alternatives were insufficiently described to allow for estimation.

Table A3: Original consequence table with Workgroup-provided estimates. Estimates may use different scales and the direction of scales may differ by objective, as captured by the Scale (Best) column.

	Objective	Value Type	Measure	Alt A	Alt A2	Alt B	Alt C	Alt D	Alt E	Alt F	Alt G	Scale (Best)
Stream Temperature	Minimize antideg below F/N mixing junction	Estimate	Probability that F/N junction < 0.3C increase (%)	50	75	55	85	100			40	0-100 (100)
		Uncertainty	% +/-	30	40	30	40	30			40	0-100 (0)
	Minimize exceeding antideg anywhere in Np, any time	Estimate	Probability that all Np stream channels < 0.3C increase (%)	0	0	5	50	95		40	4	0-100 (100)
		Uncertainty	% +/-	10	10	10	20	10		30	10	0-100 (0)
	Avoid negative thermal impacts to stream biota across whole Np network, any time	Estimate		2	2	2	1	1		1	2	1-5 (1)
		Uncertainty		2	2	2	1	1		3	3	1-5 (1)
	Emulate natural range of shade and temperature conditions at basin scale	Estimate										
		Uncertainty										
Promote or protect amphibian assemblages	Maximize probability of channel stability; no increase in percentage fines/sediment	Estimate	Constructed scale for proportion of units with direct hydrologic connectivity and affecting amphibs. 1 = very little, 5 = severe.	2	2	1	1	1		1	1	1-5 (1)
		Uncertainty	% +/-	10	10	10	10	10		20	10	0-100 (0)

Table A3, continued.

Windthrow	Minimize post-harvest windthrow to provide supply of LW distributed over time	Estimate	Constructed scale, 1 = same as uncut stand, 5 = complete loss of buffer	3	2	3	2	2		2	1	1-5 (1)
		Uncertainty	Low/moderate/high degree of uncertainty	3	3	3	3	3		3	3	1-3 (1)
Maximize ease and success of rule	Promote layout ease	Estimate		1	3	1.9	2.9	2.9	5	3	2	1-5 (1)
		Uncertainty	2 * SE for 9 sites	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	(0)
Promote operational feasibility	Maximize safety	Estimate		1.9	1.9	2.3	2.3	2.3	2.3	2.3	2.3	1-5 (1)
		Uncertainty	2 * SE for 9 sites	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	(0)
Minimize public resource damage	Minimize resource damage potential	Estimate										
		Uncertainty										
Avoid economic	Avoid economic harm to all landowners	Estimate		1.0	2.6	3.4	4.1	5.0	3.8	2.7	1.8	1-5 (1)
		Uncertainty	2 * SE for 9 sites	0.0	0.4	1.3	0.7	0.0	1.0	0.5	0.3	(0)

The Workgroup evaluated the estimates and uncertainty and determined that certain objectives were insensitive – that is, they matter greatly and are important considerations, but after filling out the consequence table the group learned that their estimates were generally the same across all estimates (Gregory et al. 2012). This type of finding allowed the decision space to become simplified, as the insensitive objectives may be acknowledged as important and set aside because their inclusion will not affect the decision one way or the other. The following objectives were deemed insensitive:

<u>Avoid negative thermal impacts to stream biota across whole Np network, any time</u>: The team reviewing this objective found that the stream temperatures were generally cool in the Hard Rock studies and that even the current Np harvest rules were unlikely to pose a great threat, thermally, to stream biota including amphibians.

<u>Maximize probability of channel stability; no increase in percentage fines/sediment; Maximize probability of channel stability; no decrease in residual pool depth, number of pools, etc.</u>: Although streams can be naturally highly variable in sediment load (Bywater-Reyes et al. 2017, 2018), there is evidence both from the Hard Rock study and from the literature (e.g., Litschert and MacDonald 2009) that maintaining Equipment Limitation Zones (ELZs) along streams is highly effective for preventing timber-harvest-related sediment from reaching water channels. Similarly, channel morphology for these streams, high in watersheds, are not defined by large wood input. Therefore, as long as all bank-rooted trees are maintained as a part of buffer prescriptions, stream channels should maintain their stability and their morphology will not change over time substantially due to a reduction in large wood input. The Workgroup agrees that the ELZs should be maintained regardless of prescriptions selected, and all buffered streams will include at a minimum all bank-stabilizing trees. Therefore, the estimates for these two objectives did not vary much among alternatives and no alternative was deemed a severe threat to them.

<u>Maintain safety</u>: This objective is unarguably important. However, its evaluation did not indicate that the alternatives under consideration would be markedly less safe than current rules, and there was not much variation in safety estimates among alternatives.

The Workgroup met again to review values and update the consequence table. Two more objectives were removed from consideration as they did not appear influential for the decision:

<u>Minimize antideg[radation exceedances] below F/N mixing junction</u>: Upon further consideration the outcome for this objective appeared to be dependent on the outcome for the other temperature objective, "Minimize exceeding antideg<u>[radation exceedances]</u> anywhere in Np, any time". There was scant information with which to evaluate this objective. Stream temperature increases may decline once a stream re-enters an unharvested reach although the extent of that decline will likely vary greatly by site and by the length of the unharvested stream portion prior to the junction (Davis et al. 2015). We also did not know the quality or volume of the receiving waters, so could not judge whether temperature elevations in the Np streams will increase the receiving waters by > 0.3 °C.

Table A4: Updated consequence table with Workgroup-provided estimates. Estimates may use different scales and the direction of scales may differ by objective. In the scale column, the most desirable (Best) score for an objective is given inside parentheses.

	Objective	Value Type	Measure	Alt A	Alt B	Alt C	Alt D	Alt E	Alt F	Alt G	Scale (Best)
Stream Temperature	Minimize exceeding antideg anywhere in Np, any time	Estimate	Probability that on average Np stream channels < 0.3C increase (%)	0	25	50	95	50	45	15	0-100 (100)
		Uncertainty	% +/-	1	2	2	1	2	2	1	1-3 (1)
Windthrow	Minimize post-harvest windthrow to provide supply of LW distributed over time	Estimate	Constructed scale, 1 = same as uncut stand, 5 = complete loss of buffer	0.25	0.4	0.5	0.6	0.5	0.5	0.4	0-1 (1)
		Uncertainty	Low/moderate/high degree of uncertainty	3	3	3	3	3	3	3	1-3 (1)
Avoid economic harm	Avoid economic harm to all landowners	Estimate	Constructed scale representing acreage encumbrance relative to current Np rules: 1 = current Np acreage, 3 and 5 = two times and four times the encumbered acres, as compared to 1	1.0	3.0	3.5 to 4.0	5.0	2.5	3.13	2.0	1-5 (1)
		Uncertainty	2 * SE for 9 sites	1	1	1	1	2	2	3	1-3 (1)

Promote layout ease: This objective was retained to this point because we valued creating rules that were understandable and executable by landowners. However, the understanding that emerged was that for landowners the loss of harvestable trees was a substantially larger issue than increased complexity of harvest unit layout. The costs of layout are dwarfed by payback of less encumbered land. Specifically, Alt E, with a variable-width buffer depending on topography and stream orientation, would represent a better option than Alt D, a 75-foot no-cut buffer extending the length of the stream, if Alt E resulted in greater harvest opportunities within that 75-foot distance. The same is true for Alt F, which is envisioned to be a simpler version of Alt E. The Workgroup decided to continue considering all alternatives with respect to the different operational capabilities of small and large landowners but remove the objective because it no longer was seen as critical for the decision.

Section A6: Explanations of evaluation approaches for objectives

This section contains descriptions of CMER and literature findings relevant for estimating the effects of alternatives on objectives. Each of the three main objectives (underlined) begins a subsection of relevant findings.

Minimize probability of exceeding measurable change standards anywhere in Np stream at any time following harvest:

We reviewed Washington CMER study results and related manuscripts to inform us about expected temperature objective outcomes for each alternative.

The Type N Hard Rock study (McIntyre et al. 2018) was designed as an intensive examination of the physical, chemical, and biological response of small streams to forest harvest with different buffer treatments. Because of the high level of sampling effort required at each of the study sites, only a relatively few sites could be included in their study: 4 reference sites, 4 with 0% (no overstory vegetation left) buffers, 4 with 100% buffer and 3 with FP buffers. The Soft Rock study increased the sample size of FP sites by 7 and incorporated sites on a different lithology. However, the sites were clustered in a small region of the state and made almost all treatment comparisons against a single control site. Therefore, the extent to which the responses observed at Hard and Soft Rock sites can be extrapolated generally to Type Np streams in western Washington remains unclear. However, there have been several other studies of water temperature response to buffer design in the Pacific Northwest over the last two decades that are relevant to the objectives of the technical workgroup.

Several recent evaluations of the effectiveness of buffers for temperature control on small fish streams have been completed in Oregon in the last decade. Groom et al. (2011a, 2011b) conducted an evaluation of two buffer designs. This study used a before-after, control-impact experimental design to evaluate 18 sites on private forest land with buffers as narrow as 25 feet wide and 15 sites on state forest land with buffers widths that ranged between 157 and 170 feet. They found no significant change in the mean-7-day-maximum water temperature after harvest at sites with buffers 110 feet wide or greater. However, the narrower buffers on private sites were associated with an average increase of 0.7 °C. A predictive model generated from the data of the study's 33 streams (Groom et al. 2018) suggested that a 100-foot buffer would result in a temperature increase of 0.2 °C (95% Credible Interval of 0.0 °C to 0.4 °C) within the first two years following harvest. It predicted a 0.5°C increase with a 75-foot buffer (0.3 °C, 0.8 °C) and an increase of 1.15 °C for a 50-foot buffer (0.85 °C, 1.5 °C). The buffer widths considered in the manuscript were slope distances, not horizontal distances; Washington forest practices rules use horizontal distances. The temperature metric was the average of daily maximum stream temperatures measured between July 13 and August 23.

Another evaluation of buffer effectiveness on small fish streams in Oregon was reported in Bladon et al. (2016). This study examined temperature response following harvest with 15-m buffers on Needle Branch, a small stream in the central Oregon Coast Range. Harvest resulted in a modest decrease in stream shade; from 96% prior to harvest to 89% after. There was a temperature response in the mean-7-day-maximum of 0.6 °C. However, the warmest temperature recorded during the post-harvest period was 14.7°C, within the thermal tolerance range of aquatic biota of conservation concern in the Pacific Northwest (McCullough 1999; Reiter et al. 2019).

Of more direct relevance to the task of the technical workgroup are several studies evaluating temperature response to harvest along non-fish streams that have been conducted recently. As would be expected, harvest without the retention of overstory trees results in water temperature increases. Bladon et al. (2018) included 18 non-fish streams in their study. Five of these sites were references that did not experience any harvest during the study. Buffer widths varied among the treated streams. Continuous buffers were retained at 4 of the sites, with width ranging from 11 m to 20 m. Discontinuous buffers were retained at two of the sites; an 8-m buffer along 60% of the channel length at one location and an 8-m buffer along 25% of the channel at the other. Removal of all overstory trees to the edge of the channel occurred at the remaining study sites. Increases in mean-7-day-maximum water temperature occurred at all the sites, with the largest increases at the locations with the least overstory retention. At sites without buffers or with partial buffers the increase in mean-7-day-maximum temperature ranged from 2.4 °C to 3.9 °C. Locations where continuous buffers were retained experienced increases in the mean-7-day-maximum temperature of less than 1.0 °C. This study also noted that temperature response at several sites was muted by the introduction of slash into the channel during logging. The slash provided enough shade to reduce temperature response. The influence of in-channel slash on water temperature has also been noted in several other studies (Jackson et al. 2001; Kibler et al. 2013).

Reiter et al. (2019) re-examined the data from a subset of the sites included in the Bladon et al. (2018) study. Rather than focusing on the regulatory metric mean-7-day-maximum temperature, this analysis examined the alteration in the frequency distribution of summer (1 July to 31 August) water temperatures for 6 years prior to harvest and for 4 years after harvest. Buffer treatments at the sites included harvest without retention of overstory trees, discontinuous buffers and continuous buffers ranging in width from 12 m to 15 m. Buffered sites exhibited a distribution of temperatures before and after harvest comparable to the distribution observed at the reference sites; the temperature metrics examined in this study were not affected by harvest with continuous buffers. The sites harvested without buffers or with discontinuous buffers experienced a post-harvest increase in temperatures. Median temperature increased about 2 °C.

In British Columbia, an assessment of temperature response to 3 buffer treatments on non-fish streams was conducted on 10 headwater streams (Gomi et al. 2006). Treatments included no buffer, 10-m buffers and 30-m buffers. Average daily maximum water temperature during summer increased consistently in streams harvested without buffers; increases ranged from 2 °C to 8 °C. In contrast, very little response was seen in average daily maximum temperature at the sites where buffers were retained, even at the site where the buffer was only 10-m wide. The effectiveness of the buffers at preventing water temperature response in this study may have been enhanced by the north-south orientation of the streams. This orientation might make the narrower buffers effective at intercepting sunlight during midday.

Results from the studies summarized above indicate that relatively narrow buffers along headwater streams can provide a significant amount of protection from temperature increases. Reiter et al. (2019) found that buffers of 12 m – 15 m wide prevented any change in the frequency distribution of summer temperatures. Bladon et al. (2018) reported that buffers ranging in width from 11 m – 20 m wide restricted temperature response to 1.0 °C or less and Gomi et al. (2006) found that even a 10-m wide buffer prevented temperature increases at their study sites. However, these studies also illustrate the high degree of variation in temperature responses to buffer configuration on small, headwater streams. Some of this spatial variation is due to factors other than shade from riparian vegetation, like underlying geology (Bladon et al. 2018), high contribution of groundwater inputs, or stream orientation (Gomi et al. 2006). In addition, some of the differences in temperature response among these studies is due to the temperature metrics used to characterize temperature response. For example, Bladon et al. (2018) and Reiter et al. (2019) examined the same data set but used different temperature metrics. Bladon et al. (2018) reported a small increase in the mean-7-day-maximum temperature at buffered sites while Reiter et al. (2019) found no change in the frequency distribution of summer water temperatures at these same locations.

Our alternative development process involved considering and including thinning in outer RMZs, and we searched for information on the effects of different thinning prescriptions on shade. Studinski et al. (2012) found that riparian thinning of a stream to 50% of original basal area resulted in a 13% reduction in canopy coverage. Drever and Lertzman (2003) and Hale (2003) found, for non-riparian stand thinning on relatively flat ground, that a 50% reduction in basal area resulted in a 19% increase in full sun exposure and a 22% increase in solar transmittance, respectively. Sonohat et al. (2004) found that solar radiation transmittance relationships by basal area varied by species examined. In summary, a thinning regime of 50% of basal area will increase solar transmission, but because the relationship is nonlinear, it will proportionally allow less transmission than a 100% clear cut (Drever and Lertzman 2003, Hale 2003).

Stream Temperature Variability:

Stream temperatures vary in time and space. This spatiotemporal variability is a function of a variety of site-specific factors that include incident radiation, canopy and topographic shade, stream water travel time, streamflow volume, stream substrate color and permeability, geology, channel width, and groundwater or hyporheic flows - both in and out of the stream channel. Streams tend to warm as watershed area increases or as water flows downstream, even under full canopy cover. Temperature variability is often highest in the summer when temperatures are highest and flows lowest. Temperature variation occurs independently of land use activities and with and without streamside buffers. However, land use impacts can affect stream temperature and the variation in stream temperature.

Guidance our team received from the Washington Department of Ecology indicated that when evaluating the measurable change standards for stream temperature, the measurable change standards apply to every mean 7-day maximum temperature for a given year. The mean 7-day maximum temperature metric is calculated as a rolling average, for which there is one value per day of the year. Therefore, human-caused measurable change may take place during any season.

Given the variability stream temperatures exhibit naturally (see above), we maintain that the only way to detect a change in stream temperatures and attribute the change to timber harvest is by conducting a programmatic evaluation of multiple sites, with the evaluation involving a carefully developed study design and statistical analysis. The Hard Rock study is an excellent example. Its study design involved incorporating control (unharvested reaches) and treatment reaches, replicating treatments at multiple sites, and establishing pre-harvest statistical relationships between treatment and control sites. Following harvest, the analysis examined the change in the relationship between the treatment and control sites and compared those against the expected (predicted) relationships. The analysis requires several assumptions, including the stability of relationships between sites over time, and the report endeavored to test those assumptions. The results were summarized across sites, producing mean estimates with confidence intervals. Those estimates were used to assess whether temperatures had increased and by how much.

The evaluation of temperature change must be programmatic again due to the variability inherent in these systems. Variability can lead to false-positive assessments of individual sites (i.e., it may appear that a site warmed by more than the measurable change standards, but we cannot rule out that factors other than harvest led to the detected warming; Groom et al. 2011b).

Uncertainty associated with temperature metrics

The Hard Rock (McIntyre et al., 2018), Hard Rock Extended (Washington DNR, in review), and Soft Rock (Washington DNR, in review) analyses all examined treatment effects by creating predictive models of expected temperatures in treatment reaches assuming no harvest had occurred, as described above. These studies were able to provide mean temperature changes due to treatment. However, their ability to inform us about treatment performance regarding the measurable change standards is limited.

The studies provided two temperature metrics used in the analysis: the MMTR and 7DTR. TR stands for Treatment Response and represents a measurement of the predicted vs. observed difference in daily maximum temperatures post-harvest. MMTR is the maximum monthly treatment response and is calculated by averaging the TR values for every day within the given month. The 7DTR is the maximum value of 7-day averages of TR values in July and August. The reports use this measure to represent the measurable change standards.

We believe that the analyses conducted using the 7DTR metric represent a reasonable approach for evaluating the measurable change standards. The measurable change standards are supposed to be constructed using averaged daily maximum temperatures while the 7DTR instead averages daily differences between predicted and expected temperatures. The care necessary to control for natural temperature variability when comparing temperatures from different reaches requires, we believe, the use of metrics such as the 7DTR. The use of July and August as the months from which to obtain the 7DTR makes sense, as generally the warmest MMTR temperatures are detected within that time frame, although as Section 4.1 Appendix Tables 1 through 12 in the Hard Rock Extended study demonstrate, there are many counter examples from other time periods. Using the single greatest seven-day averaged TR value from the July-August time period has merit – although all seven-day averaged TR values matter when evaluating the measurable change standards, using just the largest in the analysis should generally suffice and helps simplify the analysis. The fit is not perfect (results may differ for months other than July and August), which introduces some uncertainty into equating 7DTR results with the measurable change standards metric.

The metrics used in the Hard Rock and Soft Rock studies introduce additional uncertainty into our assessment of the measurable change standards, as they did not directly test compliance with the standards. The Hard Rock, Hard Rock Extended, and Soft Rock analyses all provide analysis results of 7DTR values as mean treatment effects on temperature responses and associated confidence intervals. This type of analysis does not directly evaluate the measurable change standards, although the results are informative. To accurately assess the standards, we need to know what proportion of sites met the standards. The magnitude of temperature change is less important than knowing whether the change exceeded 0.3 °C. If the mean 7DTR exceedance value is greater than 0.3 °C, it could be that a minority of sites warmed a great deal while the majority did not warm at all. Similarly, we relied on other stream temperature studies that also did not examine temperatures relative to the measurable change standards. A few studies (Groom et al. 2011b, Bladon et al. 2018) do attempt to directly examine a similar change standard, and future CMER studies could emulate their techniques. Alternatively, Washington Department of Ecology and Department of Natural Resources may decide to consider the approximations used for the Hard and Soft Rock studies sufficient.

Specific information on select sources mentioned above follow:

Hard Rock Phase I: This analysis found, for effective shade, that a 50-foot 100% buffer resulted in shade declines of 11% (95% CI ≈ 0%, -20%), canopy closure declines of 6% (95% CI ≈ +1%, -12%), and temperature (mean-7-day-maximum temperatures) increases of 1.1 °C (95% CI ≈ 0.3 °C, 2.1 °C). For the FP treatments it found for shade a decline of around 31% (95% CI ≈ -20%, -45%), canopy closure declines of 23% (95% CI ≈ -12%, -30%), and temperature increases between years 1 and 2 post-harvest of 1 °C (95% CI ranging between 0 °C and 2.4 °C). Note that some buffers (e.g., Olym 100%, Wil2-100%) were wider than 50 feet in places because of trees left for sensitive sites and this may have affected shade readings. Also, WIL2-100% and OLYM-100% relied on temperature probes that were not in the main channel of the Np streams. The no-buffer streams on average produced a 3 °C increase (95% CI = 2 °C, 4.5 °C).

Soft Rock: The seven Forest Practices Np treatment streams declined in canopy closure by 24% post-1 (95% CI = -33.9, 15.2). The mean-7-day-maximum temperature increase was 0.6 °C (95% CI = 0.29 °C, 0.92/0.90 °C) for the first two years post-harvest. Four of the streams were buffered for > 90% of their length due to sensitive site harvesting constraints. One, TRT7, had a mean buffer width of 79 ft.

Groom et al. 2018: This paper describes the results from a Bayesian analysis of stream temperature data that examined the changes in temperature relative to the intensity of the stream harvest. The study included 33 sites and data were collected before and after treatment. Riparian vegetation data were collected as well as stream temperature, channel, and shade data. The model linked a relationship between shade and riparian buffer characteristics to a relationship between shade and stream temperature (along with other variables). Because the riparian vegetation data collection utilized a 100% cruise before and after harvest, including tree distance to stream, the analysis could be used to simulate different harvests of the riparian stand, use the shade part of the model to predict shade, and the temperature portion to predict how that change in shade would affect stream temperatures. The paper reports findings and riparian buffers in slope distance. The predicted changes in shade and temperature for harvests of different horizontal buffer widths are presented in Figures 1 and 2. The temperature figure (Figure 1) reproduces Figure 11 from the paper but uses horizontal distance and feet instead of slope distance and meters. The shade figure (Figure 2) does not appear in the manuscript.

The Groom et al. (2018) paper relies on a 40-day average of mean-7-day-maximum values between mid-July and mid-August. This metric most closely resembles the Hard and Soft Rock metric for Maximum Monthly Temperature Response (MMTR). Note that for the Soft Rock study it appears that the average of the highest July and August MMTR values at the F/N break was 0.57 °C and 0.65°C (obtained from Table 4-6), while the Maximum 7-Day Treatment Response (7DTR) was estimated to be 0.6 °C. This similarity did not hold as strongly for the Hard Rock study. Due to a lack of other information, we are interpreting the Groom et al. model results as useful approximate guides for relating buffer width to temperature increases (e.g., comparing predicting temperature increases against the measurable change standards).

DeWalle 2010: For N-S streams at summer solstice most shade was achieved with buffer widths of 6-7m (19 – 22 feet) while E-W streams achieved 88% of 30-m shade at 18-20m (60 – 65 ft). This was a modeling study examining the effects of buffer width, buffer height, and buffer density.

Rationales for Temperature Estimates:

For all alternatives, uncertainty measurements were provided on a scale of 1 (least uncertainty) to 3 (most uncertainty). An uncertainty value between 0 and 20% would receive a 1, 2 is for uncertainties between 21% and 40% and 3 for uncertainty greater than 40%.

Rationale for Alternative A: The clearcut riparian areas above the buffers for Forest Practices streams should warm > 0.3 °C on average (many studies verify that clearcuts result in warming, the Hard Rock study estimated a temperature increase of 3 °C); the Hard Rock, Soft Rock, and Groom et al. (2018) studies find that 50-foot buffers do not prevent warming, shade findings of Groom et al. (2018) match DeWalle (2010) findings for N-S streams, with approximately a 15% reduction in shade at 50'. (East-west streams were modeled to only require 19 to 22-foot buffers at a latitude of 40º). Therefore, stream reaches above the buffer should be expected to warm with high certainty > 0.3 °C on average and the buffered portion of the stream is expected to warm with high certainty > 0.3 °C on average. The estimated result is that the Np prescription will have a 0% chance of meeting the measurable change standards 50% of the time anywhere in the system. The uncertainty around this finding is given a value of 1 in large part because the clearcut portions of the reaches are extremely likely to exceed the standards.

Rationale for Alternative A2 Values: Like (A), the stream above the buffer should warm. Streams below buffer should be more protected and temperature may recover at or below 0.3 °C (C). Therefore, stream reaches above the buffer should be expected to warm with very high certainty and the buffered stream is expected to warm as a consequence of temperature increases above the buffer but temperatures may fall below the measurable change standards.

Rationale for Alternative B Values: See (A) for buffered reach. Note that in Hard Rock study the measured increase did not appear to differ between (A) and (B). The Groom et al. (2018) model temperature increase curve (Figure 1) does not include 0.3 ºC in its 95% Credible Interval for a 50-foot horizontal buffer, indicating that the model did not anticipate that a 50-foot buffer would likely succeed at meeting the measurable change standards. However, many Np streams have additional buffer widths in places from sensitive site harvest restrictions. Therefore, the probability of achieving the measurable change standards is slightly higher than 0%, with an uncertainty value of 2.

Rationale for Alternative C Values: With a 75-foot no-management buffer, the Groom et al. (2018) temperature predictions (Tables A2 and A3) predict a 50% probability of meeting the measurable change standards with a horizontal no-cut distance of 75 feet (with the 95% Credible Intervals extending from 60 feet to 95 feet). The Groom et al. model was based on data for streams that may have been on average larger and less steep than Np streams, introducing uncertainty. There is also uncertainty around how well the Groom et al. model results align with measurable change standards metrics.

Allowing for timber harvest entry in the outer 25 feet of a 75-foot-wide buffer introduces additional uncertainty. If maximum entry occurred along all buffers it is possible that temperatures may warm on average above the 0.3 °C measurable change standards, since a 50% basal area thinning will likely increase light reaching the stream. Based on studies listed above, we anticipate that the thinned buffer will provide more shade than a 67.5-foot no-cut buffer (i.e., harvesting the outer half of the 25-foot outer managed buffer), especially without full entry. We therefore anticipate that with or without the thinning we would give this objective a score of 3 in Table A7, falling between 41% and 60% probability of meeting the standards.

With thinning in the outer 25 feet of the buffer, the timber extraction from thinning should be economically beneficial to landowners. However, there is reason to believe that thinning will not be fully executed in riparian buffers:

- Cable yarding operations are not well suited for thinning. Thinning may be more likely for ground-based harvest activities.
- Landowners may prefer to only conduct limited entry to harvest the most lucrative trees and may not want to invest in performing a full thinning.
- Increased risk of injury and layout costs may dissuade some landowners from performing a full thinning of the outer 25 feet.

We therefore believe that including a provision for thinning may diminish the overall likelihood of meeting the measurable change standards, but we do not know by what degree, due to the lack of directly applicable evidence on the effects of thinning on riparian shade and the anticipated landowner behavior. We select an uncertainty level of 2.

Rationale for Alternative D Values: DeWalle predicts most shade benefits should be achieved in 30 m, or 100'. The Groom et al. 95% Credible Interval falls below 0.3 °C, indicating that the model predicted little probability of exceeding 0.3 °C with such a buffer. However, with uncertainties described above we give the 100-foot buffer a 95% probability of meeting the measurable change standards on average across sites with an uncertainty level of 2.

Rationale for Alternative E Values: If we assume that the site-specific buffer allows for reductions of up to 7% of available shade and feasibly achieves these in the field, the Groom et al. (2018) model predicts that the temperature increase, on average, would be approximately 0.3 °C, providing a 50% probability of meeting the measurable change standards. The alternative is specifically designed to provide the shading based on azimuth and there is no thinning in the buffer. The Groom et al. model also applied to fish-bearing streams that may tend to be larger than Np streams and experience a difference in stream recharge flow paths (e.g., more hyporheic exchange or different relative influence of groundwater flows), introducing uncertainty. Uncertainty in the estimate was therefore set at 3 as the group does not know if a 7% shade reduction produces outcomes that are desirable enough to warrant considering. Also, the site-specific buffer model has not been field-tested.

Rationale for Alternative F Values: If the shading is successful then regardless of the stream orientation a 75-foot buffer will probably provide a sufficiently wide buffer to prevent increases above measurable change standards (C). The stream azimuth needs to be used to determine whether a one-sided buffer will be sufficient. DeWalle (2010) found that for E-W streams 30% of shade came from north bank. The minimum 25-foot buffer is expected to protect bank-rooted trees but may be insufficient to protect all north-side shade trees. It is conceivable that a daily maximum temperature (especially for streams with steep gradients and short water residency times) may not be affected by early morning or late afternoon sunlight when the north-sided buffers provide the most shade. The estimate for this objective is a score of 3 in Table A7, falling between 41% and 60% probability of meeting the measurable change standards with a high degree of uncertainty (3).

Rationale for Alternative G Values: See (A) for buffered reach. Note that in Hard Rock study the measured increase did not appear to differ between (A) and (B). It is unlikely that a 25' buffer would provide sufficient solar protection for smaller streams. There is uncertainty around the distribution of these different stream widths across the landscape, although the river-miles of smaller-width streams are almost certainly longer that wider widths. Also, there is uncertainty for what the temperature – stream width relationship is for Type Np streams.

<u>Minimize post-harvest windthrow to provide supply of large wood distributed over time</u>:

We investigated patterns of windthrow following timber harvest using Washington CMER study results and related manuscripts.

Windthrow of trees is a natural process and one of the primary mechanisms by which wood is delivered to stream channels (Bilby and Bisson 1998). One of the purposes of retaining buffers along stream channels is to ensure a continuous supply of this material for streams (Reeves et al. 2018). However, windthrow risk can increase dramatically following forest harvest. A study of windthrow in riparian buffers along 40 non-fish streams in northwestern WA reported that an average of 33% of the retained trees blew down within three years of timber harvest (Grizzel and Wolff 1998). Other studies report varying levels of post-harvest windthrow, but all indicate that some sites experienced a large increase in tree fall in buffers within the first decade following harvest (Table 1; Steinblums 1978, Hobbs and Halback 1981, Andrus and Froelich 1988, TFW 1994, Mobbs and Jones 1995).

Table 1: Average and range of blowdown rates in buffers in western WA and OR during the decade following logging.

Study	Location	# Sites	Mean Windthrow Frequency (%)	Range of Windthrow Frequency (%)
Grizzel and Wolff (1998)	WA	40	33	2 – 92
Mobbs and Jones (1995)	WA	90	5	0 – 100
TFW (1994)	WA	91	10	0 – 80
Andrus and Froelich (1988)	OR	30	22	0 – 72
Hobbs and Halbach (1981)	WA	37	5	0 – 17
Steinblums (1978)	OR	40	29	0 – 78

The physical characteristics of a site, stand-level features, soil characteristics and factors associated with individual trees all contribute to the blowdown risk in a buffer (Blackburn et al. 1988, Stathers et al. 1994). Physical site factors are related to stream orientation, size and shape of the cut unit and topography. Susceptibility of a buffer to windthrow is heavily influenced by the orientation of the buffer. In western Washington, most strong winds are from the south or southwest. As a result, buffers oriented in an east-west direction are more exposed to strong winds and typically experience higher windthrow rates than in buffers oriented north-south. Grizzel and Wolff (1998) found that 67% of all windthrown trees fell to the north, indicating they succumbed to a wind from the south. In contrast, only 3% of the fallen trees they surveyed at their 40 study sites fell to the south. Other site physical attributes that have been related to windthrow risk include distance from the buffer edge to uncut timber in the direction of the prevailing wind, change in elevation from the buffer to the uncut edge in the direction of the prevailing wind, distance from the buffer to the closest major ridge in the direction of the prevailing wind and elevation of the buffer (Steinblums et al. 1984). All these factors influence the strength of the wind experienced by trees retained in the buffer.

Stand characteristics also relate to the susceptibility to windthrow (Stathers et al. 1994). Tree density in a buffer can influence windthrow risk with denser stands tending to be more windfirm due to interlocking root systems and damping of tree swaying caused by the wind. High incidence of defects like root rot in a stand also is related to elevated windthrow risk (Hubert 1918). Thinning of trees in the buffer can elevate windthrow risk. Heavily thinned stands, in particular, experience high windthrow rates compared to unthinned stands (Stathers et al. 1994).

Soil characteristics influence rooting architecture and, as a result, influence risk of windthrow (Stathers et al. 1994). Trees on deep, well-drained soils develop large root systems making these trees less prone to windthrow. In contrast, sites with shallow soils typically restrict rooting depth and enhance windthrow risk. Rooting depth can also be limited in wet soils. Trees on these soils often develop a shallow, plate-like rooting structure. Root depth is restricted to the soil zone above the saturation level. Root systems less than 50 cm deep are common on wet soils. In addition, wet soils have dramatically lower shear stress than dry soil, reducing soil cohesion to tree roots and greatly enhancing probability of windthrow. Because wet soils are most typically associated with flat ground, blowdown rates are related to riparian landform. Andrus and Froelich (1988) observed blowdown rates in buffers on terrace or floodplain landforms that were double those of buffers on sloping ground.

Individual tree characteristics are also related to windthrow risk. Windthrow risk varies by tree species. Grizzel and Wolff (1998) reported higher windthrow rates in conifers than in hardwoods. The species most susceptible to falling were western hemlock and Pacific silver fir; over 35% of these trees fell at the 40 sites in their study. Windthrow rates of Douglas-fir and western redcedar were about 20% while red alder and bigleaf maple suffered blowdown rates of 17% and 7%, respectively. Andrus and Froelich (1988) also found that hemlock suffered the highest post-harvest blow down rates in buffers on the Oregon coast.

Tree form also influences windthrow risk. Rooting habit influences wind firmness with deeper rooted species typically being less susceptible to windthrow than shallow-rooted species. As noted above, rooting depth also can be greatly modified by soil characteristics. Trees with large, dense crowns can be more affected by wind than trees with smaller canopies (Stathers et al. 1994). Bole form also affects windthrow risk. Trees with a relatively short, conical bole, caused by a high degree of taper, tend to be less prone to windthrow than trees with a tall, cylindrical bole.

To summarize the above information relative to the alternatives under consideration, post-harvest blow-down risk is governed by the weather and is highly site specific. Blowdown risk assessment for each evaluated riparian management option would require the theoretical application of these treatments at a set of actual sites and characterizing the proportion of trees in the buffer, or proportion of buffer area, with high blowdown risk. Risk can be assigned based on:

Physical site features

Buffer orientation

Distance to uncut stand edge (fetch)

Site topography

Stand-level features

Stand density

Species composition

Crown depth

Bole form

Soil features

Soil depth

Soil moisture

Effectiveness Estimate:

Windthrow rates in buffer comparable to rates in pre-harvest stand

Windthrow rates increased < 20% over baseline

Windthrow rates 20%-50% over baseline

Windthrow rates 50%-75% over baseline

Complete loss of buffer

Uncertainty:

Low degree of uncertainty based on site characteristics

Moderate degree of uncertainty

High degree of uncertainty

The effectiveness ratings and the uncertainty value are highly site specific. Sites where buffer conditions indicate high degree of wind firmness (N-S orientation, topographic protection from wind, dry, well-drained soils etc.) would receive a high effectiveness rating (1 or 2) and a low degree of uncertainty. A site with characteristics associated with high windthrow risk would receive a low effectiveness estimate and low uncertainty score. However, most buffers will possess a combination of conditions, making the assignment of a generic score to a buffer option difficult. Effectiveness and uncertainty values are provided in Table A5.

Table A5: Effectiveness and uncertainty ratings for the windthrow objective.

Alternative	Effectiveness Estimate	Uncertainty	Rationale
Current Np buffer rules	3	3	Current blow down rates highly variable but often within the 20-50% range. Due to the overriding effect of site features on blow down risk, uncertainty of the estimate is high.
A2) 50% 75 ft. Any use of variable width? Break in slope? Want to account for blowdown and minimize economic impacts.	2	3	Likely to be similar to the current rules but with more trees in more stable, upslope locations.
100%, 50 ft	3	3	
100% 75 ft	2	3	Increased width may include more trees in upslope areas, which tend to be more stable.
100% 100ft	1	3	Increased width may include more trees in upslope areas, which tend to be more stable.
Site-specific buffer	2	3	
One-sided buffer. 100% length, bank-rooted on shade side (use crown extent as proxy for roots), 75' on less-shade side	2	3	Same effectiveness and uncertainty as 6. As the narrow buffer will be placed on the downwind (north) side of the channel, these trees will be less likely to fall. The 75 ft buffer on the windward side will have effectiveness similar to the option with 75 ft buffers on both sides.
Buffer riparian zone by stream width. < 1 ft 25', 1-5' 50'.	4	3	High degree of blowdown risk on small channels with narrowest buffers. Wind firmness may increase with width. But high variable and site specific.

Avoid economic harm:

Estimating the effects of the eight Type Np buffer alternatives on objectives associated with economic impacts (shown in Figure A1) evolved over time within the Workgroup. Evaluating buffer alternatives for avoidance of economic harm is complicated by the inherent site-specific nature of individual harvest units. To scope out potential critical harvest unit variables and assess the likely economic impacts of the proposed buffer alternatives, a total of nine Forest Practices Applications (FPAs) with Type Np stream segments (three FPAs each for three categories of Type Np streams) were randomly selected from the 2020 Western Washington Compliance Monitoring Program FPA database (hereafter referred to as the "2020 FPA Database") of 494 FPAs. Three categories of Type Np waters (as defined in WAC 222-30-021 (2) (b) (i)) were evaluated:

- Type Np Water less than 300 feet in length from the confluence of Type S or F Water,
- Type N Water 300 feet to 1000 feet in length from the confluence with Type S or F Water, and
- Type N Water greater than 1000 feet in length from the confluence with Type S or F Water

The initial FPA selection process was also restricted to those FPAs that encompassed an entire Type Np watershed. This criterion followed the same basic site selection process logic as used in the Hard Rock and Soft Rock studies. Each FPA in the 2020 FPA Database was assigned a number and a random number generator was used to select three FPAs for each category. Each category went through a separate random number generator FPA selection process.

This FPA selection process required that several hundred FPAs be examined by hand in order to identify those harvest unit FPAs that encompassed an entire Type Np watershed, covering all three Type Np Water categories. Finding individual FPAs which met the "entire watershed" criterion became more difficult as the Type Np Water length category increased. Harvest unit FPAs encompassing entire Type Np watersheds certainly occur, but such harvest units represent a relatively small percentage of harvest units in western Washington. Based on the experience reviewing several hundred FPAs from the 2020 FPA database, the majority of harvest units generally involve only portions of individual Type Np watersheds rather than entire Type Np watersheds, and Type Np streams often form harvest unit boundaries.

Based on the finding in the last sentence of the prior paragraph and as a comparison to the initial FPA selection process, a second random FPA selection process was performed for the three Type Np Water categories but without the requirement that individual FPAs needed to encompass an entire Type Np watershed. The initial set of nine FPAs and the second set of nine FPAs were then evaluated separately and combined together to scope out harvest unit operability variables.

Highlights from review of the combined set of timber harvest unit FPAs included operability findings that:

- Buffers associated with unstable slopes or rule-identified landforms may increase the length and width of buffers placed along Type Np streams under the various Type Np buffer alternatives, but the presence (or absence) of unstable slopes / rule-identified landforms is quite variable;
- Yarding corridors through riparian buffers will remain a necessary tool for all proposed buffer alternatives, in order to harvest timber in a cost-effective manner;
- Buffer alternatives with buffer gaps (non-continuous one- or two-sided buffer segments) offer greater operational flexibility and safety for yarding timber across / over Type N streams;
- The shortest Type Np streams (those less than 300 feet in length) that enter Type S / F as laterals receive significant buffer protection from the riparian buffers associated with the Type S / F buffers, much more protection than do mainstem confluence Type Np streams (which essentially receive no additional buffer protection from Type S / F buffers); the second category of Type Np lateral streams (300 to 1000 foot long streams) receive similar but a lower percentage of additional buffer protection from Type S / F buffers; and
- Depending on the width of proposed riparian buffers (and in association with unstable slope buffers), some isolated patches of otherwise accessible, harvestable timber may be created between Type Np and /or Type F/S buffers

Each of the FPAs from the two sets of FPAs were then individually scored by Lunde and Barnowe-Meyer for each of the original eight alternatives, using the "Avoid economic harm" objective measures described in Section A2: Overview for development of objectives and alternatives.

A scale of 1 to 5 scale was utilized to score the relative level of economic harm to all landowners associated with each evaluated buffer alternative. The 1 – 5 scale was:

1 = Buffer alternative reduces harvest of essentially the same or less than the acreage / timber volume associated with the current Type Np forest practices rules.

3 = Buffer alternative reduces harvest of twice the acreage / timber volume as current Type Np forest practices rules.

5 = Buffer alternative reduces harvest of four times the acreage / timber volume as current Type Np forest practices rules.

NOTE: None of the eight alternatives were evaluated to capture potential disproportionate economic harm to small forest landowners associated with specific alternatives.

The individual scores for the first set of nine FPAs for each alternative were then averaged and the average score for each of the eight alternatives was used to populate the Avoid Economic Harm estimates in Table A3. Standard errors were calculated for the scores for each alternative. An additional process of averaging scores for the second set and the combined set of al evaluated FPAs was performed for the original eight alternatives but the results are not presented here.

Based on learnings from the direct scoring and score averaging processes described above, the observed site-specific variability of the FPAs evaluated, the confounding impact of unstable slope buffers in the FPAs evaluated, as well as improved definition of and understanding of the initially proposed Type Np buffer alternatives, scoring of the final seven buffer alternatives (as shown in Table A4 above) does not rely solely on the FPA-evidenced scoring of the original eight buffer alternatives (as shown in Table A3) but relies more generically on the reductions in acreage of timber harvest associated with the proposed Type Np buffer alternatives.

<u>Section A7: Explanation for recommendation refinement procedure</u>

The Np Workgroup used values from Table A4 to create simplified, standardized scores and then ranks. The Stream Temperature estimated probabilities for achieving the measurable change standards were revised to a linear five-point scale, where 1 is the highest probability of success and 5 is the lowest (Table A6).

Table A6: Five-point scale used to simplify and standardize temperature objective values.

Five-point scale score	Probability of achieving the measurable change standards
1 (Likely to achieve)	81-100%
2	61-80%
3	41-60%
4	21-40%
5 (Unlikely to achieve)	0 – 20%

The Windthrow estimates are already on a 1-5 scale, as are estimates for Avoid Economic Harm. Both are linear scales, described in section A4, where 1 represents the best score for the objective and 5 the worst. The estimates from Table A4 may be restated as:

Table A7: Estimates for alternatives and objectives from Table A4 placed on 1 to 5 scales, with 1 representing the best possible outcome for a given objective.

	Alternatives						
Objective	A	B	C	D	E	F	G
Temperature	5	4	3	2	3	3	5
Windthrow	3	3	2	1	2	2	4
Economy	1	3	3.5	5	2.5	3	2

We then examined the performance of alternatives using only ranks of the alternatives with values ranging from 1 to 7. For visual purposes, we flipped the order of ranks relative to scores: the best rank for an objective received a 7 while the worst-performing received a rank of 1. The ranked estimates are in the following table, Table A8. The next step was to consider the weights of the objectives. If we considered all objectives equally important, we would assign them equal weights. This was done in Table A9, with each rank value multiplied by its corresponding weight. The weights allow for an overall assessment of an alternative, where the sum of the weighted ranks provides an overall value for the alternative, the Alternative Sum. An Alternative Sum value of 7 is the highest (best) score an alternative can achieve, while a 1 is the lowest. Figure A2 provides a visual depiction of the information in Table A9.

Table A8: Ranked estimates of alternatives and objectives from Table A7 with rank preferences ranging from a best-performing rank of 7 to a worst-performing rank of 1.

	Alternatives						
Objective	A	B	C	D	E	F	G
Temperature	1.5	3	5	7	5	5	1.5
Windthrow	2.5	2.5	5	7	5	5	1
Economy	7	4	2	1	5	3	6

Table A9: Weighted versions of ranked estimates from Table A8 with each objective given equal (1/3) weighting.

		Alternatives						
Objective	Weight	A	B	C	D	E	F	G
Temperature	1/3	0.5	1.0	1.7	2.3	1.7	1.7	0.5
Windthrow	1/3	0.8	0.8	1.7	2.3	1.7	1.7	0.3
Economy	1/3	2.3	1.3	0.7	0.3	1.7	1.0	2.0
Alternative Sum:		3.7	3.2	4.0	5.0	5.0	4.3	2.8

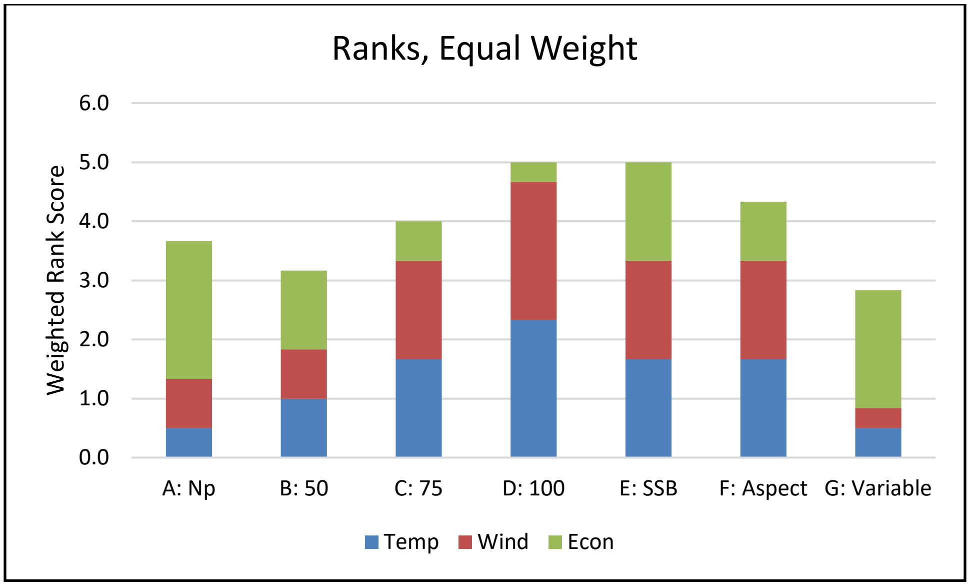

Figure A2. Performance of weighted ranks for Alternatives A through G. SSB is an acronym for Site Specific Buffer.

In Figure A2 we see that Alternatives D and E, the 100-foot no-cut buffer and the site-specific buffer, respectively, have the best overall score with a value of 5.0. The benefits for stream temperatures are high for the 100-foot no-cut buffer and moderate for the site-specific buffer, and the benefits for windthrow appear high to moderately high. Economic cost is high for Alternative D and moderate for Alternative E. Alternatives B and G ranked lowest, performing poorly for Temperature and Windthrow and moderate/high for Avoiding Economic Cost. The team then questioned the weights for the three objectives: since Windthrow is so highly variable the team did not believe it deserved equal weight to Temperature and Avoiding Economic Harm. Therefore, we recalculated the rank weights, with Windthrow receiving 10% of the weight instead of 33%, and Temperature and Avoiding Economic Cost were given equal weights of 45% (Table A10, Figure A3).

Table A10: Unequally weighted versions of ranked estimates from Table A8.

		Alternatives						
Objective	Weight	A	B	C	D	E	F	G
Temperature	0.45	0.68	1.35	2.25	3.15	2.25	2.25	0.68
Windthrow	0.10	0.25	0.25	0.50	0.70	0.50	0.50	0.10
Economy	0.45	3.15	1.58	0.90	0.45	2.25	1.58	2.70
Alternative Sum:		4.08	3.40	3.65	4.30	5.00	4.10	3.48

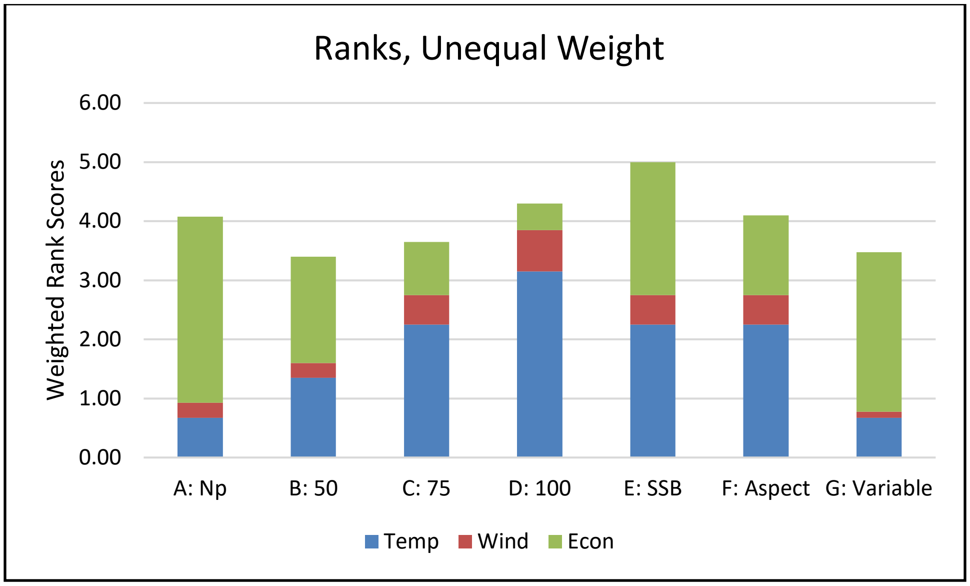

Figure A3: Performance of unequally weighted ranks for Alternatives A through G. SSB is an acronym for Site-Specific Buffer.

The overall weighted rank scores in Figure A3 show a similar pattern as Figure A2, with Alternative E again having the highest combined value and B and G the lowest. We can see more clearly that Alternative D performs well, but its score is primarily due to a high weighted rank for Temperature. Conversely, Alternative A also performs well but mainly due to a high weighted rank for Avoiding Economic Cost.

The Np Workgroup then examined the actual scores of the alternatives instead of the ranks. Ranks fail to capture the magnitude of difference between alternatives and also do not convey indications of actual success or failure to meet objectives. As was done for visualizing ranks, we flipped the scores in Table A7 to make data visualization easier. Therefore, previous scores of 5 were given scores of 1 and vice versa (e.g., now 1 = low, 5 = high). For the sake of comparison with the weighted rank scores the 5-point scales were transformed to 7-point scales and multiplied by their respective objective weights (Table A11, Figures A6 and A7).

Table A11: Transformed and weighted score values from Table A7.

		Alternatives						
Objective	Weight	A:Np	B:50	C:75	D:100	E:SSB	F:Aspect	G:Variable
Temperature	0.45	0.45	1.13	1.80	2.48	1.80	1.80	0.45
Windthrow	0.10	0.40	0.40	0.55	0.70	0.55	0.55	0.25
Economy	0.45	3.15	1.80	1.46	0.45	2.14	1.72	2.48
Alternative Sum:		4.00	3.33	3.81	3.63	4.49	4.07	3.18

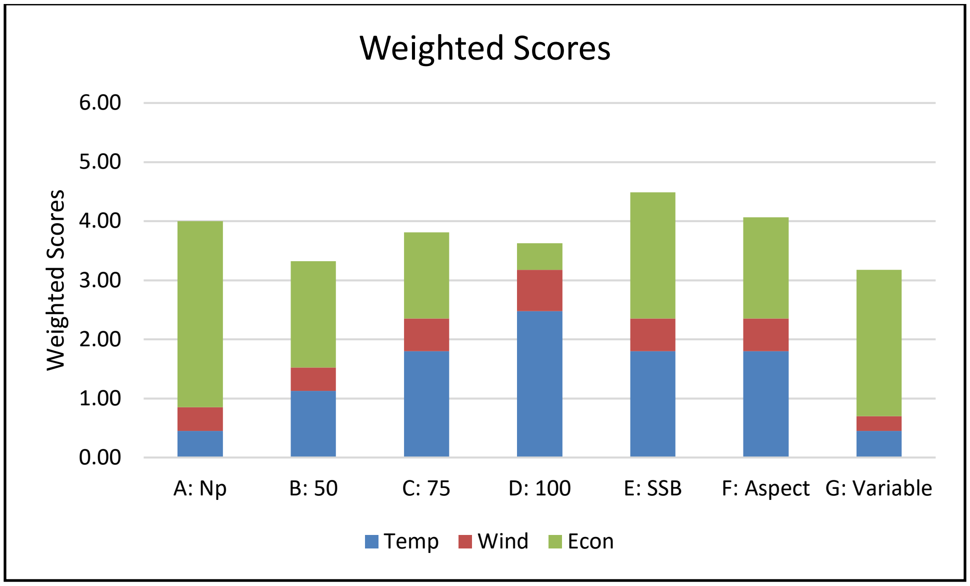

Figure A4: Performance of unequally weighted scores for Alternatives A through G. SSB is an acronym for Site-Specific Buffer.

Figures A6 and A7 portray the same information from Table A11. Figure A4 provides an easy way to assess overall alternative performance. For instance, Alternative A appears to offer the best overall value because of its high score for Avoiding Economic Harm. However, it does not perform well for Temperature. Figure A5 allows us to perform visual comparisons of the different alternatives by objective. If we seek a balance of meeting the Temperature objective while Avoiding Economic Harm to some degree, Alternatives C, E, and F appear best.

We provide in Table A12 a summary of our levels of uncertainty for each of the alternatives and objectives. The three objectives all have a 1 to 3 scale for uncertainty, defined for each above, with 3 = the least category and 1 = the most certain category.

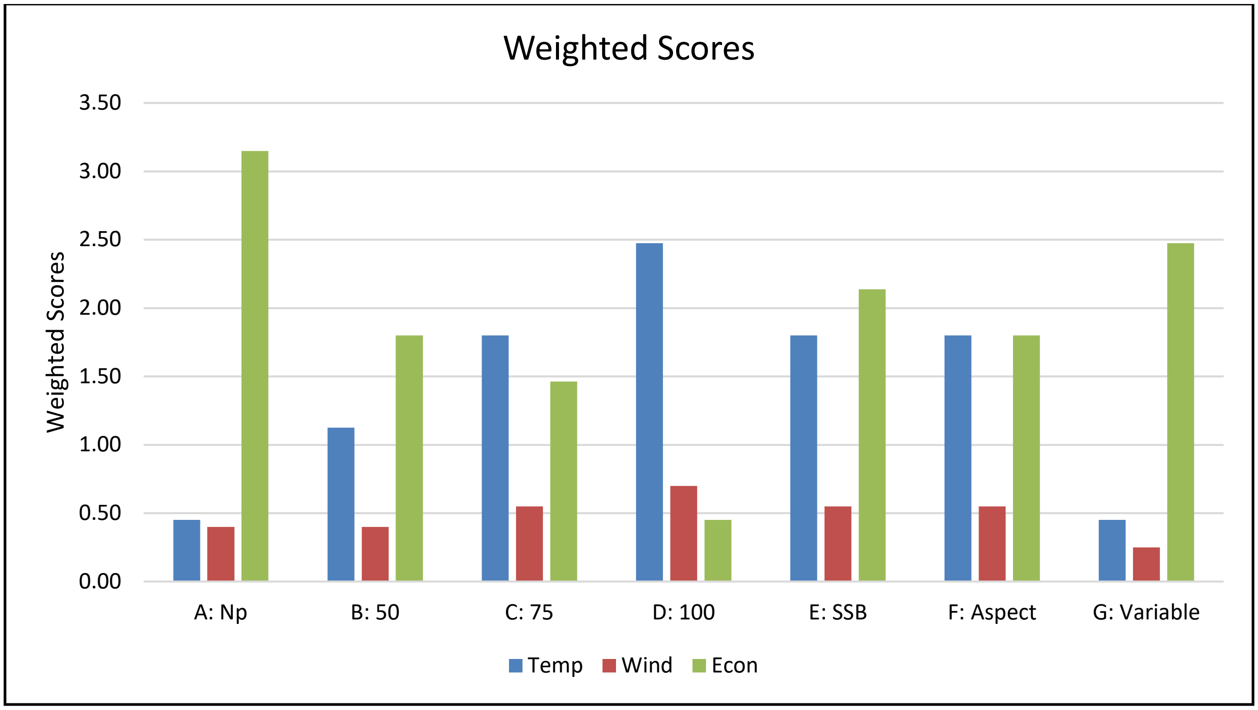

Figure A5: Performance of unequally weighted scores for Alternatives A through G. SSB is an acronym for Site-Specific Buffer.

Table A12: Estimate uncertainty values, with 1 = most certain and 3 = least certain.

		Alternatives						
Objective	Weight	A:Np	B:50	C:75	D:100	E:SSB	F:Aspect	G:Variable
Temperature	0.45	2	2	2	1	2	2	1
Windthrow	0.10	3	3	3	3	3	3	3
Economy	0.45	1	1	1	1	2	2	3

Examining Figures A6 and A7, we believe that Alternatives C, E, and F are the most likely to obtain some assurance of meeting the temperature measurable change standards while avoiding the largest costs to landowners. Levels of uncertainty for the selected alternatives are greatest for alternatives E and F as they have not been tested.