APPENDIX E

WFPB 1997 Watershed Manual

Washington Forest Practices

Board Manual:

Standard Methodology for Conducting Watershed Analysis

Under Chapter 222-22 WAC

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Washington Forest Practices Board

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Appendix to
Water Quality Module

Water Quality Module Appendix

Background Discussion of Scientific Basis For Estimating the Effects of Watershed and Management Impacts on Water Temperature

Stream temperature has been widely studied and the physical processes controlling heat transfer are well understood. Most researchers have used an energy balance approach based on the physics of heat transfer to describe and predict changes in stream temperature. The six primary processes by which heat is transferred in aquatic environments are: 1) solar (short-wave) radiation, 2) radiation (long-wave) exchange with the sky and vegetation, 3) convection with the air, 4) evaporation, 5) conduction to the soil or streambed, and 6) advection from incoming water sources. Direct solar radiation is the primary source of energy for heating streams while reradiation of energy to the sky and vegetation and evaporation are the major sources of heat loss. Standing water undergoes the same heat transfer processes as streams. Most solar energy is absorbed in the upper 2 meters of water, depending upon opacity and other specific characteristics (Henderson-Sellers and Davies 1989). This portion of the water column is most subject to heating and cooling with solar radiation and heat exchange with the air. Thus all streams and wetlands and shallow lakes are affected by heat transfer processes described in this module.

The net energy balance, which is influenced by local environmental factors, determines the water temperature at a particular location at any particular time. Meteorological conditions averaged over the day explain daily maximum, mean, and minimum temperature (Edinger and Geyer, 1968). A thorough discussion of heat transfer mechanisms as they apply to forest streams can be found in Brown (1969), Theurer and others (1984), or Adams and Sullivan (1990).

Temperature of a waterbody seeks equilibrium with air temperature (Edinger et al., 1968) as both react to solar radiation with degree of adjustment primarily regulated by the local environmental factors of groundwater inflow, openness to the sky, relative humidity, and water depth (Adams and Sullivan, 1990). The combination of these factors at a site determines the energy balance and temperature.

Heat can be transported downstream with flowing water, although water temperature adjusts to local environmental conditions as it moves. If a stream flows from an open reach into a shaded reach, it will cool. Stream depth influences the rate of response (Brown 1969, Adams and Sullivan 1990, Sinokrot 1993). Very small, shallow streams respond rapidly, on the order of hundreds to a thousand feet. Deeper streams, including most fish-bearing streams, respond more slowly and the effect of the heating in the unshaded stream segment can be felt farther downstream, on the order of thousands of feet. When numerous less shaded reaches exist, there can be a downstream cumulative effect (Beschta and Taylor, 1988).

Table G-a1. Types of environmental variables affecting stream heating processes (from Sullivan et al. 1990).

GENERAL VARIABLE	EXAMPLE
GEOGRAPHY	latitude, longitude, elevation
CLIMATE	air temperature, relative humidy, wind velocity, cloudiness
STREAM CHANNEL CHARACTERISTICS	stream depth, width, velocity, substrate composition, water clarity
RIPARIAN OR TOPOGRAPHIC BLOCKING	sky-view (% shade), canopy density, vegetation height, crown radius, topographic angle

<u>Temperature patterns within watersheds</u>. Not all parameters are equally important for determining temperature regimes at all possible stream locations within the watershed. Rather, the relative importance of stream width, depth, shading, groundwater inflow, and air temperature in determing stream temperature tends to vary systematically by stream reach location within the watershed. Stream temperature tends to increase in the downstream direction from headwaters to lowlands, even under mature forest conditions. Expected stream

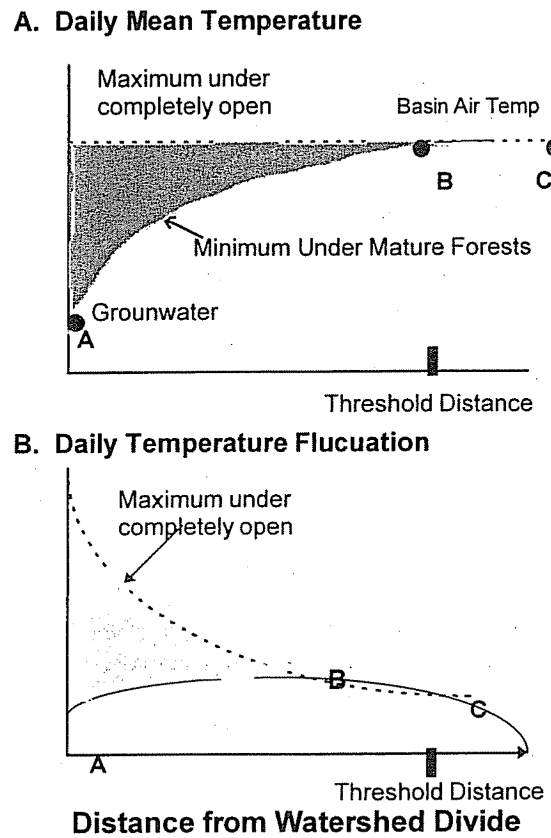
temperature characteristics at a watershed scale are schematically presented in Figure G-a1 providing a conceptual framework for examining the interaction of these processes at both watershed- and stream reach-scales. This framework is thus helpful for understanding the use of reach-specific shade characteristics for estimating stream temperature as described in this module.

Figure G-a1 depicts *daily mean* temperatures and *daily fluctuations* in stream temperatures. Note that the methods in this module estimate the effects of changes in riparian vegetation at a stream-reach scale on the *annual maximum* temperature expected for that stream reach. This time-scale was selected because it was the basis of the temperature/elevation screen (Sullivan et al. 1990), and because the stream temperature characterizations produced by this module can then be related to Washington's annual water temperature standard. In addition, estimates of the annual maximum temperature permit some interpretation about stream temperatures at other time intervals (e.g., if daily fluctuations in stream temperature increase, the annual maximum temperature would, by definition, also increase). Ongoing research and data collection on stream temperature processes is expected to produce additional methods to estimate stream temperature at other spatial scales and time intervals.

At the watershed scale, the curve A-C of the upper graph can be thought of as a probable longitudinal profile of daily average stream temperature for any given stream within the basin. That is, the curve describes, in a qualitative way, the expected increase in temperature as the stream flows from point A to C (Theurer et al, 1984). The expected temperature at point A is determined primarily by the combined effects of the riparian canopy in providing shading and the effect of groundwater inflow in depressing stream temperatures below the local daily air temperatures (Sullivan and Adams, 1989). For high elevation, or groundwater-dominated streams such as those close to source, the likely maximum summer temperature can be expected to vary from about 8-10 deg. C (Sullivan and Adams, 1990). This lower curve from point A to B thus traces a "reference" temperature profile that could be expected for streams under fully shaded mature forests. The shape of this baseline temperature would be expected to vary as a function of basin air temperatures, groundwater inflow, and differences in natural vegetation (Sullivan and Adams, 1990).

Point B on the upper schematic represents that point along the stream where mean stream temperatures equilibrate primarily to local air temperatures. This point is also referred to as the "threshold distance" (Sullivan et. a. 1990). In practice, this threshold distance is that distance from the stream's origin where water temperature is primarily determined by air tempature.

Figure G-a1. Conceptual diagram of increasing temperature with distance downstream from watershed divide.



This tends to occur where the average stream depth is approximately 0.6-1.0 meters and shade is not measureable. Upstream of this threshold distance (point B), riparian shading significantly affects stream temperature, and determines: (1) the degree to which average stream temperatures are depressed below local daily average air temperatures; and (2) the range of the daily fluctuations in stream temperature (i.e., maximum and minimum stream temperatures)(Sullivan and Adams, 1989, which Coweeta studies?). Similarly, the dashed upper curve shows the expected daily mean stream temperature expected for reaches upstream of this threshold depth. This daily average maximum temperature corresponds closely to average daily basin air temperature. The hachured area between the upper and lower curves represents the increases in daily mean stream temperature associated with varying degrees of riparian canopy removal.

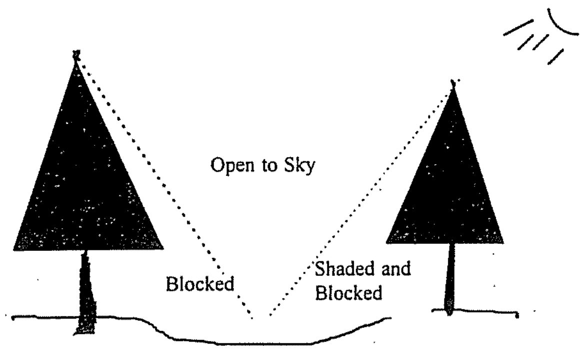
For the down-river point C, the maximum stream temperature is determined primarily by the basin air temperature. This is because low elevation, high-order streams tend to have: (1) relatively low contribution of groundwater to total streamflow; (2) stream widths that are too great for riparian vegetation to provide appreciable shading; and (3) stream depths sufficient to significantly dampen the daily stream response to solar heating (Theurer et al, 1984, Sullivan and Adams 1990). Stream temperatures that are raised above local air temperatures cool by reradiation, convection and evaporation processes, thus establishing a theoretical maximum stream temperature (Sullivan and Adams, 1990). Thus, at point C, the average stream temperature tends to equilibrate primarily to average air temperature.

The lower schematic portrays a similar longitudinal stream temperature profile from the perspective of daily fluctuations about the daily average temperature. For reaches upstream of the threshold distance, stream depth is a key parameter that determines how quickly the stream reach heats up, and how great the daily fluctuation in temperatures will be. As a general rule of thumb, the expected range in daily stream temperature fluctuations can be up to 75-80% of the daily fluctuation in local air temperatures (Sullivan and Adams 1990).

Assuming typical river valley formation, it appears that the portion of the watershed where vegetation has some effect on water temperature may lie within 50-60 km (31-37 miles) of the watershed divide in western Washington (Sullivan et al. 1990). Specific conditions within watersheds such as differences in valley form accompanying geologic substrate may alter the temperature profile and move the threshold for riparian vegetation influence up or downstream. Some valleys may be flatter or wider than average (e.g. glaciated terrain) and some may be steeper and deeper (e.g. incised or entrenched rivers). Elevation, vegetation, and summer air temperature differences may also make these relationships differ between watersheds east and west of the crest of the Cascade Mountains.

Determining shading effects of riparian vegetation. The waterbody's view-to-the-sky (the inverse of which is often inexactly referred to as "shade") (Adams and Sullivan, 1990) is a major environmental factor influencing stream temperature that can be affected by forest practices (Beschta et al. 1987). In the absense of riparian shade, water temperature will be near air temperature except where groundwater infow is significant. The proportion of the sky view that streamside vegetation can effectively block determines the proportion that water temperature will be depressed below air temperature.

Figure G-a2. Conceptual diagram of factors blocking radiation exchange and view-to-the sky.

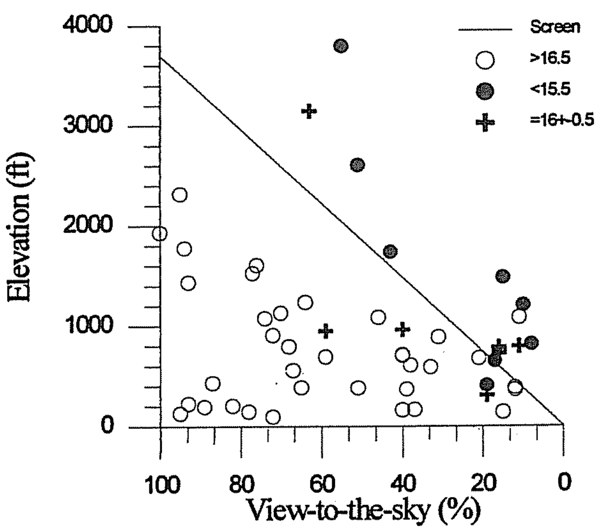


Blocking of in-coming and out-going radiation is determined by the height of streamside vegetation and topographic features within the overhead hemisphere that is the stream's "field of view" (Figure G-a2). The effect of blocking factors is very significant in small to moderate-sized forested streams, helping to maintain cool water temperature during warm summer months. Brown (1969) demonstrated that consideration of direct beam radiation to the stream surface is an important determinant of stream temperature response to solar input. Shade is a measure of the effects of incoming direct beam solar radiation. However, as a measure of heat exchange, it fails to adequately account for other important mechanisms that block outgoing radiation. Adams and Sullivan (1990) and Sullivan et al. (1990) used view-to-the-sky as a measure of blocking in modeling stream temperature with little or no loss of precision. There is some inaccuracy associated with using either view-to-the-sky or shade as a measure of factors that account for both incoming and outgoing radiation. Since view-to-the-sky is far easier to estimate than shade it is used in the calculations in this module. Treatment of the more complex elements of shade and solar angle as performed by Theurer et al. (1984) would not appreciably improve results (Sullivan et al. 1990).

The ability of vegetation to block incoming and outgoing radiation depends on its height relative to the width of the water body. Along very small streams almost any vegetation and streambanks themselves will provide shade, while tall trees and major topographic features are necessary for significant shading of larger rivers. Lakes are often too wide for any vegetation to be an effective control of water temperature. However, small or moderate-sized lakes may not be fully shaded but they may still be affected by the blocking of radiation by streamside vegetation. The maximum potential shade depends on the features of native vegetation.

View-to-the-sky and water temperature. An extensive study of temperature in Washington streams confirmed that watershed and landuse factors influenced water temperature consistent with previous research (Sullivan et al. 1990). Despite the complexities of site conditions on local control of temperature, the study was also able to identify a simple relationship between view-to-the-sky and elevation that could be used to predict the maximum allowable view-to-the-sky that would maintain temperature within water quality criteria for purposes of guiding riparian area management in state forest practice regulations. Referred to as the "temperature screen", the data and relationship is reproduced in Figure G-a3). Documentation of the basis of the simple model is provided in Sullivan et al., 1990, see chapters 6 and 7). Relationships for streams east and west of the Cascade Mountain divide have been adopted as the temperature screen by the Washington Forest Practices Board (WFPB, 1993) for use in prescribing shade requirements on a site-by-site basis.

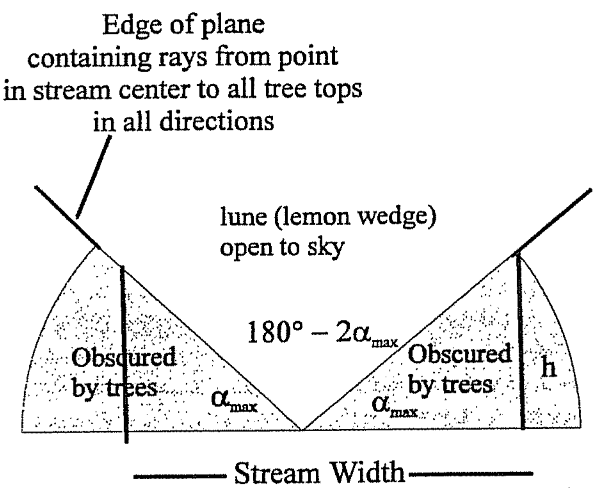
Figure G-a3. Temperature screen for westside plotted with original data from Sullivan et al. (1990). Included are 14 new data points from the Chehalis River.



Note that the screen isolates regions of the elevation/ view relationships where annual maximum temperature falls above or below 16.0oC. The line was fitted by eye to best envelope the data. When sites are misclassified, the screen tends to specify more shade than necessary (it misses more low temperature sites than high temperature sites). Only one data point on Figure G-a3 is warmer than expected given the elevation and view-to-the-sky of the site. At low elevations, considerable shade is required to maintain low temperature, and the definition of the boundary is more muted. When comparing measured versus modeled results, analysts are reminded that the screen is a first order approximation of temperature adopted on the basis of ease of use and reasonable accuracy for prescribing forest practices.

<u>Estimating view-to-the-sky based on vegetation.</u> Vulnerability to heat input is determined by evaluating potential temperature based on fully mature streamside forest conditions and likelihood that forest management can reduce shade sufficiently to exceed temperature standards. Since forest managment has altered many riparian forests from old growth forest conditions, there is rarely data available for measuring fully shaded stream conditions. This module provides a method for estimating the openness of the stream based on geometry of the riparian setting in the absence of measured data.

Figure G-a4. Definition sketch of view-to-the-sky in two dimensions.



Geometric relationships can be applied to calculate the angle from the stream center to the top of the blocking elements. In two dimensions, the sky can be represented as an arc of 180¡, and view-to-the-sky is the fraction of the arc that is unobstructed (Figure G-a4). Essentially this is in a vertical plane perpendicular to the stream banks. The larger the angle without obstructions, the larger view-to-the-sky. For a given maximum vegetation height (tree or shrub as appropriate) and stream width, it is possible to calculate view-to-the-sky as the portion of the horizon not blocked by vegetation and topography.

(Figure G-a5). If the angle α is greater than the hillslope angle (λ), then the stream does not "see" trees beyond the first solid block of trees near the bank and α is the appropriate angle for estimating view-to-the-sky and the effects of topography can be ignored. If the nearstream angle is less than the hillslope angle, than the sideslopes provide more blocking than the streamside trees and topographic effects are significant. In this case, the hillslope angle λ is the appropriate angle to use for the calculations. Topography may be a significant factor reducing view-to-the-sky along stream segments that are moderately to tightly constrained.

Stream width affects view-to-the-sky by determining the location of the closest vegetation to the stream center, and thus the angle and proportion of the overhead hemisphere blocked (Figure G-a6). Small streams can be nearly completely shaded by overhanging trees or shrubs. Medium streams can be partially shaded by trees of suitable size. The largest streams get little shade from even the tallest trees. It should be noted that the view-to-the-sky is not dependent on the angle of the sun, which will vary during the year and with latitude. Using view-to-the-sky as the measure rather than shade allows estimates based on riparian geometry.

This 2-dimensional representation over-simplifies the surface area of the 3-dimensional hemisphere above the stream. View-to-the-sky is the fraction of a hemisphere centered over the stream which is unobstructed by vegetation or topography (Figure G-a7). The hemisphere extends from horizontal to vertical (0-90¡ of elevation), and around the compass (0-360¡ of azimuth). View-to-the-sky is therefore a 3 dimensional concept. There is an occluded plane that contains the line along the center of the corridor and the line formed by the top of the trees. The intersection of this plane and the celestial sphere is a great circle. The horizontal plane at the stream surface also intersects the celestial sphere forming a hemisphere which is the potential field of view of the water surface.

Topography can also affect the view-to-the sky Similarly, the same size tree can have very different effect on the view-to-the-sky depending on the stream width. Only on a perfectly flat landscape with no vegetation or topography is it possible to attain a view-to-the-sky of 100%.

Figure G-a5. Effects of stream width on view-to-the-sky.

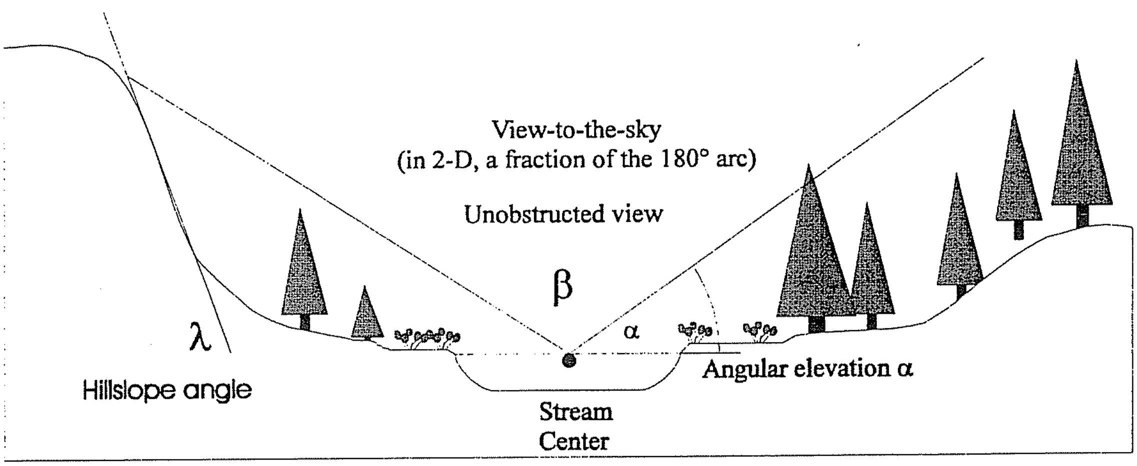


Figure G-a6. Effects of stream width on view-to-the-sky.

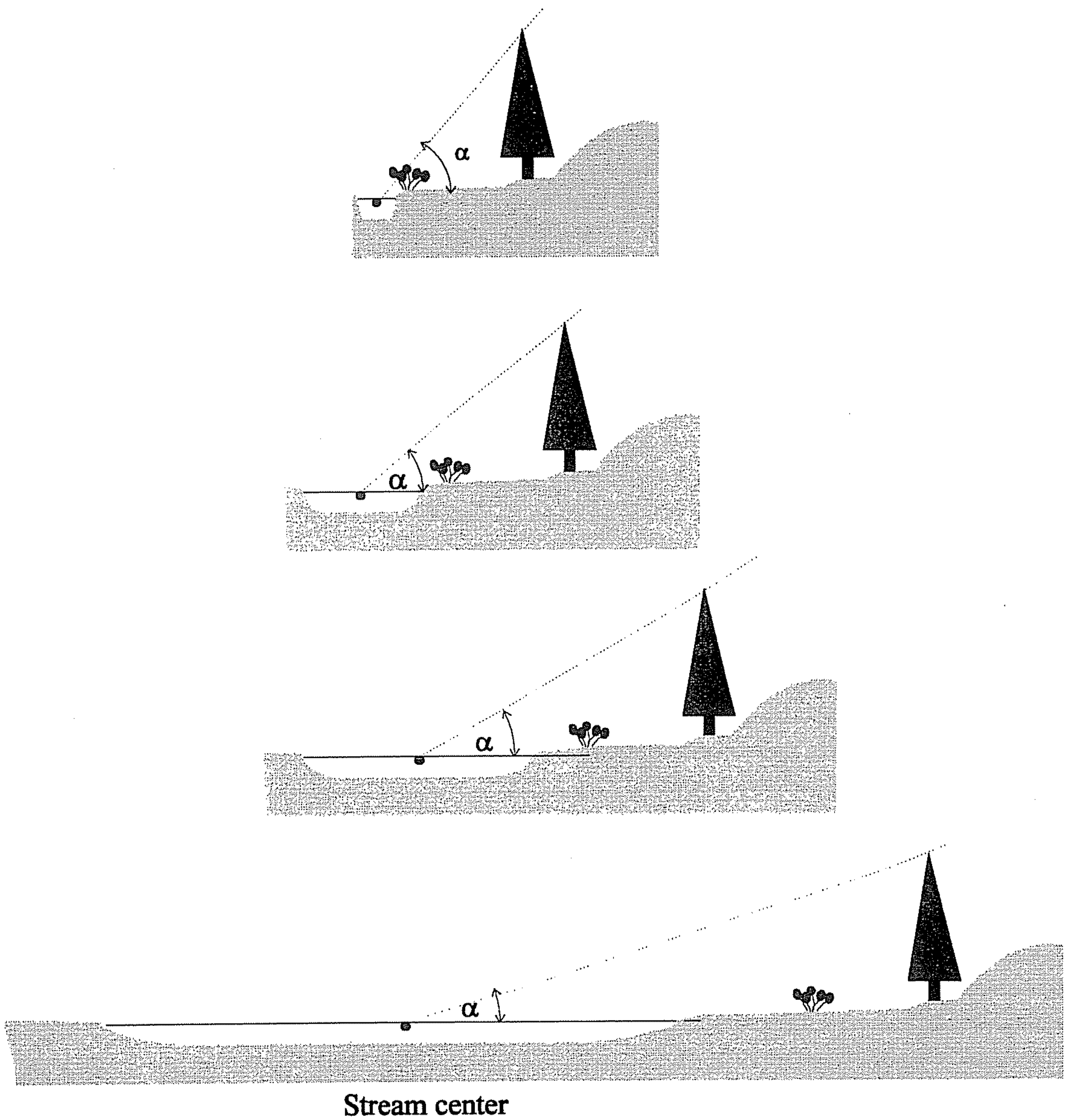
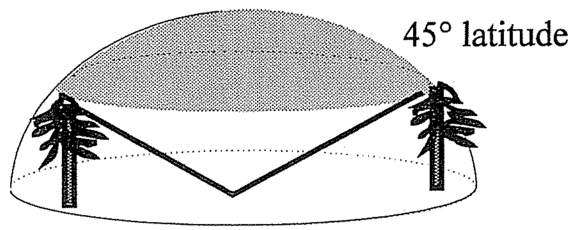


Figure G-a7. Three-dimensional representation of the sphere of view of a waterbody.



Consider the hemisphere in quadrants (Figure G-a8). On wider streams, quadrants facing the banks may have a considerable portion of the angular view blocked by vegetation, while quadrants facing up and downstream may be quite open. This geometry can have an important effect on estimations of view-to-the-sky in wider channels. The slice of sky viewed by the stream between two banks of trees is represented as the area of a geometric shaped termed a "lune" defined by the angle α (degrees) on a celestial sphere (Figure G-a4). To calculate view-to-the-sky, first determine the angle, α (in degrees) that is open above the stream (Figure G-a4). The angle α may be directly measured, or estimated from equation 1 based on the height of trees (h) and width of stream (w).

$$\alpha = \text{ArcCos}\left(w / \text{SQRT}\left(w^2+4h^2\right)\right) \qquad (1)$$

The surface area (A) for the lune whose angle is α is:

$$A = (180-2\alpha/360)4\pi r^2 \qquad (2)$$

$$= 2\pi r^2 - \frac{\pi r^2 \alpha}{45} \qquad (3)$$

The calculation of view-to-the-sky involves dividing the surface area of the lune above the stream by the surface area of the entire horizon above the stream plane.

$$\text{View-to-the-sky } (\%) = \frac{(2\pi r^2 - \pi r^2 \alpha/45)100}{2\pi r^2} \qquad (4)$$

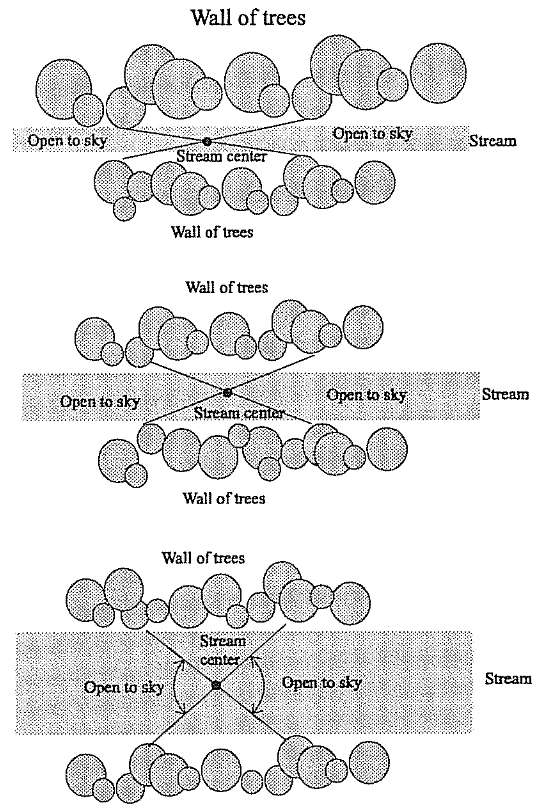


Figure G-a8 Conceptual diagram of the three-dimensional view-to-the-sky from the center of a straight reach of stream

Considering the horizon of view, and therefore r, as large, the radius cancels from the equation with division, making the area of the lune primarily dependent on the angle formed by the trees. This simplifies to

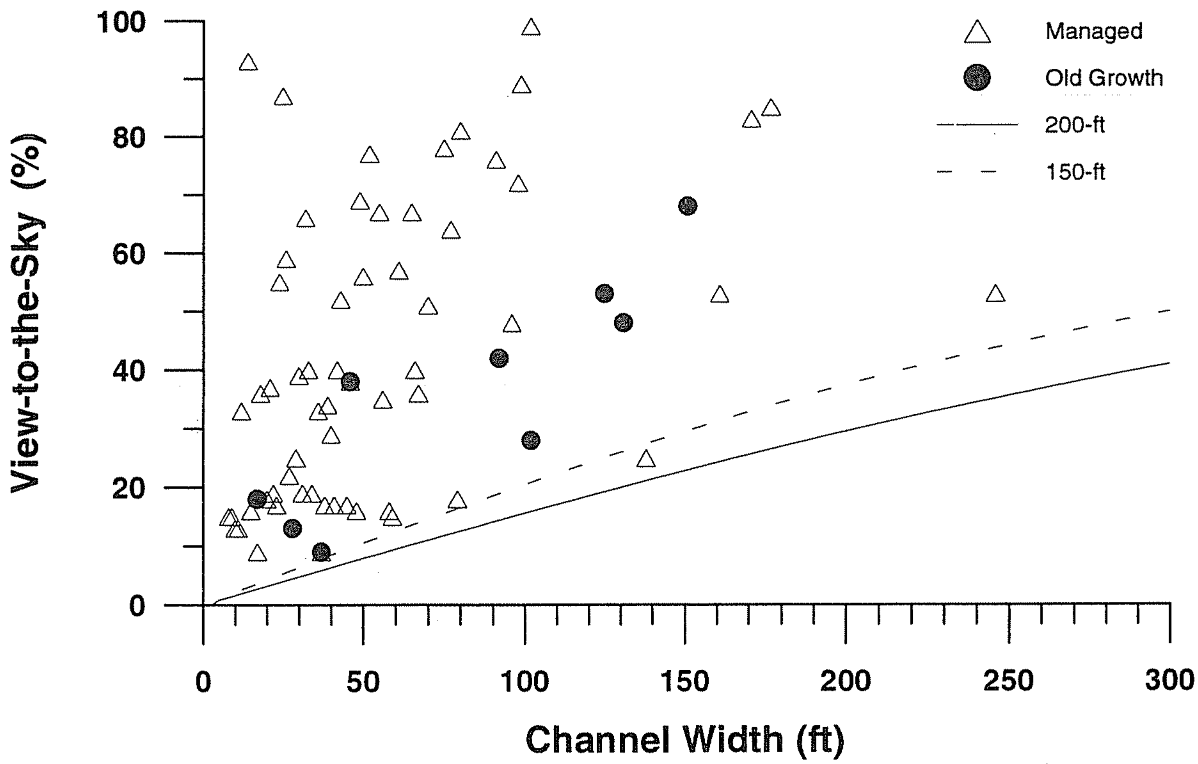
$$\text{View-to-the-sky } (\%) = 100 - \frac{10}{9}\alpha \qquad (5)$$

Several assumptions underlie potential view-to-the-sky calculations based on geometric relationships. Maximum potential height of native overstory species is assumed to be the height of blocking vegetation (h). Potential view-to-the-sky is determined by making the above calculations based on the site as it could be with mature vegetation (whether shrubs or trees). The analyst must assume an appropriate height of the forest stand or shrub commuity that would occupy the site under historic natural conditions. It is also assumed that blocking elements are the same on both sides of the stream. Bankfull stream width (w) is assumed to be the maximum distance between blocking elements on opposite banks. Calculation of view-to-the-sky at the center of the stream is sufficient to adequately represent blocking effects. Although the sides of larger streams may be partially shaded while the center is represent blocking effects. Although the sides of larger streams may be partially shaded while the center is fully open, heat is rapidly mixed in the water column and the center of the stream is likely to adequately represent the average condition. Streams may meander. This characteristic will make little difference in estimates of view since small streams are nearly fully closed based on calculations regardless of channel pattern and the horizon effect on large streams is small.

Calculations of potential view-to-the-sky were performed via spreadsheet for bankfull widths ranging from 0 to 300 feet (Figure G-a9). Calculations assumed effective tree heights of 150 and 200 feet (shown as lines). Estimates of view-to-the-sky for old growth conifer forest conditions represent the minimum view-to-the-sky possible for each segment of a given stream width. Thus the calculated lines in Figure G-a9 should be minimums and all points should plot on or above the appropriate line for forest height. Streams that have had shade removed should plot somewhere between the minimum and 100% open.

The geometric model provides a minimum fit to the data as expected, including data from larger rivers (Figure G-a9). Although the maximum height modeled was 200-feet, view-to-the-sky in old growth forests appeared to have a best fit by assuming tree height of 150-feet or less, although trees in old growth or mature forest stands were undoubtedly taller than this. There may be several reasons why streams appear to be more open than calculations suggest. Note that the above formulation assumes a solid (impenetrable) wall of trees. In fact, real trees only partially obscure view-to-the-sky, especially in the upper portion of the canopy or if vegetation is not dense. In the calculations shown in Figure G-a9 there was no compensation for opacity of the upper portions of the forest stand. These results suggest that perhaps as much as 25% of the total tree height has a significant loss of opacity which was not accounted for in calculations. Thus, view-to-the-sky calculations using total tree height bias estimates of minimum view to lower values than probably naturally occur. It also appears that 150-ft or 75% total tree height is a better estimator of the blocking effect of mature conifers on the westside of the Cascades.

Figure G-a9. Calculated result of view-to-sky equations for effective height equal to 200-ft and 150-ft. Data from TFW sources for westside sites is also plotted tocompare to the vegetation calculations. Points labeled "managed" were collected by TFW cooperators along streams with various histories of logging in riparian areas. Sites labeled "Old Growth" were reported to be representative of old growth stand conditions. Lines are labeled according to tree height used in the calculation.

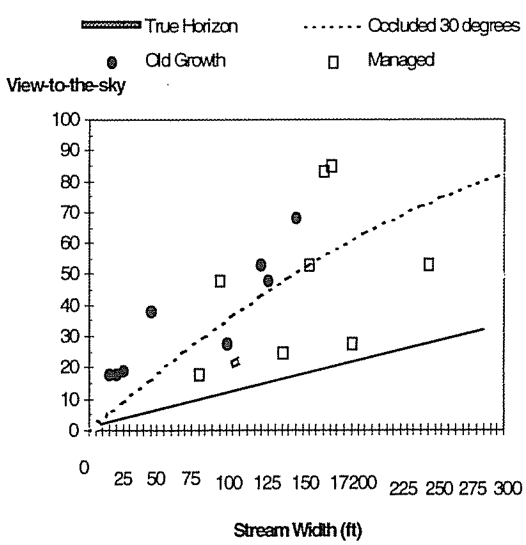


Conversely, the densiometer measuring instrument overestimates the openness of the stream. The convex mirror of the instrument is inset into the wood platform on which it is mounted. The emplacement of the mirror into the platform occludes nearly 30 degrees at the base of the mirror, thus seeing less of the horizon at the base than the stream would "see". Although an apparently small amount when gazing at the instrument, this portion represents a rather large area of the hemisphere above the stream. As much as 50% of the area of a hemisphere lies below 30 degrees on the horizon which would not be measured with the instrument. The larger the stream, the greater the effect on measured view.

However, overestimation of openness during measurement partially accounts for real differences in effectiveness of energy transfer around the celestial sphere. Energy exchange is not equal around the hemisphere: it reaches a maximum straight overhead and declines toward the horizon with the cosine of the angle according to Lambert's Law (Mills, 1992).

Algebraically solving for this factor in the above calculations for the lune illustrates the instrument bias (Figure G-a10). Note that the measured view of larger channels is more open to the

Figure G-a10. Calculated view -to-the-sky of 150-ft tall trees assuming horizon at the ground, and horizon at 30 degrees above the ground as measured by spherical densiometers. Also shown are data from Figure G-9 representing old growth sites and other sites with stream widths greater than 100 feet.



sky than predicted by the equations (Figure G-a9). For larger streams, the calculated view appears to be more representative of the true condition, and is reasonably consistent with most observations. In reality, the effective view-to-the-sky lies somewhere between that calculated using equation 4 and that measured in the field by a spherical densiometer. This analysis uses the calcuated view recognizing that it underestimates the actual view-to-the-sky.

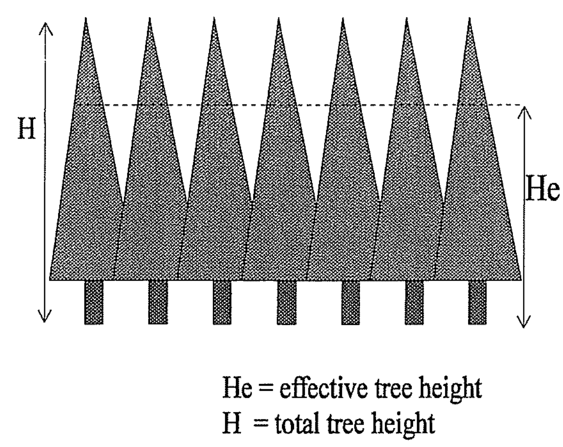
The stream's view of the hemisphere of the sky above it depends on the height and light filtering capacity of objects blocking that view. View-to-the-sky is therefore a function not only of the width of the stream but also of factors that control the height and density (Figure G-a11). To compensate for the gaps in vegetation cover, as viewed sideways from the stream, the analyst can take several steps which further improve the calculation. Since most trees are full in the mid-canopy, but less than opaque in the tree-tops, the analyst can translate that partial opacity into an effective tree height.

$$H_e = H * \% \text{ opacity} \qquad (6)$$

A 120-foot Douglas-fir might be 70% opaque. The effective tree height would then be 84 feet

View-to-the-sky can be calculated by the same formula given above, but substituting effective tree height H_e for H. An additional correction may be needed if the trees are sparse, for example in east-side situations where there are substantial gaps between trees. Use of an opacity factor should be based on field estimates from reference sites and should be ignored if these are not available.

Figure G-a11. Conceptual view of opacity factor accounting for openness of stand.



Estimated temperature based on view-to-the-sky. Data on which the temperature screen was developed from the TFW temperature study (Sullivan et. al. 1991) was used to develop a relationship between view-to-the-sky and maximum temperature. In Figure G-a3, the line representing the temperature screen approximates the relationship between elevation and view-to-the-sky where water temperature is equal to 16°C. Conceptually, the distance each point is away from the line for a given elevation should reflect the distance temperature is likely to vary from the reference. Thus, the difference between existing or potential view-to-the-sky and the screen reference view-to-the-sky can be translated to water temperature as shown in Figure G-a12.

The TFW temperature study provided a rule of thumb estimate that 10% change in view-to-the-sky results in 0.6°C (1°F). Analysis of Figure G-a12 allows recalibration of this relationship to 0.7 °C (1.3°F). The relationship plotted in Figure G-a12 was reformatted for ease of use in water quality module calculations in Figure G-a13.

This approach to calculating maximum temperature has better predictive capability than linear regression of view-to-the-sky and temperature (R^2=.34). The method can be easily applied at the watershed scale using potential or existing view-to-the-sky. The analysis should provide a generalized perspective of temperature at that scale, although it is probably imprecise in locating exact temperature profiles.

Results suggest that this simple approach to estimating water temperature should provide a first approximatation of annual maximum temperature at the watershed scale. There is scatter in the relationship (Figure G-a12) and the water quality analyst should use care in interpreting modeled results in comparison with measured results. Since the model works reasonably well for explaining measured temperature patterns in relation to riparian vegetation, it should provide reasonable estimates of modeled temperature based on estimates of potential view calculated from riparian geometry.

Figure G-a12. Annual maximum temperature in relation to the Difference in view-to-the-sky between potential and allowable based on the temperature screen.

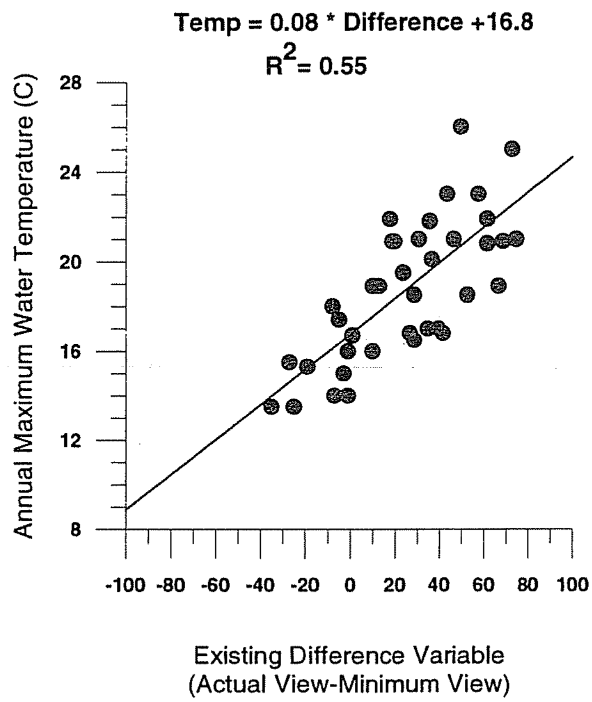
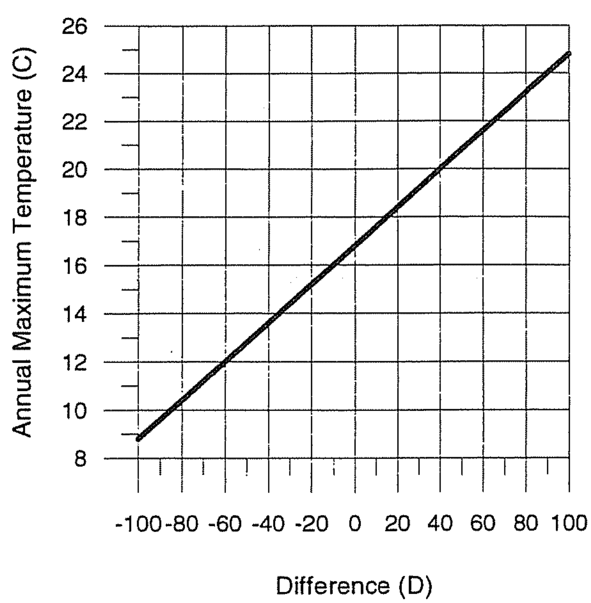


Figure G-a13. Simple model for predicting annual maximum temperature in western Washington based on view-to-the-sky and elevation.



APPENDIX F

View-to-the-Sky (VTS) Input Factors

Appendix F

View-To-The-Sky (VTS) Input Factors
and Specific Modeling Approach
for the Upper Nehalem Watershed Analysis

Technical Support for:
Chapter 9 Water Quality Assessment

VTS Input Parameters

Reference Conditions

A stream of a given size at a certain elevation should be capable of achieving a reference temperature (*reasonably achievable temperature consistent with undisturbed conditions)* as determined under the assumption of mature timber growing immediately adjacent to the channel's edge. Reference conditions for both conifer-dominated and hardwood-dominated stands are discussed below.

However, it was unlikely mature streamside vegetation provided continuous cover along all streams. Channel disturbance regimes likely created a mosaic of vegetation cover with occasional openings and varying vegetation age class structures along streams. To assess the effect of historical disturbance regimes on reference stream temperatures, we used the VTS model with the effective height option (Section "Vegetation Height – Effective Tree Height Option") to predict a range of potential reference conditions.

Conifer. The VTS methodology defined mature timber along the coast as 45 m (150 ft) tall. This approach should be adequate for the Upper Nehalem watershed in the North Coast basin and it approximated a typical 100-year site potential tree height for conifer species in the two Ecoregions in the watershed.

Hardwood. A preponderance of hardwood galleries, especially red alder, occurred along the stream channels in the watershed (Chapter 6). Hardwoods may have been historically present due to natural disturbances and wet soil conditions. Wide bands of hardwood trees were naturally anticipated along unconfined channel habitat types (CHTs) in both ecoregions in the watershed. In this situation, mature alder tree heights of 30m (99 ft) adjacent to the channels are used for determining the reference temperature condition.

Elevation Bands

The maximum allowable VTS to maintain current state water quality standard for core, cold-water habitat of 16ºC (60.8ºF) at different elevation zones (Sullivan et al. 1990; WFPB 1997) are shown below.

Elevation (ft msl)	**View-to-the-Sky (percent angle)**
>3920	99+
3600	90
3280	80
2960	70
2400	60
1960	50
1640	40
1160	30
680	20
<200	<10

This screen is based on providing sufficient canopy closure to maintain a maximum instantaneous summer peak temperature (1-Dmax) of 16ºC. The temperature/elevation screen was adjusted for 7-day moving average of the maximum water temperatures (7-Dmax.) based on the analysis of 244 continuous temperature gauging records in the upper Cowlitz River basin in Washington after Campbell and Kvam (2003) as follows:

$$\text{7-Dmax} = 0.93(\text{1-Dmax}) + 0.49^{\circ}C \qquad \textbf{(EQ.1)}$$

Where: N = 244 records of continuous temperature gauges
Adjusted $R^2 = 0.98$

The regression formula used to convert 1-Dmax to 7-Dmax compares extremely well with a similar regression formula prepared by Sugden et al. (1998) for Plum Creek's Native Fish HCP at high elevations in Idaho and Montana. Campbell and Kvam (2003) determined their regression relationship held up regardless of elevation, aspect, stream flow and other attributes tested. Based on these studies, we felt the model was appropriate for use along the Northern Coast Range in Oregon. The original temperature elevation screen from Sullivan et al. (1990), and comparisons to the screen were adjusted for 7-day moving averages of daily peak temperatures by Campbell and Kvam (2003) and Sugden et al. (1998) are shown in Figure 8-1.

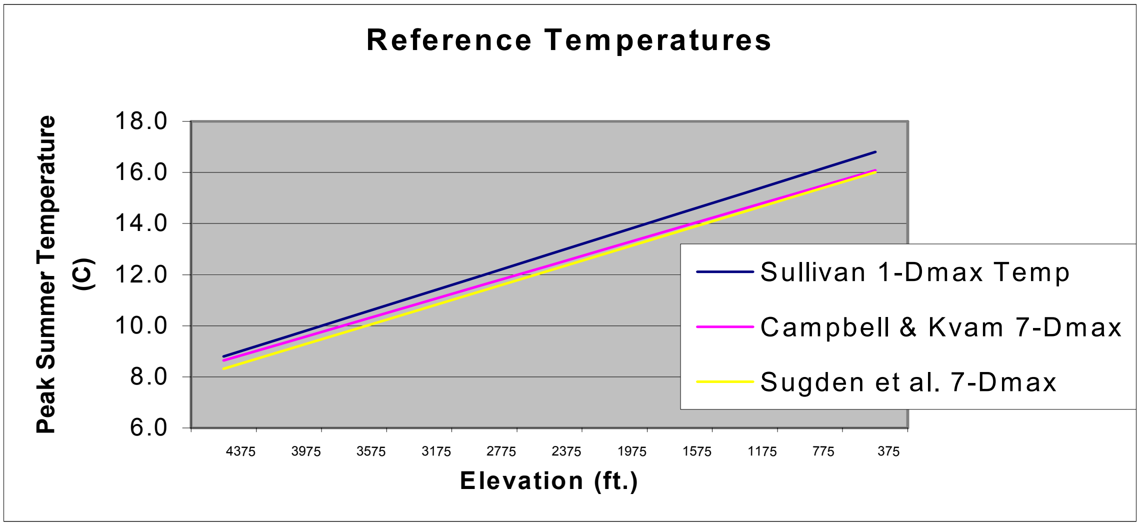


Figure F-1. Examples of reference temperatures predicted for small streams at various elevations.

Channel Sizes

VTS estimates for potential reference temperatures and estimated current temperatures were calculated for each of the small, medium and large channel sizes in the watershed. Estimated average channel sizes for each category using active channel widths from the aquatic inventory project (Kavanagh et al. 2005) were applied across the landscape as follows.

ODF Channel Size	Mean Active Channel Width
Small	3 m (10 ft)
Medium	6 m (20 ft)
Large	12 m (40 ft)
Mainstem	23 m (75 ft)

Vegetation Height

Current and future surface water temperatures were based on the approximate degree of channel openness as determined by: (1) estimated vegetation height at a site and (2) channel width and confinement class. Vegetation height was calculated based on the three-digit riparian vegetation condition code for both conifer-dominated and hardwood-dominated stands using the Watershed Professionals Network (1999) size class break points as follows:

Tree Size Category	Size Class (dbh)
Small	4 – 12"
Medium	12 – 24"
Large	>24"

Subsequent tree heights for conifer and hardwood species were calculated in accordance with height-diameter logarithmic regression equations from the Elliott State Forest Watershed Analysis - Riparian Assessment (Biosystems et al. 2003).

Elliott State Forest Watershed Analysis Tree Height Regression Equations:

Conifer Tree Ht. = *-189.8 + 114.6 * ln(dbh) - 1.029 * dbh* ***(EQ. 2)***

R2 = 0.34

N = 204

Hardwood Tree Ht. = *-16.9 + 36.5 * ln(dbh)* ***(EQ. 3)***

R2 = 0.34

N = 199

Where: dbh = inches; Ht. = feet; ln = natural logarithm

Calculated heights of the size-class break points for each community type are shown below:

		Tree Height		
Size dbh	**ln(dbh)**	**Conifer (ft)**	**Hardwood (ft)**	**Mixed (ft)**
4	1.38629436	30	34	30
12	2.48490665	83	74	83
24	3.17805383	150	99	150

In mixed stands, when conifer overtop the hardwood trees they are free to grow. Therefore, for this assessment, the overall stand heights of conifer–dominated and mixed stands were assumed to be the same.

To provide context and to assess if the estimates were the right order of magnitude, stand characteristics for Douglas-fir of a given breast diameter and tree height provided the following typical stand characteristics.

Douglas-fir Stand Characteristics (after Drew and Flewelling 1979).

Diameter (dbh)	Density (TPA)	Height (ft)	RD (I)	Tree Vol (ft^3)
4	800	30	0.20	1
12	200	83	0.40	15
24	100	150	0.80	150

The relationship between tree diameter and height is a function of stand density. The regression equations (Equation 2 and 3) assume growing conditions of fully-stocked stands and that trees in the riparian zone are not open-grown. Conversely, soil site classes are an index of the rate of tree height growth. Lower site class values indicating faster growing trees. The 150 ft-height for mature Douglas-fir in this example, approached the low end of a Site Class II condition, which should be a good approximation, on average, for the upper Nehalem watershed. From a perspective of riparian stand conditions and feasible stocking levels, the tree height approximations based on diameter size class seemed to be reasonable assumptions for the level of accuracy in the VTS methodology.

Effective Tree Height Option

The VTS methodology recognizes openings in the riparian canopy can influence the level of radiation blocking elements adjacent to a stream. Dense riparian stands may offer more thermal cooling properties than sparse stands. The impact on stream temperatures is probably not a precise function of stand density, since filtered light has little, if any, influence on water temperature compared to open canopy (Cross 2003). However, complete openings in the riparian stand will influence VTS. The VTS method includes an option to decrease the average tree heights to account for decreased opacity in a stand. To compensate for gaps in vegetation cover, the VTS calculations can be improved by translating decreased opacity into “effective tree height.”

Effective tree height (H_e) was defined conceptually in the VTS model as follows:

$$H_{(e)} = H \, x \;\; percent\ stand\ opacity \qquad \textbf{(EQ. 4)}$$

Continuous Temperature Monitoring Data

Current estimated surface water temperatures determined via VTS calculations were compared to actual measurements performed during long-term monitoring surveys (Upper and Lower Nehalem River Watershed Councils, DEQ Lasar database). Deviations from the expected temperature values are discussed subsequently in relation to site-specific variables.

Aerial Photo Interpretation

The existing photo-based inventory (Upper Nehalem Water Council, Unpublished Data) quantified current riparian conditions over 305 miles of ODF streams in the Nehalem watershed using 1995 aerial orthophotos. The results were electronically digitized into a GIS riparian data layer (Upper Nehalem Water Council, Unpublished Data). For this assessment, the existing UNWC GIS coverage was used as the base riparian layer for the watershed. R2 Resource Consultants, Inc., performed aerial photo interpretation of 2004 ortho-photographs along areas extending 150 feet on either side of the centerline of fish-bearing channels not covered previously by UNWC and along streams identified as potentially prone to debris flows in Chapter 7; Sediment Sources. A new riparian data layer incorporating both the original UNWC polygons and the most recent photo assessment was created for this watershed analysis as discussed in Chapter 6; Riparian/Wetland Assessment.

Field Verification

Riparian ground-truthing to confirm general riparian stand characteristics (i.e., stand composition, tree-size, height and density) as mapped on the existing riparian coverages or photo-based interpretation of additional stream segments occurred during March 2005. Stand characteristics and subplot data were collected from 19 locations in the watershed along various channel sizes and types as described in Chapter 6, Riparian/Wetland Assessment.

Riparian measurements and observations during the field verification surveys specific to the channel temperature assessment included: (1) angle and distance from mid-channel to height of blocking element (VTS); (2) tree plot data including species, density, diameters and heights measured in a standard 30m x 30m (100 ft x 100 ft) sample plot; (3) inner riparian zone (RA1) width and composition [OWEB three-digit riparian condition code, see Chapter 6]; (4) outer riparian zone (RA2) width and composition [OWEB three-digit riparian condition code] out to a distance of 150 feet on either side of the channel.

Assessment Procedures

Reference Riparian Conditions

Reference conifer and hardwood tree heights representing a 100-year site potential tree growth of 150 ft and 99 ft respectively, for the ecoregions encompassing the watershed were modeled as if they existed growing immediately adjacent to three channel types (small, medium, and large) in accordance with the VTS methodology (WFPB 1997). Surface water temperatures were subsequently estimated for 6 elevation bands encompassing the watershed. Openings in the riparian canopy and the influence of varying vegetation ages, to simulate the effect of occasional disturbance regimes, were modeled using the effective tree height option with a 20 percent reduction in opacity. This approach was included to provide potential variability and ranges to surface water temperatures that may have occurred historically. The resulting thermal regimes were assumed to represent reasonably achievable surface water temperatures consistent with historical conditions under occasional disturbances in mature forest conditions.

Existing Stand Conditions

Riparian stands categorized in Chapter 6 according to a three-digit alpha code identifying species composition, stand size and density were used to identify the potential range of tree heights existing along channels in the watershed. Effective tree heights (using stand characteristics including species composition, density and mean stand diameter) were incorporated with the three channel types (width and confinement class). Surface water temperatures were subsequently estimated for the elevation bands covering the watershed in accordance with the VTS model (WFPB 1997).

The resulting water temperatures under existing stand characteristics were compared to the range of reference temperature conditions found in these zones. From a stream temperature perspective, if a riparian stand was consistent with the historic vegetation site potential it was assumed to offer natural canopy closure levels and it should provide reference surface water stream temperatures, unless the stream was influenced by groundwater inputs or surface water runoff from lakes, wetlands, or ponded waters.

Forecasted Stand Conditions 50 to 100 Years in the Future

The existing riparian vegetation layer was used as the starting point to project conditions into the future under an assumption of no silvicultural riparian management. Each riparian condition code was qualitatively extrapolated to 50 years and 100 years assuming forest succession pathways typical of unmanaged growing conditions (WFPB 1997).

The future codes were assessed for: (1) effective tree height (using stand characteristics including species composition, density and mean stand diameter) and (2) anticipated stream water temperatures using View-to-the-Sky (VTS) blocking angles represented by stand height and opacity. A determination was made whether or not the forecasted future stands were consistent with the potential riparian community composition for each CHT and Ecoregion.

Assumptions and Forecasts related to Initial Riparian Stand Conditions

Specific assumptions and forecasts for each of the vegetation categories leading to low, moderate or high predictions of the current, 50-year and 100-year VTS blocking potentials are summarized below:

(1) Initial and future riparian stand conditions providing existing low VTS blocking potential

Water. For this analysis it was assumed a water body would not change in 100 years and the potential radiation-blocking height from this class would remain nil throughout the entire period.

Bare Ground. This assessment assumed that bare ground meant hard rock or other soil types incapable of growing a forest stand. As such, potential radiation-blocking height would remain low throughout the entire period.

Grass. Grass as ground cover was assumed to preclude tree establishment; except for shade tolerant species (STS) that might initially develop in 100 years. These tree species would not be of sufficient size to provide significant height in the 100-year time frame (< 15 ft).

Shrubs. Shrubs were assumed to preclude tree establishment; except for STS that might initially develop in 100 years. Shrubs and developing STS tree species would not be of sufficient size to provide significant radiation-blocking angles in the 100-year time frame (< 15 ft).

Conifer Regeneration Sparse (CRS). This assessment assumed sparse conifer regeneration would add crown closure and could develop appropriate stand heights and densities to offer a moderate and high amount of radiation-blocking angles in 50 to 100 years, respectively. Depending upon the initial density, it is also possible stand conditions would remain sparse leaving the stand opacity and effective tree height short of reference conditions within 100-year time frame.

Conifer Regeneration Dense (CRD). It was assumed dense conifer regeneration would add crown closure, thin by stand suppression and develop appropriate stand heights in 100 years to comply with reference temperature conditions.

Hardwood Small Sparse (HSS). As a starting point, young hardwood stands (< 12 in dbh) would grow in excess of 12 in dbh (> 74 ft in height) in 50 years with an occasional large hardwood (99 ft) remaining in the stand at 100 years. However, the stand would not regenerate a second cohort so the stand would have low opacity. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. The radiation blocking heights under this successional pathway were likely appropriate for the hardwood reference condition but due to the sparse density, stand opacity and effective tree heights would likely remain low throughout the 100-year time frame.

Hardwood Small Dense (HSD). This assessment assumed dense, young hardwood stands (< 12 in dbh) would grow in excess of 12 in dbh (74 ft in height) in 50 years with an occasional tall hardwood (99 ft) remaining in the stand at 100 years due to a short life span. The stand would not likely regenerate a second cohort, so the density at 100 years would become sparse. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. Red alder would probably not mature to a large (> 24" dbh; > 99 ft) category, but black cottonwood and broad leaf maple have the potential to exceed 99 feet in 100 years. The VTS potential under this successional pathway would comply with reference conditions (HMD) in 50 years, but could deteriorate at 100 years due to senescence.

Mixed Small Sparse (MSS). Mixed sparse stands would likely grow from small to medium (> 83 ft) to large trees (> 150 ft) in 50 to 100 years, respectively. However, they would not likely develop a second cohort. Stands with sufficient numbers of conifers may outgrow the hardwoods in the overstory and become free to grow. Medium-aged and mature, mixed stands could grow to similar heights as conifer stands and could offer appropriate angles for blocking radiation to develop the potential for reference temperature conditions in 100 years. However, if the original sparse stand is near the lower limit of the category, stand opacity and effective tree heights would likely remain low throughout the 100-year time frame.

Mixed Small Dense (MSD). Mixed, dense stands were anticipated to grow from small to medium (> 83 ft in height) to large trees (> 150 ft) in 50 to 100 years, respectively. The hardwood component would begin to decrease in 100 years such that conifer might begin to dominate the stand composition. Ingrowth of a second cohort would likely include only STS. The stand conditions should offer a moderate VTS blocking angle within 50 years and a high VTS blocking potential within the 100-year term.

Conifer Small Sparse (CSS). Depending upon the initial density, young, sparse conifer stands (CSS as well as CRS) have the capacity to provide canopy closure and to mature into dense stands with high degree of opacity in 50 and 100 years. It is possible the stand conditions could offer reference temperature conditions in 100 years.

However, depending upon the initial density, it is also possible stand conditions would remain sparse leaving the stand opacity and effective tree height short of reference conditions within 100-year time frame.

Conifer Small Dense (CSD). This assessment assumed young, dense conifer stands (4 - 12 dbh) would likely grow to greater than 12 in. dbh (> 83 ft in height) in 50 years and greater than 24 in. dbh (> 150 ft) in 100 years in unmanaged conditions, without a significant loss of overstory density. These conditions should offer a high VTS blocking potential within 100 years commensurate with reference conditions.

Hardwood Medium Sparse (HMS). It is assumed medium-sized hardwood stands (12 - 24 in. dbh) as a starting point would approach 74 feet in height in 50 years with an occasional large hardwood > 99 ft in height remaining in the stand at 100 years. However, the stand would not likely regenerate a second cohort, so the density should remain sparse and the stand opacity low. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. Red alder would probably not mature to the large (> 99 ft) category, but black cottonwood and broad leaf maple have the potential to exceed 99 feet in height. As a result of sparse stand conditions, the stand opacity and hence VTS blocking potential would remain lower than the reference conditions for the duration of the 100-year time period.

Hardwood Large Sparse (HLS). Large-sized hardwood stands (> 24 in. dbh; > 99 ft in height) as a starting point would deteriorate with an occasional large hardwood remaining in the stand in 50 years and only shrubs (< 15 ft) at 100 years (WFPB 1997). The stand was not projected to regenerate a second cohort so the density remains sparse to none. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. As a result of sparse stand conditions, opacity and effective VTS blocking angles would remain low for the duration of the 100-year time period without either a stand disturbance event or silvicultural manipulation.

(2) Initial and future riparian stand conditions providing existing moderate to high VTS blocking potential.

Mixed Medium Sparse (MMS). This assessment assumed medium-sized (> 83 ft in height), sparse, mixed composition stands would grow to large trees (> 150 ft) in 50 years potentially offering reference temperature conditions. Depending upon the initial density, it would be possible that the stand would remain sufficiently open to reduce the effective radiation blocking height and fall short of reference conditions. It is anticipated the hardwood component would begin to decrease in 100 years such that conifer might dominate the stand composition. Ingrowth of STS as a second cohort would not likely contribute to the large wood potential until 150 to 200 years in the future. It is likely future stands on this pathway would retain the same temperature condition at 100 years as was estimated to occur in 50 years.

Conifer Medium Sparse (CMS). Medium-sized, sparse, conifer stands (> 83 ft in height) would likely grow large trees (> 150 ft) in 50 years, offering reference temperature conditions. Stands near the upper limit of the "sparse" category may reach "dense" stands by 50 or 100 years offering a high level of stand opacity adding to the potential to retain reference stream temperatures. Ingrowth of STS as a second cohort would not contribute to much height until 150 years in the future. As such, sparse stands near the lower limit of the category may offer sufficient openings in the canopy to lower the effective VTS blocking angle and lower the stands capacity to meet reference conditions in 50 or 100 years.

Conifer Large Sparse (CLS). This assessment assumed large-sized, sparse, conifer stands (> 150 ft in height) would retain their composition, size and density over the next 50 years. They may or may not comply with the reference conifer temperature condition depending upon the degree of openness associated with the sparse stand conditions. Stands near the upper limit of the "sparse" category may reach "dense" stands by 100 years due to crown closure and less suppression mortality than fully stocked stands offering, a high level of stand opacity and VTS blocking angles. Ingrowth of STS as a second cohort also may begin to contribute to stand opacity and the shade potential within the 100-year time period.

Mixed Large Sparse (MLS). Mixed, sparse stands greater than 24 inches dbh (> 150 ft in height) would remain large in size over the next 50 to 100 years. These stands have the capacity to offer reference temperature conditions throughout the 100-year time period if openings in the stands are not large. The hardwood component would likely deteriorate, giving way to a conifer-dominated stand in 100 years, but conifers would be unable to reach "dense" level unless a second cohort of shade tolerant conifer species grows to sufficient size to contribute shade in 100 years. The VTS blocking potential would likely remain moderate to high for the next 100 years, depending upon the level of stand openness. If an understory of STS develops, the VTS blocking potential could tend more toward a high potential than a moderate potential in 100 years.

(3) Initial and future riparian stand conditions providing existing high VTS blocking potential.

Hardwood Medium Dense (HMD). Medium-sized hardwood stands (> 12 in. dbh; > 74 ft in height) complied with the reference hardwood condition as a starting point. These stands should approach or exceed 99 feet in height in 50 years with an occasional large hardwood (black cottonwood or broad-leaf maple) remaining in the stand at 100 years. The stand would likely remain dense for the first 50 years retaining its reference temperature condition. However, due to hardwood senescence, tree densities should thin considerably in the subsequent 50-year period. Unmanaged, these hardwood stands were not anticipated to regenerate a second cohort so the stand opacity would become low. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. As a result of sparse stand conditions, the VTS blocking potential would likely deteriorate in the 100-year time period, without ongoing stand disturbances or silvicultural manipulation.

Hardwood Large Dense (HLD). Large-sized hardwood stands (> 24 in. dbh; 99 ft and greater in height), as a starting point, complied with the reference hardwood temperature condition. These stands would deteriorate with an occasional large hardwood remaining in the stand in 50 years and only shrubs at 100 years (WFPB 1997). The stand was not projected to regenerate a second cohort, so tree density should decrease over time. Hardwood canopy and shrub understory was anticipated to preclude conifer regeneration. The initial VTS blocking potential was anticipated to deteriorate due to openings in the stand by year 50 and it would continue to decrease over the balance of the assessment period. Potential thermal conditions in the associated streams would likely similarly deteriorate especially in the 100-year time frame.

Conifer Medium Dense (CMD). This assessment assumes medium-sized, dense, conifer stands (> 83 ft in height) would grow to large trees (> 150 ft) in 50 years offering reference conifer temperature conditions. The stand would continue to offer reference temperature conditions at 100 years. Ingrowth of STS as a second cohort would not likely contribute shade until 150 years in the future.

Mixed Medium Dense (MMD). Medium-sized, dense, mixed stands (> 83 ft in height) were assumed to grow large trees (> 150 f t.) in 50 years, offering reference conifer temperature conditions. The hardwood should begin to decrease in 50 to 100 years, such that conifer dominate the stand composition. Ingrowth, with only STS as a second cohort, would not contribute substantial levels of shade 150 to 200 years in the future. The VTS blocking potential should remain high throughout the 100-year assessment period.

Mixed Large Dense (MLD). Large-sized, dense, mixed stands (> 150 ft in height) were anticipated to retain their size and reference conifer stream temperature conditions throughout the 100-year term. The hardwood component would likely decrease in 50-100 years such that conifer dominate the stand composition. Ingrowth, with only STS as a second cohort, would not contribute substantial shade until 150 to 200 years in the future.

Conifer Large Dense (CLD). This assessment assumed large-sized, dense, conifer stands (> 150 ft in height) would retain their composition, size, density and reference conifer temperature condition throughout the 100-year term. Ingrowth of STS, if any, as a second cohort may begin to contribute additional shade in 100 years.

Table F-1. Predicted Surface Water Temperatures (ºC) in accordance with projected VTS openings at various elevations (see next page for Legend).

Elevation 680 ft. msl

		Riparian Stand Vegetation Starting Point							
				Hardwood			Conifer		
Stream Class	Year	Grass	Shrub	Small (HSX)	Medium (HMX)	Large (HLX)	Small (CSX)	Medium (CMX)	Large (CLX)
Small	0	19.7	16.3	15.5	15.1	15.1	15.6	15.1	15.0
	50	19.7	16.3	15.1	15.1	15.1	15.1	15.0	15.0
	100	19.7	16.3	15.1	15.1	16.3	15.0	15.0	15.0
	Reference	15.1	15.1	15.1	15.1	15.1	15.0	15.0	15.0
Medium	0	20.9	17.6	16.1	15.4	15.3	16.3	15.4	15.1
	50	20.9	17.6	15.4	15.3	15.3	15.4	15.1	15.1
	100	20.9	17.6	15.3	15.3	17.6	15.1	15.1	15.1
	Reference	15.3	15.3	15.3	15.3	15.3	15.1	15.1	15.1
Large	0	21.5	19.2	17.3	16.1	15.8	17.6	15.9	15.4
	50	21.5	19.2	16.1	15.8	15.8	15.9	15.4	15.4
	100	21.5	19.2	15.8	15.8	19.2	15.4	15.4	15.4
	Reference	15.8	15.8	15.8	15.8	15.8	15.4	15.4	15.4

Elevation 1640 ft. msl

		Riparian Stand Vegetation Starting Point							
				Hardwood			Conifer		
Stream Class	Year	Grass	Shrub	Small (HSX)	Medium (HMX)	Large (HLX)	Small (CSX)	Medium (CMX)	Large (CLX)
Small	0	18.2	14.8	14.0	13.6	13.6	14.1	13.6	13.5
	50	18.2	14.8	13.6	13.6	13.6	13.6	13.5	13.5
	100	18.2	14.8	13.6	13.6	14.8	13.5	13.5	13.5
	Reference	13.6	13.6	13.6	13.6	13.6	13.5	13.5	13.5
Medium	0	19.4	16.1	14.6	14.0	13.8	14.8	13.9	13.6
	50	19.4	16.1	14.0	13.8	13.8	13.9	13.6	13.6
	100	19.4	16.1	13.8	13.8	16.1	13.6	13.6	13.6
	Reference	13.8	13.8	13.8	13.8	13.8	13.6	13.6	13.6
Large	0	20.1	17.7	15.8	14.6	14.3	16.1	14.4	14.0
	50	20.1	17.7	14.6	14.3	14.3	14.4	14.0	14.0
	100	20.1	17.7	14.3	14.3	17.7	14.0	14.0	14.0
	Reference	14.3	14.3	14.3	14.3	14.3	14.0	14.0	14.0

Elevation 2400 ft. msl

		Riparian Stand Vegetation Starting Point							
				Hardwood			Conifer		
Stream Class	Year	Grass	Shrub	Small (HSX)	Medium (HMX)	Large (HLX)	Small (CSX)	Medium (CMX)	Large (CLX)
Small	0	16.7	13.4	12.5	12.2	12.1	12.6	12.1	12.0
	50	16.7	13.4	12.2	12.1	12.1	12.1	12.0	12.0
	100	16.7	13.4	12.1	12.1	13.4	12.0	12.0	12.0
	Reference	12.1	12.1	12.1	12.1	12.1	12.0	12.0	12.0
Medium	0	17.9	14.6	13.2	12.5	12.3	13.4	12.4	12.2
	50	17.9	14.6	12.5	12.3	12.3	12.4	12.2	12.2
	100	17.9	14.6	12.3	12.3	14.6	12.2	12.2	12.2
	Reference	12.3	12.3	12.3	12.3	12.3	12.2	12.2	12.2
Large	0	18.6	16.2	14.3	13.1	12.8	14.6	13.0	12.5
	50	18.6	16.2	13.1	12.8	12.8	13.0	12.5	12.5
	100	18.6	16.2	12.8	12.8	16.2	12.5	12.5	12.5
	Reference	12.8	12.8	12.8	12.8	12.8	12.5	12.5	12.5

LEGEND	
	= Reference T^{o}C condition for the specific channel size and elevation
	= Predicted water temperatures < 16^{o}C
	= Predicted water temperatures between 16 and 18^{o}C
	= Predicted water temperatures between 18 and 20^{o}C
	= Predicted water temperatures > 20^{o}C

APPENDIX G

Comparison of Predicted and Measured Surface Water Temperatures On and Near ODF Lands in the Upper Nehalem Watershed

Table G-1. Comparison of Predicted and Measured Surface Water Temperatures on and near ODF lands in the Upper Nehalem Watershed.
DEQ:LASAR Monitoring Stations List on or near ODF lands in Nehalem Watershed
Parameter: Surface Water Temperature Stations

Station ID	Location Description	Latitude	Longitude	ODF Lands (Y/N)	Elev. (ft. msl)	Water Type (L,M,S)	Est. Mean BFW (ft)	Riparian Code	Est. VTS (%)	Summer Temperature Stations: Grab Samples (N)	Temp. Range (°C)	Temp. Mean (°C)	7-day Max (°C)	VTS[1] Predicted Temp. (°C)
Upper Nehalem														
11843	Lousignont Creek @ RM 7.0	45.7340	123.3388	Y	1040	L	40	HMD	16.8	1	11.0	11.0		15.5
23274	Lousignont Creek @ Timber Rd. Bdg 1390	45.7521	123.2954	N	784	L	40	HMD	16.8	2448	9.8 - 18.4	13.7	17.3	15.9
18783	Lousignont Creek Tributary w/in Landslide	45.7236	123.3511	Y	1375	M	20	HMD	8.6	1	13.1	13.1		14.4
17155	Lousignont Creek Tributary upstream of Landslide	45.7236	123.3530	Y	1398	M	20	HMD	8.6	1	11.2	11.2		14.4
23592	Nehalem River - SF Nehalem @ Cochran Rd.	45.7135	123.3910	Y	1503	M	20	MMD	7.6	4393	8.0 - 13.2	10.7	12.9	14.1
23273	Nehalem River @ Cochran Rd. Bdg 1393	45.7073	123.3197	Y	1014	L	40	HMD	16.8	4093	9.2 - 17.2	12.8	16.4	16.9[2]
23591	Nehalem River just upstream of SF Nehalem River	45.7140	123.3910	Y	1496	L	40	HMD	16.8	4007	8.4 - 14.5	11.3	14.1	14.8
21813	Nehalem River near Timber	45.7367	123.2846	N	837	L	40	HMD	16.8	1087	8.2 - 18.4	13.6	17.3	15.8
21813	Nehalem River near Timber	45.7367	123.2846	N	837	L	40	HMD	16.8	3572	9.6 - 19.7	15.0	18.8	15.8
23276	Nehalem River upstream of Wolf Creek at Timber Rd. Bdg.	45.7606	123.2968	N	758	L	40	HMD	16.8	3956	9.8 - 19.9	14.6	19.1	15.9
23589	Rock Creek - SF Rock Creek @ HWY 26 (Nehalem Trib RM 90.7)	45.7938	123.4572	Y	1434	L	40	MMD	15.1	4009	8.3 - 14.3	11.1	13.7	14.8
23588	Rock Creek @ HWY 26 upstream of SF Rock Creek	45.8044	123.4737	Y	1381	L	40	CMD/SHR	37.1	4009	8.4 - 17.2	12.8	16.3	16.5
13265	Tributary to NF Wolf Creek @ RM 0.45	45.7947	123.3837	Y	1139	M	20	CMD	7.6	1128	10.1- 15.5	12.4	14.7	14.7
23275	Wolf Creek at HWY 26	45.7618	123.2962	N	755	L	40	HMD	16.8	4072	10.1 - 18.4	13.9	17.5	15.9
Middle Nehalem														
22928	Fishhawk Cr. 10 ft upstream of Fishhawk Lake STP Outfall	46.0318	123.3665	N	541	L	40	HMD	16.8	1	22.5	22.5		20.3
23283	Fishhawk Cr. @ Northbank Rd. (Nehalem RM 65.7) nr mouth	46.0019	123.3368	N	492	L	40	MMD	15.9	5286	8.7- 22.9	16.5	21.8	16.7
24966	Fishhawk Cr. upstream of Water Plant	46.0348	123.3528	N	554	L	40	HMD	16.8	1881	10.2 - 20.3	14.5	19.3	16.3
24964	Fishhawk Cr. 300 yds downstream of Fishhawk Lake	46.0288	123.3677	Y	538	L	40	HMD	16.8	1880	15.9 - 25.2	19.6	23.9	17.7[2]
12328	Fishhawk Cr. @ RM 1.7	46.0089	123.3546	N	509	L	40	MMD	15.9	2	15.0 - 17.0	16.0		16.3
23284	Nehalem River @ Fishhawk Rd. Bdg (RM 66.5)	46.0027	123.3258	N	489	L	40	HMD/HSD	37.2	3571	14.9 - 25.9	19.2	24.6	17.9
23873	Nehalem River @ HWY 202 Bdg in Vesper	45.9802	123.3663	N	479	L	40	HMD/HSD	24.9	5316	14.3 - 24.2	18.7	23.1	17.3
24976	Northrup Cr. At Headwaters	46.0366	123.4386	Y	850	M	20	CSD/CRD	26.9	2179	7.0 - 17.1	12.5	16.3	16.6
23288	Northrup Cr. At mouth	45.9858	123.4246	N	486	L	40	HMD	16.8	6546	6.5 - 18.9	12.8	18.1	16.4
24968	Northrup Cr. At mouth (Nehalem)	45.9842	123.4228	N	486	L	40	HMD	16.8	1710	11.4 - 19.1	14.7	18.0	16.4
Lower Nehalem														
23285	Beneke Creek @ Hwy 202 (Jewel)	45.9347	123.5013	N	584	L	40	MMD	15.9	4177	10.3 - 19.7	15.0	18.7	16.2
23286	L. Fishhawk Cr. @ Hwy 103 Jewell (Nehalem RM 46.9)	45.9340	123.5032	N	466	L	40	MMD	15.9	4043	9.6 - 21.4	15.5	18.1	16.4
21810	Fishhawk Cr. @ RM 1.7	45.9322	123.5070	N	482	L	40	MMD	15.9	1	19.4	19.4		16.3
29937	Gilmore Cr. Tr.	45.9601	123.5329	Y	768	M	20	MMD	7.6	1	10.6	10.6		15.2
23510	Humbug Cr. @ mouth (Rierson's Bridge - Nehalem)	45.8432	123.5849	N	358	L	40	MMD	15.9	3893	10.6 - 21.3	15.8	20.2	16.6
23287	Nehalem River @ Hwy 202 (Jewel)	45.9353	123.4910	N	446	L	40	MMD	15.9	7	18.2 - 21.6	18.9		16.8
10522	Nehalem River @ Hwy 26	45.8703	123.5656	N	413	L	40	MMS/MMD	18.4	6	15.0 - 19.0	17.3		16.7
23509	Nehalem River downstream Humbug Creek at Lower Nehalem Rd.	45.8438	123.5900	N	354	L	40	MMD	15.9	7	14.3 - 25.1	19.0	22.2	18.4
29933	Quartz Creek	45.8440	123.5563	N	410	L	40	MMD	15.9	1	10.9	10.9		16.5

1) VTS = View-to-the-Sky Temperature Assessment Model (WFPB 1997)
2) Predicted per distance from divide temperature regression (Biosystems et al. 2003)
Y= Yes, ODF land ownership
N = Near ODF Lands

Temperature Prediction Summary

Frequency	Precent	Comment
5		Groundwater Signal or spot measurements
2	8%	Slightly cooler; all upstream of 1381 ft msl
6	24%	Predicted temperatures fall within the range of measured water temperatures; 350 to 1484 ft msl
8	32%	Slightly warmer
10	40%	Much warmer; all downstream of 837 ft msl
2		Lake Outflow; reservoir influence

APPENDIX H

Recorded Water Quality Data in and Near ODF Lands in the Upper Nehalem Watershed

Table H-1. Recorded Water Quality Data in and near ODF lands in the Upper Nehalem Watershed.
DEQ:LASAR Monitoring Stations List on or near ODF lands in Nehalem Waters
Parameter: Water Quality Stations

Station ID	Location Description	ODF Lands (Y/N)	Elev. (ft. msl)	Water Type (L,M,S)	Est. Mean BFW (ft)	Riparian Code	Data Metrics	Temp (°C)	DO mg/L	DO Sat (%)	pH units	Cond umhos/cm	Turbidity NTU	TSS mg/L	NH3 mg/L
Upper Nehalem															
11843	Lousignont Creek @ RM 7.0	Y	1040	L	40	HMD		11.0	10.4	98.0	7.2	51	<1	<1	<0.020
18783	Lousignont Creek Tributary w/in Landslide	Y	1375	M	20	HMD		13.1	9.0	91.0	7.2	50			
17155	Lousignont Creek Tributary upstream of Landslide	Y	1398	M	20	HMD		11.2	9.7	92.0	7.2	63		<1	<0.020
23273	Nehalem River @ Cochran Rd. Bdg 1393	Y	1014	L	40	HMD	minimum					60			
							maximum					66			
							mean					62			
21813	Nehalem River near Timber	N	837	L	40	HMD	minimum	8.2	9.1	94.0	7.4	43			
							maximum	11.9	11.2	97.0	7.6	56			
							mean	10.4	10.0	95.4	7.5	50			
Middle Nehalem															
22928	Fishhawk Cr. 10 ft upstream of Fishhawk Lake STP Ou	N	541	L	40	HMD		22.5	8.5	97.0	7.5	50	2	1	<0.02
12328	Fishhawk Cr. @ RM 1.7	N	509	L	40	MMD	minimum	15.0	7.8	80.0	7	34	4	2	0.02
							maximum	17.0	8.0	80.0	7.2	67	8	14	0.03
							mean	16.0	7.9	80.0	7.1	52	6	9	0.025
23873	Nehalem River @ HWY 202 Bdg in Vesper	N	479	L	40	HMD/HSD	minimum					60		1	
							maximum					106		54	
							mean					83		7	
Lower Nehalem															
21810	Fishhawk Cr. @ RM 1.7	N	482	L	40	MMD		19.4	8.3	89.0	7.2	66	1	<1	0.07
29937	Gilmore Cr. Tr.	Y	768	M	20	MMD		10.6	10.8	101.0	7.2	42	3.0	4.0	<0.02
23287	Nehalem River @ Hwy 202 (Jewel)	N	446	L	40	MMD	minimum	8.2				43			
							maximum	22.5				66			
							mean	12.6				55			
10522	Nehalem River @ Hwy 26	N	413	L	40	MMS/MMD	minimum	15	8.4	84.0	6.6	50		5	0.10
							maximum	19	11.5	103.2	7.3	111		18	0.34
							mean	17.3	9.4	92.9	7.0	75		10	0.21
23509	Nehalem River downstream Humbug Creek	N	354	L	40	MMD	minimum	3.1				60			
	at Lower Nehalem Rd.						maximum	20.5				104			
							mean	9.7				79			
29933	Quartz Creek	N	410	L	40	MMD	minimum		10.4	95.0	7.7	110			0.02
							maximum		11.2	101.0	7.7	111			0.03
							mean	10.9	10.7	98.0	7.7	111	2.0	3.0	0.03
Nehalem Watershed		N = Near; immediately downstream					minimum		7.8	80	6.6	34	1	1	0.02
		Y= Yes, ODF land ownership					maximum		11.5	103.2	7.7	111	8	54	0.34