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TEMPERATURE MONITORING AND MODELING OF THE MARYS RIVER WATERSHED

EDITED BY
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FOR
The Marys River Watershed Council
AND
The Oregon Watershed Enhancement Board
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TEMPERATURE MONITORING AND MODELING OF THE MARYS RIVER WATERSHED

SUMMARY

This was a study to better understand the temperature patterns of the Marys River watershed, how they may affect the distribution of native cutthroat trout during the summer, and where opportunities may exist for improvement of stream temperatures. This report is in two parts. Chapter 1 summarizes the results of monitoring stream temperatures, and Chapter 2 describes a modeling study of stream temperatures.

Monitoring was based on the placement of 42 temperature data loggers during the summer of 1998 and 26 during the summer of 1999. Seven day moving averages of maximum water temperatures for August indicated that most tributaries had temperatures that were favorable for cutthroat trout. However, the main channel of the Marys River downstream from the confluence of the Tumtum and Marys rivers, and the lower portions some tributaries, had temperatures that often approached or were above 69º F, temperatures considered unsuitable for cutthroat trout. Segments of streams were identified where reduced temperatures would provide major benefits for native trout.

The general trend for downstream warming was similar during both years, with most rapid rate of warming occurring in headwater tributaries. However, some sites were consistently warmer or cooler than expected. These deviations are explained by variations in stream shading, groundwater and tributary influxes, and stream channel morphology. All these factors contributed to the natural warming in the lower reaches of the watershed.

Stream temperatures in a section of the Marys River near Wren were accurately predicted with a temperature model that used *in situ* measurements of air temperature and relative humidity and incorporated factors for hydrology, channel geometry, meteorology, and riparian shade. The results suggested that increased riparian shading could effectively improve habitat conditions for rearing of cutthroat trout in this portion of the Marys River.

Chapter 1

Water Temperature Monitoring of the Marys River, Greasy Creek, and Muddy Creek Watersheds During the Summers of 1998 and 1999

by

Chip Andrus and William Pearcy

Introduction

Cutthroat trout is the only native species of trout in the east slope of Oregon's coast range. Marys River cutthroat trout has been identified as a priority population because of suspected declines due to alteration and loss of habitat (Oregon Dept. Fish and Wildlife (ODFW) 1993; Mamoyac et al. (1995). One reason for the suspected decline may be related to elevated summer water temperatures that restrict distributions of fish.

Preliminary monitoring of stream temperatures at nine sites in the Marys River between Corvallis and Blodgett during the summer of 1996 suggested that temperatures were too warm for coastal cutthroat trout (*Oncorhynchus clarki clarki*) from Wren to the confluence with the Willamette River at Corvallis. Maximum temperatures in this section of the Marys River exceeded 72º F (22º C).

Coastal cutthroat trout, like other salmonids, are not usually found in water above 72º F, although they can acclimate to temperatures as high as 75º F and tolerate temperatures as high as

79º F (Coutant 1972; Dickerson and Vinyard 1999; Johnson et al. 1999). Temperatures above 68º F have been found to reduce growth in juvenile fish (Dwyer and Kramer 1965). In this study we assumed that temperatures above 69º F were suitable for cutthroat trout in the Marys River watershed.

The purpose of this study was to better understand the water temperature patterns throughout the Marys River watershed (Figure 1). Particularly, we wanted to know where water temperature was favorable for cutthroat trout during the summer and where opportunities existed to reduce water temperature to benefit trout.

Methods

Temperature data loggers were purchased from Onset Computing Corp to evaluate water temperature in the Marys River watershed. We also borrowed temperature data loggers from the Philomath High School and Vemco Ltd. data loggers from the Santiam Watershed Council. Forty two temperature gauges were successfully deployed in summer of 1998, and 26 were successfully deployed in summer of 1999, most at the same locations used in 1998. We put about one-half of the gauges in locations throughout the upper Marys River watershed and the Marys River main channel downstream to Corvallis. The other one-half were placed in the Greasy Creek and Muddy Creek sub-basins. We selected sites to correspond with locations were water temperature changes were anticipated. This included major tributaries, especially at their junction with the main channel, and selected sites along the main channel. Obtaining landowner permission to place a gauge in a stream flowing through private land was a time-consuming process so we often used public road crossings for access to gauging sites.

When we began this study we realized that some landowners were sensitive to how the temperature data might be used by government agencies in the future. There was particular

concern that the data would be used by the Department of Environmental Quality (DEQ) to identify stream segments for inclusion on the 303d list. Streams on the 303d list are considered water quality limited and, in the future may be subject to a total daily maximum load (TMDL) allocation process. We felt that the water temperature study should occur without the threat of landowners being subject to a 303d listing so we purposely did not complete all the quality control measures recommended by DEQ. This means that our data will be categorized as educational□and officially not of appropriate quality for placing a stream on the 303d list. Nevertheless, we feel confident that the data are of good quality and are appropriate for the purposes of this study. All temperature loggers were calibrated in water baths before installation in the field.

Groundwater enters streams in the Marys River watershed at about 55 ° F and then warms as it flows downstream Groundwater inputs, ground temperature, and water evaporation cool a stream, and solar radiation and air temperature warm a stream. (See Chapter 2, Table 1 for other factors that affect stream temperatures.) A useful way of comparing streams and displaying longitudinal patterns of stream temperature is to plot temperature against distance from drainage divide. Distance from drainage divide is determined by measuring the length of stream from the gauging site upstream to the drainage divide along the longest tributary (Figure 2). These distances were measured along straight line and do not include river sinuosity. The drainage divide can be envisioned as that upstream area which funnels rainfall to the gauge site.

Both the Onset and Vemco data loggers are small and capable of storing temperature information for months at a time. We set the gauges to take a reading of water temperature every 40 minutes. The gauges were placed such that they remained underwater during low summer flows. Gauges were placed in flowing water and anchored to a rock or root. At the end of summer, the gauge records were compiled and daily maximum values extracted. We then calculated a 7-day moving average of these maximum values and identified periods when these values were the highest (Figure 3). The 7-day moving average of maximum temperature is the

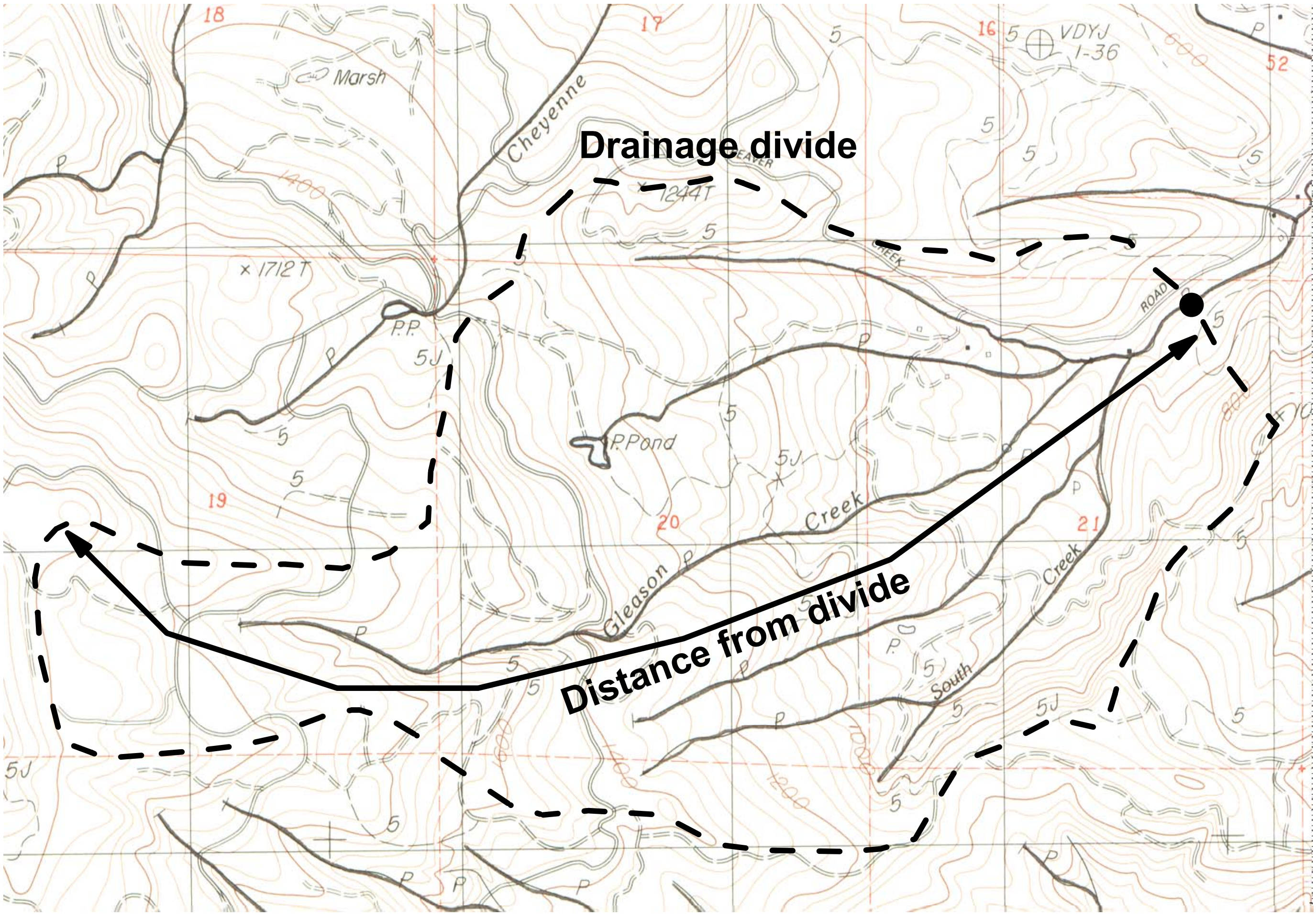


Figure 2. Distance from divide is determined by measuring the length of stream from measuring site upstream to the drainage divide along the longest tributary. The drainage divide defines that area which funnels rainfall to the measuring site.

way temperature is expressed in water quality standards established by the State of Oregon. In addition, the reaction of fish to water temperature is assumed to be more related to high temperatures over a week than simply one day.

Streamflow was measured at selected sites in late summer 1998 using a Marsh-McBurney velocity meter. In addition, vegetative cover above the stream was measured using a spherical densiometer, either at the monitoring site or at 50-foot intervals from 0 to 300 feet upstream of the temperature gauge site. Stream width was measured and substrate type (cobble, gravel, sand/silt, clay, bedrock) was also determined at 50-foot intervals. Furthermore, the type, density, and height of vegetation was described for each interval. Finally, channel gradient was determined using a clinometer at some sites.

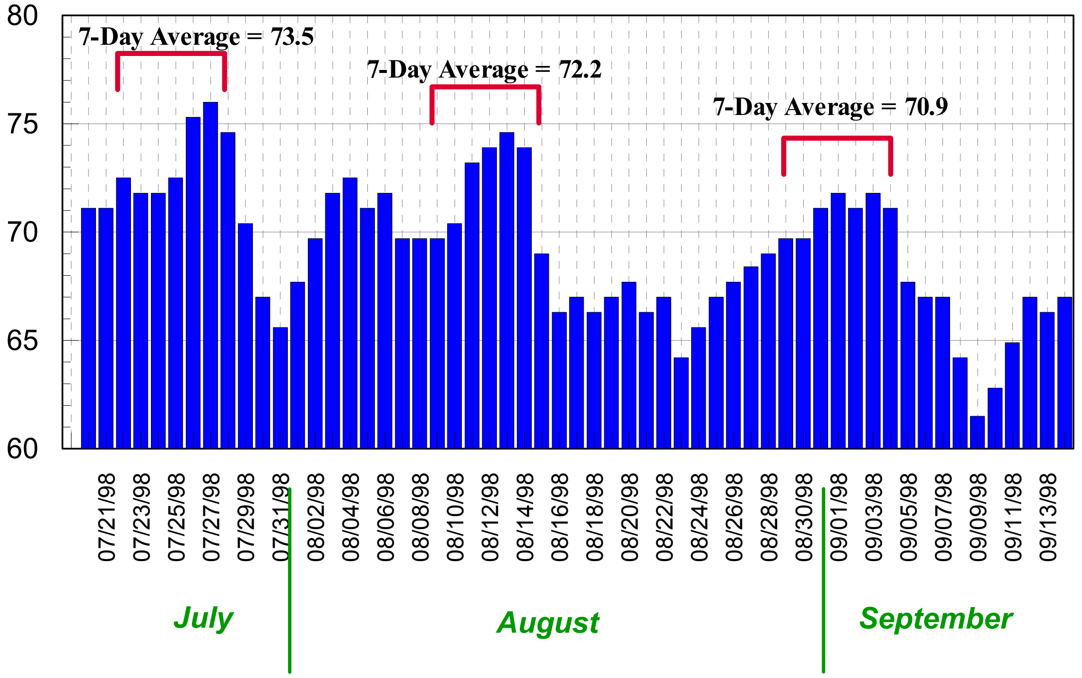
Results

Figure 3 shows records of water and air temperatures during the summers of 1998 and 1999 at one site on the Marys River near Wren. This figure illustrates the summer fluctuations in both air and water temperatures. In 1998, there were three periods when the water temperature was unusually high. The warm spell in late July was the warmest. However, we did not have all gauges installed in the watershed by late July. Therefore, we used values from the mid-August hot spell in 1998. For 1999, we used values for a early August hot spell, which was also the hottest period of the summer. Maximum water temperature values averaged about 2 ° F greater in August of 1998 than in 1999 (Table 1 and Table 2).

Air temperatures averaged several degrees higher in 1998 than 1999 (Figure 3a). Water levels were higher early in the summer of 1999 than 1998 due to abundant rain from winter to early summer. Higher air temperature usually leads to warmer water temperature while higher water levels usually lead to cooler water temperature. By late summer stream levels in 1999 were lower than those in 1998 due to a prolonged period with no rain. Differences between years are great

Site #5 - 1998
Upper Marys River Watershed
Marys River - Harris Bridge

Daily Maximum Water Temperature (deg F)



7-Day Average Water Temperature (deg F)

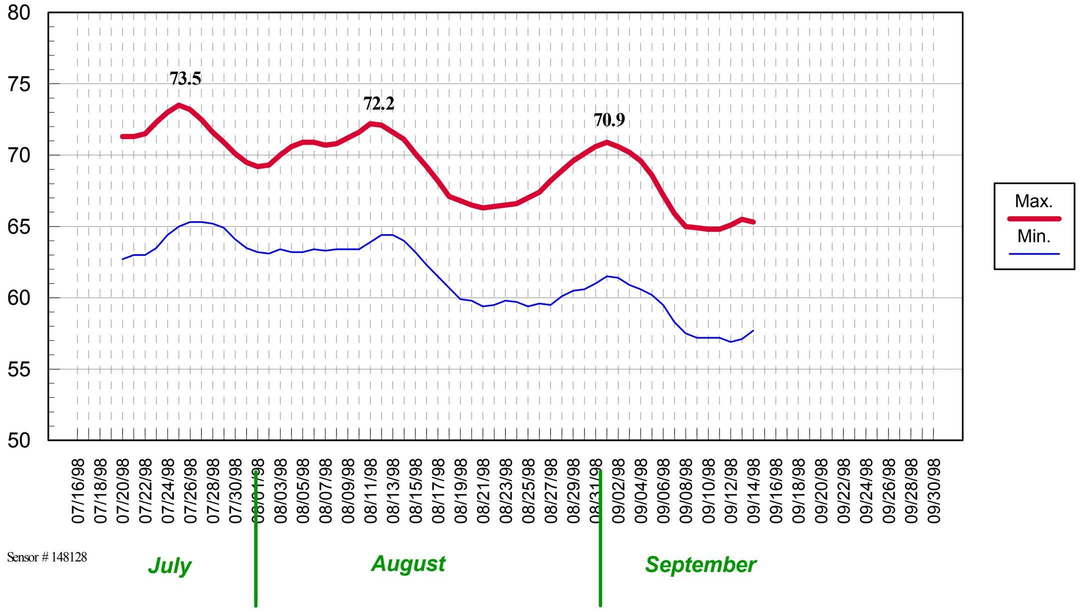


Figure 3. Daily values for maximum water temperature and 7-day running average. The period of the greatest 7-day averagein August was from the 9th to the15th. The 7-day average for maximum and minimum water temperatures for the complete record for site 5 in 1998 are shown in the lower graph.

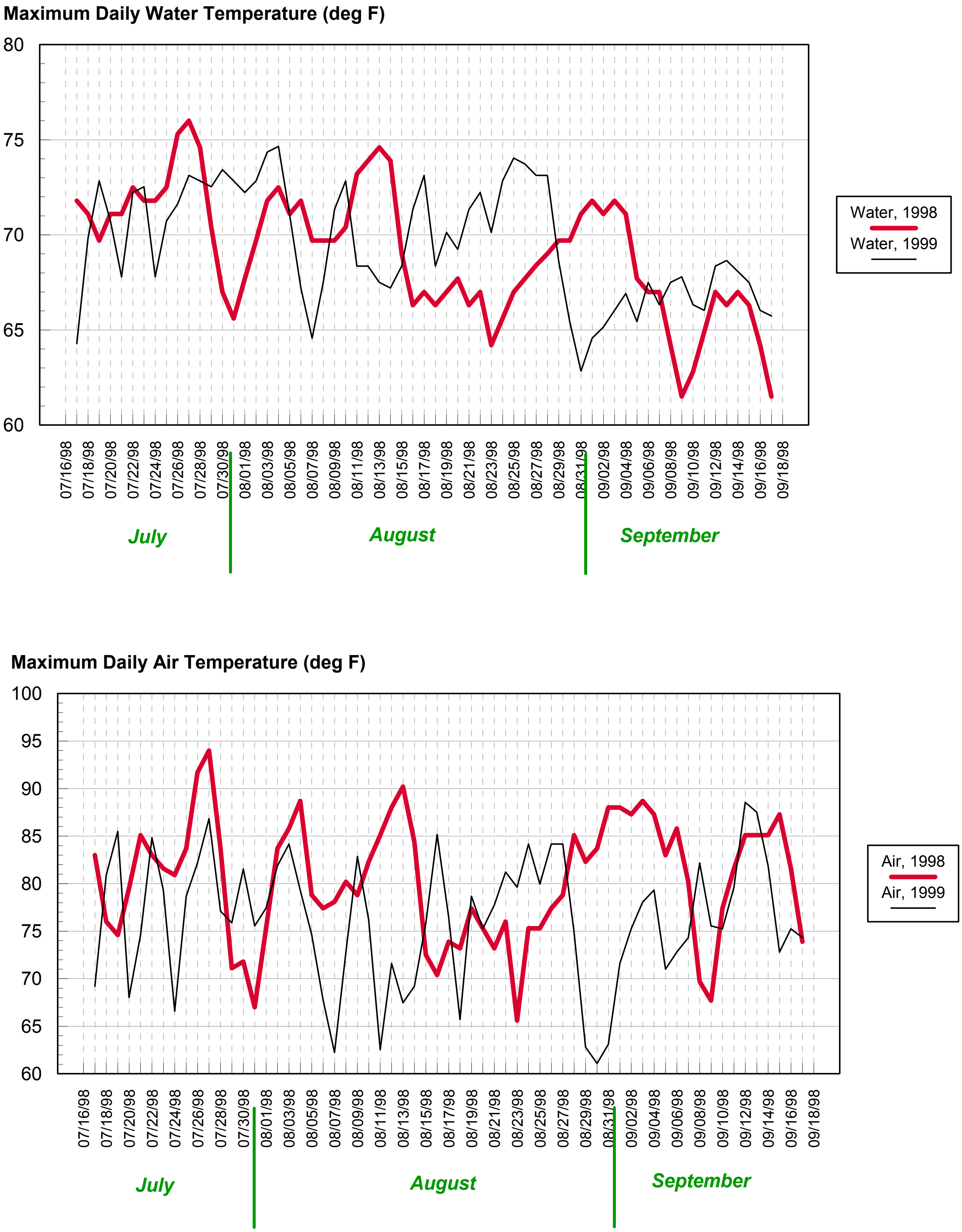


Figure 3a. Daily values for maximum water temperatures for site 5 near Wren are shown in the upper graph and maximum water temperature are shown in the lower. Both maximum water temperature and air temperature were higher in 1998 than in 1999.

enough to prevent pooling data for the two years. Consequently, results for the two years are reported separately.

Downstream and Geographic Temperature Trends.

Maximum 7-day water temperatures were cool throughout much of the watershed in 1998. Tributary streams were commonly in the low to high 60's (Figures 4 and 5). Assuming that cutthroat trout can inhabit streams where the 7-day maximum water temperature is less than 69 ° F, the Marys River main channel downstream of Harris Covered Bridge, Muddy Creek downstream of Bellfountain, and the very downstream portions of Greasy Creek and Woods Creek had temperatures unfavorable for cutthroat trout in August, 1998. The pattern was similar for the cooler 1999 summer, with slight increases in the extent of stream system capable of supporting trout (Figures 6 and 7).

The general warming trend with increasing distance from ridge divides is shown for 1998 and 1999 in Figures 8 and 9. Warming trends with increasing distance from drainage divide were generally similar for both 1998 and 1999. Trends were also similar among the three sub-basins, although there were significant variations from the trends at some sites. Values for some sites that deviated from the general trend can be explained by certain physical characteristics. Streamflow at Site 108 (Beaver Creek) was a mere trickle and probably explains why the water is warmer than expected. Site 204 at the downstream end of Greasy Creek had sparse shade upstream of the gauge. Finally, Site 34 was warmer than expected in both 1998 and 1999, possibly because the river in this region runs from north to south allowing maximum solar heating, which is retained by basaltic bedrock.

A cluster of sites were cooler than expected compared to the general warming curves in Figures 8 and 9. Sites near the western boundary of the watershed in the Tumtum River (Sites 15 and 16), West Fork of the Marys River (Sites 11 and 18), and immediately below the

Table 1. Water temperature and other site characteristics for the Marys Watershed.

Site	Distance from Divide (miles)	Mid-August, 1998 7-Day Max. (Deg F)	Early August, 1999 7-Day Max. (Deg F)	1998 Minus 1999 (Deg F)	September Flow, 1998 (cfs)	Vegetative Cover (percent)[1]
30	1.9	63.0				100
12	2.4	61.0	59.5	1.5		90
8	3.0	62.9				100
9	3.2		60.9			
1	3.4	65.2	63.8	1.4		98
13	3.6	62.9				90
19	3.7		61.2			80
31	4.5	65.9	63.3	2.6		5
25	4.5	64.1				95
10	5.0	65.5				15
22	5.7		65.0			
21	6.5	70.3				95
20	6.9	65.8	63.1	2.7		10
14	7.1	68.1				5
11	10.0	65.2	62.1	3.1		80
15	11.7	67.8	65.3	2.5		40
18	12.4	65.7	63.5	2.2	2.2	60
17	14.0	64.9	64.5	0.4		20
16	14.5	64.8	62.9	1.9	4.6	94
6	18.1		72.0			
5	18.6	72.2				16
7	20.2		71.8			
4	21.3	73.0	71.0	2.0		19
2	24.9	73.9	73.3	0.6	9.8	20
34	27.3	76.8	74.6	2.2		
35	28.6		72.6			
36	29.8		73.2			
37	32.4		70.9			
103	34.2	75.2	72.2	3.0		
119	36.1	75.0				
101	39.2	75.7	72.7	3.0		

[1] Only one measurement per site

Table 2. Water temperature and other site characteristics for the Greasy and Muddy Watersheds.

	Distance from Divide	Mid-August, 1998	Early August, 1999	1998 Minus 1999	September	Vegetative

Site	from Divide (miles)	7-Day Max. (Deg F)	7-Day Max. (Deg F)	1999 (Deg F)	Flow, 1998 (cfs)	Cover (percent)[1]
Greasy Watershed						
206	1.2	57.7				95
201	2.4	62.4			1.5	99
207	3.1	61.4			2.7	95
205	3.4	61.3			5.0	98
202	4.5	67.0			3.6	87
208	4.7	64.5				93
203	5.7	67.2			2.7	85
209	7.0	66.6			5.0	
204	9.7	71.8			5.3	82
Muddy Watershed						
115	2.4	61.2				100
112	3.1	62.4			1.1	99
108	3.2	66.8			1.2	
107	4.2	64.3				71
113	5.3	65.4			3.4	93
110	6.0	68.1			3.0	88
114	6.4		64.5		1.8	
111	8.7	68.0			4.9	54
106	9.7	67.0	64.9	2.1	4.5	92
105	18.3	73.3	71.8	1.5	4.1	61
118	25.2		69.0		9.2	
Oak Watershed						
102	7.2	69.5				

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[1] Average of 7 measurements per site. Measurements taken at 50- foot intervals upstream of gauge.

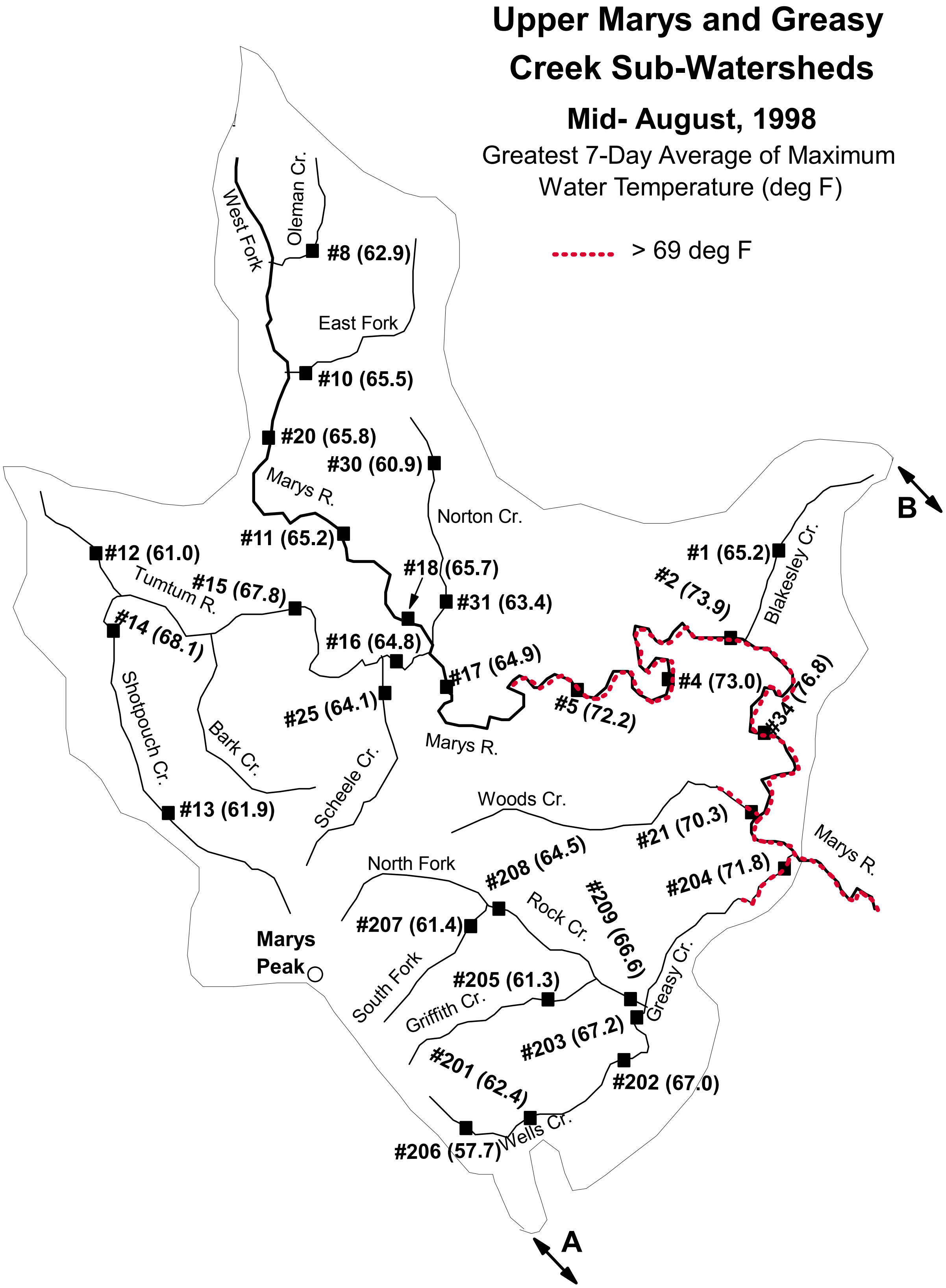


Figure 4. Values for the greatest 7-day average of maximum water temperatures for mid-August 1998.

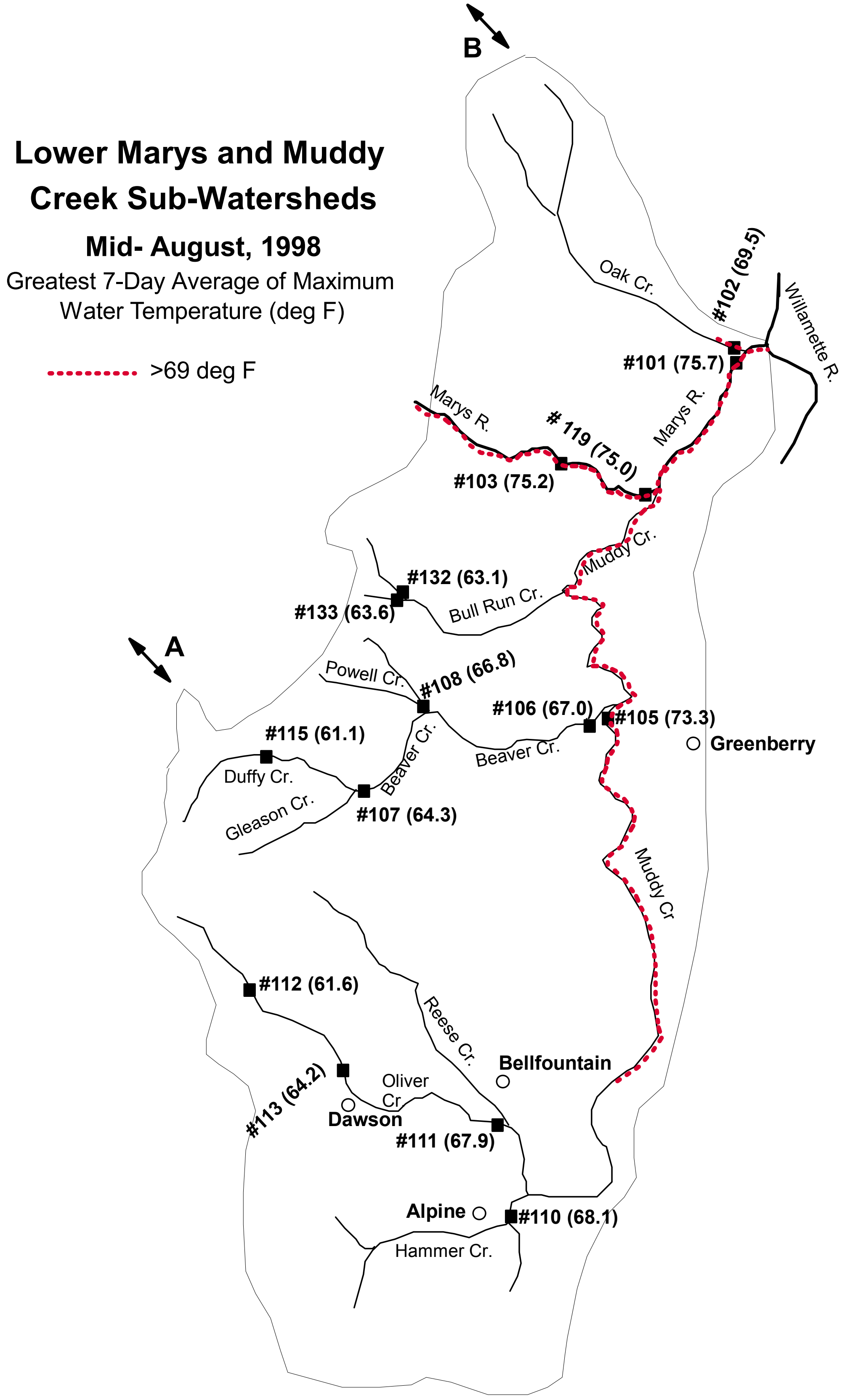


Figure 5. Values for the greatest 7-day average of maximum water temperatures for mid-August 1998.

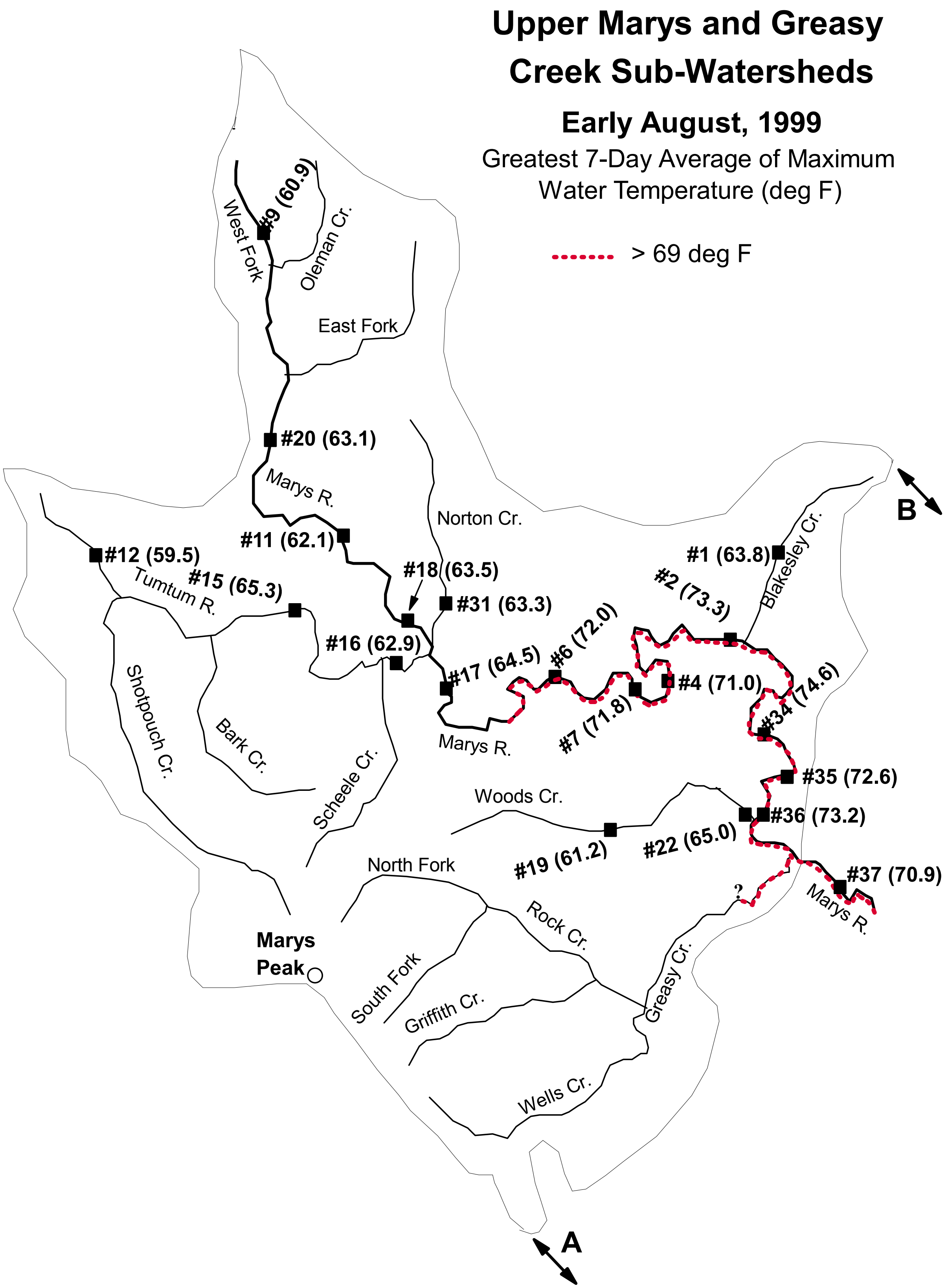


Figure 6. Values for the greatest 7-day average of maximum water temperatures for early August 1999.

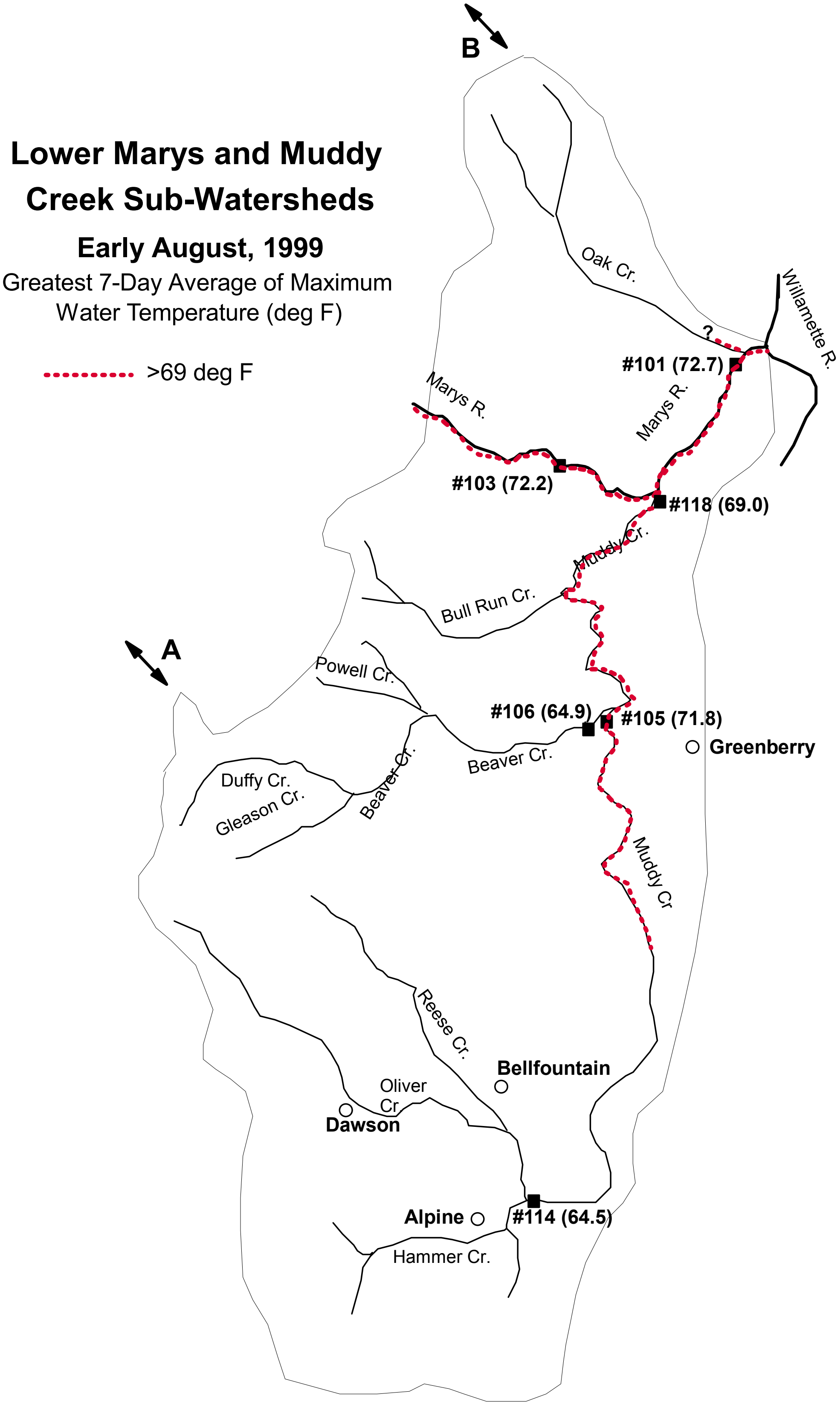


Figure 7. Values for the greatest 7-day average of maximum water temperatures for early August, 1999.

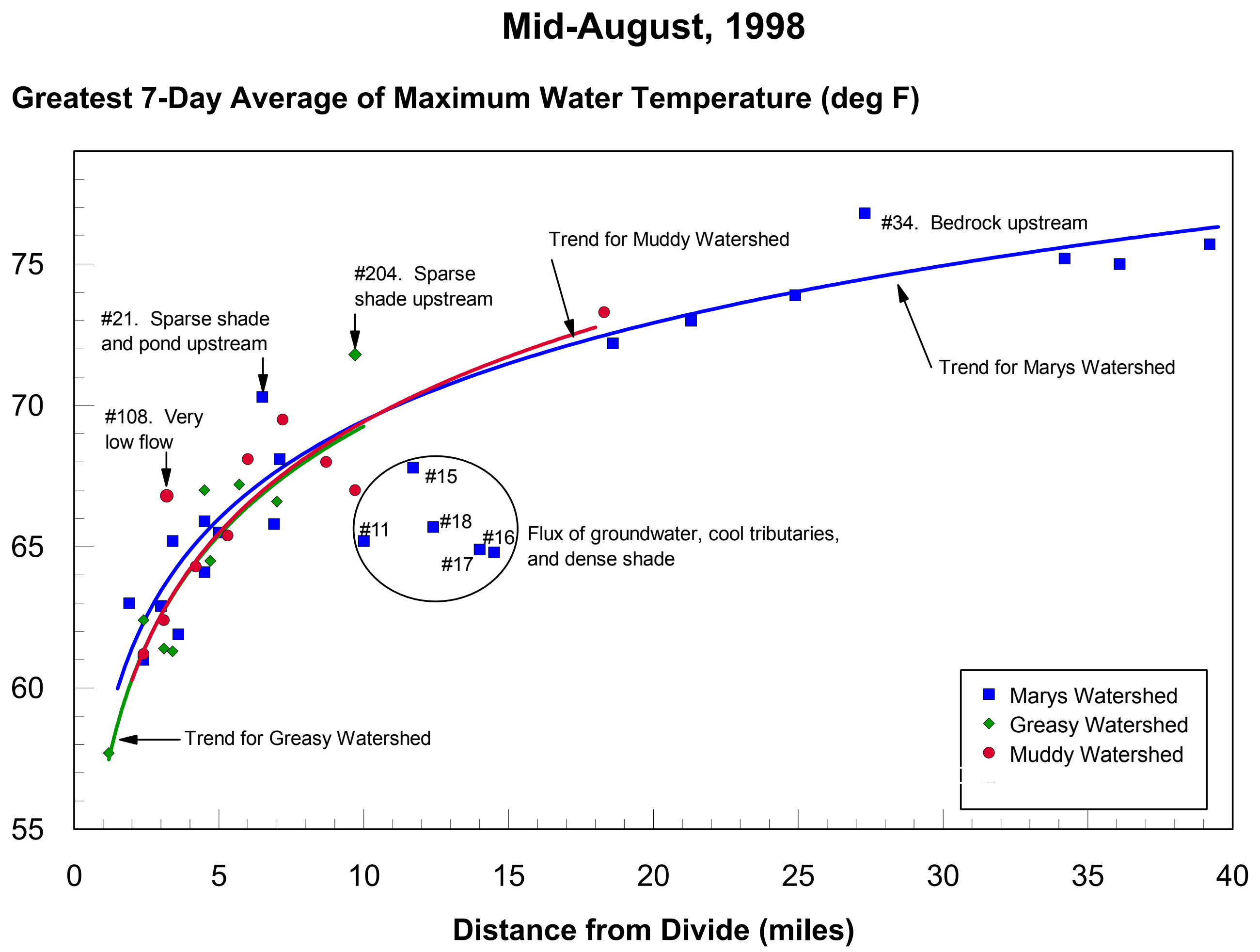


Figure 8. General warming trend for streams the watershed. The 3 sub-watersheds in 1998 warmed at about the same rate. Certain sites may deviate from the general trend due to unusually large amounts of groundwater entering the stream, sparse shading, or low flow, as shown in the figure.

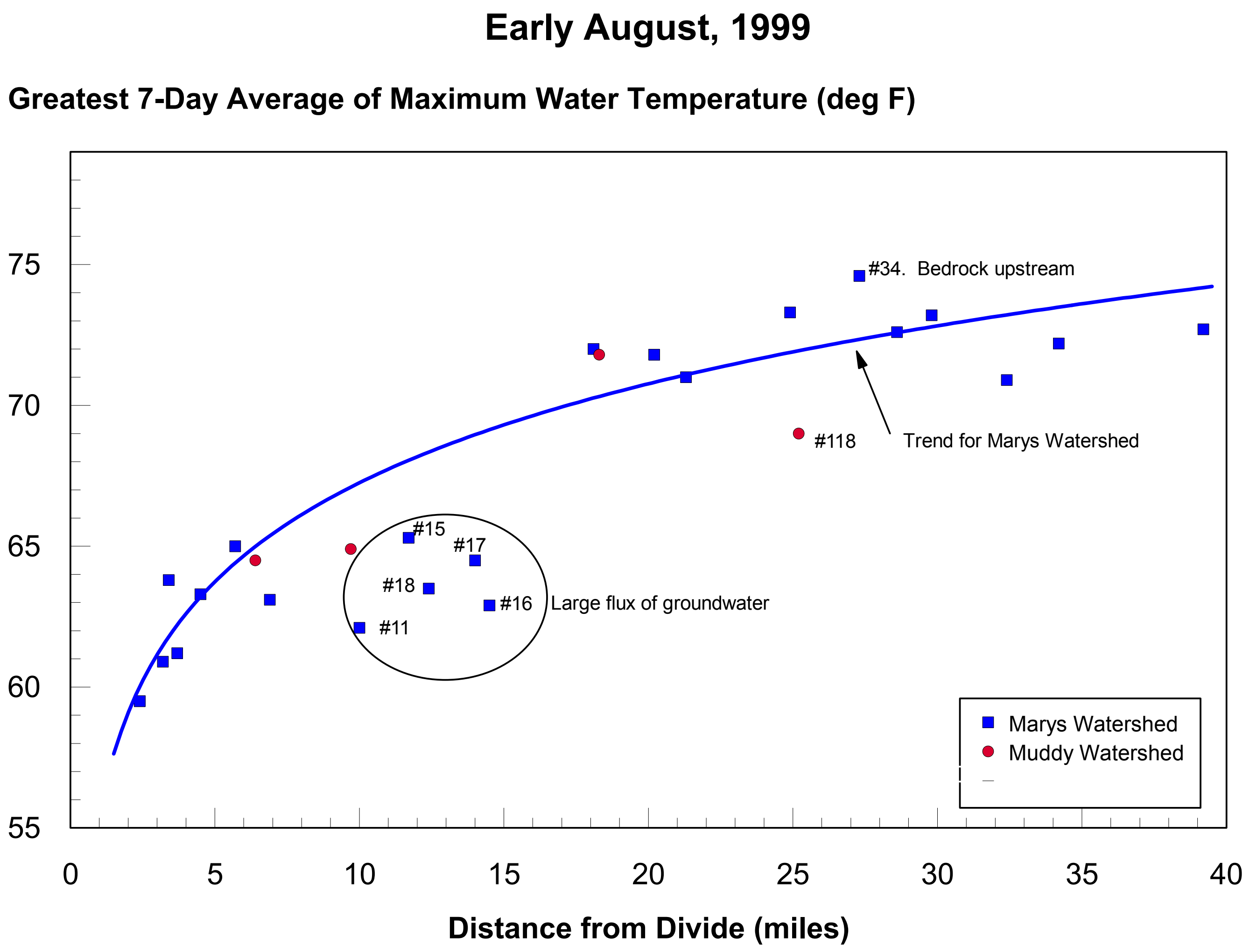


Figure 9. The general trend for stream warming in 1999. Extra sites at a greater distance from the divide were added in 1999, thereby highlighting the variability in temperature from Wren to Corvallis.

confluence of these two streams (Site 17) were cool. These cool temperatures are likely caused by entry of water from cool tributaries, dense shading, and possible influx of ground water.

The data for just the Tumtum and Marys rivers are plotted in Figures 10 and 11 to provide a more detailed examination in the longitudinal profiles of stream temperatures. Trends are very similar, with slow warming and even cooling in the lower Tumtum River and West Fork of the Marys River, followed by rapid increases in the Marys River reach below its confluence with the Tumtum River to the Harris Covered Bridge. Then warming approaches a plateau below Site 5 and 6, with an anomalous increase at Site 34, followed by some cooling in the river before it reaches Avery Park and the confluence with the Willamette River. This cooling may be related to the change from a bedrock-dominated channel to a gravel-rich channel. The presence of deep gravels may cause a decline of temperature as part of the flow becomes subsurface and avoids exposure to solar radiation. Downstream of Site 37 the channel is dominated by hard clay banks and the river temperature again increases.

Lower Shotpouch Creek is several degrees warmer than the Marys River until it is cooled by Scheele Creek and the flux of groundwater that occurs near the confluence with the Marys River. It is unclear why this section of the Tumtum River is warmer than the Marys River but it could be due to reduced shading as the Tumtum River parallels Highway 20.

A comparison of sites along Rock Creek and Greasy Creek in 1998 indicates that Rock Creek is several degrees cooler than Greasy Creek (Figure 12). Where they converge the flow of Rock Creek is nearly two-thirds of the total flow. The City of Corvallis withdraws water from Rock Creek and its tributaries. Without the withdrawals the dominance of Rock Creek in the Greasy Watershed would be even more pronounced. The streamflow within Greasy Creek declines from 3.6 cfs at Site 202 to 2.7 cfs at Site 203 (Figure 12). Furthermore, the flow decreases from 7.7 cfs immediately downstream of the Rock Creek confluence to 5.3 cfs at Site 204. A portion of this decreased flow may be due to irrigation withdrawals. However, some of the loss may be due

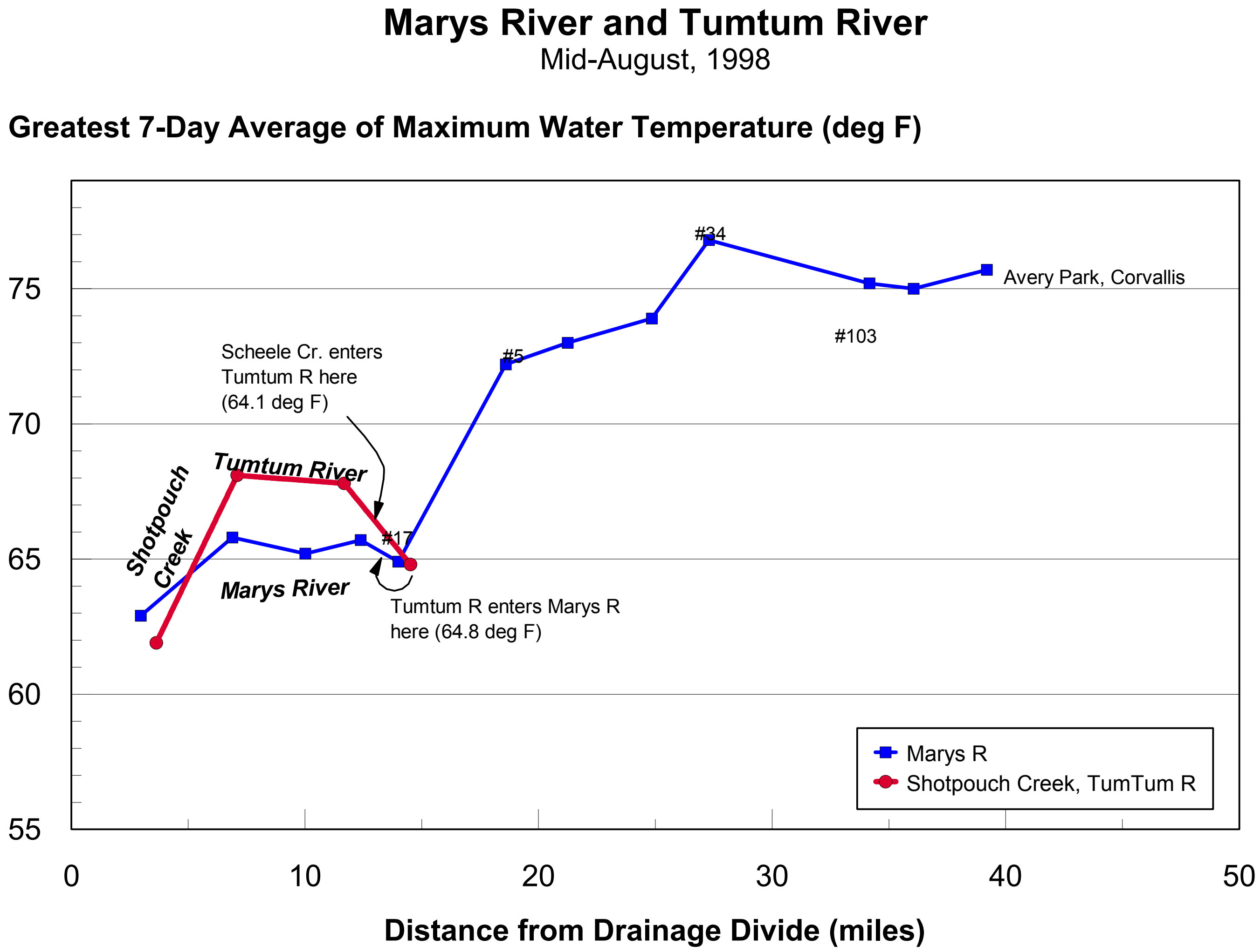


Figure 10. Longitudinal temperature profile of the Marys River and Shotpouch Creek/Tumtum River from headwaters to Corvallis in 1998

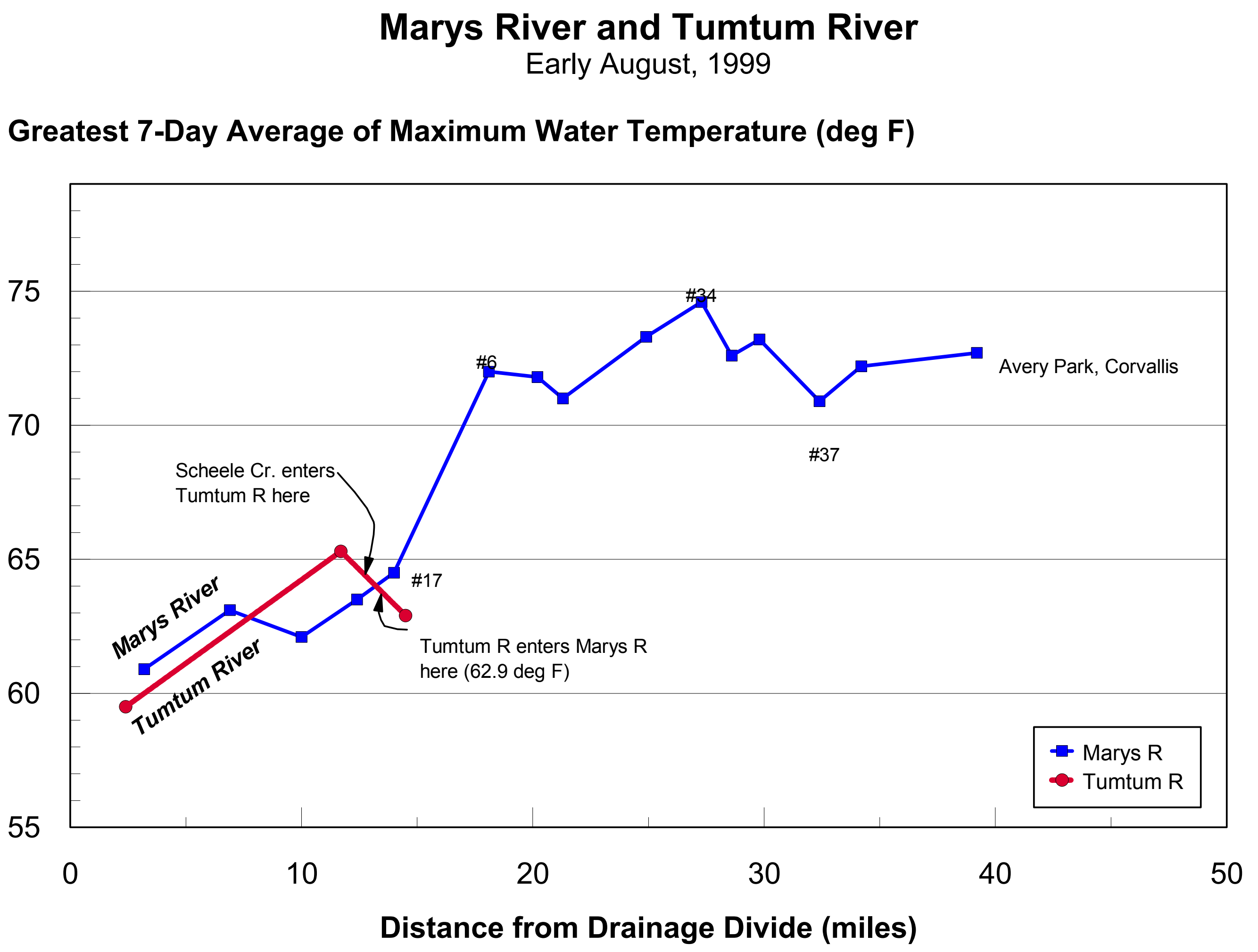


Figure 11. Longitudinal temperature profile of the Marys River and theTumtum River from headwaters to Corvallis in 1999.

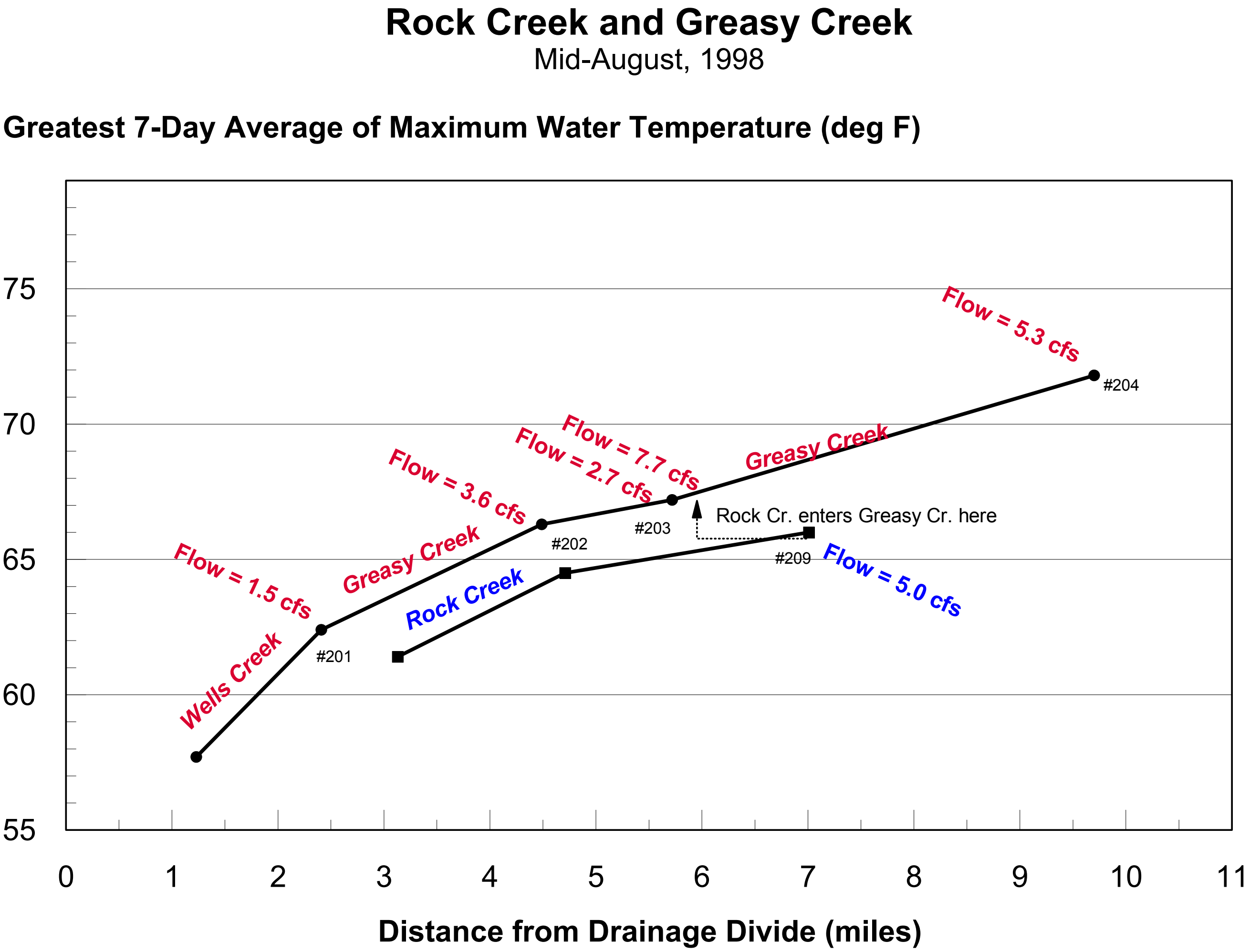


Figure 12. Longitudinal temperature profile and summer stream flows of Greasy Creek and Rock Creek from headwaters to the Marys River confluence in 1998.

subsurface streamflow. The lower Greasy Creek channel is underlain by deep gravel deposits in some areas and this can cause a portion of the flow to travel through the gravels rather than on the surface.

In contrast, Oliver Creek and Beaver Creek in the Muddy sub-watershed gain flow throughout their length (Figure 13). Both streams originate in mountainous terrain that is underlain by fractured basalt and then flow through broad valleys of lower gradient. Oliver Creek starts out cooler than Beaver Creek but then becomes warmer than Oliver Creek in its lower reaches where vegetation next to the stream is sparse (Figure 14). Beaver Creek is shaded throughout its length except for segments near Site 107.

Stream Warming Rates

As streams flow downhill they gain tributary flow, generally broaden and deepen and groundwater flow becomes less important. Because they become wider, shading is less effective, and as they loose elevation, air temperatures generally warm. Thus streams naturally warm downstream. The rates at which a stream warms between two sites (degrees per mile) are plotted against the water temperature at the upstream site are shown for August 1998 in Figure 15. The coolest tributaries in the watershed warmed the most rapidly, with only small incremental warming once the stream reaches about 66 ° F. The section of Marys River downstream of the Tumtum River confluence (Site 17) to the Harris covered bridge (Site 5) warmed considerably faster than would be expected from the general trend shown in Figure 8. Again, water temperature upstream of Site 17 was probably being kept abnormally cool by dense shading, cool tributaries, and the flux of cool groundwater. These cooling influences are less downstream of Site 17. Some of this downstream warming in this region is caused by a sparse riparian canopy (Bennett 1999) and so temperatures increased rapidly here, over 7 ° F in only 4.6 miles.

When stream warming rate is plotted against distance from divide, it is apparent that most

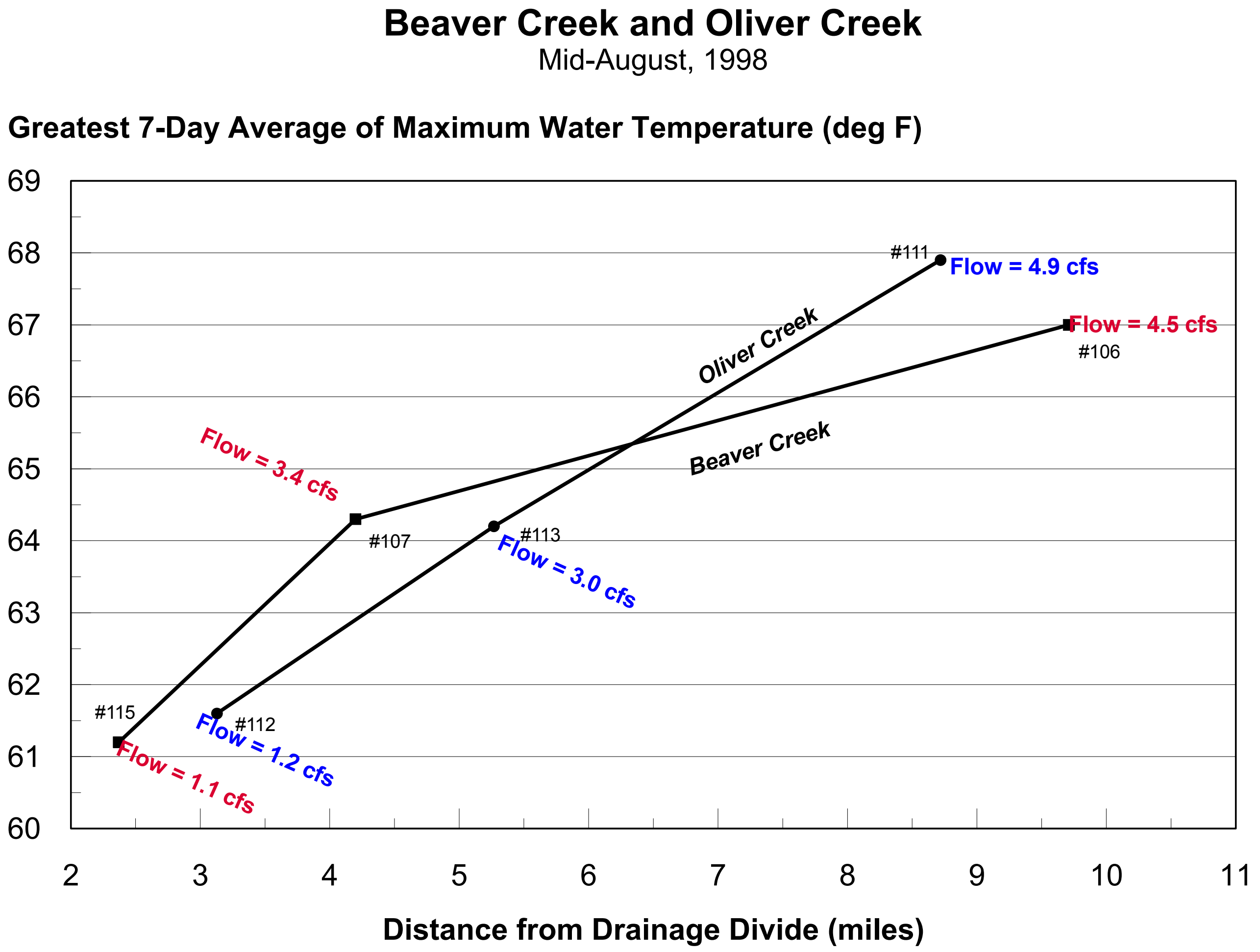


Figure 13. Longitudinal temperature profile and summer streamflows for Oliver Creek and Beaver Creek from headwaters to the MarysRiver confluence in 1998.

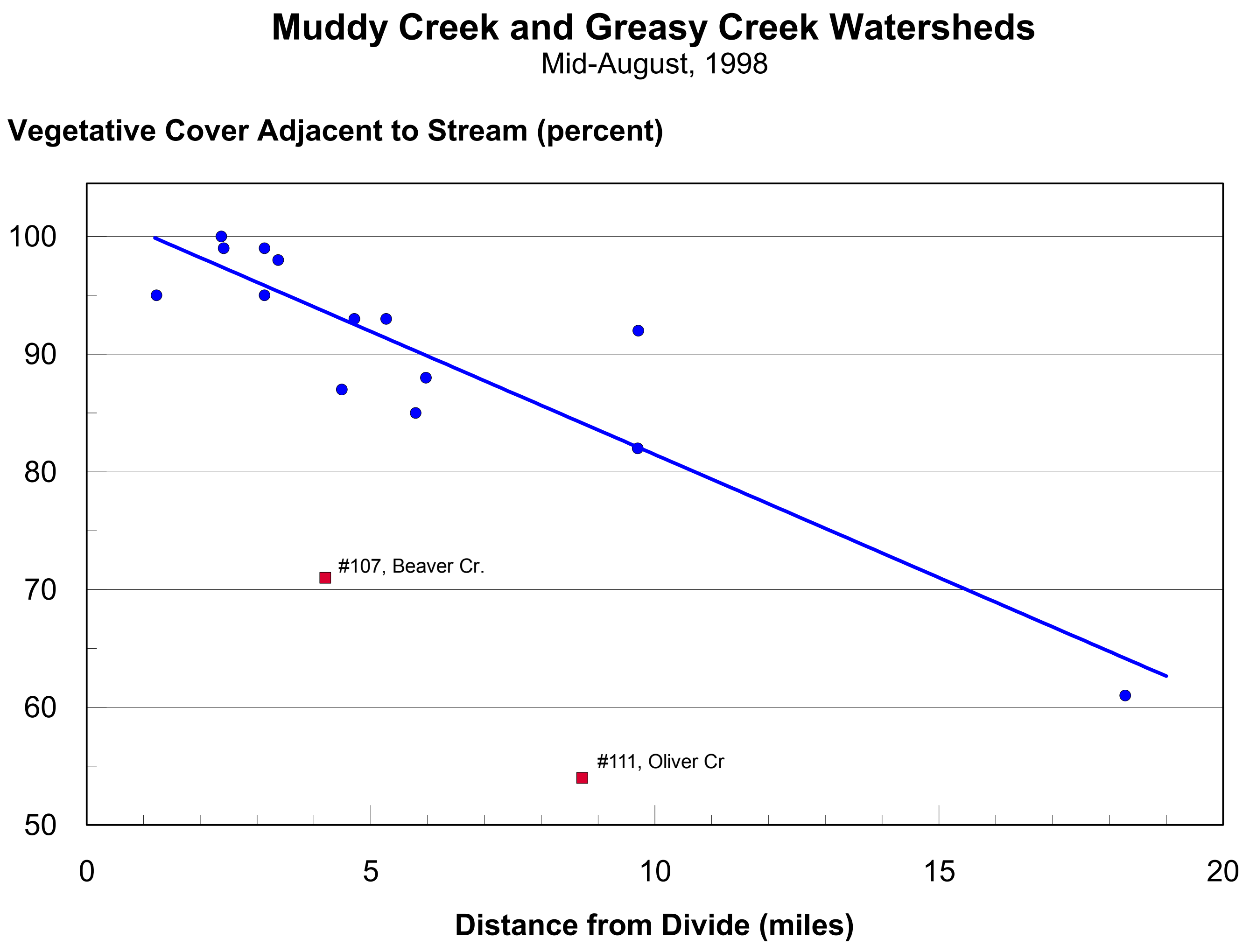


Figure 14. Vegetative cover generally decreases with increasing stream size as indexed by distance from divide. Shown are sites from Muddy and Greasy Watersheds.

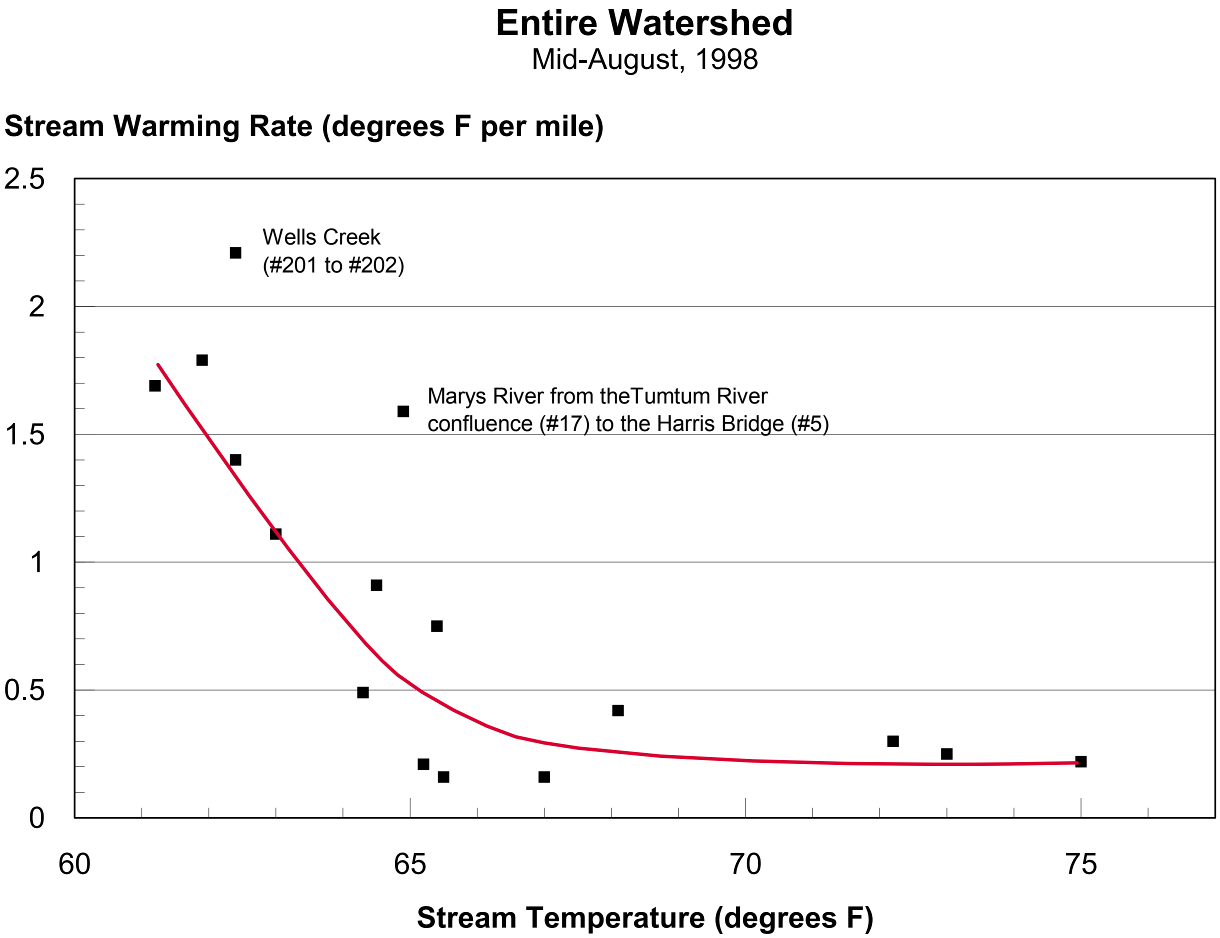


Figure 15. Stream warming rate (degrees per mile) vs. stream temperature. Warming rates were greatest where the stream is coldest and then approaches a low value once the stream temperature reaches about 66 deg F. Variability among sites is probably due to differences in groundwater and tributary inputs and shade.

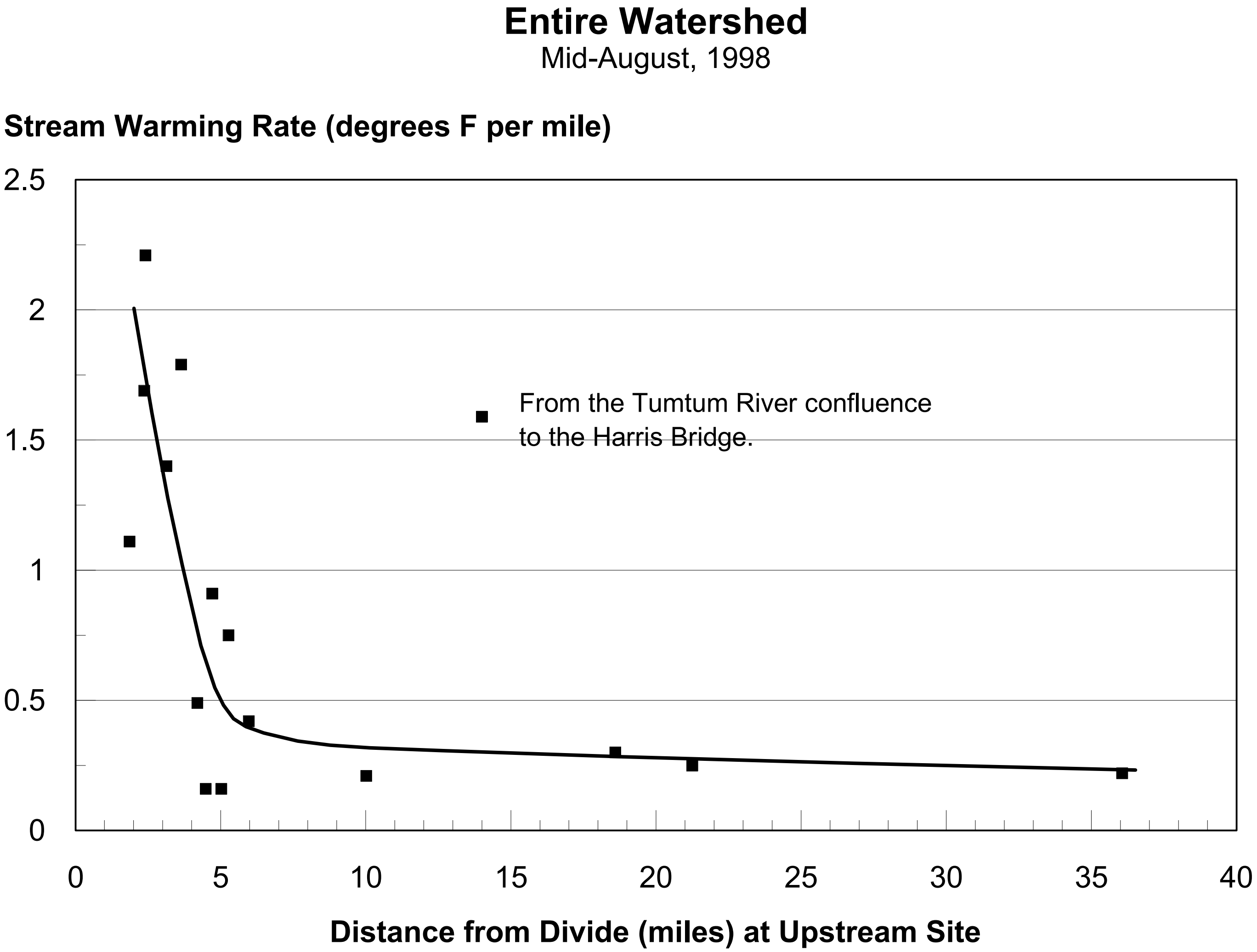


Figure 16. The stream warming rate (degrees F per mile) vs. distance from divide. Warming rates were greatest in the headwaters, decrease rapidly in a downstream direction, and then approach low values at about 6 miles from the divide. Variability among sites is probably due to differences in groundwater and tributary inputs and shade.

stream warming (over 0.5º F/mi) occurred within 1 to 7 miles from the divide (Figure 16). At further distances from divide the stream warming rate drops to about 0.2 ° F per mile. Again, the warming rate within the section of Marys River from the Tumtum River confluence to the Harris covered bridge appears as an large anomaly because of rapid warming below the confluence of the Tumtum and West Fork of the Marys River.

Conclusions and Recommendations

Water temperatures during the summer generally increase as they flow downstream in the Marys River watershed, generally attaining temperatures that exceed 72º F. Rates of warming were most rapid in headwater reaches and decreased greatly downstream. Stream temperatures are modified by the degree of shading, stream flows, tributaries, stream morphology, and influxes of ground water. Some sites were consistently warmer or cooler than expected from general relationships between stream temperature and distance from topographic divides.

Water temperatures are mostly favorable for cutthroat trout in the Tumtum and upper Marys rivers, Greasy Creek and tributaries to Muddy Creek, but are probably too warm during the summer along some lower portions of tributaries and the lower, main channels of the Marys River and Muddy Creek. As a result, connectivity among sub-basins is reduced and movements of cutthroat trout during the summer is probably restricted.

The warm temperatures in the Marys River main channel downstream of the Harris Bridge (Site 5) and in the Muddy Creek main channel downstream of Bellfountain are a result of natural warming patterns that all rivers experience and the low amount of cool groundwater within the valley floor. Stream temperatures may have been cooler in the past, however, when there was more riparian shading. According to Bennett (1999) the percent of riparian area in forest decreased between 1945 and 1993 along the mainstem Marys River.

Increasing shade and maximizing water stream flows to cool stream temperatures in segments of tributary streams that approach or just exceed 69 ° F during warm summers will provide the greatest benefits for native cutthroat trout. These segments include:

- The downstream portion of Shotpouch Creek (Site 14) to Site 15 below its confluence with the Tumtum River.
- The portion of lower Woods Creek that parallels Highway 20 (near Site 21).
- Lower Greasy Creek from the Rock Creek confluence to the Marys River confluence (Site 204).
- Oliver Creek downstream of Dawson to the Muddy River confluence.

There are obstacles to restoring vegetation along some of these reaches to provide shade in the future. These segments have relatively low gradient and therefore are often the home to beaver that are likely to dine on planted trees (wire mesh around the trunks can reduce beaver damage). Competition from exotic grasses and blackberries will be intense in other streamside areas, especially where reed canary grass grows. This may require removal of competing vegetation adjacent at planting spots to encourage tree establishment. All of these stream segments are privately owned so landowner cooperation will be required. Because these streams are relatively small during the summer, the planted vegetation does not need to be particularly tall to be effective at shading the stream. Willows may suffice at a number of sites.

Irrigation and municipal withdrawals from these stream segments also increase water temperatures during the summer. As streamflow decreases the depth of water decreases while the surface area remains relatively constant. Solar radiation striking the water surface can more readily increase the temperature of a shallow stream. In addition, reduced flow in a stream decreases the amount of habitat for fish. Fish often find protection from predators by moving to deeper water, and the production of aquatic insects is reduced when the wetted stream surface is less. A strategy of encouraging landowners to decrease or suspend the use of streams for irrigation would enhance the thermal habitat for trout use throughout the basin.

In the future, the water temperature data provided in this report could be used to help prioritize the actions by the Marys River Watershed Council to improve and restore stream and riparian habitat for native cutthroat trout through modifications of riparian vegetation, culverts, and water withdrawals.

Chapter 2

A Model of Stream Temperature for the Marys River, Oregon: The Influence of Riparian Shade on Cutthroat Trout Habitat

by

Jeffrey M. Dambacher and William G. Pearcy

Introduction

The Marys River (Figure 1), a subbasin of the Willamette River system, drains the east side of the Oregon Coast Range. It supports populations of coastal cutthroat trout (*Oncorhynchus clarki clarki*), which are the only native species of trout in the basin. The Marys River cutthroat trout has been identified as a priority population because of suspected habitat degradation (Oregon Department of Fish and Wildlife 1993, Mamoyac et al.1995).

Monitoring in the basin during 1996 (see Chapter 1) showed stream temperatures in headwater reaches were suitable for cutthroat trout during summer periods; however downstream of Wren to its mouth, the Marys River has daily maximum water temperatures in excess of 23^{o}C (73^{o}F), and average 7-day maximum temperature exceeding 21^{o}C (70^{o}F). Depending on acclimation temperature, exposure of salmonids to temperatures in excess of 22^{o}C (72^{o}F) has induced mortality in laboratory settings, with temperatures near 25 ^{o}C to 26^{o}C (77 ^{o}F to 79 ^{o}F) acting as an upper lethal threshold (Coutant 1972, Dickerson and Vinyard 1999). While cutthroat trout in particular can acclimate to temperatures as high as 24^{o}C (75 ^{o}F) with no mortality, temperatures above 20^{o}C (68 ^{o}F) have been found to reduce growth in juvenile fish. This has been found for both the coastal cutthroat trout (Dwyer and Kramer 1975), and for Lahontan cutthroat trout *O. clarki henshawi* (Dickerson and Vinyard 1999).

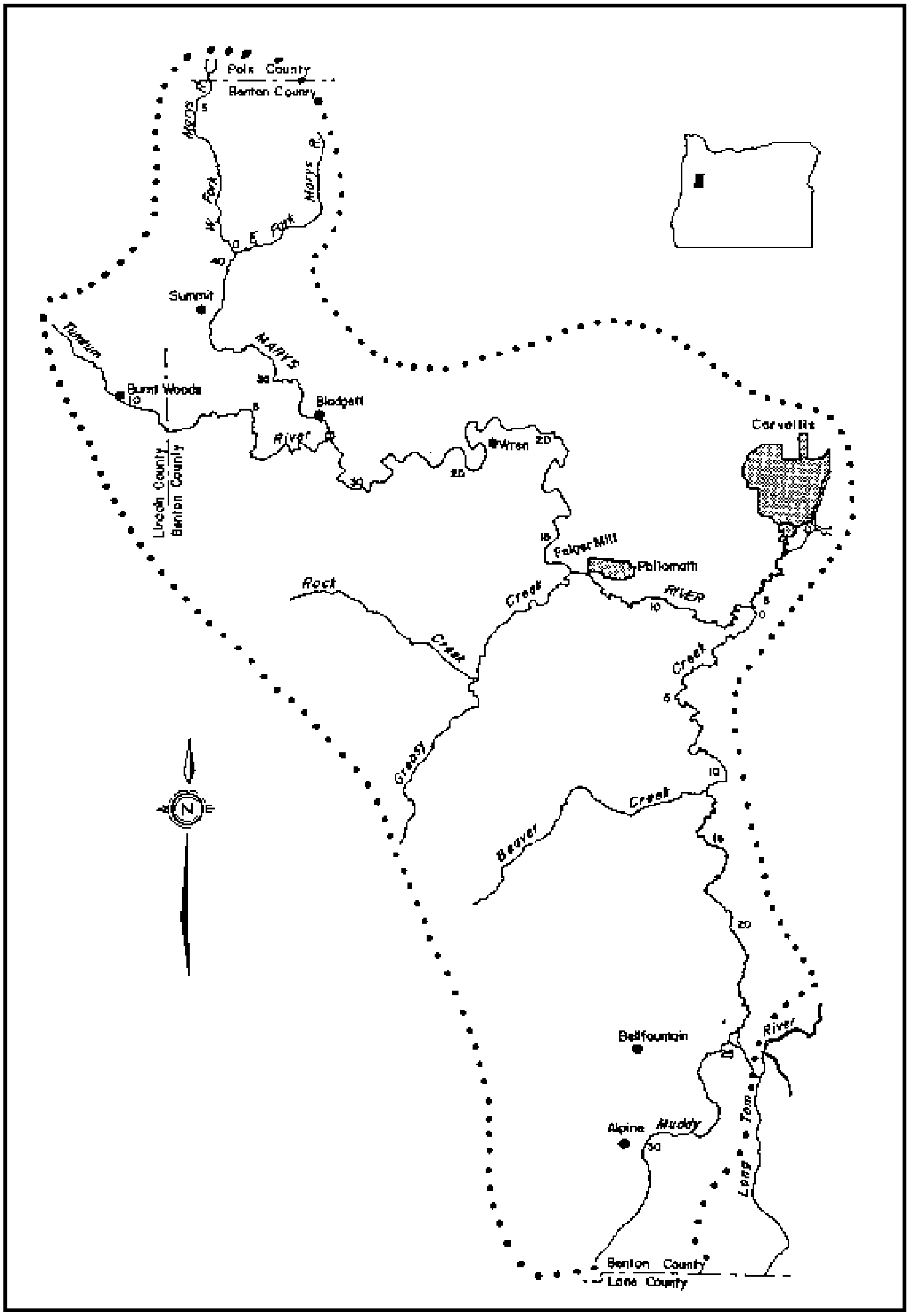


Figure 1. Marys River basin, adapted from a 1979 Oregon Division of State Lands map, with distance from mouth denoted in river miles

Bennett (1999) concluded that there was a decrease in the amount of riparian forests along the Marys River between 1945 and 1993, based on analysis of aerial photographs. To investigate whether riparian shade could be important for cutthroat trout rearing, we applied a stream temperature model to data collected during the summer of 1998, and used it to simulate the influence of riparian shade on summer water temperatures in the Marys River system.

Methods

Study Design and Data Collection

The stream temperature model SSTEMP (version 1.1.0; Bartholow 1989) was employed to model changes in water temperature along the Marys River from the confluence of the Tumtum and Marys rivers near Blodgett downstream 23 km to the Highway 20 bridge (Figure 2). This is a section of the river that is of concern for cutthroat trout rearing based on preliminary temperature monitoring in 1996. SSTEMP is a reach based model that predicts the mean and maximum water temperature at reach outflow using physical variables associated with hydrology, channel geometry, meteorology, and riparian shade (Table 1). SSTEMP also gives as output the heatflux values and equilibrium temperature that are used in calculation of water temperature. These values can be useful in understanding thermal dynamics possibly operating in a given reach of stream.

In this study the SSTEMP model was applied to 5 sites downstream of the confluence of the Tumtum River (Figure 2), which defined 4 sequential reaches. Model predictions were made for sites 2-5, but not site 1, as the model only predicts temperature at the downstream end of a pair of sites. Flow was measured at select periods during summer flow recession, and compared to more frequently collected stage height measurements from a gauging site. Stream water temperature, air temperature, and relative humidity were monitored with Onset Hobo© data loggers. Stream geometry parameters were either measured in the field, or obtained as

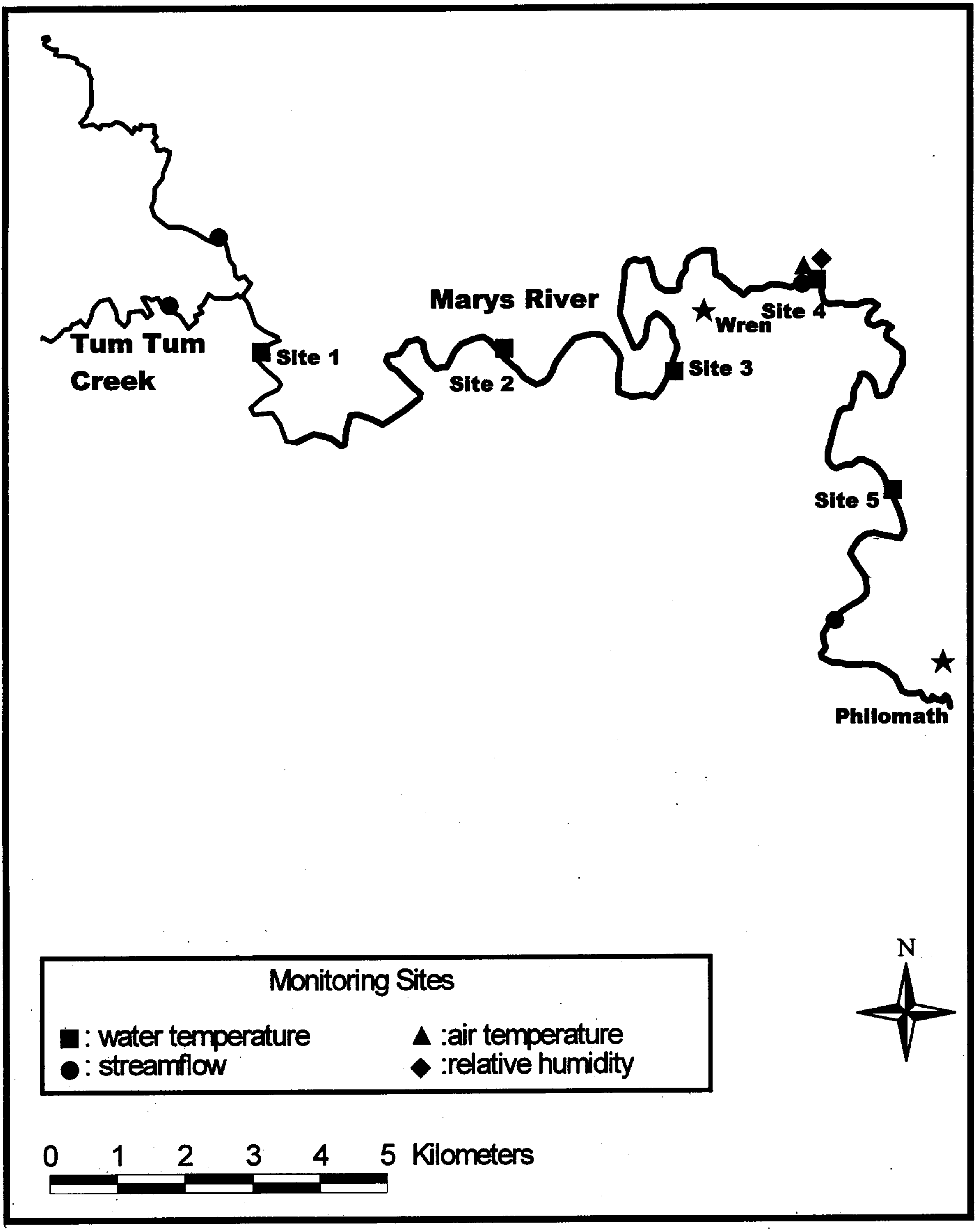


Figure 2. Location of monitoring sites on Marys River, Oregon, summer 1998.

Table 1. SSTEMP version 1.1.0 model variables and method of parameterization for this study.

Variable	Parameterization/methods
Hydrology	
flow ($m^3 s^{-1}$)	direct gauging with flow velocity meter, and with stage height interpolation
inflow temperature (^oC)	hobo© recorder placed in direct channel flow in shade
accretion temperature (^oC)	groundwater temperature measured from local wells
Segment geometry	
latitude (radians)	1:250,000 scale map
length (km)	1:250,000 scale map
elevation (m)	1:250,000 scale map
width-depth-flow geometry	channel and flow measurements
Manning's n	inferred as 0.80 from model calibration
Meteorology	
mean and maximum air temperature (^oC)	hobo© recorder placed in shade of riparian area
relative humidity (%)	hobo© recorder placed in shade of riparian area
wind speed ($m s^{-1}$)	1998: inferred as 2.5 $m s^{-1}$ from model calibration 1999: measured by anemometer 1.5m above channel at site 4, also inferred from 1998 calibration
ground temperature	inferred as groundwater temperature measured from local wells
thermal gradient ($j m^{-2} s^{-1} {}^oC^{-1}$)	standard value of 1.65 ($j m^{-2} s^{-1} {}^oC^{-1}$) (Bartholow 1989)
possible sun (%)	standard regional value of 75% (Bartholow 1989)
dust coefficient	standard value of 5 (Bartholow 1989)
ground reflectivity (%)	standard value of 25% (Bartholow 1989)
Shading Parameters	
topographic altitude (radians), segment azimuth (radians)	field measurements with clinometer, 1:250,000 scale maps
vegetation: height (m), crown (m), offset (m), and density (%)	field measurements with clinometer and handheld rangefinder

measurements from 1:250,000 scale maps. Vegetation and shade parameters were estimated from field observation. Values for thermal gradient, percent possible sun, atmospheric dust, and ground reflectivity were taken from standard values suggested by Bartholow (1989).

Model Calibration

The model was first utilized with data from August 13, 1998, which had the maximum water temperature during that month. The mean daily temperature of the segment of stream between sites 3-4 was modeled first. Wind speed, which was not measured in this study, was used as a calibration factor. It was adjusted to correspond exactly to the measured mean water temperature for site 4 on August 13, 1998 only. A wind speed value of 2.5 m s^{-1} was derived by this process. This had the effect of lowering the predicted mean water temperature by 1.6^{o}C, compared to the predictions from a wind speed of 0 m s^{-1}. Manning's n (channel roughness), which only affects maximum water temperature in the SSTEMP model, was also used as a calibration factor to accurately predict the maximum water temperature at site 4 on August 13, 1998. A value of 0.8 was derived which, compared to a standard value (Bartholow 1989) of 0.035, had the effect of lowering the predicted maximum temperature by 3.9^{o}C.

Model Validation

The values for wind speed and channel roughness developed from the calibration of segment 3-4 were applied to the other 3 segments, and the accuracy of the predictions compared. To test the validity of the model on other days, the model for segment 3-4 was parameterized by data for all days in August 1998. Wind speed and channel roughness was held fixed at the August 13 value, but daily values for flow, inflow temperature, air temperature, and relative humidity were input to the model as measured. The model automatically adjusts solar input based upon day-of-year sun angle calculations.

Riparian Treatment Simulation

The model was used to evaluate the relative benefits of riparian improvements to cutthroat trout in this section of the Marys River. Specifically, we ask whether improvements in headwater reaches will be more effective than those in downstream reaches, and whether improvements in both have a complementary effect. Three hypothetical treatments for riparian shade were modeled to simulate a) upstream effects, b) local effects ("local" meaning within the model reach downstream of site 1), and c) both upstream and local effects together. Upstream effects of increased riparian shade were simulated by a -3^{o}C change in the mean inflow temperature at site 1. This treatment supposes that upstream riparian conditions improve to the extent that stream temperatures are significantly reduced above site 1, but that there is no change in riparian conditions below site 1. Local effects were modeled by a 30% increase in the existing amount of riparian shade along the entire modeled reach, sites 1-5.

Results

Model Accuracy and Validation Results

A near perfect correlation between stage height and flow allowed for a very accurate estimation of daily stream flow in the Marys River (Figure 3). Model error (measured minus predicted) for August 13, 1998 at sites 2-5 was <0.3 ^{o}C for mean water temperature, and $\leq$0.5 ^{o}C for maximum water temperature (Figure 4). Model error of predictions for all days of August 1998 at site 4 averaged –0.1^{o}C (error range –1.1 to 0.7 ^{o}C, error standard deviation 0.5 ^{o}C). A regression of measured vs. predicted temperatures (Figure 5) explained about 90% of the variation in daily maximum (R^2=0.89) and mean (R^2=0.87) temperature for segment 3-4 during the month of August 1998.

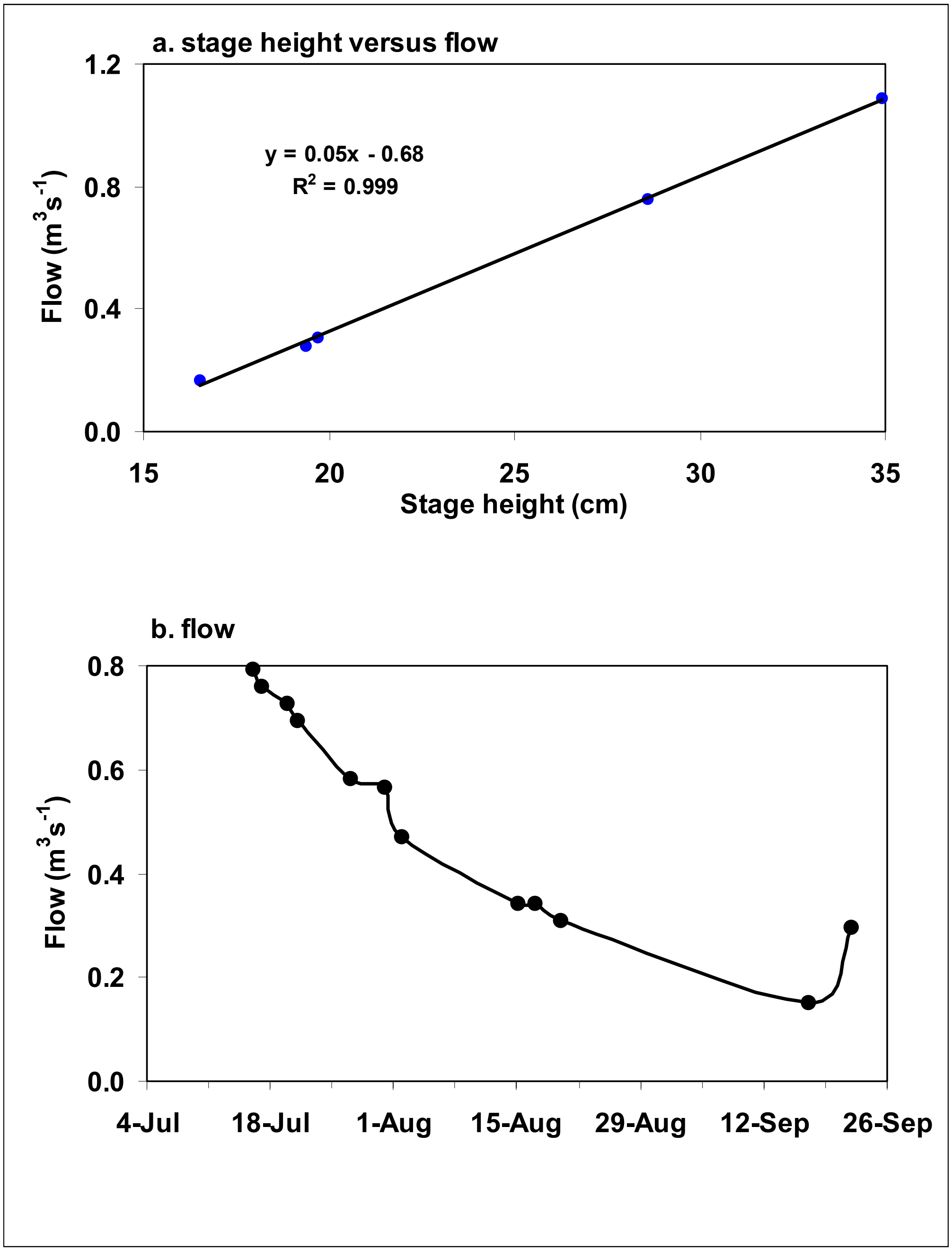


Figure 3. Streamflow gauge calibration (a.) and flow (b.) of Marys River at Cloud Run Farm (site 4 in Figure 2), Oregon, summer 1998.

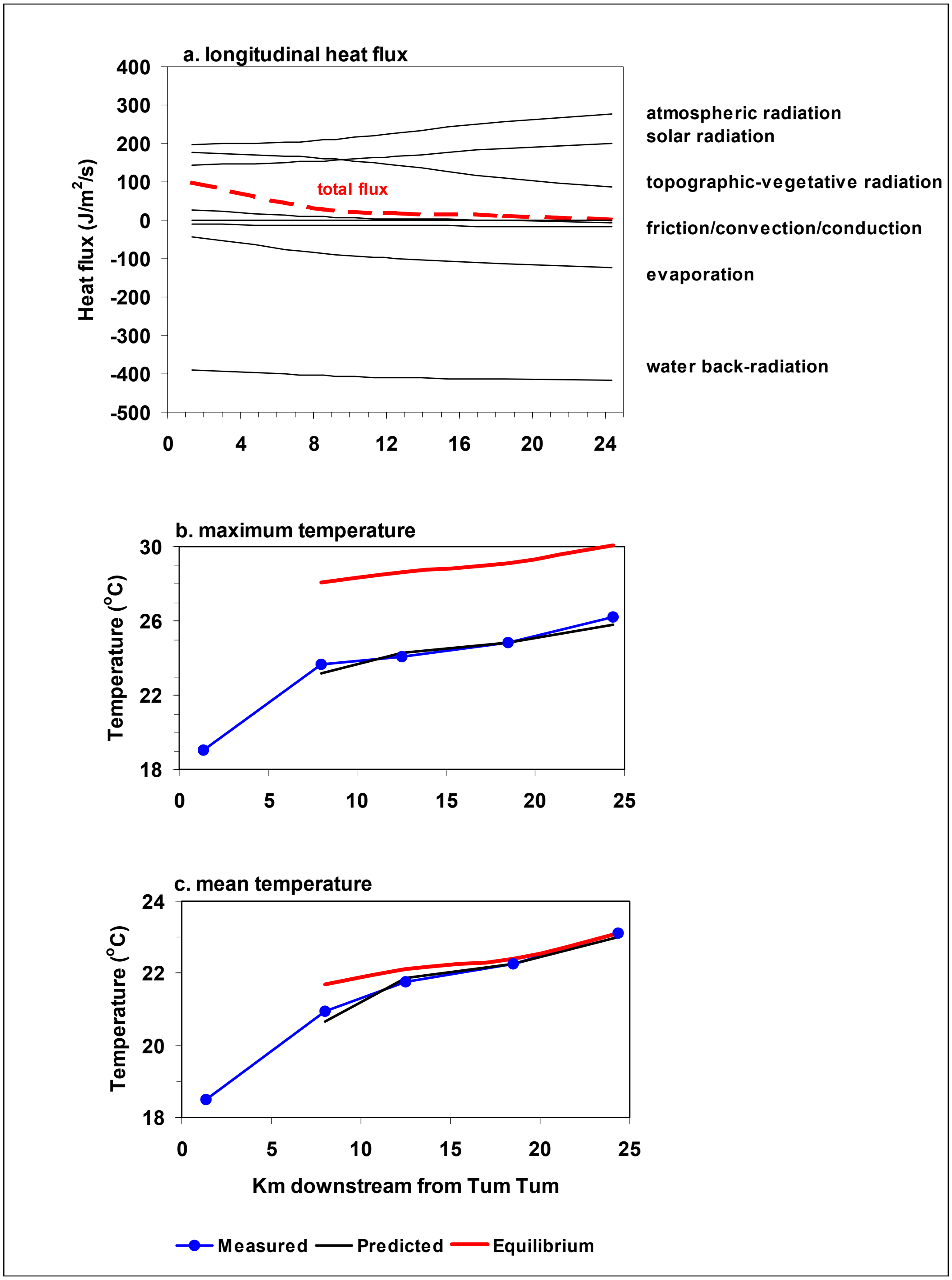
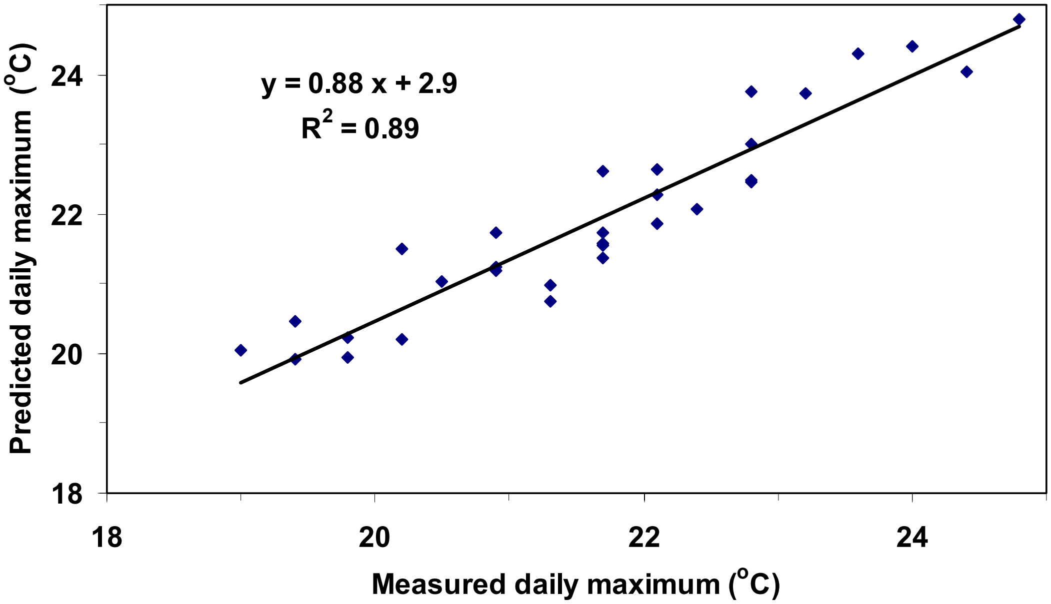


Figure 4. SSTEMP (version 1.1.0) model predictions of heat flux (a.), maximum stream temperature (b.), and mean stream temperature (c.) of the Marys River, Oregon, for August 13, 1998. Measured values correspond to sites 1-5 in Figure 2.

a. measured versus predicted maximum water temperature



b. measured versus predicted mean water temperature

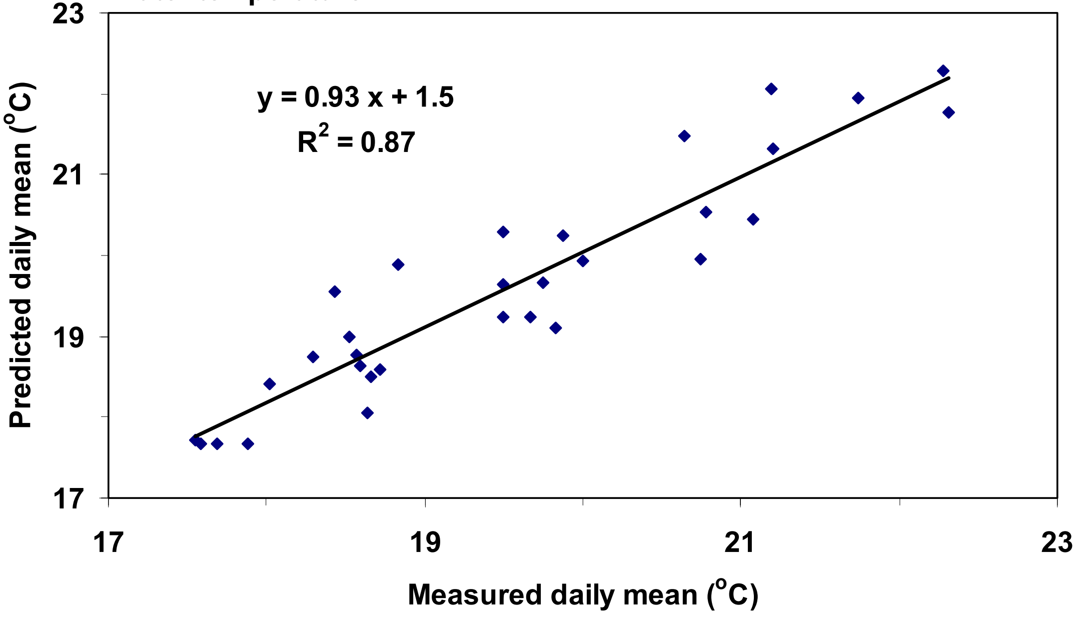


Figure 5. Validation of SSTEMP model (version 1.1.0) for site 4 (Figure 2) of the Marys River, Oregon, with daily maximum (a.) and mean (b.) stream temperature, compared to predictions for all days of August 1998.

Unexplained Error

Model error varied sinusoidally with time (Figure 6), suggesting that a weather related phenomenon may have been associated with the unexplained error. Since wind speed and percent possible sun were both input as constants for all days of August, surrogate measurements for these variables were sought from meteorological data collected at the nearby (13 km distance) Corvallis Municipal Airport. Hourly averaged wind speed data was recorded at the airport, however cloud cover data was descriptive in nature, and therefore not translatable to the units of percent possible sun required by the model. A comparison of wind speed variation measured from the Corvallis Municipal Airport revealed a similar, but not synchronous pattern (Figure 6). The sinusoidal nature of the airport wind speed variation appeared to capture the weekly pattern of onshore breezes from the nearby (50 km distance) coast, which are strongly funneled through east-west oriented Marys River valley. This was suggestive that additional model error could be explained by daily wind speed measurements, however use of airport wind speed data did not reduce model error. It was suspected that while wind speed was important, the airport data did not represent the local in-channel conditions of the modeled reach.

To address this additional model error, data collection was repeated during the summer of 1999, with the addition of a single anemometer placed in site 4 at 1.2 m above the channel water surface. Instantaneous wind speed recordings were logged approximately every 10 minutes on a Hobo© data logger and averaged daily. Daily average wind speed, as recorded by the anemometer for the entire month of August was zero, except for one day in which a rainstorm disabled the data logger. Use of zero wind speed values for all days of August 1999 gave an average model error of –1.9 °C for both mean and maximum water temperature. Regression of measured-on-predicted temperatures explained 80% of the variation in daily maximum and mean temperature for segment 3-4 during the month of August 1999. Use of the calibrated wind speed value of 2.5 m s^{-1} that was used for 1998 modeling, reduced the August 1999 average model error to around -0.8 °C for both mean and maximum temperature. Curiously it explained 6% less model error,

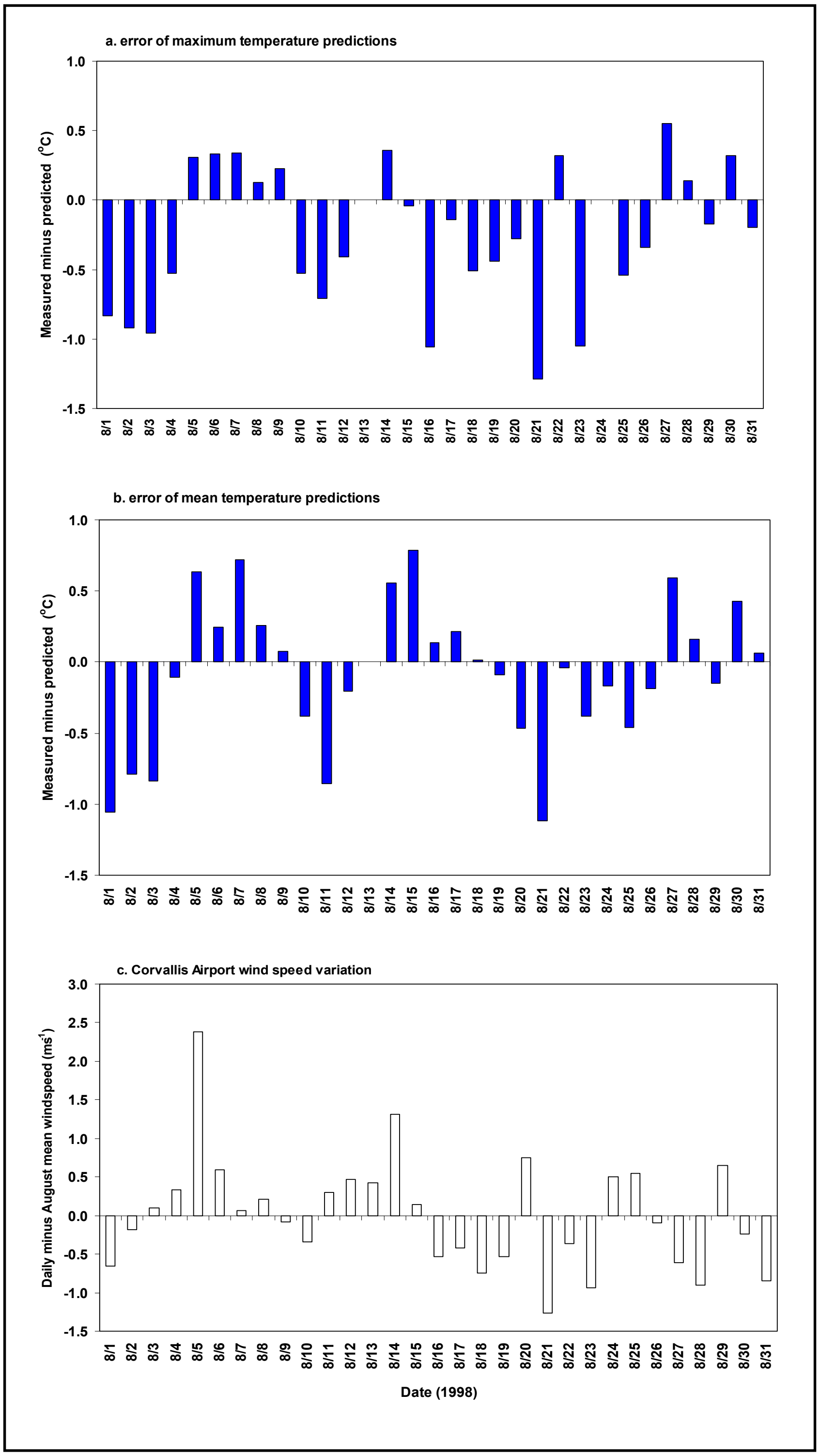


Figure 6. SSTEMP model (version 1.1.0) error for predictions of maximum (a.), and mean (b.) stream temperature at site 4 (Figure 2) in the Marys River, Oregon, August 1998. Windspeed variation (c.) recorded at the nearby (13 km distance) Corvallis Municipal Airport suggests a sinusoidal pattern that is similar, but not synchronous with model error in a. and b.

with an R^2=74% for both mean and maximum temperature.

Simulation Result

Riparian treatment simulations were run based on data from August 13, 1998. Model simulation of upstream and local effects of riparian shade showed a fundamental difference in their influence on stream temperature (Figure 7). The –3°C reduction in inflow temperature was quickly lost in downstream portions of the reach; the effect was predicted to be <0.5°C (mean and maximum) at 7 km downstream, and <0.01°C by the end of the 23 km reach. Conversely, the 30% increase to existing riparian shade was predicted to reduce water temperature by as much as 0.5°C to 1.0°C through the lower 2/3rds of the reach. Inspection of the area over the curves in Figure 7 shows that reductions in temperature by summing both upstream and local treatments were exactly the same as predictions from modeling both treatments simultaneously. This indicates that there were no interactive effects between the two treatments within the model; if there had been, then the simulation of both treatments together would have produced a greater reduction in temperature than was observed in Figure 7.

Discussion

The use of the SSTEMP model achieved very accurate predictions of stream temperature for the Marys River. Analysis of model error suggested that wind and/or percent possible sun were likely important variables to measure, but our efforts to do so produced confusing results, as model accuracy declined. Wind speed can be highly variable along a reach of stream due local differences in riparian vegetation and stream bank height. Future modeling efforts would likely be improved by an increased number of anemometer stations to more accurately assess the effects of wind speed, as well as some effort to quantify percent possible sun. The other model variables not measured in this study (ground temperature, thermal gradient, dust coefficient, ground reflectivity) are relatively insensitive parameters in the stream temperature models

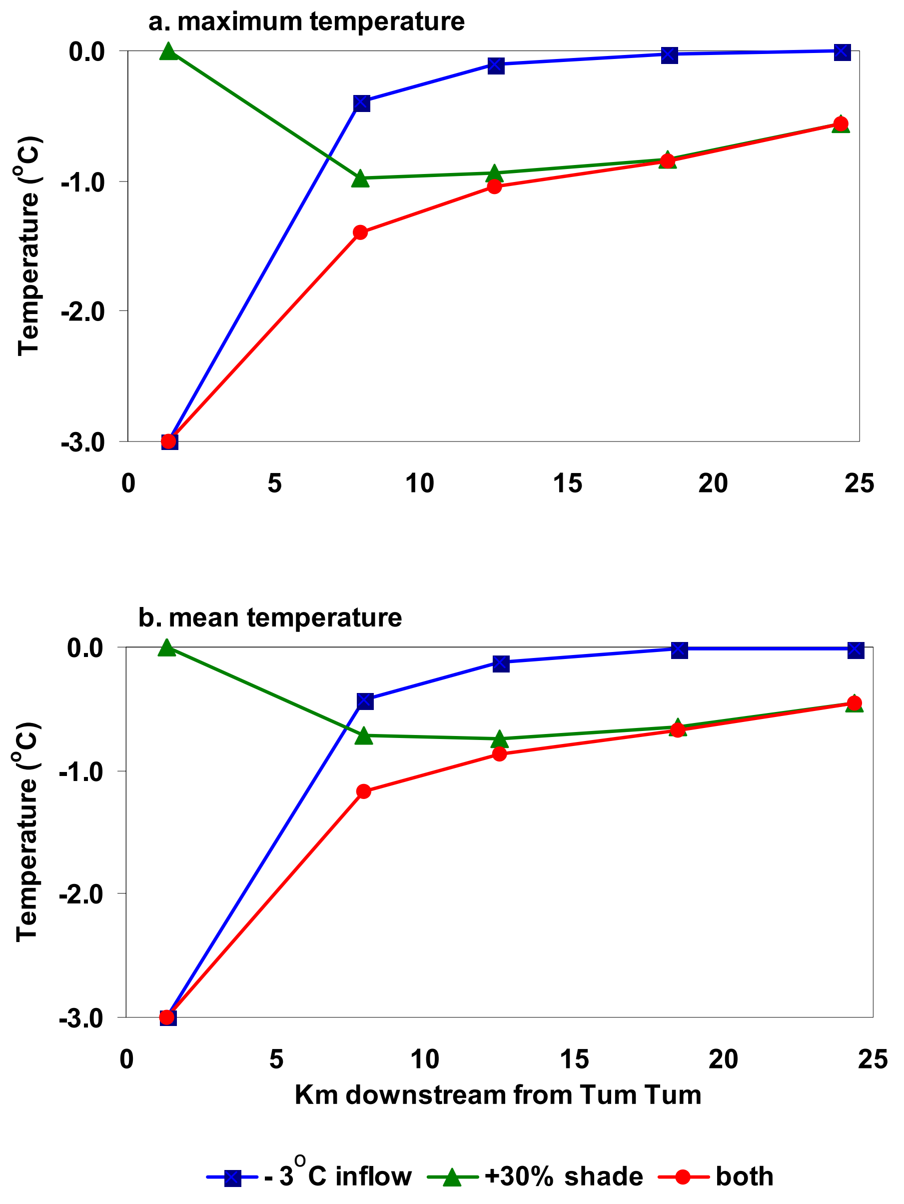


Figure 7. Predicted reduction (August 13, 1998 predicted minus treatment predicted) in maximum (a.) and mean (b.) stream temperature along a 23 km reach of the Marys River, Oregon, resulting from three hypothetical treatments that mimic upstream effects, local effects, and both. Upstream improvements to headwater channels are portrayed as a –3°C change to mean inflow temperature at the start of the reach; and local effects by a 30% increase in riparian shade along the entire 23 km reach.

(Bartholow 1989), and by their nature are constant over time, and therefore unlikely to account for the unexplained error in this study.

Model simulations of riparian enhancement suggest that sustained reductions in stream temperature in the Marys River below its confluence with the Tumtum River can most effectively be achieved by increases in local riparian shade. According to Bennett (1999) the percent canopy density and closure over this section of the Marys River is low, indicating a lack of shading. Increased riparian shade here could improve the suitability of rearing habitat for cutthroat trout in this section of the Marys River. Summer maximum water temperatures here are just above the threshold considered acceptable for cutthroat trout. This modeling effort suggests that a reduction of approximately 1^{o}C, to below the threshold value, could be achieved by a 30% increase in existing riparian shade in this portion of the river. While greater reductions in temperature could be achieved by higher levels of shade, the feasibility of such a goal would need to be placed in context of the local site potential for riparian vegetation.

This modeling effort did not investigate the effects of some other factors that could be important for water temperature in the Marys River, such as changes in flow due to water withdrawals, or changes in the channel width-to-depth ratio from stream bank erosion. Furthermore results of this study are restricted to the 23 km of channel below the confluence of the Tumtum River. Nonetheless the SSTEMP model developed here would easily lend itself to an analysis of these other factors, and lower reaches of this system.

Acknowledgments

A number of volunteers who live in the Marys River watershed or Benton County contributed to this project. Jesse Ford coordinated gauge placement and site measurements for the Greasy Watershed. Jim Fairchild also assisted with the site measurements. Tom Thompson, Amy Schoener, Dan O'Brien and Bill Richardson also participated in field observations. We appreciate all the landowners who agreed to have gauges placed in streams that flow through their property. Thanks to Philomath High School for the use of their water temperature gauges in 1998 and helping in downloading data. We also thank Amy Schoener for reviewing both chapters and Cascade Pacific Resource Conservation & Development Area, Inc. for administering this grant. In total, we estimate that the volunteers contributed over 250 hours to the monitoring and modeling studies.

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