DEPARTMENT OF
NATURAL RESOURCES

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October 31, 2024

Notice of Final Determination
SEPA File No. 24.100202
FPA No. 2617912
Agreement No. 30-102017
Timber Sale: Parched

The Department of Natural Resources issued [X] Determination of Non-significance (DNS), [ ] Mitigated Determination of Non-significance (MDNS), [ ] Modified DNS/MDNS on **October 31, 2024** for this proposal under the State Environmental Policy Act (SEPA) and WAC 197-11-340(2).

This threshold determination is hereby:

[ ] Retained.

[X] Modified. Modifications to this threshold determination include the following:

Unit boundary adjustment to Unit 3 due to the discovery of Special Plant Communities within the harvest boundaries. These areas have been delineated from harvest which has resulted in a reduction of harvest size of Unit 3 from 59 acres to 48 acres.

[ ] Withdrawn. This threshold determination has been withdrawn due to the following:

[ ] Delayed. A final threshold determination has been delayed due to the following:

Summary of Comments and Responses (if applicable):
See attached.

Responsible Official:	William Wells
Position/title:	Olympic Region Manage
Address:	411 Tillicum Lane Forks, WA 98331
Phone:	(360) 374-2800

Date: 11/01/2024 Signature: William Wells

There is no DNR administrative SEPA appeal.

Comment: **Public Outreach**

Response:

The Department of Natural Resources has conducted numerous public meetings, presentations, and outreach regarding this specific proposal and DNR management of state trust lands in the Elwha watershed. This includes reaching out to stakeholders, beneficiaries and local tribes. The DNR has specifically addressed concerns raised by the City of Port Angeles and public comment regarding potential impacts of harvest activities within the Elwha Watershed and on the City's water supply. The Trust Land Transfer application submitted by the City of Port Angeles was evaluated by DNR staff and found it to be not in the best interest of the trust. In addition, Clallam County and the Revenue Advisory Committee which consists of all the County's Junior Taxing districts who are the direct beneficiaries, unanimously asked for this application to be denied. These decisions were outlined in a letter addressed to the City of Port Angeles along with an invitation to continue dialogue regarding DNR's management of these state trust lands.

Comment: **Proposal impacts on the Elwha Watershed and the City's water supply**

Response:

162 acres of the Parched Timber sale is located within the Elwha Watershed, which equates to 0.08% of the Elwha Watershed. The Alley Cat, Parched, and Tree Well timber sales being reviewed through the SEPA process represent approximately 0.14% of the Elwha watershed. DNR's 5-year harvest plan within this watershed, including these three sales, is 668 acres or 0.3% of the watershed. Over 90% of the Elwha Watershed is permanently deferred from harvest in federal ownership including Olympic National Park and Olympic National Forest. These acres, along with DNR manage lands, provide a large percentage of mature and old growth forests within the watershed which is why the Elwha Watershed is one of most protected watersheds in the country.

It is true that peer reviewed research shows that intensive and extensive logging within small watersheds can lead to lower summer stream flows and higher peak flows. That research does not suggest that managing 0.14% of a large watershed that is primarily composed of mature forests will have the same effect. In the Elwha Watershed, which is a not small headwater basin, but rather is a large basin, where the total proposed harvest area of these three timber sales will account for roughly 0.0014 or 0.14% of the watershed, no changes in low flow are expected because no changes have been observed in large basins with harvest-area-rations as high as 65% (Coble et al. 2020) The DNR added a hydrologic report dated October 31, 2024 titled "Proposed DNR Harvests in the Elwha watershed and impact on low flows and peak-flow-driven sediment transport" to the record of the SEPA. This report from the State Hydrologist reviews the scientific literature, some of which was cited by commentors, and reaches the conclusion that the likelihood that proposed harvest activities will reduce low flows at the City of Port Angeles water supply to be extremely low. The Elwha basin is a large watershed, the harvest-area-ratio of the proposed DNR timber sales are well below the threshold at which a reduction in low flows might occur, the ratio of mean annual potential evaporation to mean annual precipitation is low and only a small proportion of the basin is managed and those lands that are manage consist of a variety of stand ages. See this report for more information regarding the analysis of hydrology within the Elwha River Watershed. This outcome was also reached in the 2018 final Port Angeles Water System Plan, which states, "ongoing and periodic logging on private and DNR lands is expected to continue in the lower watershed and is not expected to present a problem for the City's Elwha supply. These activities have not presented a problem for the City's Elwha Ranney collector supply since it was placed into service in 1977."

Protections outlined in the SEPA for Parched, Alley Cat and Tree Well clearly identify large stream and wetland buffers and small contiguous harvest acres that will ensure these sales have no impact to the City of Port Angeles water supply. During the field layout for these three sales, a combined 121 acres of riparian management zones, 11 acres of wetlands and wetland management zones, 25 acres of leave trees and 81 newly identified acres of Old Growth have been identified and permanently protected in the Elwha Watershed. Furthermore, earlier this calendar year, DNR also identified 180 acres from one planned and one sold timber sale for permanent deferral from harvest as part of the 2,000 acres of structurally complex, carbon dense forestland to be set aside directed by the Legislature's Natural Climate Solutions proviso. In total, DNR has permanently deferred from harvest more acres (418 acres), than are planned for harvest (343 acres) within the Elwha Watershed with these proposals.

DNR timber sales have played an important role in habitat restoration projects across the Olympic Peninsula including projects on the Elwha River. For example, the recent restoration project on the Elwha River, specifically the engineered log jams below the Elwha River Highway 101 bridge, included wood removed from DNR timber sales. DNR is approached regularly by local tribes, conservation groups, and other stakeholders to supply restoration projects with larger diameter trees and stumps. Due to DNR's management of state lands, DNR is one of the very few large forest landowners that can supply the wood needed to meet the design specifications of these restoration projects.

Comment: Older Forest Management

Response:

There are over 180,000 acres (~88%) of federally managed lands within the Elwha watershed that consists of predominantly old growth forests or structurally complex older forests. The DNR owns under 8,000 acres (>4%) within the watershed and provides forests stands that contribute older forests. DNR has designated forest stand acreage within regeneration harvest deferred areas in each HCP planning unit to meet or exceed the policy's 10% older-forest target. This identified acreage is designated in DNR's GIS database as the Westside Forest Cover (Conservation Areas) and Older-Forest in Conservation Areas layers. The Parched Timber Sale is not identified as one of those stands designated to meet older-forest targets over time. Following the timber sale, the variable retention harvest units will be replanted with native, conifer tree species that will be supplemented by natural regeneration expected to occur as a result of the conservation areas in and around the harvest units. Additionally, as part of the layout and design of this timber sale, 73 acres of Old-Growth forests were newly identified and deferred from all future harvest activities. Older and structurally complex forests will continue to exist throughout the Elwha watershed on DNR managed lands, and on the over 180,000 acres of federally managed lands in Olympic National Forest and Olympic National Park.

Comment: Watershed Analysis not completed

Response:

The DNR received the following comment, “As stated in Question 8, the DNS notes that a watershed analysis was not conducted as part of the determination.” The Watershed Analysis that is referenced in Question A.8 is referring to the Forest Practice Board rules on Watershed Analysis.

The Watershed Analysis was adopted by the Forest Practices Board in 1992. The Watershed Analysis addressed effects of timber harvest and road building within Watershed Administrative Units, and helped landowners develop specific prescriptions and management strategies to protect public resources within these areas. Watershed Analysis were conducted on watersheds across the state prior to the adoption of new rules.

In 2001, the Washington State Forest Practice Board adopted the Forests and Fish Report’s habitat protection and administrative measures into forest practice rules which is called - the Forest and Fish Rules. The Timber, Fish, and Wildlife (TFW) group of stakeholders (state agencies, tribes, forest landowners, conservationists, and federal agencies) documented these scientifically based protective measures and administrative processes which did not exist prior to.

Per WAC 222-22-070 (3)(e), “effective July 1, 2001, the forest and fish riparian rules supersede all existing watershed analysis riparian prescriptions.” Additionally, the WAC adds that no new Watershed Analysis were to be written. Within Olympic Region, only 5 Watershed Analysis were completed prior to adoption of the Forest and Fish rules and the watersheds within these proposals were not one of the five approved. Therefore, there is no forest practice Watershed Analysis to list in Question A.8. of the SEPA checklist. Per the WAC and the Forest Practice Board manual, DNR is following all policies and procedures within these Watershed Administrative Units.

Comment: Recreation Impacts

Response:

The DNR is very aware of possible impacts to the NW Cup and other events that the DNR licenses on Dry Hill and throughout our region. The DNR timber sales team along with DNR’s recreation program has worked with various event coordinators over the past decade to ensure there will be no impacts to their events. DNR lands provide many opportunities for people to recreate while providing crucial jobs and raw resources for the economy. RCW 79.10.120 directs the DNR allow for other uses of State lands that are “…additional to and compatible with those basic activities necessary to fulfill the financial obligations of trust management…” As a note, Unit 5 of this proposal is being evaluated by the DNR recreation program as a site for future infrastructure expansion of the Dry Hill mountain bike recreation site. The DNR and Olympic Region remain committed to supporting these events at Dry Hill and throughout the region.

Comment: **Presence of Whipplea modesta**

Response:
The DNR received comment regarding the presence of Whipplea modesta in Unit 3 of the Parched Timber sale. The DNR contacted the Natural Heritage Program and worked with a State botanist to field review unit 3. After field review, the presence of Whipplea modesta was found within the unit, along with four separate plant association groups. After completing the survey, three of these plant association groups were identified as element occurrences (EO). Areas of Whipplea modesta were already protected within existing Leave Tree Areas, however, after conferring with the Natural Heritage Program, it was determined that the EO's and areas of dense Whipplea modesta should be deferred from harvest. Leave Tree Areas within Unit 3 were expanded and new Leave Tree Areas were added, to protect more of the species and related EO's. These areas have been removed from the harvest area, which has resulted in a reduction of harvest size of Unit 3 from 59 acres to 48 acres. The three identified EO's are identified as EL Codes CEGL002848, CEGL000468, and CEGL000456.

Comment **Harvest activity impacts to Marbled Murrelets, Northen Spotted Owl, Salmon, Riparian Areas, Critical/Sensitive Areas, and Wildlife Corridors**

Response:

Since 1997, DNR has managed its forests in compliance with a Habitat Conservation Plan that has resulted in approximately 48% of its lands being permanently deferred from harvest to protect endangered species and develop critical habitat where it is needed the most. DNR's HCP is a landscape level, legally binding agreement between DNR and the US Fish and Wildlife Service (USFWS), regarding how to best protect critical fish and wildlife habitat while also allowing for timber harvest and other land management activities. Managing trust lands in this way supports climate resilience, supports the needs of threatened and endangered species while simultaneously providing revenue for trust beneficiaries. All of our designated marbled murrelet and northern spotted owl habitat areas are defined and maintained under this agreement. Under the HCP, stream and wetland buffers, leave tree requirements, and sensitive habitat protection are beyond what is required by Forest Practices, and are designed to promote functional wildlife corridors and habitat connectivity for all fish and wildlife species native to Washington. In Western Washington, protection and restoration of riparian acreage and function on forested state trust lands is an integral part of DNR's HCP. The objectives of the HCP's riparian strategy are to 1) maintain or restore salmonid freshwater habitat on DNR-managed lands, and 2) contribute to the conservation of other aquatic and riparian obligate species. To meet these objectives, the HCP requires establishment of riparian management zones, including wetland management zones, and provides protection measures that exceed the requirements of the state forest practices rules.

Upland forest habitat connectivity for wildlife movement within the Elwha watershed drainage is robust. Stream and wetland buffers retained on state land provide forested wildlife corridors connecting with other forested set-aside areas. State, Federal, Tribal and private forestlands, and other undeveloped areas provide a wildlife corridor that extends from the interior of the Olympic National Park to the mouth of the Elwha River. Timber harvest creates temporary changes to an area's vegetation cover that do not preclude wildlife use, and that can encourage different suites of wildlife species to use the area as the next forest matures.

Comment: **Slope Stability Concerns**

Response:

This proposal has been reviewed by a licensed engineering geologist and their recommendations have been incorporated into the proposal. Unstable features around this sale include inner gorges, bedrock hollows, shallow landslides and a recharge area of glacial deep-seated landslide. These features and all other forest practice rule identified landforms have been delineated and excluded from the sale area. DNR professionally licensed geologists and the Forest Practice program concur that no harvest will occur within the groundwater recharge area of a glacial deep-seated landslide as evidence by the Class III Forest practice application. Additionally, all DNR timber sales are reviewed by the Forest Practice Science Team and their professionally licensed geologists as part of the forest practice application process to ensure that all DNR timbers sale are following Forest Practice rules and regulations related to slope stability and protections of public resources.

Comment: **Alternatives to Timber Harvest**

Response:

One of the purposes of the proposal is to generate revenue for the institutional beneficiaries of the lands at issue in this sale. Making the trusts productive is one of DNR's responsibilities as a trust manager, and DNR's statutes include directives to harvest timber in accordance with its sustainable harvest level. RCW 79.10.340. This timber sale implements in part this statutory directive, and alternatives such as thinning or partial cutting, or not cutting at all what is currently proposed for harvest inherently produce less revenue than DNR's current proposal. The Department has proposed and implemented substantial mitigation measures as part of its development of this site, including providing protections to riparian and wetland areas that far exceed Forest Practices minimums. Mitigating measures are properly considered as alternatives in SEPA, and properly considered as part of the threshold determination process. WAC 197-11-792(2)(b); -786; 330(1)(c); and 197-11-350(1). After the timber sale is completed, the site will be planted and naturally forested, and will remain available to the spectrum of multiple uses identified in RCW 79.10.120. The timber on this site is a renewable resource, consistent with DNR's sustainable forest management under RCW 79.10.300-.340. Thus, the other uses of the site in RCW 79.10.120 will not be precluded in the future, except for the relatively short period of time where timber harvest operations occur.

Comment: **Carbon Analysis**

Response:

Leadership and staff at DNR are concerned about how sustainable forest management can mitigate the effects of climate change. For instance, the DNR's Natural and Working Lands Carbon Sequestration Advisory Group is actively considering our role in carbon sequestration on managed and un-managed forest lands. Forests are the most efficient means we have for removing carbon from the atmosphere. They draw in vast amounts of carbon dioxide and store carbon as biomass. But we know this is only one way that forests contribute to climate solutions. By balancing ecological, economic, and social outcomes, we can compound the benefits forests provide. To begin with, active management of forests for timber and revenue enables us to push back against economic pressure to convert those forestlands to non-forest uses. Management for timber also helps maintain a steady supply of local logs to local mills. When we source our wood from nearby forests, we reduce the amount of fossil fuel required to bring logs from forests to mills and from mills to local retailers. We know that a substantial percentage of wood from State lands ends up as dimensional lumber, plywood, and other manufactured building materials. Forest products used in construction store more carbon—and their manufacture emits far less carbon dioxide, methane, and nitrous oxide—compared to non-wood alternatives such as concrete, steel, brick, and plastics.

When it comes to sequestering carbon in our working forests, DNR does more than most large forest landowners in Washington. For example, our rotation ages tend to exceed the industry average for forest managers in the Pacific Northwest. On lands covered by our Habitat Conservation Plan, we leave larger riparian buffers and more habitat trees than are required by law. In total, close to half of the forested trust lands we manage are deferred from harvest for ecological reasons. To quantify these carbon benefits, we worked with partners at the US Forest Service to conduct an inventory of carbon on both private and public forestlands across Washington.

Comment: Herbicide Use

Response:

Our site prep treatments are only applied to vegetation and soil and are never applied to water. These treatments are also performed during dry weather with backpack sprayers to ensure that the mixture will not run off site but will instead dry on the ground and/or vegetation which in turn maximize the effectiveness of the products and mitigates spray drift and runoff. Additionally, a peer reviewed article by Thistle et al 2009 titled "Deposition of Aerially Applied Spray to a Stream within a Vegetative Barrier" showed that vegetative buffers effectively mitigate off site movement of herbicides. As you know, all of our streams are buffered by trees and other vegetation further reducing the risk of runoff and leaching into groundwater. The environmental checklist notes that it is possible that herbicides might be used on the site in the future, but that assessment will occur after harvest. If herbicides are applied to the sale area, they will be products approved for use by the Washington Department of Agriculture, applied per the labeling directions, and the application conducted and monitored by persons certified by the Department of Agriculture. The products we use, and the manner in which we use them, are safe, legal, and have been and continue to be extensively studied and evaluated.

Comment: Cultural Resources and Tribal Outreach

Response:

A check of the Department of Archaeology and Historical Preservation (DAHP) database, historic USGS map on available GIS layer, and Land Resource Manager (LRM) Special Concerns Report was used to identify cultural resources in the proposed project area. Proposed harvest areas were also checked against historic topographic and GLO maps. No significant cultural resources were identified during these screenings or during field work. If a presently unknown cultural resource is discovered during project operations, DNR will comply with the Cultural Resources Inadvertent Discovery Guidance dated March 2010 or its successor procedure. Additionally, the DNR has conducted outreach with local tribes regarding this proposal and others within the Elwha watershed. Local tribes and their cultural resource specialists review all DNR timber sales and regularly provide comment and feedback, which includes site visits with DNR staff, Cultural Resource Technicians, and State Lands Archeologists.

Comment: General Comments regarding further SEPA analysis

Response:

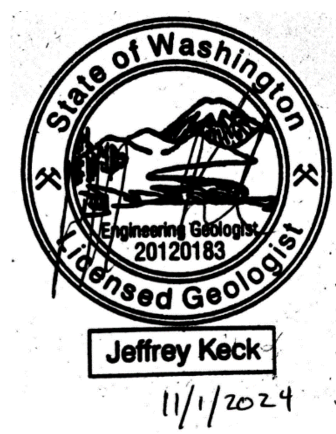
The DNR received multiple comments regarding proposed activities within this proposal requesting the need for further analysis. The proponent states that the DNR is following all internal policies and procedures related to these activities. Additionally, this proposal and activities related to this proposal have an approved Forest Practice Application. The proponent has enough information to make a determination that significant environment impacts will not occur with these activities therefore further analysis is not required.

Nov. 1st, 2024

TO: Drew Rosanbalm, State Lands Assistant Manager, Olympic Region

FROM: Jeff Keck, P.E., L.E.G., Forest Hydrologist, Forest Resources Division

SUBJECT: Proposed DNR harvests in the Elwha watershed and impact on low flows and peak-flow-driven sediment transport



Overview

This memo summarizes my assessment of the potential impact of three proposed DNR harvests in the Elwha River watershed on low flows and peak-flow-driven sediment transport. In Section 1, I synthesize current scientific knowledge on forestry impacts on low flows. In Section 2, I review the science on forestry impacts on peak flows and subsequent sediment transport. Then, in Section 3, I apply current scientific understandings, conditions in the Elwha River watershed and site characteristics of three proposed DNR harvests to assess the likelihood that the harvests will impact low flows and peak-flow-driven sediment transport rates, with special emphasis on conditions at the City of Port Angeles water intake as well as various smaller-scale subbasins within the Elwha River watershed. Finally, in Section 4, in response to helpful public comments about distributed hydrology modeling and their potential use as an assessment tool in the Elwha, I discuss distributed hydrology model applications.

Here, low flow refers to the annual minimum daily mean flow rate, which in the Pacific Northwest, typically occurs in the late summer and early fall months. Following Coble et al. (2020), after tree harvest and planting of a new stand, low flow response undergoes three phases: Phase 1 - low flow increases while the planted trees are small, surface runoff rates are relatively high and interception rates and water uptake rates are relatively low; Phase 2 - changes in low flow are variable and insignificant as the trees begin to mature and intercept and transpire water at a rate similar to the harvested stand and; Phase 3 - a decrease in low flow as evapotranspiration (ET) losses associated with the planted trees begin to exceed those of the harvested stand. In this memo, I focus specifically on Phase 3 changes, which occur roughly 15 years after harvest (Perry and Jones, 2016) but may begin as early as 6 years and as late as 41 years following harvest (Coble et al. 2020). Peak flows refer to the highest instantaneous flow rates caused by precipitation and/or snow-melt runoff.

Section 1. Forestry impacts on low flow

Significant changes in low flow have been observed following tree harvest in small catchments (area < 40 km^2 [~15.4 mi^2]) in which a large proportion of the basin was harvested and the harvest was conducted in a single entry (e.g., Perry and Jones 2016; Segura et al. 2020; Table 1). In large basins (area > 400 km^2 [~154.4 mi^2]), significant tree-harvest- or disturbance-caused changes in low flow have not been observed (Coble et al. 2020; Table 2). In large basins, differences in stand age, including stands of recently planted trees (~ 1-to-15 year old trees) that add to baseflow and young, vigorously growing trees (~15-to-80 year old trees) that take away from baseflow as well as multiple water reservoirs, including flood plains, wetlands and bedrock aquifers, result in a flow response to disturbance that is more complex, attenuated and less distinct (Moore et al., 2020).

Table 1. Maximum reported reduction in low flow versus harvest area for small, headwater basins studied in Segura et al (2020) and Perry and Jones (2016)

Study	Site	Area, km^2	Disturbance area, % of basin	Low flow reduction, %
Perry and Jones (2016)	AND1	0.96	100	65
	AND 6	0.13	100	50
	AND 7	0.15	50	50
	AND 10	0.10	100	55
	COY 3	0.50	100	60
	COY 1	0.69	50	40
	AND 3	1.01	25	35
	COY 2	0.68	30	10
Segura et al. (2020)	Needle	0.75	82	58
	Deer	3.11	25	10

Table 2 Maximum reported reduction in low flow versus harvest area for large basins, summarized from Coble et al. (2020)

Study	Site	Area, km^2	Disturbance area, % of basin	Low flow reduction, %
Zhang and Wei 2012	Baker	1570	62.2	0
Buttle and Metcalfe 2001	AND 6	8940	25.2	0
	AND 7	1140	18.9	0
	AND 10	401	4.9	0
Li et al. 2018	COY 3	1810	37	0
Zhang and Wei 2014	COY 1	2860	29	0
	AND 3	3500	25	0

In addition to basin size, whether or not a harvest will alter low flow rates also depends on the proportion of the basin disturbed by the harvest (herein, I refer to this proportion simply as the disturbance area, expressed as percent of the basin area) and whether or not the harvest was completed in a single entry, or multiple entries. For a harvest that is completed in multiple entries, low flows may remain elevated or never decrease (i.e., low flow Phase 3 never occurs), even if 100% of the basin is harvested (disturbance area = 100%) because increases in low flow caused by the initial harvest offset low flow reductions caused by the maturing planted stands (Coble et al. 2020).

For single entry harvests, a review of studies conducted at various forested regions of the planet suggests that the disturbance area needs to exceed at least 25% of a watershed before a low-flow response will be observable (Johnson, 1998). In small, headwater basins of the Pacific Northwest, low flow response was observed following harvests that ranged from 25% to 100% of the watershed (Perry and Jones 2016; Segura et al. 2020; Table 1). In Figure 1, the findings from Perry and Jones (2016) and Segura et al. (2020) are fit a with a logarithmic regression line, which captures the threshold-like low-flow response to disturbance area described by Johnson (1998); however from the regression, an estimate for the disturbance area, below which, no reduction in low flow would be expected, can be determined for the Pacific Northwest sites by solving for the area at which the max reduction in low flow is zero. Doing this indicates that for small, headwater basins in the Pacific Northwest, the disturbance area at which a decrease in low flows becomes measurable is 13% or roughly half of that estimated by Johnson (1998).

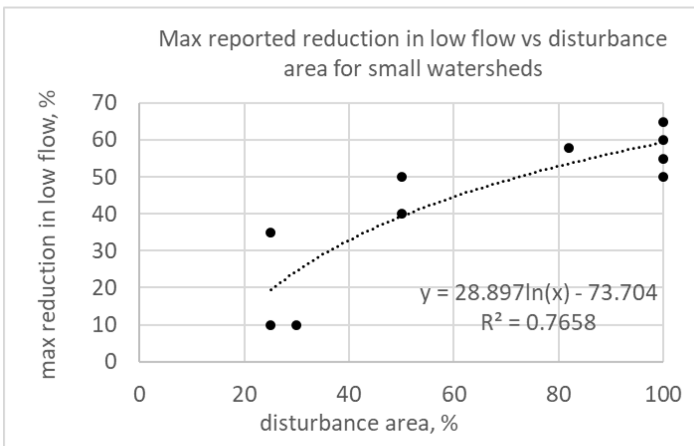


Figure 1 Regression model fit to maximum reported reduction in low flow versus disturbance area for small, headwater basins studied in Segura et al (2020) and Perry and Jones (2016)

In addition to basin size and the disturbance area, whether or not a tree harvest and replanting will reduce low flow rates, to a certain degree, also depends on the age of the initial stand harvested (Coble et al. 2020). A young stand of Douglas fir has higher sap flow per sap wood area and more sap wood area than mature trees (herein defined as ~100 years and older, see below) and the needles have less stomatal control when vapor pressure deficits are high, so ET does not turn off like it does in a stand of mature trees (Perry and Jones, 2016). If a mature stand of trees is harvested and replaced with a stand of young trees, increased water uptake by the planted trees will leave less water available for runoff relative to the replaced (mature) stand. Conversely, if a young stand of trees is harvested and replaced by a similarly aged young stand of trees, there will be no reduction in runoff relative to the replaced stand once the planted trees grow, even if the watershed is fully harvested, because the planted stand returns to the growth state of the replaced stand. Ultimately, whether or not any change in water uptake by a planted stand affects low flows at the basin scale depends on the basin size (large vs small) and the disturbance area but the if the disturbance area is sufficiently large and basin sufficiently small, the low flow response will then depend on the condition of the reference stand.

From the literature, for small basins that have been ~100% harvested and replanted with a stand of young trees, a relationship between stand age and the maximum-expected decrease in low flow can be determined. Perry and Jones (2016) reported that 80 to 100% harvest of 450-year-old mature mixed conifer trees and replacement with a stand of 35- to 40-year-old stand of Douglas Fir resulted in an average maximum reduction in low flow of roughly 58%. Segura et al. (2020) reported that an 85% harvest of a primarily 105-year-old Douglas fir stand and replacement with a 40-to-50-year-old stand of primarily Douglas fir also resulted in a maximum reduction in low flow of roughly 58%. If we assume the ET rates of planted stands in Perry and Jones (2016) and Segura et al. (2020) were roughly equal, the results of these two studies suggest after a stand of trees reaches an age of 105 years, ET rates remain relatively constant (i.e., a 105-old-stand and 450-year-old-stand may have nearly equivalent ET rates). Coble et al. (2020) reported that a 100% harvest of 80-year-old mixed conifer stand and replacement with a 40-year-old stand of mixed conifers resulted in a maximum reduction in low flows of roughly 17%. If we assume that the low flow rates associated with the 40-year-old stand in Coble et al. (2020) were equal to 58% of the low flow rates expected a from a 105 to 450 year old-stand of trees (as observed in Segura et al. 2020 and Perry and Jones 2016), then the low flow of the original 80 year stand in Coble et al. (2020) equates to roughly 50% of the low flow expected from the 105 to 450 year old-stand of trees.

Site index curves of tree height versus age for conifer trees are highly nonlinear (e.g., Bell and Dilworth 2002). If water uptake by a conifer tree scales with the derivative of tree height vs age (i.e., the growth rate), water uptake by the tree versus the age is likely also highly nonlinear. In Figure 2, a non-linear model is fit to the stand age versus maximum decrease in low flow observations from Perry and Jones (2016), Segura et al. (2020) and Coble et al. (2020). The model is valid for tree ages between 35 years and 100 years old and indicates that water uptake by a stand of conifers rapidly returns to a mature-tree state between an age of roughly 80 to 100 years old. After 100 years, the max reduction in low flow is assumed to remain constant and equivalent to a mature stand of trees, as suggested by results of Segura et al. 2020 and Perry and Jones (2016). Notably, an age of 100 falls within the age bracket at which growth rates in conifers and in particular Douglas fir trees rapidly slow (Bell and Dilworth, 2002).

While it may not be possible to use the results of empirical studies discussed above to predict low-flow response to harvest in the Elwha River watershed (Moore et al. 2020), especially given the influence of basin size, disturbance area and initial stand age on low flow response to harvest, nonetheless, the empirical results do provide insight into the directionality of a potential response following disturbance. In this respect, key among their findings is that: First as basin size increases, low low-flow response to forestry decreases and no changes in low flows have been observed in large basins for disturbance areas ranging from 5 to 62%; Second, in small basins, response increases as disturbance area increases (as illustrated in Figure 1) and: Third, reductions in low flow tend to be larger at drier sites, during hotter summers in lower latitude sites (Perry and Jones, 2020; Goeking and Tarboton, 2020). In other words, in small, headwater basins, with lower precipitation rates, higher potential evapotranspiration rates, and large disturbance area, harvest impacts on low flows tend to be relatively large.

Given the above, it stands to reason that while changes in low flow may not be observable in large basins, in small basins, the relative susceptibility or sensitivity of low flow to harvest and planting (i.e., a change from mature to young trees) can be inferred based on some metric that incorporates the potential evapotranspiration and precipitation at the site. One such metric is the aridity index which is the ratio of mean annual potential evapotranspiration (PET) to mean annual precipitation (P), PET/P (e.g., Budyko, 1974; Istanbulluoglu et al. 2012). When PET is larger than P (PET/P>>1), evaporative potential is large and vegetation can potentially use much more water than is available for runoff; when the PET/P << 1, the site is energy limited and vegetation can potentially use only a fraction of precipitation (Jones et al. 2012). The small basins investigated in Perry and Jones (2016) and Segura et al. (2020) are located within paired-basin research sites: Coyote Creek of the South Umpqua Experimental Forest in the Umpqua National Forest, the H.J. Andrews Experimental Forest in the Williamite National Forest and the Alsea Watershed Study in the Siuslaw National Forest. In Table 3, each location is characterized in terms of the PET/P ratio. PET is determined as a function of both mean annual temperature and mean annual incoming short-wave radiation at the site using equation ii in Cristea et al. (2014). Values for P, mean annual temperature and mean annual incoming short-wave radiation are from the PRISM 30-year normal dataset (PRISM, 2024). Of the basins studied in Perry and Jones (2016) and Segura et al. (2020), the largest reduction in low flows were observed at Coyote Creek, which has the highest PET/P ratio and the smallest reduction in PET/P values were recorded at the Alsea River and HJ Andrews research station, which have lower PET/P values relative to Coyote Creek.

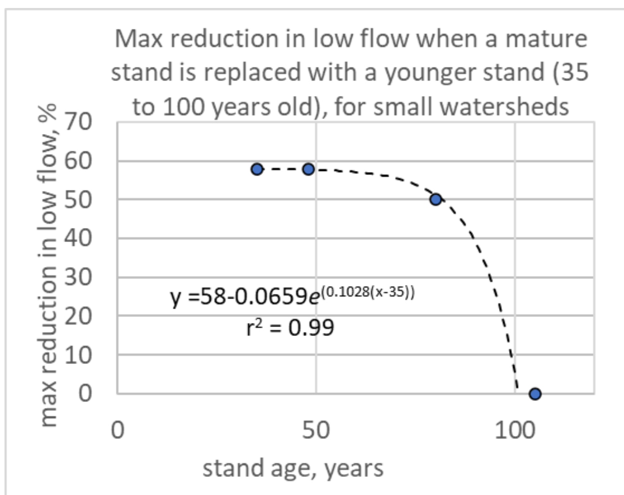


Figure 2. For small basins that have been ~100% harvested and replanted with a stand of young trees, a relationship between stand age and expected decrease in low flow is fit to values reported in the literature. Fit model is valid for a stand age of 35 to roughly 100 years. For stands greater than 100 years in age, the max reduction in low flow is assumed to be zero.

Table 3. Site descriptions and historic PET/P ratios for the Perry and Jones (2016) and Segura et al. (2020) study sites and the Elwha River watershed. Elwha River watershed values include a basin average value and a value in the vicinity of the proposed harvests for both historic and future PET/P values (year 2080).

Site	Latitude, Longitude	Mean annual average temperature [°C]	Mean annual solar radiation [W m^{-2}]	Annual average PET [mm]	Annual Average P [mm]	PET/P
Coyote Creek, Southern Oregon, historic	42.7333, 122.5167	10.2	171.8	1037.2	1129.5	0.92
H.J. Andrews, Oregon Cascades, historic	44.2000, 122.2500	10.2	146.5	799.4	2152.1	0.37
Alsea Watershed, Oregon Coast Range, historic	44.5333, 123.8667	10.8	146.4	806.4	2273.5	0.35
Elwha - basin average, Olympics, historic	47.9054, 123.4723	6.7	120.7	514.8	2035.6	0.25
Elwha - managed lands, Olympic foothills, historic	48.0685, 123.5503	8.9	133.4	661.5	1378.5	0.48
Elwha basin average, Olympics, future	47.9054, 123.4723	6.7	120.7	514.8	2035.6	0.29
Elwha - managed lands, Olympic foothills, future	48.0685, 123.5503	8.9	133.4	661.5	1378.5	0.55

Section 2. Forestry impacts on peak flows and sediment transport

Like low flows, measurable changes in peak flows following upstream forest disturbance have generally only been observed in small basins (Grant et al. 2008). As disturbance area increases, the expected change in peak flow rises (Jones and Grant 1996; Beschta et al. 2020). In primarily rain-dominated forests, where peak flows tend to occur during fall and winter atmospheric river events, peak flow response to forest management is generally undetectable at flows larger than a 5- to 6-year-return-interval-flow rate (i.e., a flow rate that on average occurs every 5-to-6 years; Grant et al. 2008; Perry et al. 2016) because as the rate of precipitation that drives the peak flow response increases, peak flow sensitivity to vegetation disturbance decreases because forest-interception and evaporation rates become small relative to the precipitation rate (Dingman, 2002). In contrast, in snow dominated forests, where peak flows tend to occur during the spring and early summer melt-season, peak flow response to upstream management increases with flow magnitude (Schnorbus and Alila, 2012).

Grant et al. (2008) reviewed and summarized studies on peak flow response to forest management. Studies included in that review were located in rain-dominated and transient (rain and snow melt runoff) zones in the Pacific Northwest. Observed peak flow response to upstream harvest was reported as a function of disturbance area for each dominant peak-flow runoff process. Each dataset (rainfall and transient) was graphically fit with maximum, mean-flow and no-change response envelopes. The no-change envelope represented situations where no observed change in flow was observed following upstream timber harvests. The max-flow-response line represented the maximum observed change in flow as a result of the harvest. The mean-flow-response line represented a visually approximated, linear fit to the data, but as a measure of conservatism, excluded all no-response observations (e.g., the mean-flow-response line was biased towards the higher peak flow response observations). Any change in peak flow predicted by the flow-response envelopes that is less than 10% was considered undetectable or unmeasurable because it falls within the uncertainty range of the observed peak flow data.

To use the Grant et al. (2008) flow-response lines to estimate potential response to forest disturbance, a decision on whether to use the max, mean or a no-change response envelope must be made based on an evaluation of hillslope runoff connectivity to the channel network. Grant et al. (2008) provides guidance for doing this, which relies on a qualitative assessment of road density, road connectivity to the channel network, drainage efficiency, patch size and riparian buffers (see Figure 12 and 13, and pages 37 to 48 of Grant et al., 2008). Hillslopes that are highly connected to the channel network are typically found in steep basins in which there are no buffers between the harvest and the channel network, most roads are channel adjacent or mid-slope, road ditches, road surfaces and logging corridors/trails drain directly into the channel network and soils are shallow and/or impermeable, which causes rapid subsurface or infiltration excess runoff. For watersheds that consist of highly connected hillslopes, the max flow envelope should be used.

Hillslopes that are moderately or poorly connected to the channel network typically have large (> 30 m) buffers between the harvest and the channel, ridge-top roads, road drainage that is hydrologically disconnected from the channel network (e.g., ditch and surface water from roads and logging corridors is not directed towards channels but instead is dispersed back onto hillslopes with frequent relief culverts and ditches) and soils that are relatively deep (>=1.5 m) and permeable. For a basin in which hillslopes are moderately or poorly connected to the channel network, a flow envelope somewhere between the no detection limit and the mean flow envelope is appropriate.

Grant et al. (2008) also provides guidance on assessing the likelihood that a forest-disturbance-triggered change in peak flows will result in additional sediment transport based on the morphology of the channels draining the watershed. In low-gradient channels (<2.5%) that are covered in gravel and smaller grain sizes, sediment transport is responsive to changes in 6-year and smaller return interval flow events and thus sensitive to changes in peak flows caused by forestry. Higher gradient channels (>4%), which often consist of cobble bedded step-pool and cascade channels at channel slopes ranging between 4 to 14% and colluvial channels in woody and rocky debris at higher slopes (Montgomery and Buffington, 1997) generally require a large and infrequent flow to mobilize the channel bed (e.g., flow rate >> 6-year event) and are less sensitive to changes in peak flows caused by tree harvests (Grant et al. 2008).

Section 3. Likelihood that the harvests will impact low flows and peak-flow-driven sediment transport rates

Having synthesized the low-flow forestry literature and reviewed the peak-flow forestry literature, I now discuss the potential impacts of the three proposed Department of Natural Resource timbersales in the Elwha River watershed (Tree Well, Parched, Alley Cat) on low flows and peak flows and sediment transport at various spatial scales within the watershed. The scales considered include the watershed to the intake of the City of Port Angeles water supply, Little River watershed, which contains many of the proposed harvest areas, as well as seven small, headwater subbasins within the Elwha River watershed. The seven small, headwater subbasins were selected because they include a large proportion of the proposed harvest area relative to other subbasins and/or are drained by relatively low-slope channels. Site characteristics of the headwater subbasins are listed in Table 4.

Table 4. Site characteristics of select headwater subbasins within the Elwha River watershed, upstream of the City of Port Angeles water intake.

subbasin	area km^2	harvest area, %	High flow envelope (Grant et al. 2008)	Minimum channel slope, %	channel type
A	2.22	6	transient	4	step-pool to cascade
B	0.59	10	rain	>30	cascade
C	1.02	9	rain	20	step pool to cascade
D	0.64	16	transient	>30	cascade
E	1.7	7	transient	3	step pool to cascade with one section of forced plane bed
F	0.71	11	rain	>30	cascade to colluvial

Section 3.1 Low flows at the City of Port Angeles Water Intake

The Elwha River watershed above the water intake to the City of Port Angeles water supply is roughly 823 km^2 (Figure 3). Within that area, 89 percent is National Park. Another 6 percent is designated as Forest Service and Army Corps of Engineers land. The remaining 5 percent is a mix of private, tribal and state managed land that consists of a mosaic of stand ages that vary from recently cleared, young and mature as well as agricultural, road and residential areas. The three sales include over 25 units, with an average area of roughly 0.05 km^2 (12 ac) and a total area of 1.21 km^2 (300 ac). The stands that will be harvested are on average 90- to 100-years old.

Based on the model developed in Figure 2, in a hypothetical, small, headwater basin covered by a 90- to 100-year old stand of conifers, if 100% or nearly 100% of basins were harvested and replaced with a stand of 40- to 50-year-old trees, the resulting low flows would be 58% lower than low flows from the replaced stand. In the Elwha River watershed, which is not a small, headwater basin, but rather, is a large basin, where the total proposed harvest area will account for roughly 0.0014 or 0.14% of the watershed, no changes in low flow at the City of Port Angeles water intake are expected because no changes have been observed in large basins with disturbance areas as high as 65% (Coble et al. 2020). If we assume large basins do respond to forest management similarly to small basins, the analysis presented in Figure 1 indicates that a reduction in low flow may be observable only if the disturbance area exceeds 13%. Since the cumulative disturbance area of these sales is almost two orders of magnitude below 13%, no change in low flow is expected.

Regarding the combined effect of the proposed harvests and other managed lands in the Elwha River watershed, the proposed harvests are within a zone of managed and private lands that consist of a mosaic of stand ages and land uses. Coble et al. (2020) showed that when stand age varies as a consequence of multiple entries and rotation ages, even when 100% of the area of a small, headwater basin is harvested, low flows may not change or may even increase because increased flow from stands in low-flow Phase 1 offset decreased flow from stands in low flow Phase 3. However, if by chance the rotation schedule of the managed lands were to become synchronized so that Phase 3 low-flow coincided across the managed landscape, the area of the managed landscape (5%) is well below the disturbance area at which a reduction in low flow might occur (again, assuming the Elwha watershed responds to forestry like a small headwater basin) and no change in low flow is expected.

In terms of PET/P ratios, the Elwha River basin is much lower than any of the Oregon sites (Table 1), suggesting that when considered at the basin scale, the susceptibility for changes in low flow due to vegetation disturbance are relatively low. When the PET/P ratio is determined near the outlet of the watershed, where precipitation totals are less and temperatures are higher than the basin average, PET/P is larger but still low relative to the Coyote Creek experimental basin, where changes to low flows were largest among the Oregon sites.

Climate change will alter both temperature and precipitation rates by the time the planted trees are 40- to 50-years old. Human activities, such as forestry can augment, mask or even counteract the effects of climate change on streamflow (Jones et al. 2012). Assuming the harvest occurs and the new trees are planted in the next 2 to 3 years, the planted trees will be ~50 years old by 2080. According to the University of Washington Climate Impacts Group (CIG, 2024a), in 2080, mean annual precipitation will be roughly the same at the basin scale, with increasing amounts in the higher reaches of the basin and decreasing amounts near the mouth of the basin; however in the vicinity of the proposed sales, precipitation will be roughly 5% lower (CIG, 2024a). In terms of mean annual temperature, the most severe projections suggest warming could be as high as 4.3 deg C of warming (7.7 deg F; CIG, 2024b) Using these estimates for future annual precipitation and temperature, future PET/P values will be 0.29 at the basin scale and 0.55 in the vicinity of the proposed harvests. Both PET/P values rise in the future, indicating that plants will use more available water, but the future PET/P values are still relatively low (e.g., closer to the historic HJ Andrews Research Forest and Alsea Watershed values than the historic Coyote Creek value).

To summarize: (1) the Elwha River basin is a large watershed; changes in low flow (Phase 3) following forest management have not been observed in large basins; (2) the proportion of the proposed DNR timber sales are well below the threshold at which a reduction in low flows might occur, even when evaluated relative to low-flow response observed in small basins; (3) PET/P of the Elwha River watershed and the proposed harvest locations are relatively low and will remain relatively low in the future; (4) only a small proportion of the basin is managed and that managed land consists of a variety of stand ages and a mixture of Phase 1, 2 and 3 low flow response periods. Given these findings, I consider the likelihood that the proposed harvests will reduce low flows at the City of Port Angeles water supply inlet to be extremely low.

Section 3.2 Low flows at smaller scales within the Elwha River watershed.

When the area of the proposed harvests is compared to the area of a subbasin of the Elwha River watershed, the proposed harvests represent a larger disturbance area. For example, in the Little River watershed, which is 59.3 km^2 in area, the cumulative area of the proposed harvests accounts for roughly 2.5% of the watershed area (Figure 4). Assuming the Little River watershed responds to forestry like a small headwater basin, at a disturbance area of 2.5%, no change in low flow is expected.

Regarding the combined effect of the proposed harvests and other managed lands in the Little River watershed, like the larger Elwha watershed, the proposed harvests are within a zone of managed and private lands that consist of a mosaic of stand ages and land uses; however in the Little River watershed, the managed lands make up roughly 26% of the basin. As noted above, Coble et al (2020) showed that when stand age varies as a consequence of multiple entries and rotation ages, even when 100% of the basin area of a small, headwater basin is harvested, low flows may not change or may even increase because increased flow from stands in low-flow Phase 1 offset decreased flow from stands in low-flow Phase 3. However, if by chance the rotation schedule of the managed lands became synchronized so that Phase-3 low flow coincided across the managed landscape, assuming the Little River watershed responds to forest management like a small basin, the area of the managed landscape would be above the disturbance area at which a reduction in low flow might occur.

At the headwater subbasin scale, the proposed harvests make up 6% to 16% of each basin (Table 4). Based on the model presented in Figure 1, and assuming most of the subbasins are covered in mature timber, following the proposed harvests, low flow is not expected to change at six of the seven headwater subbasins. At headwater subbasin D, low flows may decrease by 10%. Regarding the combined impact of the proposed harvest and other managed lands, at such small scales, because there are fewer stands in each headwater subbasin to interact with, the reduction in low flows caused by the proposed harvest may or may not be mitigated by other stands.

At all of the proposed harvests, buffers of the older forest will be retained along the perennial streams. While the low-flow literature is inconclusive on the role buffers, early results suggest that by retaining mature forest buffers, some of the low flow impacts of a harvest can be mitigated (Moore et al. 2020). Nonetheless, assuming the buffers have no mitigative effect on reducing the impact of the harvests on summer low flows, and assuming the worst-case-scenario that the Phase-3 low flow of most rotations in the managed area become synchronized, I consider the likelihood that the proposed harvests will reduce low flows in the Little River watershed to be low-to-moderate. At headwater subbasin scale, I consider the likelihood that the proposed harvests will reduce low flows to be moderate.

Regarding the potential impact of a reduction in summer low flows on aquatic habitat, Coble et al. (2020) noted that while the relationship between a forestry-caused-reduction in low flows and aquatic invertebrates/fish is still not well understood, many studies have examined aquatic invertebrate/fish response to experimentally reduced low flow in small streams. Those studies found that a low flow reduction of at least 50 to 75% must be exceeded before causing fish and invertebrate populations to drop.

Section 3.3 Peak flows at various scales in the Elwha River watershed

In this section, I use the approach described in Grant et al. (2008) to assess the likelihood that peak flow and sediment transport increase following the proposed harvests. Like the low-flow assessment, I consider multiple scales, ranging from the watershed upstream of the City of Port Angeles water intake to small, headwater subbasins containing the proposed harvest areas (listed in Table 4). Hillslope runoff connectivity to the channel network given the proposed harvest locations is as follows:

Although 80 to 85% of the proposed harvest areas are in low-elevation-rain-dominated zones, the remaining 15-20% of the harvest area is located in the transient zone. As a measure conservatism, for the Elwha River watershed and Little River watershed, runoff response to the harvests is assumed to follow the transient response lines in Grant et al. (2008). For each of the headwater basins, if any of the proposed harvest falls within the transient zone, the transient response line is selected. Otherwise, the rain-dominated response line is used.

Most active roads are located on or near ridge tops, where they intercept little hillslope runoff but several roads are located at mid-slope locations. The basin falls in the "moderate" category for road density and the moderate category for road connectivity because several roads cross channels.

The terrain varies from gentle slopes (25%) to moderately-steep slopes (55%) but is not as incised as other regions of the Olympic Peninsula that receive more rain. As is typical in our region, hillslopes near the harvest do not exhibit evidence of infiltration excess runoff, suggesting most runoff is via subsurface pathways. Overall, watershed drainage efficiency is considered "moderate".

As noted above, the harvest consists of 12 acre (0.05 km^2) units that make up 0.12% of the watershed to the City of Port Angeles water intake and 2.5% of the Little River watershed and 6 to 16% of the headwater subbasin area. The patch size is considered small to moderate. Most of the harvest is near or on a broad ridge. A 30-meter buffer separates the proposed harvest from all perennial streams. Riparian buffers are considered "wide".

Based on the above observations, I conservatively assume flow response will follow the mean-flow-response line. As described in Section 2, the mean-flow-line excludes all observations of zero-peak-flow response to upstream harvests and is thus biased towards a larger response than indicated by the empirical data. Using the mean-flow-response line, the predicted change in peak flow rates at the City of Port Angeles water intake and in the Little River basin is 0%. The risk for changes in peak flow and a subsequent increase in sediment transport in response to the proposed tree harvests at the City of Port Angeles water intake and within the Little River watershed are considered extremely low.

As noted above, at the headwater-basin scale, the harvests account for a larger proportion of each affected subbasin (Table 4). In all of the headwater subbasins except headwater subbasin D, the area is less than the threshold at which a peak-flow response is expected. In headwater subbasin D, the harvest area is equal to the threshold at which a measurable change in peak flows may occur.

In all but two of the headwater subbasins, channels are steep and morphology is step-pool to cascade or colluvial. For the two headwater subbasins that contain relatively low-slope channels, I field reviewed the channels at the location of their lowest slope. Generally, at the lowest-gradient reaches of these channels, their channels are still step-pool to cascade morphology but in one of the basins, I found a 50-meter-long reach of forced plane-bed morphology. The forced plane bed morphology, based on grain size alone is potentially sensitive to changes in peak flow; however, the channel geometry is unconfined (because woody debris has trapped sediment within and filled the original channel walls) and any increase in peak flow is expected to mostly widen the flow rather than make the flow deeper(and more conducive to sediment transport). Overall, at the headwater-basin scale, the likelihood that peak flows will measurably increase is considered low (subbasins A, B, C, E and F) to moderate (subbasin D). If any measurable increase in peak flow rates does occur, because the channel morphology is generally cascade to colluvial, or where forced-plane bed morphology occurs, has a geometry that will spread the flow rather than raise the flow level, the risk of sedimentation at the headwater subbasin scale is considered low.

This evaluation assumes that the road network, including the yarding corridors are disconnected from the channel network via the use of relief culverts and ditches. If drainage from the roads or yarding corridors are directed to the channel network, the risk of elevated sediment transport at the headwater subbasin scale is considered moderate.

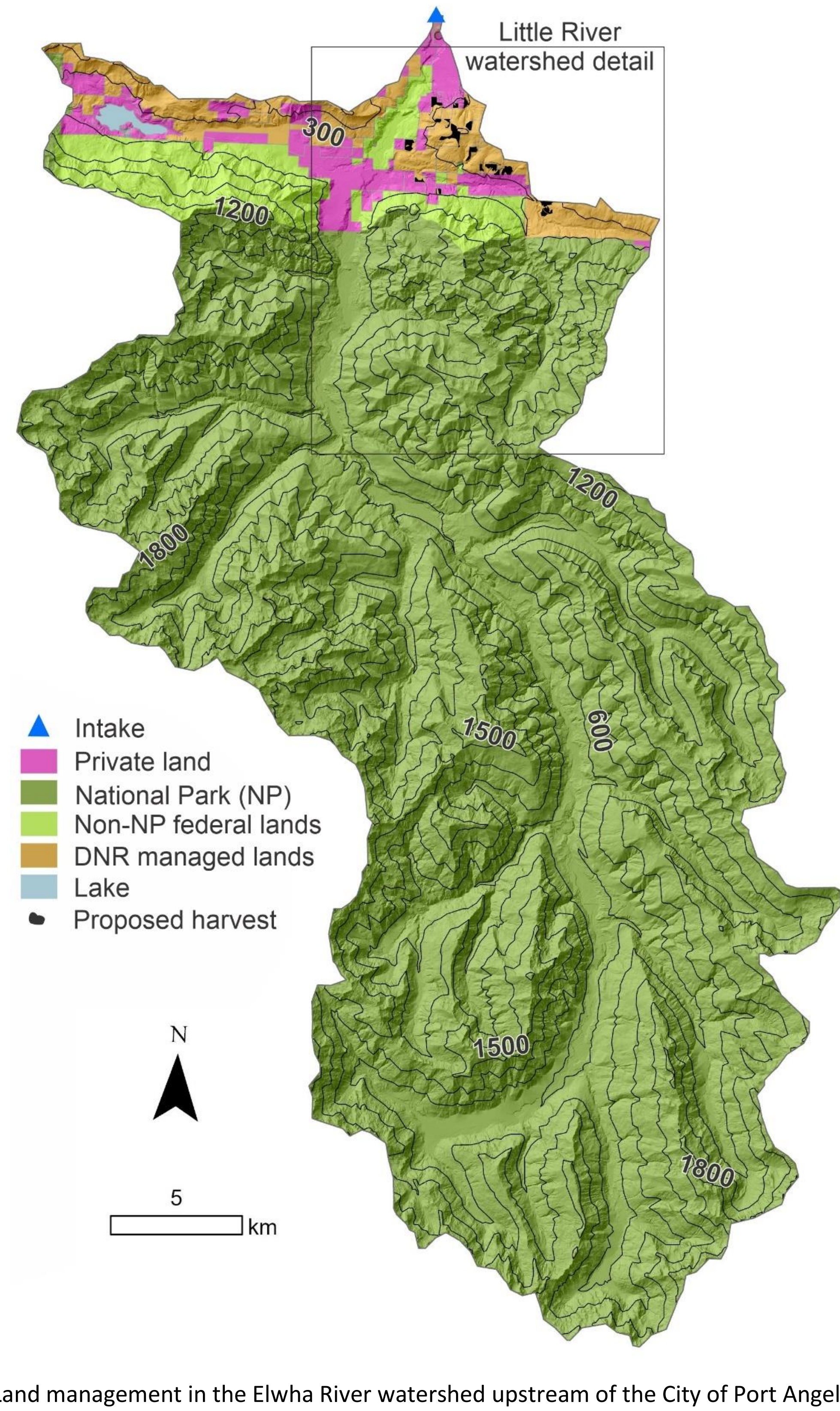


Figure 3. Land management in the Elwha River watershed upstream of the City of Port Angeles water intake. Proposed harvest area shown as black polygons in the DNR managed lands, which add up to roughly 0.0014 of the total watershed area above the intake to the. Contours are 1000 meters.

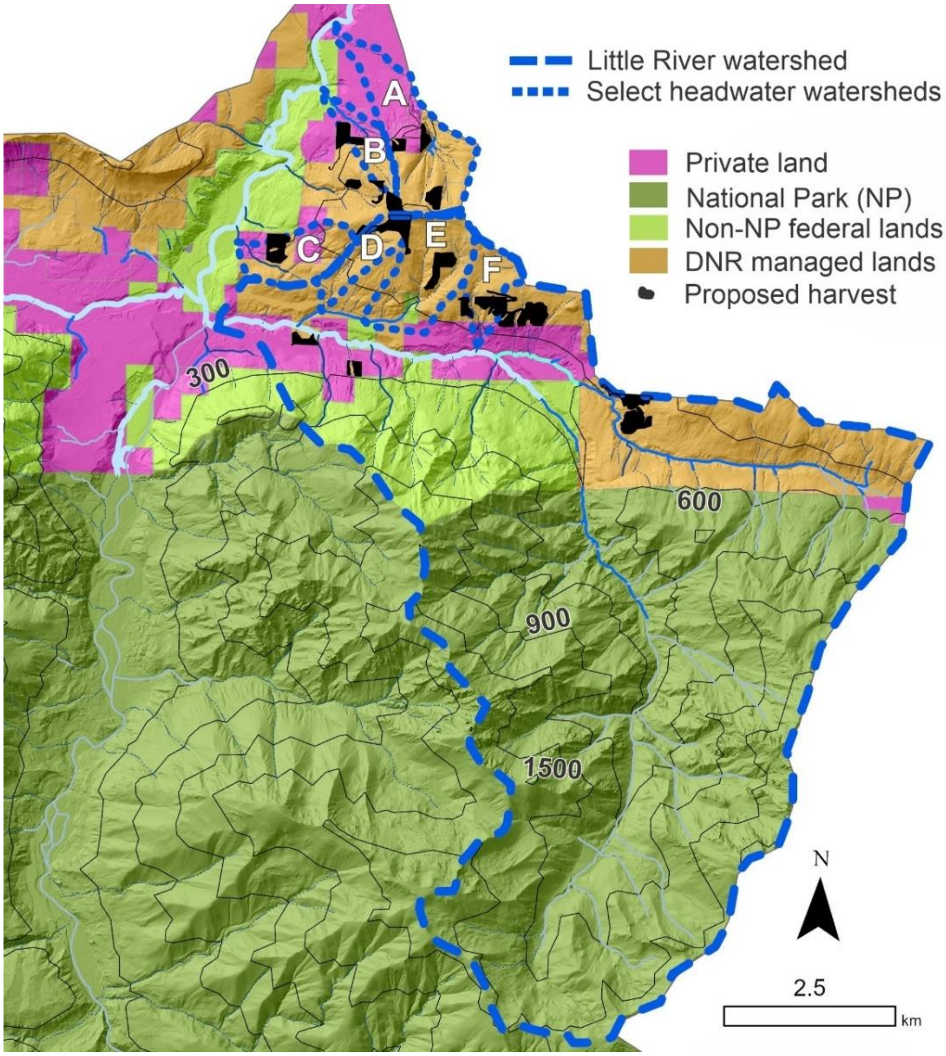


Figure 4. Little River watershed detail: zoomed-in view of the Little River watershed and select subbasins that drain towards a perennial stream and include a proposed harvest. Contours are 1000 meters.

Section 4. Use of a distributed hydrology model for low-flow risk assessment at the City of Port Angeles water intake

Depending on implementation and the number of processes explicitly included, a numerical model can be a valuable tool for both exploratory and predictive applications (Murray, 2007). An example exploratory application is a hillslope stability model used to determine the failure mode of a landslide given different hydrologic triggers such as rainfall versus seepage from bedrock. In this case, the numerical model is not used to determine the rainfall or seepage rate at which a specific landslide fails, rather, the model is used to explore and understand basic landslide response in terms of landslide geometry, shape and size to the different hydrologic triggers. An example exploratory application of a hydrology model is the use of a hydrology model to determine the low-flow response direction (e.g., does low flow increase or decrease) to different stand conditions and/or climate and the mechanistic processes that drive that response.

In contrast, predictive applications attempt to determine a future value or state of a system. Predictive application requires a numerical model with the demonstrated ability to replicate reality. Models of fluid motion that can be derived from basic physics achieve this with little parameterization (Murray, 2007); however, in the case of hydrology models, which range from simple linear-reservoir lumped models that treat a watershed as a black box and make no attempt to explicitly represent the physical processes that control the movement of water, to complex distributed models, that attempt to explicitly represent as many physical processes as possible, parameterization is key to getting the model to replicate real world behavior.

While the Distributed Hydrology Soil, and Vegetation Model (DHSVM; Wigmosta et al., 1994) is an extremely detailed, physically based hydrology model, it still does not fully represent actual site conditions and all processes that control the movement of water in a basin. This is particularly true when applied to basins as large as the Elwha because grid cells within the model can be ten to hundreds of meters wide, which limits model ability to accurately represent the heterogeneous nature of soil and vegetation characteristics in basin. The Visualizing Ecosystems for Land Management Assessments model (VELMA; Abdelnour et al. 2011), like DHSVM, also includes explicit representation of many of the physical processes that control the movement of water but also conceptualizes a basin as a grid and is thus dependent on area-average-value representations of soil and vegetation, particularly at large-basin scales.

As a consequence of using a grided, spatially-averaged representation of reality, no single in-situ point measurement can be used to parameterize a model like DHSVM or VELMA, because the in-situ measures represent conditions at a point, not the spatial average represented by the model (Beven, 2001). As a consequence of not perfectly representing reality, model equifinality, or the situation in which multiple parameter combinations result in an equally calibrated model as judged by model ability to replicate stream or soil water flow becomes a problem; any one parameter combination is an equally qualified representation of the real world (i.e., a behavioral model, Beven, 2006).

If the intent of a hydrology model is exploratory, model equifinality can be ignored, because precise prediction is not the goal. However, if the intent of the hydrology model is prediction, to ensure model (and modeler) transparency, any model prediction should be presented in terms of all possible behavioral models. Beven (2006) describes how this can be done using the quantile value from the sample of behavioral models to estimate confidence limits and an average modeled value. Example hydrologic models used for predictive applications that also characterized model equifinality include Surfleet et al. (2014) and Zegre et al. (2010).

Predictive application of hydrology models like DHSVM and VELMA in the Elwha would thus require rigorous and iterative calibration to identify all model realizations that adequately (and equally-well) recreate observed hydrology. Any attempt to predict low flow or peak flow response to potential land management or future climate, without characterizing model uncertainty due to model equifinality, would give an incomplete and possibly biased impression of model results.

Given the empirical data presented in Sections 1 and 2 and that: (1) the Elwha is a relatively large basin, (2) the proposed harvests represent a very small disturbance area, (3) historic and future PET/P values at the Elwha are relatively low, (4) a relatively small proportion of basin is managed and (5) the fact that the managed lands consist of a mix of stand ages, the empirical evidence very clearly indicates minimal risk to changes in low flows at the City of Port Angeles water intake.

While a distributed hydrology model of the Elwha River watershed could be used to investigate a host of interesting scientific questions in an exploratory sense (e.g., Beveridge et al., 2022), given the challenge of model parameterization when grid scale greatly exceeds the scale of spatial variability of the model inputs as well as the challenge of correctly parameterizing the model to represent stand composition and runoff conditions that represent pre- and post-harvest conditions (e.g., Goeking and Tarboton, 2020), I think model equifinality would be large and in this case, model results unlikely to add much to the assessment.

That is not to say that there are no basins or situations in which a predictive modeling approach can improve such risk assessments. At smaller scales within the Elwha, such as the headwater subbasins or possibly even the Little River watershed, where management makes up a larger proportion of the basin area and the empirical data is less conclusive, a DHSVM or VELMA model, that utilizes a small grid cell size, is calibrated to observations and accounts for equifinality, might improve low-flow hazard assessments. Also, there are examples of large basins where a distributed hydrology modeling approach may be necessary to develop a reliable low-flow risk assessment. Dickerson et al. (2022) used DHSVM and VELMA to model the impacts of land use on future flows in the South Fork Nooksack watershed, which like the Elwha is a large basin (480 km^2 in area) but unlike the Elwha is relatively unprotected and heavily managed: over 70% of the South Fork Nooksack watershed is managed for forestry, residential and agricultural uses. The remaining land is managed by the Forest Service (18%) and in mixed private, local government and tribal conservation lands (9%). None of the South Fork Nooksack basin is protected in a National Park. Even though the basin is large, the proportion of the basin that could potentially be impacted by land management is larger than the disturbance area in all of the reported large basins in Coble et al. (2020) (see Table 2) and a low-flow risk assessment that utilizes a distributed hydrological modeling approach, especially one that accounts for model equifinality, is justified.

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