Roger Nichols roger.nichols@comcast.net March 14, 2023

Comments on North Fork Stillaguamish Landscape Analysis Project # 61659

Thank you for the opportunity to provide comments.

I support the need to commercially thin second growth outside of riparian area reserves at a prescription commercially thin spacing at 20’ X 20’ or 25’ by 25’. This first thinning should be followed by a 2nd thinning with a larger spacing thin 30-40 years later. This design will develop a multi layered forest. The staggered thinning will provide commercially viable wood, and produce higher value wood for later thinning operations in sequential harvesting in a predictable manor. This approach also minimizes loss of water storage in the form of snow.

My issues with North Fork Stillaguamish Landscape Analysis Project # 61659 are:

Riparian thinning alternatives and commercial area openings are likely to worsen water quality and negatively affect downstream fisheries.

Water quality: subject to elevated temperatures since tracking started in 1960’s. Shade, sediment loading and summer drought regime are characteristics of the majority of the streams and tributary stream channels in the study area.

As proposed, the sale will likely have a negative effect on already existing condition of marginal water quality, specifically high temperature and low summer flows.

Timber Thinning as proposed with the suggested opening will result in less snow pack retention in spring months and quicker snow pack loss during a rain on snow event (pineapple express).

Riparian Thinning Buffers should be based on soil stability, landform dissection, wind throw potential and moisture. Width should vary accordingly and range from 150-300’ for wind resistance. Riparian areas are frequently unstable, highly dissected landforms which are often subject to failure with as little as 2-6 % disturbance. Inter-gorges and draws should not be managed. Historically timber removal in these riparian areas has been highly problematic. The alternatives as proposed are generic and reflect unfamiliarity with the area.

Road for decommissioning: many of the roads shown for decommissioning if drainage structures and fills have been removed are usually hydraulically stable. Removing road prisms beyond hydraulic stability is a questionable practice, an expensive venture for little gain.

Road 17: concrete fords needs to be removed and replaced with bridges to allow conveyance of stream sediments. Interrupted transport of stream bed sediments results in downstream channel bed starvation, increase in channel scour and loss of fish habitat access and spawning suitability loss. Sec 17 R7E T34N; Sec 22 T34N R7E

Road 17 near FSR road 1732 Sec 16 T34N R7E: culvert replaced for sediment transport and fish passage. Currently bedload transport has been interrupted, leaving downstream fish passage for steelhead with an unpassable gap.

Road 1755: culvert needs to be removed and replaced with fish passage (steelhead) structure; 2nd channel is a blocked by a concrete encased fill with a undersized culvert that should be removed and replaced with fish passage; and 3rd farther out a cedar bridge needs replacement to continue fish passage.

Rivers and stream channels will continue to enlarge (widen and shallow) to accommodate flasher flows due to retention.

Listed and endangered fish stock now listed, their spawning and rearing areas will continue to be marginalizing due to loss of water retention. This area physically described as a summer drought area, a point commonly overlooked except during fire season..

Refer to: Curt Kraemer noteworthy documentation on both increase in frequency and size of the 100 year flood from North Fork Stillaguamish, USGS gauge near Arlington (record since 1929)

Climate: The analysis area lies in a convergence zone between Pacific weather systems from the ocean and Arctic weather systems from the north. During the summer the Pacific system dominates and brings periods of generally clear weather and reduced precipitation. During the winter the Arctic system usually dominates, with winter storms and increased precipitation. The influence of these two major weather system types contributes to the physical and biological diversity of the area. The mountains also can be important in influencing local climate. The extreme rise in topography over a short distance increases the quantity of water precipitating from winter storms from a process known as orthographic lifting.

Snow falls above 2,500 feet elevation from November to April. In the transitory snow zone (1,500 – 3,500 feet), rain-on-snow events occur from late-October through February, often resulting in rapid snowmelt. These events are characterized by accumulation of wet loosely packed snow that is subject to large, warm, and windy rainstorms that melt snow and cumulatively combine with rain as heavy runoff over a short period. These rain-on-snow events often trigger debris and snow avalanches, debris torrents (i.e. large accumulations of wood scouring out a stream), and landslides.

North Fork Stilly, and its major tributaries, including Segelson Crevice, Cascade and in Deer Creek and its tributaries Little Deer , Higgins and Deforest Creek follow fault and rock contacts and flow through valleys that were initially stream-cut and later modified by glacial action. Expressions of these faults can be seen today by the incisive nature of the channels and different rock types in the lower portions of the stream and river valleys.

Geology, Soils and Hydrology

The area consists of glacially scoured basins resulting from past continental, and late alpine glaciation.

North Fork Stilly area consists of thin covering of glacial outwash over meta-phyllite /aggillite bedrock material. The upper channels consist of broken phyllite/argillite rock. This is a very incompetent rock for construction purposes.

The Deer Creek area consists of Chuckanut sandstone in fault contact, with schist to the north and volcanic material to the south. During retreat of continental ice sheet 10,000-13,000 years ago deep surface deposits of glacial till and lacustrine material occur within the valley bottom. Deposits of sand and gravel were deposited during the period continental Glaciers blocked the Skagit River resulting in water gap deposits in NW upper Deer Creek and Little Deer junction of Deforest Creek and the opposite side of Deer Creek Valley. Infilled fault traces are locations where glacial ice scoured out the zone of weakness and these hollows were later filled with retreating glacial deposits. In Deer Creek this faulting infilling forms the upper valley of Little Deer and the Upper Deer Finney Creek area.

Soil Stability Soil types that are prone to land sliding in the Northwest Cascade Region (Skagit /Nooksack) have similar glacial history, parent material, landform, and texture. This is evident when comparing the results of Heller (1978), Paulson (1996), Parks (1992) and Peak Northwest (1986). Increases in slope and water are major factors in soil instability. General areas where unstable soils are most likely to occur are the glacial lake sediments margins, along the steep side slopes, margins of in-filled channels, and faulted stream channels (Fiksdal and Brunengo 1981, Hale 1992).

The glacial lake sediment margins are affected by percolation of ground water. The level of ground water rises during wet periods. This results in an increase in pore pressure (the pressure of water in the spaces between particles in the soil) in the coarser layers of varves (layered glacial lake sediments). The increase in the pore water pressure can bring about spontaneous failure in slopes (Terzaghi and Peck 1961). Timber harvest and large fires change soil moisture and the way snow accumulates and melts. When snow melts rapidly or melts at a period of high water, failures in glacial lake sediments are more prevalent because of high pore pressure.

Landslides and Mass Wasting

Landslide activity has been identified as a concern within the watershed because of water quality concerns and downstream events like what happened downstream of the Deer Creek headwaters in Oso area on the North Fork Stillaguamish. Glacial lake sediment deposits have significant influence on the turbidity of and erosion processes within the Little Deer and Deer Creek. Remnant deposits of this material occur in the valley walls. This material can be subject to spontaneous liquefaction. Liquefaction occurs when saturated sand or silt is shaken violently and undergoes a sudden loss of shear strength. Vibrations generated by idling track dozers, rock blasting, or a passing train can be enough to trigger the subsequent landslide (Noson et al., 1988). Puget Sound earthquakes generated 20 landslides as far as 112 miles from the epicenter of the 1949 Olympia earthquake, magnitude 7.1, and 21 landslides were generated as far as 62 miles from the epicenter of the 1965 Seattle-Tacoma earthquake, magnitude 6.5 (Keefer, 1983; 1984). Keefer (1983) noted that geologic environments in the Puget Sound Region have high susceptibilities to ground failure including areas of postglacial stream, and lake sediments, river deltas, and areas having slopes steeper than 35 degrees. Types of ground failures to expect include landslides, soil liquefaction, and differential compaction. Both of the above Puget Sound earthquakes occurred within the Puget Trough. A seismic event of this nature could trigger a massive landslide similar to the one ran down the Deer Creek in 1984 and ran into the North Fork Stilly River at Olso and likely influence downstream reaches below Whitehorse.

Road related landslides have been fairly isolated to where shallow outwash material is overlaying bedrock on slopes greater than 30 percent. The combination of these shallow soils over bedrock, poor road construction techniques of the 1960s, and insufficient drainage has resulted in fill slope failures with sediment delivery to next order channel. The road systems in this analysis area are highly susceptible to collection and misdirected water from either ditches of drainage crossing. Of concern is that over 80% of the roads in this sale area where built before 1975 of side cast unconsolidated material. Layered place fill construction and full bench occurred after 1975 following the 1962 Washington Floods (road drainage failures) and 1964 Oregon Christmas day storms (stream and river wood flush outs) both rain on snow events. Note: Out sloping of roads built before 1975 is a problem due to unconsolidated nature of side cast fills. Two things usually happen. The geometry of the road doesn’t work and results in draining across the road due to existing road geometry (grade vs out sloping) and or fill settlement due to lack of consolidated. Both result in saturate road fill, and result in a debris slide /torrent into next order stream channel. This happens frequently off the 28 road South Branch of the North Fork Stillaguamish River.

Infiltrating water can generate unstable conditions on hill slopes by increasing the weight of the soil and increasing the pore water pressure. Rain infiltrating the ground surface easily penetrates the underlying sand, but the relatively impermeable silt or clay layer impedes further downward movement of the water. A zone of saturation at the top of the impermeable layer causes slumps in the overlaying sand. When disturbed, the saturated sand oozes over the steep slope as a mudflow. Landslides also occur where bedrock is close to the surface (Heller, 1978, Hale, 1992). Heller suggests the bedrock is not only trapping water percolating from above, but may also direct ground water flow to the slide site along the bedrock surface. The level of the groundwater table rises in wet periods. This results in increased pore pressure (pressure in saturated soils due to presence of interstitial water) in the coarser layers of the varves (layered glacial lake sediment). The increased pore pressure force soil particles apart and thus reduces shear strength (friction surfaces between particles) of the fine sediments. When pore pressure increases high enough to exceed sheer strength this brings about instantaneous slope failure. This is relevant in light of the possibility that reductions in evapotranspiration due to logging may result in increased rates of landslides due to the associated rise in the height of the water table. Soils that have had the highest frequency of landslides are glacial outwash and meta-sedimentary rock. The ground slope was greater than 30 percent, and underlain with broken meta-sedimentary rock.

Flooding

Historically, flooding in the Stilly basin has been severe and frequent. Floods over the past two decades have been some of the most damaging on record, causing millions of dollars in property damage. Ketcheson (1992, 1998) conducted a review of the most recent flood events in Western Washington which included the following findings:

• Flooding primarily occurs from October through February, when winter storms produce 75 percent of the annual precipitation in western Washington.

• During the winter season, precipitation builds up groundwater reserves and saturates the soil.

• Strong, two-to-five-day storms with heavy rainfall will result in high runoff and flooding.

• The largest and most damaging storms are often rain-on-snow events, when warm wind on snow causes snowmelt runoff in addition to that from rain.

• Occasionally local flooding may occur during spring runoff, but it is not usually damaging.

Recent years have seen some of the larger floods on record

The North Fork Stilly is more likely to respond to rain-on snow events (melting of snow between 1,500-3,500 feet elevation) and high elevation rainfall.

Water Quality

Water Quality Water quality is commonly thought of as the chemical standards which water must meet for certain designated beneficial uses such as drinking water, swimming, or supporting aquatic life. Water quality is in fact a more holistic concept. The objective of the 1972 Clean Water Act is “to restore and maintain the physical, chemical and biological integrity of the nation’s waters.” The chemical and physical components of the act have been written into state and federal standards for such parameters as temperature, dissolved oxygen, sediment, fecal coliform, etc. These measures, while important indicators do not represent the full range of values necessary to assure a functional aquatic ecosystem. Current understanding of what is required to support the beneficial uses (e.g. fisheries, potable water, etc.) of water has broadened to include parameters such as flow regime, biotic factors, energy source, and habitat structure (Bauer and Ralph, 1999).

High water temperatures (>70 degrees Fahrenheit) can stress salmonids and increase their susceptibility to disease, and if temperatures reach the mid-70s F, can even result in mortality.

Particularly downstream of the National Forest, forest management has also affected temperatures - through removal of river and tributary riparian vegetation, initiation of debris flows in tributaries, increased sediment production, routing and channel widening in low gradient storage reaches, and potentially through loss of logjams and increased un-vegetated gravel bars, and through hydrologic changes associated with clearcutting and forest roads (USSFWS 2004).

Recognizing that treating roads was the most cost effective way to reduce sediment delivery into streams in managed forested areas), the Forest Service began correcting the backlog of drainage insufficiencies for mainline roads starting in changes associated with clearcutting and forest roads (USFWS 2004).

This effort was financed in the 1990s by funding with multiple partners including Stilly Tribe and Snohomish Co Conservation District. The effort started with correcting a backlog of drainage insufficiencies in Deer Cr and Little Deer. A backload of fish passage insufficiencies remain in Little Deer and drainage insufficiencies in North Fork Stilly.

Road infrastructure

Sediment Inputs from Roads Findings

Decreased timber harvest has removed the need for new road construction and heavy vehicle traffic, but also reduced the available money to maintain roads. Without proper maintenance, roads deteriorate and increase the risk of failure and sediment delivery to streams.

In the Upper Deer and Little Deer watershed, the valley floor is located on glacial lake deposits (fine silts and sand) overlain by glacial outwash (sand and gravels). These deposits are located between Forest Service Road 17, 18, and 28 the, and below 2500’ elevation. These deposits are subject to failure (e.g. landslides) when they exist on slopes greater than 30%. The outwash material which comprises the surface material consists of sand and gravel, a non-cohesive soil type which fails when saturated on slopes greater than 30%. Failure locations are typically on the margins of terraces and in and along stream channels. Failure from this soil unit delivers coarse sediment to streams. The underlying glacial lake sediments consist of alternating silts and fine sands. It is cohesive and fails in large mass failures contributing fine sediments to the streams. This soil unit fails more often when soil moisture content, and therefore pore pressure, is elevated or stream bank erosion occurs to remove the toe of the slope. Near the toe, bank erosion lowers the estimated stability by nearly 75%. Upslope, high pore pressures can lower soil stability by 30% or more (Miller 1997). The probability of a landslide is related to soil depth and depth of soil saturated. Small increases in water delivery during wet periods are enough to increase the amount of saturation sufficient to destabilize sensitive soils (Berris and Harr 1987). Rain-on-snow events occur in an elevation zone where temperature hovers around 32 degrees F where snow accumulations can experience rapid snow melt when cold fronts are followed by tropical warm fronts. The term "rain-on-snow event" is actually a misnomer, because it is the wind and not rain that actually melts the snow. In this area, these winds are usually a product of a rapid change in weather fronts. The largest floods in the Pacific Northwest are caused by rain-onsnow events, and landslides are more likely to occur during these events. A forest that consists of mature timber with a layered canopy can modify the effect of rain-onsnow events due to its ability to intercept snow and moderate the effects of wind. The canopy of a mature forest provides a great deal of surface area for interception, and stronger branches which often support large amounts of snow. Because a mature forest differs in stand structure from a young forest plantation, air flow through the two can also differ. Young plantations offer little surface area to intercept snow and little strength to support the intercepted snow. This difference can last up to 80 years (Coffin 1992). Periodically snow is shed from the weaker crowns of young forest stands, and it accumulates under the stands. When this accumulated snow melts, it adds to the soil moisture content thus adding to soil instability through increased pore pressure. The amount of forest cover at a site can affect a number of snowmelt processes and the relative importance of the various heat sources. Initially, the forest canopy plays an important role in altering both the amount and distribution of snow over the landscape. Then, because the microclimate within a forest differs depending on canopy closure and other factors, rates of snowmelt can vary substantially. The rest of this discussion is taken from Coffin (1991): The large surface area of a coniferous forest canopy is capable of intercepting and storing large quantities of snow. Interception reported from a number of studies has generally fallen between 10 and 35% of total snowfall measured in the open (Wilm and Dunford 1984, Rowe and Hendrix 1951, Kittredge 1953, Satterlund and Haupt 1970). However, Ingebo (1955) measured interception ranging from 5% to 45% over a number of different plots with different canopy densities. Connaughton (1935) found that a virgin stand of timber intercepted an average of 24% of the snow fall, but a young reproduction stand intercepted an average of only 5%. These results support observations by Haupt (1972) and Berris and Harr (1987) that limbs of younger trees are often incapable of supporting a snow load. Timber branches were observed to flex downward in response to snow loading, and snow masses would fall to the ground. The amount of snow retained in a canopy is a function of the air temperature during snowfall and the amount of interception storage capacity of the canopy. At lower temperatures, less snow has been found to remain in the forest canopy because it does not adhere to the branches as well and is more easily blown off (Miller 1964, Satterlund and Haupt 1967). Interception storage capacity for a canopy is a function of canopy density, stiffness of branches, branch angle, type of needle or leaf, and the age, height and type of vegetation, (USACE 1956). Snow that is held in the canopy can be melted and released to the forest floor as drip, evaporated, or unloaded in clumps before completely melting (Miller 1966, Berris 1984). When snow is retained in the canopy, it may be subject to increased melt rates as compared to snow accumulated on the ground, because of the larger surface area per unit volume exposed, and the higher temperature often found in the canopy (Miller, 1966). Berris (1984) and Beaudary (1984) both measured snowmelt from forest canopies occurring sooner than snow accumulations on the ground.

While limiting the timing and amount of snow reaching the forest floor, the canopy also affects the quality of the snow pack and the rate of melt in the forest. As snowmelt occurs in the forest canopy, it contributes drip water to the snow pack below. The drip water increases the water content of the snow pack, but can also contribute to raising the snow temperature through the release of latent heat of fusion when the rain freezes in the snowpack. As the snow water content rises underneath the dripping canopy, subsequent canopy drip may exceed the liquid water holding capacity of the snow pack, and water may flow directly into the soil (Smith, 1974) or across the surface if the ground is frozen. In this way, a forested site can begin routing water offsite before a site in the open does (Berris and Harr, 1987). If some of the forest’s water has been routed offsite in this manner prior to rain-on-snow event, then the forest has less snow to melt and less water available for increasing soil moisture content, and therefore pore pressure and subsequently the probability of a landslide are lower during a rain-on-snow event. Two primary factors affecting water outflow during rain-on-snow events are the amount of prior snow accumulation (esp. its water content) and the subsequent rate of melt. As a plantation grows from individual seedlings to mature trees, the individual tree canopies enlarge and coalesce, forming a more complete and dense canopy layer. Throughout this process, the increased density of vegetation and branch strength alters interception and accumulation rates within the stand as well as the penetration of wind into the stand. In the upper South Fork Nooksack watershed, most of the timber stands located on the deposits mentioned above were harvested in the late 1960s and early 1970s. These areas are now occupied by plantations consisting of pre-commercially thinned stands of Douglas fir, western hemlock and silver fir with diameters greater than 11”. These young forest stands exist on flatter ground, on south, southeast and east aspects with slopes of 5-15%. Canopy density is 75-100% with very little under story vegetation. The canopy cover is complete and the stands have high stem densities. Because the trees are young and spindly, they cannot support much snow in the canopy. Thinning is currently being used to try to increase limb diameter, and thus stiffness, on Weyerhauser lands to improve habitat for spotted owls and marbled murrelets. If this is accomplished, and a layered canopy created, interception storage capacity could be increased. Hypothetically, this could accelerate stand development enough to effectively change the amount of snow at a given site. If rain-on-snow events occur long enough after the snow accumulation has occurred, the magnitude of increase in soil pore pressure could be reduced to the point of decreasing the probability of landslides occurring on the unstable soils to a measurable degree.

Prescription commercially thinning stand s to 20’ X 20’ or 25’ by 25’ spacing has been used successfully on Darrington District as well as Mt Baker District on the Mt Baker –Snoqualmie Nation Forest through the 1990’s into early 2000’s. Selection for dominant larger diameter trees and resistant species (fir) is desired. If the stand consist of hemlock then intermediate thinning may be necessary to allow for increase in root mass to prevent substantial wind throw. The objective is to obtain optimal thermal cover defined as a layered canopy where the dominant trees average at least 21" diameter and the stand has at least 70% crown closure with reentry in 40 years for additional thin.

The North Fork Stilly Landscape Analysis Project plans proposed thinning design of 1+ acre patchwork of opening will not reduce the wind effect on snow melt, nor delayed runoff response. Size openings which approximately the size of a football field will not offset rain on snow effects. It can get pretty windy on a football size opening. Water quality will likely suffer in quality and (temperature) and lower low flows.

The first AMA Sale in Finney EA approximately 4 years ago was patterned after this 1 acre + opening not 5-10 year canopy closure thinning, and not for snow water retention.

After the Finney AMA timber sale harvest, Finney Creek Channel flushed dramatically.

Forest Service Road System:

Skagit Watershed Council, Seattle City Light, Skagit County Soil Conservation District roads in the Finney portion of the AMA helped stabilized Forest Service roads with Salmon Recovery Dollars. This was also the case for stabilizing roads off Segelsen Road 18 and 18 road from Whitehorse up through Deer and Little Deer by Stillaguamish Conservation District and Stillaguamish Tribe. It was recognized early in watershed recovery process that it was more important to reduce potential road related sediment inputs to stream and rivers for Forest Health, than wait for Forest Service to correct road related drainage issues.

This was not the case up North Fork Stillaguamish Road System.

Roger Nichols

Lic. PEG Oregon and Washington

Beaudry, P.G. 1984. Effects of forest harvest on snowmelt during rainfall in coastal British Columbia. M.S. Thesis, University of British Columbia, Vancouver, 185 pp

Berris, S.N. and Harr, R. D. 1987. Comparative snow accumulation and melt during rainfall in forested and clear cut plots in the western Cascades of Oregon. Water Resources Res. 23 (1): 135-142.

Connaughton, C.A.1935. The accumulation and rate of melting of snow as influenced by vegetation. J. Forestry 33: 564-569.

Berris, S.N. and Harr, R. D. 1987. Comparative snow accumulation and melt during rainfall in forested and clear cut plots in the western Cascades of Oregon. Water Resources Res. 23 (1): 135-142.

Chambers, C.J. 1980. Empirical growth and yield tables for the Douglas fir zone: Washington state Department of Natural Resources Report n.41.

Coffin B.A, and Harr, R.D. 1991. Effects of Forest Cover on Rate of Water Delivery to Soil during Rain-on-Snow. M.S. Thesis, University of Washington Seattle WA , 106 pp.Coffin, B.A., R.D. Harr. 1992. Effects of Forest Cover on Volume of Water Delivery to Soil during Rain on Snow. Washington State Department of Natural Resources, Timber/Fish/wildlife program report TFW-SH1-92-001.

Fiksdal, Allen J. and Brunengo Matthew J. 1981. Forest Slope Stability Project, Phase II. Department of Ecology WDOE 81-14 Volume I and II. Olympia, WA.

Hale, James W. 1992. South Fork Nooksack Drainage, Mass-Wasting History Inventory. USDA Forest Service, Mt Baker Snoqualmie National Forest, Mt Baker Ranger Station, Sedro Woolley WA. 27p.

Ingebo, P.A. 1955. An instrument for measurement of density of plant cover over snow course points. In: Proc. 23rd Annual Western Snow Conference, pp 26-28.

Haupt, H.F. 1972. The release of water from forest snowpacks during winter. U.S. Dept Agriculture, Forest Service. Research Paper INT-114, 17pp.

Heller, P.L. 1978. Paleocene geology and related landslides in the Lower Skagit and Baker Valleys, North Cascades, Washington. M.S. Thesis, Western Washington College, Bellingham. 154 p.

Parks, D.S. 1992. A Landslide Inventory of the Finney Creek Watershed, Skagit County Washington. M.S. Thesis, University of Washington, Seattle, Washington. 164 p.

Keefer, D.K. 1983. Landslides, soil liquefaction, and related ground failures in Puget Sound earthquakes. In Yount, J.C., Crosson, R.S., editors, 1983. Proceedings of Conference XIV, Earthquake hazards of the Puget Sound region, Washington; U.S. Geological Survey OpenFile Report 83-19, p 280-29

Keefer, D.K. 1984. Landslides caused by earthquakes; Geological Society of America Bulletin 95(4):406-421.

Ketcheson, G. 1992. Flooding in west Cascades mountain river basins; a perspective on the November 1990 flooding in Western Washington. USDA Forest Service.

Ketcheson, G. 1998. Flooding in west Cascade mountain river basins an update based on floods of November 1995 and February 1996. USDA Forest Service.

Kittredge, J. 1953. Influences of forest on snow in the Ponderosa-Sugar Pine –Fir Zone of the central Sierra Nevada. Hilgardia 22(1): 96pp.

Miller, D.H. 1964. Interception processes during snowstorms. U.S. Dept Agriculture, Forest Service. Res. Paper PSW-18, 24pp

Miller, D.H. 1966. Transport of interception snow from trees during snow storms. U. s. Dept of agriculture, Forest Service Res. Paper.

Miller, D.J. and Sias, J. 1998. Deciphering large landslides: linking hydrological, groundwater and slope stability models through GIS. Hydrological Processes, 12, 923-923-941 pp.

Nichols, R.A., A.D. Zander, and J.M. Shultz. 1990. A Methodology for Watershed Cumulative Effects Analyses Utilizing Vegetative Disturbances. USDA Forest Service, Mt. BakerSnoqualmie National Forest. Mt. Baker Ranger District. Sedro Woolley, Washington. 6 p.

Noson, L.L., A. Qamar, G.W. Thorsen. 1988. Washington State Earthquake Hazard. Washington State Department of Natural Resources. Washington Division of Geology and Earth Resources Information Circular 85.

Paulson, K. 1996. Estimates of land-use effects on sediment supply in the Finney Creek watershed, Skagit County, Washington. Prepared for the Skagit System Cooperative and submitted in partial fulfillment of U.S. Forest Service Cost Share Monitoring Agreement #CCS-94-04-05-01-050. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 32

Peak Northwest, Inc. 1986. Nooksack River Basin Erosion and Fisheries Study: Boulder Creek, Canyon Creek, Cornell Creek, Howard Creek, and Racehorse Creek, Whatcom/Skagit Counties, Washington. Washington State Department of Ecology, 205 J Grant.

Rowe, P.B., and T. M. Hendrix. 1951. Interception of rain and snow by second growth ponderosa pine. Trans Amer. Geophys. Union 32 (6): 903-908.

Satterlund, D. R. and H. f. Haupt. 1970. The disposition of snow caught by conifer crowns. Water Resource. Res. 6 (2): 649-652.

Smith, J.L. 1974. Hydrology of warm snow packs and their effects upon water delivery… some new concepts. In: advanced concepts and Techniques in the Study of snow and ice resources. National Academey of Sciences, Washington, D.C., pp 76-89.

Terzaghi K. and R.B. Peck. 1961. Soil Mechanics in Engineering Practice, second Edition. John Wiley and Sons, New York.

USACE (U. S. Army Corps of Engineers). 1956. Snow Hydrology. U. S. Army Corps of Engineers, Portland, OR, 437 pp.

USFWS. 2004. Draft Recovery Plan for the Coastal-Puget Sound Distinct Population Segment of Bull Trout (Salvelinus confluentus). Volume I (of II): Puget Sound Management Unit (Including the Chilliwack River and associated tributaries flowing into British Columbia, Canada). May 2004. U.S. Fish and Wildlife Service Region 1. Portland, Oregon. 389 pp. http://pacific.fws.gov/bulltrout/jcs/vol\_I.html.

Wilm, H.G., and E. G. Dunford. 1948. Effect of timber cutting on water available for stream flow from a lodge pole pine forest. U.S. Dept Agriculture., Tech Bull No 968, Washington D. C., 43 pp.