Chapter 5. Water Quality

WATER TEMPERATURE

When groundwater enters into a stream channel, its temperature is immediately influenced by the new surroundings. Solar radiation striking the water surface and heat exchange with the air result in warming. To some extent, this warming is offset by heat lost to the channel substrate, by water evaporating, and by vegetation intercepting the solar radiation. The subsurface component of stream flow, that portion which meanders under the stream substrate, experiences a somewhat different energy exchange. Most notable is the lack of solar radiation input and heat exchange with the air. Consequently, the subsurface component of flow is usually cooler than the surface flow, and where the two intermix (such as in a deep pool), the net result is a cooling of the aboveground component of stream flow. The subsurface component of stream flow does not exist for streams with a bedrock bottom.

Complex interactions driven by local climate, shading, substrate, and channel dimensions result in water temperatures that continually change along the length of a stream. Nevertheless, streams generally warm from their headwaters to mouth. Another generalization is that the maximum temperatures for any given reach of stream vary annually, depending on the timing of maximum air temperature and low flows. Usually, maximum water temperatures in Oregon coastal streams occur from mid-July to mid-August, a time when the sun is high in the sky, flows are relatively low, and air temperature is the highest. However, summer fog in coastal areas can result in extended periods of low air temperature, high humidity, and intercepted solar radiation.

Maximum water temperature is often expressed as the greatest 7-day running average of daily maximum temperatures occurring each summer. Hereafter, this is referred to as the 7-day maximum and is used for expressing maximum water temperature throughout this section. The 7-day maximum, in contrast to the annual daily maximum, better reflects the response of fish to high water temperature. Fish can often endure one day of 75° F water by eating more or moving into zones of cooler water. However, if the water peaks at 75° F for a week, these survival strategies are less effective. The annual maximum water temperature is usually 2-3° F higher than the 7-day maximum for coastal streams. State standards for water temperature also are expressed as the 7-day maximum.

The water temperature standard adopted by the DEQ that applies to Forest streams is 64° F. Most activities that increase the temperature of a stream above 64° F are prohibited. This is not to suggest that all streams are naturally cooler than this standard; Oregon coastal streams with abundant shade commonly exceed 64° F. The goal of the temperature standard is to maximize the time that cold water rearing habitat is available for juvenile salmonids and to minimize warm water stress that can occur when these cold water fish are exposed to elevated temperatures. The Oregon Forest Practices rules, as modified in 1994, were designed to result in the retention of most existing shade along fish-bearing streams and all other streams without fish, except those that are in the small size classification. A specific shade standard is not stated in the rules. Instead, a specified number and basal area of trees is

required to be left along streams and is assumed to result in a level of shading that is similar to the original stand. Monitoring by ODF's Forest Practices Division has confirmed that, in most cases, shade loss to streams when timber harvest occurs outside of buffers is minimal under these rules. The Forest is required to meet or exceed the Forest Practices rules.

The state standard for water temperature is not an indicator of what fish can tolerate. Salmonids commonly live in streams that exceed 64° F. However, physiological and behavioral changes often occur in fish when temperatures approach 70° F. Being cold-blooded, fish must consume more food when the water is warmer or they will lose weight. Warm water also can lead to sluggish movement and to fish congregating around zones of cooler water, which further limits their ability to search for food, as well as making them more prone to predation. Since warm temperatures in Forest streams do not correspond to periods of adult holding or spawning by salmon and steelhead, water temperature is not a spawning or egg development issue.

Methods

Suitable water temperature records were available for 14 sites in the West Fork Millicoma Basin and for 7 sites in various streams draining into the Tenmile Lakes. The Forest and DEQ jointly monitored the West Fork Millicoma sites in 1996, 1997, and 1999; the Tenmile Lakes Watershed Council monitored the Tenmile Lakes sites in 2002. Only three of the West Fork Millicoma sites had a temperature record that covered all 3 years of monitoring. Most had at least 2 years of record, and an examination of the 7-day maximum temperatures at these sites indicated that, on average, values for 1996 were 1.027 higher than 1997 values and 1997 values were 1.016 times higher than 1999. Because of the data gaps and temperature differences among summers, temperatures for sites that had missing data for 1-2 years were estimated by multiplying the temperature of known years by these ratios. The average temperature values (actual and estimated) over the 3 years then were calculated.

The Tenmile sites were analyzed separately from the West Fork Millicoma sites because the records were from 2002 and there was no way of determining possible differences in summer conditions between 2002 and the late 1990s. Also, it was suspected that marine air and summer fog would result in a unique spatial pattern of maximum water temperatures in the Tenmile region. Stream flow was unusually low in 2002. Some of the late summer temperatures for the Tenmile gauges appeared to deviate widely from patterns observed earlier in the summer. This may have resulted from the gauges being partially out of the water during later summer as flows receded. Therefore, a warm 7-day period centered on July 11 was used instead of the greatest 7-day maximum for the entire summer. A few gauges with erratic records, even in mid-July, were not used in the analysis.

An indicator of stream shading upstream of each gauging site was obtained from stream surveys conducted by the ODFW in the 1990s or in 2001. This estimate of vegetative cover over the stream, as measured by a clinometer, is not a direct measure of stream shading but a determination of the sun-blocking capability of the top of the tree line or the topography on each side of the stream. Hereafter, it is referred to as "ODFW shade" and was expressed for three distance intervals upstream of the gauging site, 0.5, 1, and 2 miles. Other possible correlates to water temperature were extracted from reach summaries upstream of the sites,

including active channel width and the percent of substrate consisting of silt/sand and gravel. Shade derived by DEQ using measurements from aerial photographs and topographic maps, and calculated using the SHADOW model (Forest Service 1993), also was included in this analysis as another indicator of shade. These data were available only for the West Fork Millicoma Basin, and hereafter is referred to as "DEQ shade."

A GIS overlay of contour isopleths, stream channels, and gauge locations provided measures of the distance between the gauge and the basin divide. Distance from divide is the channel distance along the longest possible path extended to the upper basin ridge top. For each of two data sets (West Fork Millicoma and Tenmile Lakes sites), multiple linear regression was used to evaluate variables that may explain temperature variance among sites. Maximum water temperature and related information for Forest streams is shown in Table 5-1.

Table 5-1. Maximum water temperature and related information for Forest streams.

Stream	Max. Temp.	ODFW Shade (%)			DEQ Shade (%)			Divide
		0.5 mi.	1 mi.	2 mi.	0.5 mi.	1 mi.	2 mi.	
Coos Region (1996, 1997, 1999)								
WF Millicoma above Cougar Cr	59.1	98	95	91	80	76	76	2.3
WF Millicoma below Elk Cr	65.5	72	85	88	76	80	80	5.5
WF Millicoma above Knife Cr	67.6	80	81	78	65	65	65	7.0
WF Millicoma at 8000 road bridge	69.8	77	81	75	73	57	59	8.5
WF Millicoma below Stulls Falls	73.3	81	81	78	50	47	56	19.6
WF Millicoma at hatchery	76.1	71	66	60	66	61	54	22.8
WF Millicoma at mouth	74.2*	---	---	---	---	---	---	35.9
Kelly Cr at mouth	64.6	88	88	88	76	83	85	1.9
Panther Cr at mouth	65.3	70	71	75	59	54	69	2.7
Fish Creek at mouth	62.4	93	93	94	83	83	83	3.4
Elk Cr at mouth**	64.7	90	86	87	76	80	80	9.1
Knife Cr at mouth**	63.4	84	87	87	70	69	74	3.5
Deer Cr at mouth	67.6	78	77	73	81	79	64	4.3
Trout Cr at mouth**	62.0	97	98	92	82	82	91	2.5
Tenmile Region (2002)								
Benson, upper	70.2*	74			---	---	---	4.1
Big, lower (dam pool)	68.1*	51			---	---	---	4.9
Big, upper	64.1*	83			---	---	---	3.6
Noble, upper	63.7*	86			---	---	---	2.1
Murphy, upper	61.3*	96			---	---	---	1.9
Big, Alder Fork	60.3*	89			---	---	---	2.6
Johnson, upper forks	59.1*	80			---	---	---	3.8

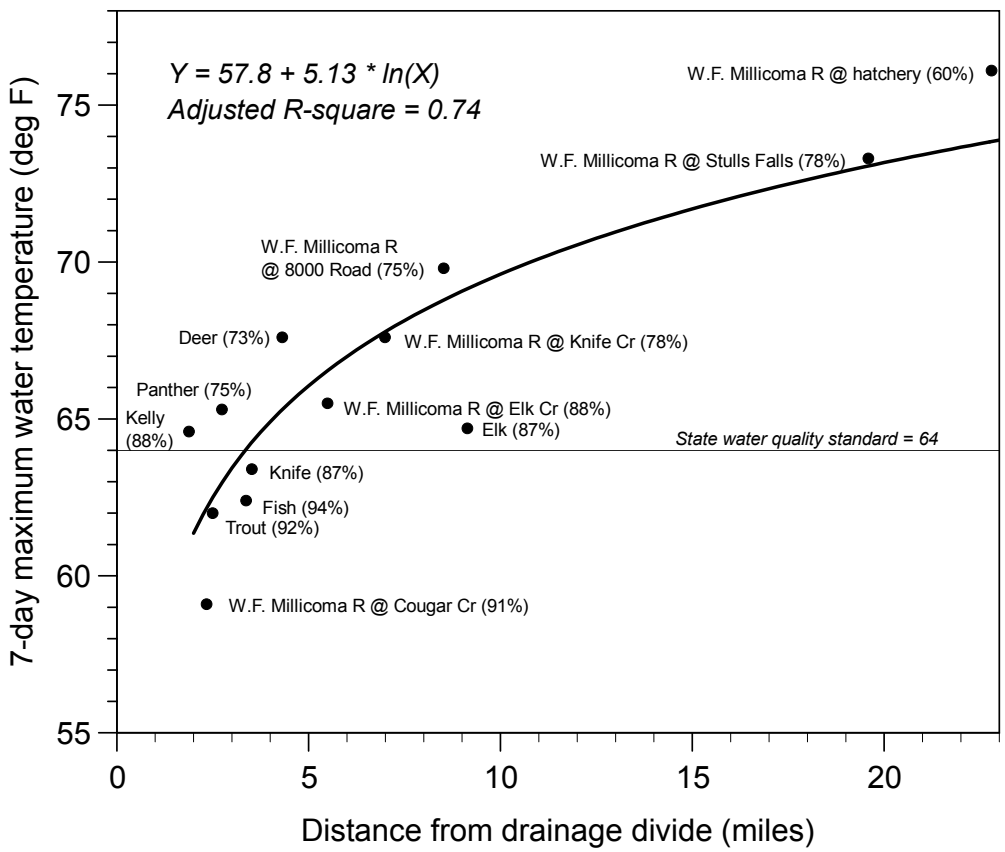
Max. temp. = greatest annual 7-day average of maximum water temperature (°F).
ODFW shade = shading over stream obtained using a clinometer in the field (%).
DEQ shade index = shading over stream obtained from aerial photographs, topographic maps, and simulation using the SHADOW model by DEQ (%).
Divide = distance from gauging station along stream (miles) to the maximum distance to the drainage divide.
* Stream record not used to develop predictive equation.
** Site included a temperature value for each of 3 years; for all other sites temperature values for 1 or 2 years were estimated using common years of record.

Results

West Fork Millicoma Sites

Distance from drainage divide (natural log transformed) explained nearly three-quarters of the temperature variance among sites in the West Fork Millicoma data set (Figure 5-1). The 7-day maximum water temperatures were less than the DEQ water quality standard (64° F) at only 4 of the 13 sites, despite relatively high values of shading at all sites. These four sites were small streams and three of these had the highest ODFW shade values. Sites with more shade tended to plot below the regression line, so shade was added to the regression equation to better quantify sources of variation in water temperature.

Figure 5-1. Variation in maximum water temperature with distance from drainage divide for 13 West Fork Millicoma sites.



Note: Average percent shade values 0-2 miles upstream of the site are shown in parenthesis.

The multiple regression equation is:

Temp = 81.0 + 3.17 ln(Distance) - 0.243 * Shade*

where: Temp = 7-day maximum water temperature (°F)
Distance = distance to drainage divide (miles)
Shade = ODFW shade (%)
n = 13

Adjusted squared multiple R = 0.89
P-value for the distance term was 0.002.
P-value for the shade term was 0.003.

No correlation was found when the residuals associated with this equation were plotted against percent substrate consisting of silt/sand or active channel width. The regression equation indicates that most of the water temperature variance among sites (89%) can be explained by a combination of variables that include distance from divide and ODFW shade (integrated 0-2 miles upstream of the gauging site).

Other intervals of shade-averaging upstream of gauging sites were examined to determine whether the predictive equation could be improved. The distance over which shade was averaged was reduced to 1 mile and 0.5 mile. Substitution of these values resulted in a reduction in the R-square values in the regression equation (Table 5-2), thereby showing that the 2 mile distance is more appropriate for explaining variance in water temperature than shorter distances.

The DEQ shade values calculated using the SHADOW model were substituted for the ODFW shade values in the regression equation. The DEQ shade values were not significant at the P=0.05 level, leaving only the independent variable, distance from divide, as a significant term (Table 5-2). Therefore, ODFW shade was better at explaining variance in maximum water temperature for this data set.

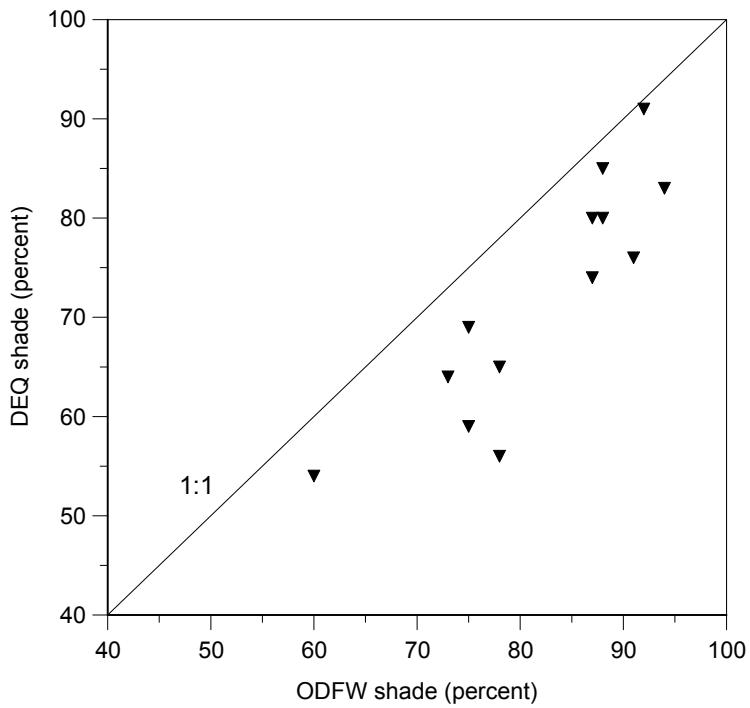
Table 5-2. Significance and fit for a multiple regression equation examining variance in the 7-day maximum water temperature and the independent variables distance from divide (natural-log transformed) and shade.

Shade Measure Method	Shade Averaging distance (mi.)	Adjusted Squared Multiple R	P-term for Distance from Divide	P-term for Shade
ODFW	0 to 0.5	0.82	0.0004*	0.0275*
	0 to 1	0.85	0.0009*	0.0105*
	0 to 2	0.88	0.0019*	0.0028*
DEQ	0 to 0.5	0.75	0.0016*	0.2566
	0 to 1	0.75	0.0019*	0.2137
	0 to 2	0.80	0.0153*	0.0576

* Significant at the 0.05 level.

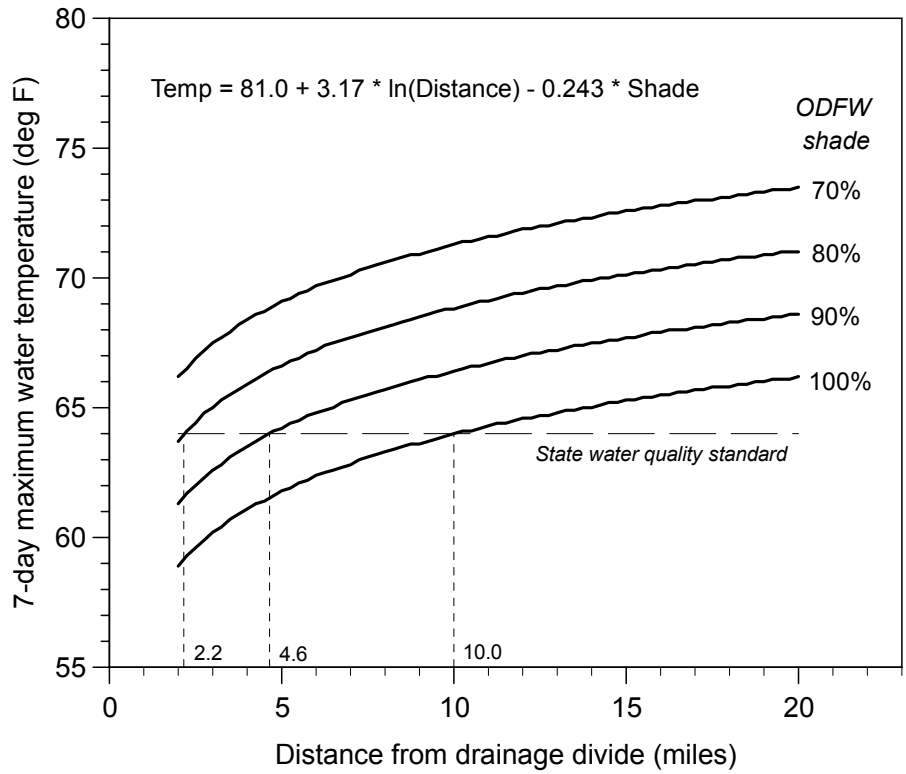
Examining the ODFW and DEQ shade values in more detail, it became apparent that there was only fair correlation between the two methods, and that the ODFW shade values averaged about 10 percentage points higher than the DEQ shade values (Figure 5-2).

Figure 5-2. Comparison of DEQ and ODFW shade integrated 2 miles upstream of the gauge sites.



The predictive equation for the West Fork Millicoma Basin indicates that a 10% loss of shade results in about a 2.4° F increase in water temperature (Figure 5-3). This equation is applicable only for the range of values included in the data set (2-20 miles for distance from drainage divide and 70% to 100% for shade).

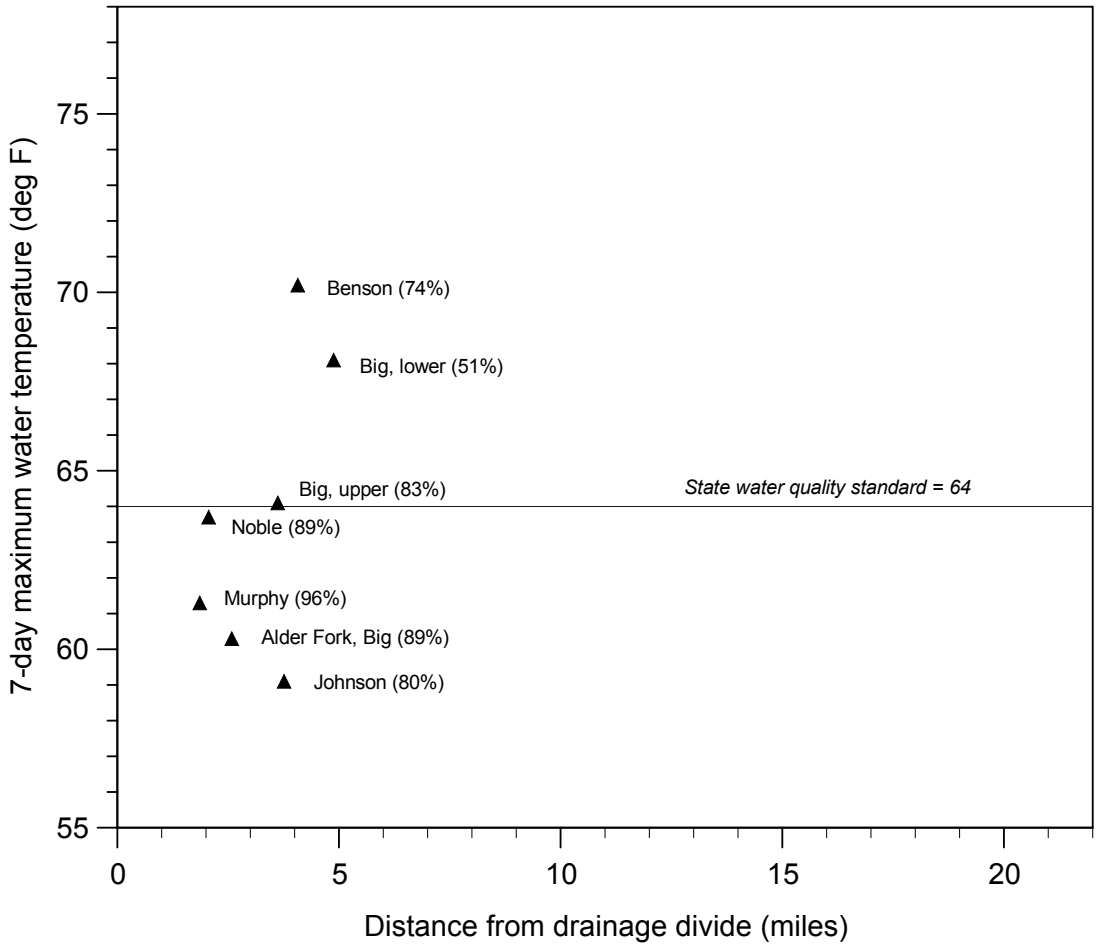
Figure 5-3. Predicted increases in 7-day maximum water temperature for West Fork Millicoma sites.



Tenmile Sites

A similar examination of variance was conducted for the Tenmile sites and no correlation was found between the 7-day maximum water temperature and the independent variables (distance from divide, ODFW shade, percent substrate as silt/sand and gravel, and active channel width). Five of the seven sites (71%) had 7-day maximum temperature values that were equal to or less than the state water quality standard (Figure 5-4). The temperature of Johnson Creek was exceptionally cool (59° F) considering that the gauging site was 3.8 miles from the drainage divide.

Figure 5-4. Variation in maximum water temperature with distance from drainage divide for seven Tenmile sites.



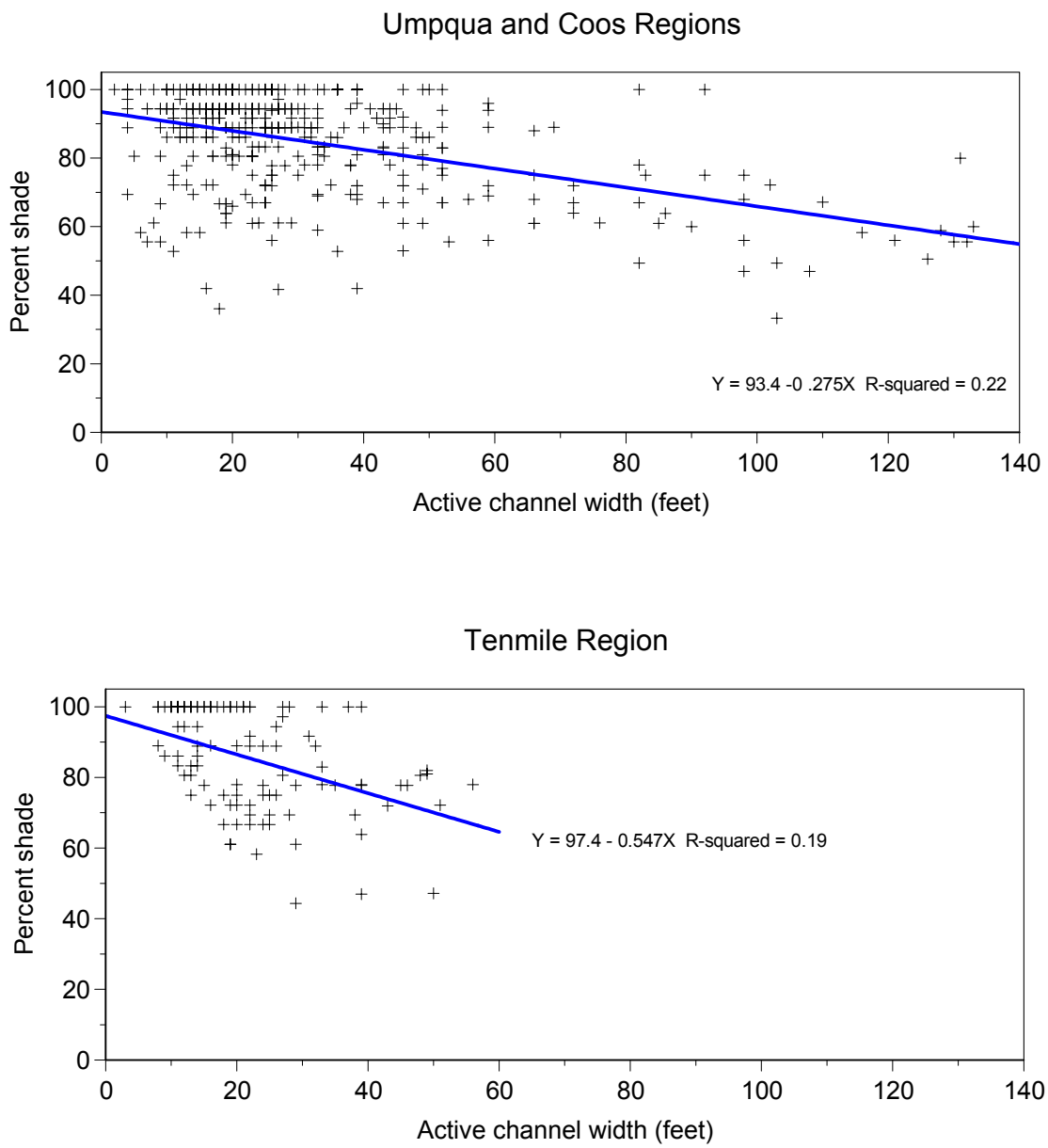
Note: ODFW shade values in parenthesis.

Stream shade values throughout the Forest were obtained from ODFW stream surveys. Nearly 500 points had both active channel width and shade information, and these were used in the following discussion. Shade values did not vary much among regions for streams with the same active channel width (Table 5-3). Correlations between shade and channel width were weak, with only about 20% of the variation around mean shade values explained by width (Figure 5-5).

Table 5-3. Mean ODFW shade values by active channel width by region.

Region	Mean Percent Shade for Active Channel Width Categories (standard deviation in parenthesis)		
	0 - 30 feet	**31 - 60 feet**	**6 - 120 feet**
Coos	89 (12)	83 (13)	68 (11)
Umpqua	82 (14)	83 (13)	65 (21)
Tenmile	87 (14)	78 (15)	---

Figure 5-5. Variation in ODFW shade with active channel width along fish-bearing streams.



NUTRIENTS AND DISSOLVED OXYGEN

The abundance of nutrients, the amount of sunlight striking a stream's surface, and the type of channel substrate largely controls the production of aquatic plants (including algae) and insects occupying a stream. Usually, productivity is greatest and species most varied where nutrients and sunlight are abundant and the substrate consists of gravel and cobbles. Nevertheless, the conditions that lead to high productivity can sometimes have side effects. Profuse aquatic plant growth in a stream can lead to elevated pH values that are detrimental to fish. The nighttime decay of plentiful aquatic plants can lead to depressed levels of oxygen in the water. The abundant sunlight, which boosts primary productivity, also may warm the water to the point that a fish's metabolism exceeds its ability to feed itself.

Timber harvest invariably leads to some short-term losses of nutrients from surrounding slopes because the dense root mat dies and roots from the new trees and brush take a few years to reoccupy the site. Although nitrogen is highly mobile in soils, its uptake by roots, bacteria, and other organisms in the soil help keep it on site. The loss of phosphorus after timber harvest is less of a problem since it tightly adheres to soil particles. The main pathway for phosphorus to enter a stream is through erosion of the soil. Even when in the stream, the phosphorus usually remains attached to soil particles, although low dissolved oxygen levels, such as those commonly found in the bottom of lakes, can cause phosphorus in the bottom sediment to come into solution. The following studies done on small (less than 10 square miles) watersheds in Oregon provide some perspective on the amount and timing of nutrient loss following timber harvest.

Complete clearcut harvest of a small basin in the South Umpqua River drainage caused nitrate concentrations in the stream to increase for a 5-year period following harvest (Adams and Stack 1989). Pre-harvest concentrations were 0.005 milligrams per liter (mg/L) but increased to 0.120 mg/L by the third year. Nitrate levels returned to normal after the fifth year. An adjacent watershed that had 30% of its area harvested as patch cuts exhibited only small increases in nitrate.

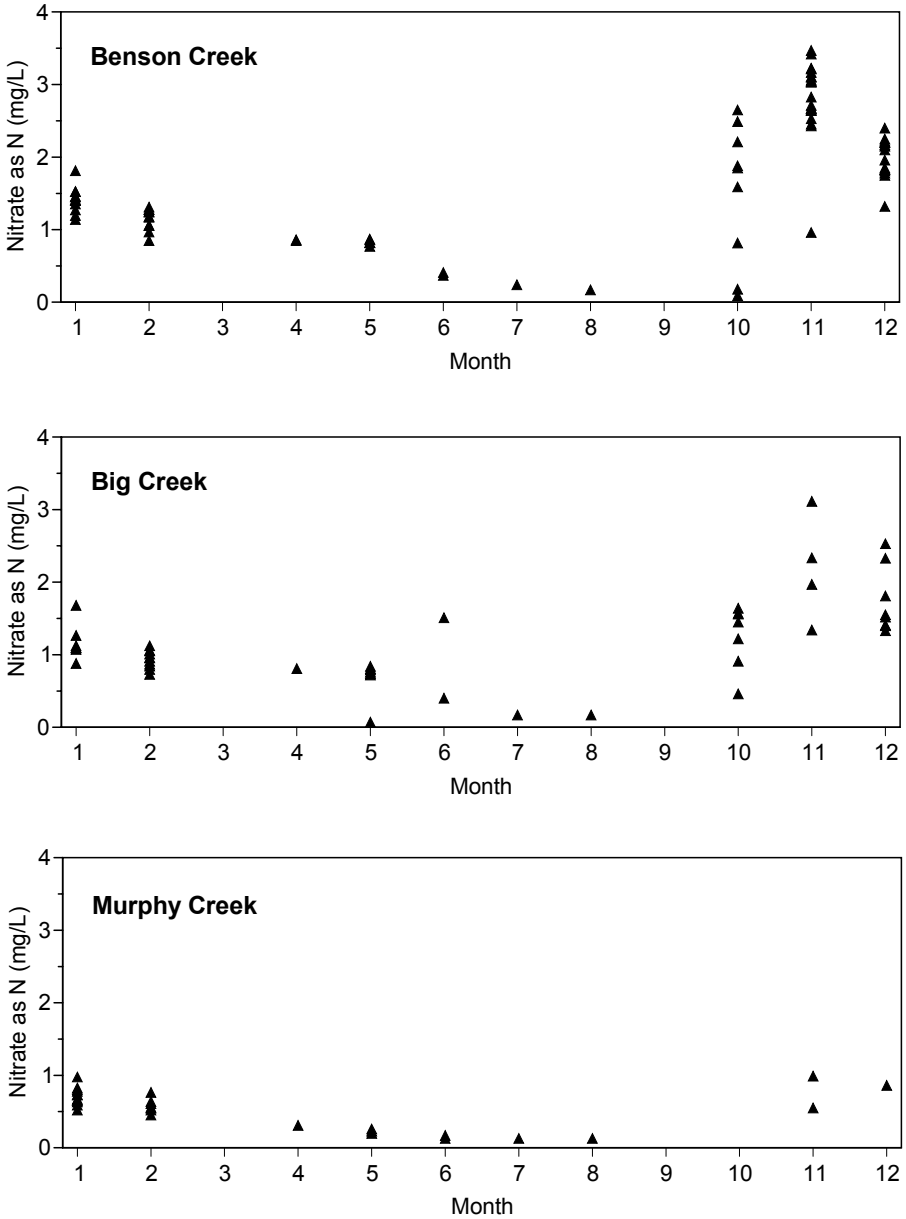
Nitrate concentrations in a small Alsea River tributary, which had been 100% clearcut and then intensely burned increased 4-fold over pre-harvest levels although the increases lasted only 2 years (Brown et al. 1973). Nitrate concentrations did not change for an adjacent small stream, which had 25% of its basin clearcut and lightly burned. Concentrations of phosphorus in the water column were unchanged for both streams.

Nitrate levels in a small stream in the central Oregon Cascades increased from 0.01 mg/L to 0.036 mg/L for the first 3 years after the entire basin was clearcut and lightly burned (Martin and Harr 1989). By the sixth year, nitrate concentrations were back to pre-logging levels. Phosphorus concentrations in the water column did not change.

Accelerated nitrogen leaching from a small basin may not necessarily show up in downstream waters during the summer. Oregon coastal streams are naturally low in nutrients, especially during the summer, and these nutrients are tightly recycled by aquatic

life and streamside vegetation. In fall and winter, much of the nitrogen is released back into the water column after the algae and other plants decay (Figure 5-6).

Figure 5-6. Seasonal changes in nitrate concentrations for three streams draining from the Forest to Tenmile Lake.



Note: data from Eilers et al. 2001 and DEQ; samples taken from 1998-2002.

High nitrogen levels in streams during fall and winter are rarely a problem since cool temperatures keep dissolved oxygen concentrations high and the decay of organic material is low. Also, photosynthesis by aquatic plants during winter and spring is low and flows are high, which keeps any high pH conditions from occurring. Dissolved oxygen problems are most likely to occur during fall conditions when dying algae and leaves are abundant and when stream flow is low due to a lack of rain.

Methods

Information on nutrients and related water quality parameters is scarce for Forest streams. Samples have been gathered at only seven sites. Three sites are in the West Fork Millicoma Basin and three are in the Tenmile region. The remaining site is in the headwaters of the West Fork of Lake Creek (Umpqua region). Sampling was done by the U.S. Environmental Protection Agency (USEPA REMAP project), by the DEQ, or by Eilers and others (2001, 2002). Information on recent timber harvest upstream of the sampling sites was not included in the USEPA and DEQ data sets. It can be assumed that an array of stand ages ranging from recent clearcuts to stands older than 100 years exist upstream of most sites.

Variability among sampling periods for sites with multiple records was small so a mean value was calculated and is used in the following discussion. For orthophosphate values that were below the detection limit (0.005 mg/L), a value of one-half the detection limit (0.0025 mg/L) was used in the calculation of a mean value. All nitrogen/nitrite values were at or above the detection limit (0.02 mg/L). Also, results from a study on nutrients within Tenmile Lakes (Eilers et al. 2001, 2002) are included in the discussion of phosphorus.

Results

Summer orthophosphate concentrations were exceedingly low at all stream sites, suggesting that the summer aquatic biota readily extracts most available phosphorus from the water (Table 5-4). Mean orthophosphate concentrations were only 0.003 to 0.012 mg/L. The lowest values occurred in the West Fork Millicoma Basin.

Summer nitrate/nitrite concentrations varied from a low of 0.04 mg/L in upper West Fork Lake Creek to a high of 0.56 mg/L in Big Creek. The average value was 0.24 mg/L among the other sites, which is typical for coastal Oregon streams during the summer. The lack of phosphorous in the water column probably limits further uptake of nitrogen by algae.

Values for pH (average of 7.3) are somewhat higher than would be expected for forest streams in Oregon, which tend to be slightly acidic. Calcium is abundant in the sandstone rock common to the Forest and may be responsible for the somewhat elevated pH values. Values for pH did not vary much among sites.

Consistently high values of dissolved oxygen among samples taken before 10 AM confirm that high pH values are likely a result of geology and not algae productivity. Samples taken prior to 10 AM are least affected by water oxygenation due to photosynthesis by algae. Expressed as percent saturation, oxygen levels ranged from 87% to 100% (morning and afternoon combined) and represent favorable conditions for fish rearing during summer.

However, none of the sampling took place during the fall, the time most critical for fish survival. In fall, dissolved oxygen problems are most likely to occur because leaves are falling into streams, accumulated algae biomass is decaying, and streams often have low flow.

Table 5-4. Selected water quality parameters for streams within or immediately adjacent to the Forest, June through September.

Stream	Date	Time	N	P	pH	DO	DO%
Elk Creek at RM 1.4 (USEPA or DEQ)	9/7/99	1:55 PM	0.16	<0.005	7.2	9.7	96
Elk Creek at RM 3.0 (USEPA or DEQ)	7/26/94	8:00 AM	0.23	0.007	7.3	8.7	87
	8/18/94	9:00 AM	0.17	<0.005	7.6	9.1	92
	9/12/94	10:00 AM	0.14	<0.005	6.9	9.4	86
	8/3/95	9:00 AM	0.22	0.007	7.6	9.6	97
	8/29/95	9:00 AM	0.16	<0.005	8.3	9.6	95
	7/16/96	8:30 AM	0.18	0.006	7.4	8.9	90
	9/10/96	9:20 AM	0.15	<0.005	7.1	9.0	85
	Mean	**---**	**0.18**	**0.004**	**7.5**	**9.2**	**90**
W.F. Millicoma River at RM 22.5 (USEPA or DEQ)	7/27/94	8:00 AM	0.23	<0.005	6.7	9.6	99
	7/18/96	9:38 AM	0.14	---	7.7	9.8	97
	Mean	**---**	**0.19**	**0.003**	**7.2**	**9.7**	**98**
Unnamed tributary of W.F. Lake Creek (USEPA or DEQ)	8/9/94	8:30 AM	0.06	0.015	7.3	9.8	92
	7/8/96	4:00 PM	0.02	0.009	7.7	10.0	95
	Mean	**---**	**0.04**	**0.012**	**7.5**	**9.9**	**94**
Benson Creek at RM 5.0 (USEPA or DEQ)	8/15/95	12:00 PM	0.24	0.009	7.4	9.6	99
	7/17/96	5:00 PM	0.57	0.010	7.5	9.5	93
	Mean	**---**	**0.41**	**0.010**	**7.5**	**9.6**	**96**
Benson Creek (Eilers et al. 2001)	6/13/99	---	0.45	---	7.0	---	---
	6/26/99	---	0.40	---	7.0	---	---
	7/13/99	---	0.14	---	---	---	---
	8/1/99	---	0.13	---	---	---	---
	Mean	**---**	**0.28**	**---**	**7.0**	**---**	**---**
Big Creek 0.5 mi. below Forest (USEPA or DEQ)	9/22/98	12:44 PM	0.19	0.006	7.2	9.1	87
Big Creek (Eilers et al. 2001)	6/13/99	---	1.50	---	7.3	---	---
	6/26/99	---	0.46	---	---	---	---
	7/13/99	---	0.13	---	---	---	---
	8/1/99	---	0.13	---	---	---	---
	Mean	**---**	**0.56**	**---**	**7.3**	**---**	**---**
Murphy Creek (Eilers et al. 2001)	6/13/99	---	0.18	---	6.9	---	---
	6/26/99	---	0.13	---	6.9	---	---
	7/13/99	---	0.13	---	---	---	---
	8/1/99	---	0.13	---	---	---	---
	Mean	**---**	**0.14**	**---**	**6.9**	**---**	**---**

N = nitrate and nitrite (mg/L as N); P = orthophosphate (mg/L as P); pH = standard units; DO = dissolved oxygen (mg/L); DO% = dissolved oxygen (% of saturation).

A recent study of nutrient dynamics within Tenmile Lakes (Eilers et al. 2001, 2002) was sponsored by the Tenmile Lakes Basin Partnership (TLBP) to better understand processes that influence water quality. The study demonstrated that phosphorus concentrations in the water column control algae growth within Tenmile Lakes, and that the phosphorus is delivered to the lake attached to sediment particles and by leaching from lakeside septic systems. Low dissolved oxygen concentration at the lake bottom during the summer releases some of the phosphorus attached to bottom sediments, thereby making more phosphorus available for additional algae growth.

The authors also examined suspended sediment inputs from streams, including those that primarily drain the Forest. Suspended sediment loads were measured for three streams (Big, Benson, and Murphy Creeks) for 1 year and then modeled using the SWAT model (Arnold et al. 1995). This model was originally developed to estimate sediment production due to rill and gully erosion; it has no mechanism for determining sediment yields due to landslides, which are a major source of sediment delivery into Forest streams. The modeling results indicated that Forest streams have suspended sediment loads that were less than measured sediment loads for three similar coastal watersheds with no previous timber harvest, and were much less than watersheds with various levels of timber harvesting (Table 5-5).

Table 5-5. Annual suspended sediment yield from coastal watersheds and modeled sediment yields for five streams draining into Tenmile Lakes.

Study	Geology	Watershed	Condition	Annual suspended sediment yield (tonnes/sq.km./yr)
Reid 1981, Olympic Mountains, Washington	Steep, sedimentary	Clearwater	Partially clearcut; road landslides	126*
Beschta 1978, Coast Range, Oregon	Steep, sedimentary	Flynn	100% forested.	98*
		Deer	100% forested.	97*
		Deer	100% forested, 25% recent clearcut; road landslides.	136*
		Needle	100% forested.	53*
		Needle	100% clearcut and severely burned.	146*
Eilers et al. 2002, Tenmile Lakes nutrient study; only subbasins with a majority of area in the Forest were included.	Steep, sedimentary	Murphy	90% forested, 7% recent clearcut.	7**
		Big/Noble	92% forested, 5% recent clearcut.	36**
		Benson	92% forested, 3% recent clearcut.	26**
		Johnson	94% forested, 2% recent clearcut.	28**
		Adams	84% forested, 8% recent clearcut	9**

* measured ** modeled using SWAT

HERBICIDES

Herbicides are used on the Forest to remove competing plants in new clearcuts prior to or shortly after planting conifers, and less commonly to release young conifer trees that are in danger of being overtopped by brush and hardwood trees. A third use of herbicides is for eliminating invasive Scotch broom from roadside areas or portions of older clearcuts. No insecticides or fungicides are currently used on the Forest.

Most herbicides are aerially applied during dry weather in September. At this time of year, glyphosate and imazapyr, the most common mix of herbicides used on the Forest, are most effective at killing competing vegetation. Occasionally, an aerial herbicide application will occur during dry weather in July; this has happened only once since 1999. Site preparation applications usually apply glyphosate at a rate of about 0.5 gallons/acre combined with imazapyr applied at a rate of about 0.04 gallons/acre. Common brand names for glyphosate include Roundup and Accord. The common brand name for imazapyr is Arsenal. Both are considered to be of low toxicity to fish. Glyphosate is not mobile in the soil while imazapyr is considered to have high soil mobility (Table 5-6).

Table 5-6. General characteristics of herbicides that have been applied on the Forest since 1999, in order of volume of use.

Compound	Brand Name	Acute Toxicity to Fish (LC50*)	Mobility in Soil
Glyphosate	Roundup, Accord	Low (30)	Low
Imazapyr	Arsenal	Low (>100)	High
2,4-D		Variable**	Moderate
Triclopyr		Low (120)	Moderate
Clopyralid	Transline	Low (110)	High
Sulfometuron	Oust	Slightly (12)	High

* LC50 is the dose (mg/L) that kills 50% of fish after 96 hours of exposure.
** Highly variable depending on formulation.
Toxicity and mobility information from http://infoventures.com/e-hlth.

Since 1999, the herbicide 2,4-D (sometimes combined with imazapyr) has been used on the Forest only for eliminating Scotch broom. Its toxicity to fish is variable depending on the formulation and it is moderately mobile in soils. Three other herbicides, clopyralid, triclopyr, and sulfometuron (in combination with glyphosate) each have been used once since 1999. They have low toxicity to fish except for sulfometuron, which is slightly toxic, and they are moderately or highly mobile in soils (Table 5-6). In addition to aerial or roadside applications of herbicides, red alders on 394 acres were killed with imazapyr by stem injection (hack and squirt) in 1999.

Glyphosate is used on the Forest as a general spray to control a wide array of broadleaf plants, shrubs, and grass. However, since glyphosate is not effective at controlling evergreen huckleberry, rhododendron, or Oregon myrtle, imazapyr is often used in combination. Clopyralid was used one time to control red elderberry. Triclopyr is effective at controlling Scotch broom and evergreen blackberry, and sulfometuron has been used to control Scotch broom. Herbicide applications in the Forest have averaged 550 acres annually over the last 4

years (Table 5-7). Therefore, about 0.6% of the land base is treated each year with herbicides. Imazapyr has been used on 91% of the total area sprayed during the last 4 years, while glyphosate has been used on 80% of the area.

The concentration of a chemical in a stream is usually expressed as mg/L; 1 milligram per liter is the same as 1 part per million. For perspective, adding 1 liter (about 1 quart) of chlorine to an Olympic-size swimming pool (253,000 gallons) results in a chlorine concentration of about 1 part per million.

Since it is commonly used near water, the toxicity of glyphosate on fish has been tested extensively over the last 10 years. One formulation of glyphosate (Rodeo) has federal approval for use in water. Fish have a relatively high tolerance for salt of glyphosate, which is the active ingredient in formulations such as Roundup, Accord, and Rodeo. It is the surfactant used with Roundup that is more toxic to fish. The term commonly used to quantify the toxicity of a compound on fish is LC50. It is the minimum concentration that kills 50% of fish (following 96 hours of exposure) in tank tests. The LC50 for rainbow trout for salt of glyphosate is 140 mg/L (Folmar et al. 1979) but 2-3 mg/L for the surfactant that is included in Roundup (Norris and Dost 1992). The LC50 for salmonids exposed to the combined salt of glyphosate and surfactant ranges from 11-55 mg/L (Table 5-8). A surfactant is used to make the glyphosate stick to vegetation so it can be absorbed through the leaves. It also makes the leaf surface more receptive to the entry of the glyphosate. In the discussions below, references to glyphosate include the formulation of salt of glyphosate plus its surfactant.

The vegetation conditions and the manner in which an herbicide is applied can greatly influence the herbicide concentration to which fish are exposed. When glyphosate was sprayed over streamside areas with no provisions to keep the spray out of the stream, Feng and others (1989) measured peak levels up to 0.16 mg/L in the stream. Following the first rains, concentrations peaked again at 0.11 mg/L. Similarly, Newton and others (1984) measured peak concentrations of 0.27 mg/L when a small forest stream was oversprayed with glyphosate. Thompson and others (1991) found peak concentrations of triclopyr reached 0.23-0.35 mg/L following overspray of a stream in Ontario, Canada. The use of best management practices to avoid direct entry of spray into stream and minimize drift, combined with the presence of streamside buffers of trees and brush that intercept much of the spray, greatly reduces the concentration of herbicides that end up in streams. Rashin and Graber (1993) monitored six clearcuts in Washington that had been sprayed with various herbicides and found glyphosate concentrations never peaked above 0.008 mg/L and imazapyr concentrations stayed below 0.001 mg/L (Table 5-9). Concentrations of 2,4-D were below 0.002 mg/L and below 0.001 mg/L for triclopyr.

Combined with information from Table 5-8, this means that glyphosate concentrations in streams were less than 0.03% of the LC50 acute toxicity concentration for fish when current best management practices were used. For imazapyr and triclopyr, stream concentrations were less than 0.001% of the LC50 values. Although no studies have been conducted on the Forest to monitor the concentrations of herbicides in streams following treatment of clearcut units, the best management practices used are similar to those in Washington.

Table 5-7. Aerial application of herbicides on the Forest, 1999-2002.

Year	Month Applied	Purpose	Acres	Glyphosate *(Roundup, Accord)*		Imazapyr *(Arsenal)*		Clopyralid *(Transline)*		Triclopyr		Sulfometuron *(Oust)*	
				Rate (gal/ac)	Use (gal)	Rate (gal/ac)	Use (gal)	Rate (gal/ac)	Use (gal)	Rate (gal/ac)	Use (gal)	Rate (gal/ac)	Use (gal)
1999	Sept.	Site prep.	143	0.75	107.3	0.034	4.8	---	---	---	---	---	---
1999	Sept.	Site prep.	100	0.50	50.0	0.036	3.6	---	---	---	---	---	---
1999	Sept.	Release	14	0.31	4.4	---	---	---	---	---	---	---	---
1999	Sept.	Release	40	---	---	---	---	0.078	3.1	---	---	---	---
1999	?	Alder stem injection	394	---	---	---	44.0	---	---	---	---	---	---
Total			**691**		**161.6**		**52.4**		**3.1**		**---**		**---**
2000	Sept.	Site prep.	40	0.75	30.0	0.031	1.2	---	---	---	---	---	---
2000	Sept.	Site prep.	392	0.50	196.0	0.038	14.9	---	---	---	---	---	---
Total			**432**		**226.0**		**16.1**		**---**		**---**		**---**
2001	July	Site prep.	278	0.50	139.0	0.047	13.0	---	---	---	---	---	---
2001	Sept.	Site prep.	274	0.37	101.4	0.047	12.9	---	---	---	---	---	---
2001	Sept.	Site prep.	55	0.50	27.5	0.023	1.3	---	---	0.31	17.0		---
Total			**607**		**267.9**		**27.3**		**---**		**17.0**		**---**
2002	Sept.	Site prep.	293	0.37	108.5	0.047	13.8	---	---	---	---	---	---
2002	Sept.	Site prep.	125	0.75	93.8	---	---	---	---	---	---	---	---
2002	Sept.	Site prep.	42	0.25	10.5	0.016	0.6	---	---	---	---	0.023	1.0
2002	Sept.	Release	10	0.31	3.1	---	---	---	---	---	---	---	---
Total			**470**		**215.9**		**14.5**		**---**		**---**		**1.0**

Other projects:
2001: Road application to kill Scotch broom using triclopyr (5.5 gallons) and 2,4-D (3.6 gallons) on about 25 acres.
2002: Aerial application (April or May) to prevent flowering of Scotch broom using 2,4-D (73 gallons) on 146 acres.

Table 5-8. Studies on the toxicity of Roundup and salt of glyphosate on salmonids.

Study	Herbicide	Species	LC50* Toxicity (mg/L)	Comments
Folmar et al. 1979	Roundup Salt of glyphosate only	Rainbow trout Rainbow trout	11 140	No changes in fecundity or gonadosomatic index when exposed to concentrations of Roundup as much as 2 mg/L.
Servizi et al. 1987	Roundup	Juvenile sockeye Rainbow trout Juvenile coho	28 27 42	---
Wan et al. 1989	Roundup	Juvenile coho Juvenile chinook Juvenile rainbow	27 27 15	---
Hildebrand et al. 1982	Roundup	Rainbow trout	55	10-fold and 100-fold increases over recommended aerial application rates (2 lb/ac) resulted in no morality of rainbow trout during field studies.
Holtby and Baillie 1989	Roundup	Juvenile coho	---	Some stress and 3% mortality for caged juvenile coho in a side-channel that had been oversprayed. No stress or mortality for free-swimming coho. No changes in fish mortality, growth, or migration of coho 1-2 years after spraying.
Newton et al. 1984	Roundup	Juvenile coho	---	Following aerial application of Roundup (3lb/ac) on a forest brush patch with a small stream flowing through it, half-life of glyphosate on vegetation was 10-27 days and twice as long in the soil. Glyphosate concentrations in stream peaked at 0.27 mg/L and rapidly declined. No detectable amounts of glyphosate found in juvenile coho salmon that lived in stream.

- LC50 is the dose that kills 50% of fish. In the above studies, exposure was for 96 hours.

Table 5-9. Peak and maximum 24-hour average concentrations of herbicide within streams for treated clearcuts in western Washington.

Site	Herbicide	Peak Concentration (mg/L)	Maximum 24-hour Average Concentration (mg/L)
FH3	Glyphosate	0.0044	0.00029
FH2	Glyphosate Imazapyr	0.0076 0.0011	0.00056 0.00036
FH1	Glyphosate Imazapyr	0.0024 <0.0005	0.00032 <0.0005
SH1	Triclopyr	0.0013	0.0013
SH3	2,4-D Triclopyr	<0.00004 0.00002	<0.00004 <0.00002
SH2	2,4-D	0.0025*	0.00069*

*Rainfall occurred shortly after application of herbicide.
Source: Rashin and Graber 1993.

Herbicide application methods used by the Forest to minimize risks to streams and humans include:

- Use of half-boom techniques when applying herbicides near streamside buffers, where the boom on one side is shut off and the wash of air from the helicopter blade forces the spray downward with little scatter to the side.
- No spraying is done over perennial streams (and all of these streams also are buffered by retained trees), wetlands, seeps, or other wet areas.
- All spray mixing and handling is done on landings away from stream channels.
- Spraying occurs only on calm, dry days in order to avoid drift of spray into adjacent areas or wash-off of spray by rain.
- Nearby landowners are contacted prior to the herbicide application.

The Forest Practice Rules include a number of other restrictions on herbicide use on forestland that further minimize the risk of chemicals entering streams.

WATER QUALITY LIMITED STREAMS AND LAKES

The DEQ oversees a process, as required by the federal Clean Water Act, of listing certain streams and lakes that are deemed to be water quality limited. Data for an individual stream, lake, or estuary can be submitted by agencies or individuals to the 303(d) List. If the data suggests that a water body does not meet water quality standards, the water body is identified on the 303(d) List as water quality limited. A water quality limited stream is not necessarily one impaired by human activity; its designation simply means that a numeric or qualitative water quality standard established by DEQ has been exceeded. The question of whether or not human activities caused the standard to be exceeded is dealt with through a subsequent Total Daily Maximum Load (TMDL) process. The 303(d) List was last updated on March 24, 2003. Since many streams exist throughout Oregon for which information on basic water quality has never been collected, the 303(d) List is not complete.

No segments of stream flowing on the Forest are currently included in the 303(d) List. However, several water bodies to the west of the Forest are on the list (Map 5.1). Larson Slough is listed for both water temperature and bacteria from the confluence of Larson and Sullivan Creeks (1.8 miles downstream of the Forest boundary) to Haynes Inlet, a northern appendage of Coos Bay. The upper portions of Larson and Sullivan Creeks are managed by the Forest and are heavily shaded throughout their lengths. Once Larson Creek exits the Forest, it flows through pasturelands and is exposed to sun through much of its length. A future DEQ assessment of the potential sources of high bacteria counts in lower Larson Creek will address wildlife, cattle grazing, and possible human sources. Portions of the bacterial load from wildlife likely originate on the Forest. These loads are often considered background and are not part of human-caused loads. The downstream end of Scholfield Creek also is listed for bacteria; cattle graze along this stream downstream of the Forest.

Both North Tenmile and South Tenmile Lakes are listed for weeds and algae. Forest streams that flow into these lakes include (from north to south) Wilkins, Murphy, Big, Noble, Benson, Roberts, Johnson, and Adams Creeks. A TMDL of Tenmile Lakes is in progress

and Forest staff will be asked to evaluate the contribution of nutrients from Forest streams into the lakes. The ODF has been involved in two previous TMDL processes throughout the state that involved nutrients. One was for the Tualatin River Basin near Beaverton and the other was for Bear Creek near Medford.

ANALYSIS

Water Temperature

The information in this chapter indicates that ODFW shade values of 80% or more typically keep the 7-day maximum water temperature of Forest streams below 70° F, even at distances of 20 miles from the drainage divide. Surveys by ODFW indicate that existing shade along Forest streams currently averages 78% to 89% (depending on region), even for streams up to 60 feet wide. Current management practices on the Forest result in the retention of nearly all existing shade since buffers along fish-bearing streams extend 100 feet or more each side of the channel, and at least to 50 feet on each side of perennial streams without fish. Streams that were exposed to full sunlight decades ago, a time when the harvest of trees extended to the edge of the channel, have since grown back with dense vegetation. Most areas that were once bared to construct streamside roads also have grown back to dense stands of trees.

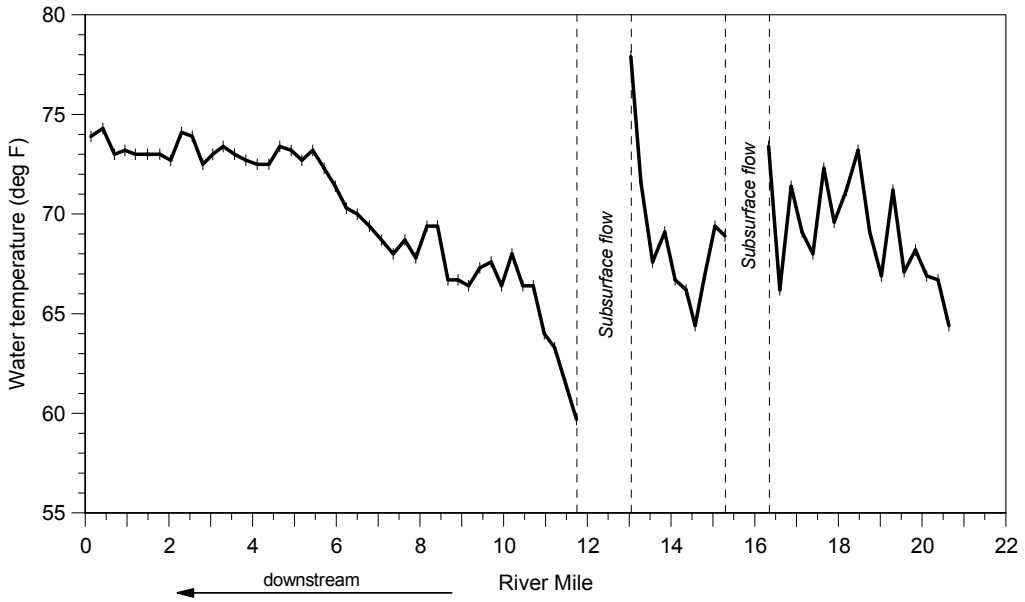
The above information suggests that even with 100% shading, the temperature of a Forest stream is predicted to warm beyond 64° F at distances greater than 10 miles from the drainage divide. The temperature regression equation presented in this chapter provides a more appropriate indicator of natural maximum water temperatures throughout the Forest than does assuming that the state standard of 64° F represents natural conditions. While many smaller streams in the Forest are cooler than the state standard, natural processes warm many larger streams beyond the standard, even with high levels of shading. The ODFW inventories of existing shade along fish-bearing streams show relatively high overall shading throughout the Forest.

While the predictive temperature equation was developed from data gathered in the Coos region, it likely also applies to the Umpqua region because of its similar climate. However, the equation would likely over-predict maximum water temperature for many streams in the Tenmile region, especially those that are influenced by cool marine air or fog during hot spells. Estimating the 7-day maximum temperature of a point along a stream using the predictive equation requires data on distance from divide (obtained from a topographic map) and the shade integrated 0-2 miles upstream of the point (obtained from ODFW surveys).

A limited number of studies on gravel-rich streams (McSwain 1987, Morrice et al. 1997, Poole and Berman 2001) indicate that overall stream temperature can cool considerably when all or some of the stream flow goes subsurface and then resurfaces downstream. The current scarcity of gravel in Forest streams (due in part to the removal of large wood) could be causing streams to be warmer than normal. Figure 5-7 illustrates the magnitude of stream cooling that occurred in Meacham Creek, a northeast Oregon stream, which had two reaches where flow went completely subsurface (data from Jim Webster, Confederated Tribes of the

Umatilla Indian Reservation; reported in the 2003 *Meacham Creek Watershed Analysis and Action Plan*). During the summer, Meacham Creek has about the same flow as the lower West Fork Millicoma River. The analysis team could not find any studies that have been done on streams dominated by bedrock channels where water temperature was evaluated before and after placement of logs and subsequent gravel accumulation in the channel.

Figure 5-7. Downstream trend in water temperature for Meacham Creek, an eastern Oregon stream that has abundant gravel.



Source: 2003 *Meacham Creek Watershed Analysis and Action Plan.*

Nutrients

Limited monitoring of nitrogen and phosphorus during the summer for Forest streams, along with related water quality parameters, indicates that the values are not elevated and fall within the natural range of conditions for Coast Range streams. Since nutrients are naturally scarce in Coast Range streams, the temporary increases of nutrients released when clearcut harvest occurs in small tributary basins are readily assimilated into the aquatic biota in downstream waters. The release of these additional nutrients occurs in the late fall and winter, a time when growth of nuisance algae and low dissolved oxygen levels do not occur.

Tenmile Lakes presents a special situation, in that streams deposit sediment with attached phosphorus into the lakes during the winter, and some of this phosphorus enters the water column during the summer when dissolved oxygen levels at the lake bottom become low. Theoretically, adding more sediment to a lake above background levels can lead to accelerated algae growth since bioavailable phosphorus is the most limiting of the two nutrients needed to support algae. Modeled sediment loads for streams flowing through the

Forest in the Eilers and others (2002) study suggest that sediment loads from Forest streams were not elevated when compared to undisturbed forested streams elsewhere in the Coast Range where sediment loads were actually measured. The SWAT model used in Eilers and others (2002) does not include a process for dealing with landslides, which is a dominant source of sediment within steep terrain underlain by sandstone geology. An appropriate accounting of suspended sediment loads in streams requires direct monitoring over a number of years, in order to account for both dry and wet winters since sediment yields among years can be 10 times higher in wet years than in dry years (Beschta 1978).

HERBICIDES

From 1999-2002, herbicide use on the Forest has averaged about 550 acres annually. Most of these acres have been treated with a combination of glyphosate (about 0.5 gallons/acre) and imazapyr (about 0.04 gallons/acre). No monitoring of these herbicides in streams following spraying of adjacent clearcut harvest units has been done on the Forest. However, monitoring of similar spraying operations in western Washington indicate that glyphosate concentration measured within streams was typically only 0.03% of the LC50 toxicity concentration for salmonids. For imazapyr, the measured concentration was about 0.001% of the LC50 concentration for salmonids. Neither insecticides nor fungicides have been used on the Forest, nor does the Forest staff see any near-term need to use these chemicals.

Under the federal ESA, the USEPA is required to ensure that the pesticide use it authorizes will not jeopardize endangered species. The USEPA is required to register pesticides for use only after a consultation process with affected parties is completed. Federal District Court Judge John Coughenour found the USEPA not in compliance with the ESA with respect to pesticides that pose a threat to salmon because of the lack of the required consultation process. In July 2002, he ordered the USEPA to consult with the NOAA Fisheries (formerly National Marine Fisheries Service) and review 54 pesticides. Although most of these pesticides were insecticides, the list also included 2,4-D and triclopyr, two herbicides that recently have been used on the Forest.

On July 16, 2003, fishing and environmental groups asked the court in the interim to impose no-spray buffer zones of 300 feet wide on each side of stream (for aerial applications) in order to protect salmon until USEPA complies with the order. In a subsequent order, the court found, "…with reasonable scientific certainty, that the requested buffer zones – 20 yards for ground applications, 100 yards for aerial applications – will, unlike the status quo, substantially contribute to the prevention of jeopardy" to salmon. The buffers would remain in place until the USEPA adopts guidelines ensuring that pesticide use does not jeopardize endangered species. The judge heard testimony on August 14, 2003, and told the plaintiffs to develop a recommendation for interim no-spray buffer widths among themselves and other affected parties.

RECOMMENDED ACTIONS AND MONITORING

Water Temperature

The DEQ indicates it will soon propose that the West Fork Millicoma River Basin be added to the 303(d) List, based on temperature measurements that exceeded 64° F in 1996, 1997, and 1999. Once a water body is added to the 303(d) List, a TMDL process may then be initiated. During this process, the DEQ will gather information about natural and human causes of stream warming, determine how much human causes influence temperature and, if human causes exist, develop an energy budget that allocates heat loads to various entities that contribute to water warming. Goals also are set for bringing the water temperature back into compliance. The multiple regression equation developed for the West Fork Millicoma Basin is useful for explaining the variation in stream temperature patterns seen in existing data sets and could be incorporated into the TMDL process as a comparison for any other temperature modeling conducted by DEQ.

One factor that does not normally enter into a temperature TMDL, and may be causing streams to be somewhat warmer than natural, is the role of streambed gravel in keeping water cool. Large wood plays an important role in trapping gravels in Forest streams and, as large wood recovery occurs in the future, a drop in water temperature may occur. The analysis team recommends that Forest staff monitor water temperature when logs are intentionally added to streams to provide habitat for fish, in order to understand the magnitude of such temperature reductions. Monitoring involves the placement of temperature gauges upstream and downstream of the area a few years before and after log placement and gravel trapping, as well as concurrent monitoring of stream temperatures in an upstream control reach.

No Forest streams in the Umpqua region have been monitored for temperature. The climate for most of these streams seems similar to the Coos region, although a gradient of decreasing marine air influence from west (Scholfield Creek) to the east (Mill Creek) probably exists. Monitoring of selected streams in the Umpqua region during a single summer (so that interannual variation can be avoided) would help fill this data gap.

Nutrients

The DEQ has indicated that they will incorporate results of Phase I and Phase II of the Tenmile Lakes study to support an upcoming TMDL of nutrients and nuisance algae in Tenmile Lakes. This will result in some focus on suspended sediment loads within streams that flow from the Forest.

The analysis team does not recommend that Forest staff begin monitoring suspended sediment for streams draining into Tenmile Lakes. An appropriate monitoring effort would require many years of data and involve costly automated measurements of flow and suspended sediment during the wet season. Furthermore, with no information on historic sediment loads from these basins, little could be learned by knowing current sediment loads.

Instead, the analysis team recommends that an update to the 1997-1998 road inventory be conducted in the basins flowing into Tenmile Lakes in order to detect any new discrete sources of accelerated sedimentation.

Herbicides

Studies on herbicide toxicity combined with typical spraying practices used by the Forest indicate a very low risk of harm to fish. Nevertheless, no stream monitoring of herbicides has been conducted on the Forest. Since some members of the public regard the topic of herbicides in streams as very important, the analysis team recommends that Forest staff include stream monitoring as a part of several upcoming herbicide applications. The analysis team also recommends that the methods used by Rashin and Graber (1993) in the western Washington study be adapted by Forest staff in any future herbicide monitoring efforts.

The future use of 2,4-D and triclopyr near Forest streams is uncertain because these two herbicides appear on the list of 54 pesticides under a court-ordered review. An interim ruling may soon restrict the use of these herbicides within 300 feet of streams for aerial applications. The analysis team recommends that brush control plans for the Forest include other herbicides that could be substituted for 2,4-D and triclopyr in case their use becomes further restricted.