2003 Stream Temperature Monitoring Report

Entiat and Chelan Ranger Districts
Phil Archibald, Fishery Biologist and
Emily Johnson, Fishery Biologist

Objective: In accordance with the Clean Water Act of 1977, which set federal standards for water quality, the State of Washington developed state standards to meet or exceed the CWA 303(d) list of federal standards. There are five water quality parameters that have standards set by the State, including water temperature. Water temperature is a key component of fish habitat and aquatic ecology. Cold water fish species such as trout and salmon are particularly sensitive to very high and very low temperatures. Water temperature criteria set by the State (Class AA Streams <60.8ºF, Class A Streams <64.4ºF) and water temperature criteria set by the Wenatchee Forest Plan (<61ºF), focus mainly on summer maximum water temperatures. However, as postulated by the Entiat Watershed Analysis (WNF 1996), harsh winter rearing conditions could be more limiting than summer increases in stream temperatures within the Entiat and Mad Rivers. In order to describe water temperature reference conditions of streams and rivers within the Entiat and Chelan Ranger Districts and to evaluate water temperature conditions in CWA 303(d) listed waterbodies (e.g. mainstem Entiat River), a water temperature monitoring program was instituted by the USFS. In 1993 the Entiat Ranger District began monitoring summer maximum stream temperatures within the Eniat and Mad River watersheds and tributaries to Lake Chelan. In 1998, the stream temperature monitoring program was expanded and a network of continuous-recording thermographs was placed at multiple locations in the mainstem Entiat and Mad Rivers for an extended period of time (late-March to early-November). This expanded network of stream temperature monitoring will be continued in order to provide information on the thermal regime of these watersheds and to contribute to District and Forest efforts to describe reference conditions. Annual water temperature data are used for multiple purposes including; the development of a regional data base that may be used to revise Washington State temperature standards for Eastside streams, for future iterations of Watershed Analyses and future Forest Plans to describe desired future conditions, to support the water quality element of the the Entiat WRIA 46 Management Plan being written by the Entiat Watershed Planning Unit (EWPU) and Chelan County Conservation District (CCCD) and by District personnel in project analysis for proposed actions on National Forest lands and in biological assessments for three ESA listed species (bull trout, spring chinook salmon and steelhead trout). The Entiat Ranger District data also supported SNTEMP model calibration of water temperature in the Enitat River (Hendrick and Monahan 2003) by providing observed water temperatures for the years 1995-2002.

Methods: The procedures used in 2003 (and all previous years) are outlined in the TFW Stream Temperature Module, Level 1 methodology (Rashin et al. 1994) with some departures as noted. The monitoring period was chosen to encompass expected low flows and the highest air temperatures for this area (mid-June to mid-Sept). In the Mad and Entiat Rivers, the monitoring period was extended to include the steelhead spawning period from March to May and the declining period of stream temperatures that typically occurs during the fall spawning period for chinook salmon and bull trout (September to November). In 2003, four thermographs were left in place from January 1st to December 31st (see Table 1) in the Entiat and Mad Rivers. The USFWS Entiat hatchery data for Entiat RM 7.1 encompassed February to the end of October.

Water temperatures monitored by the Entiat Ranger District included 9 streams/rivers (33 stations) within the Entiat and Mad River watersheds and 10 streams (12 stations) on the Chelan Ranger District. Additional stream temperature monitoring data provided by the Entiat National Fish Hatchery (USFWS) for river mile 7.1 of the Entiat River are included. See attached Table 1 for specific locations and monitoring periods.

Measurement methods included TidbiT® temperature loggers on loan from the USFWS deployed at 7 locations in Lake Chelan tributaries on the North and South shores of the lake. StowAway Temp loggers® were deployed at 33 locations in the Mad River drainage and the Entiat River drainage and at five locations in Lake Chelan tributaries (see Appendix A). Data were continuously recorded during the deployment period and devices were routinely checked to ensure they were functioning appropriately during the monitoring period.

Temperature data loggers were encased in open-ended PVC plastic tubes that were anchored by one-pound weights and secured with stainless steel 1.5 mm cables. This procedure was used to: (1) prevent "sand-blasting" of thermograph cases, (2) to prevent direct sunlight from striking the thermographs and warming them, and (3) to allow deployment into deeper water thereby decreasing occurrences of dewatered devices. Unfortunately, during high water the cables tended to break and six PVC cases and thermographs were lost (see Table 1). Hand-held thermometers were used for quality control comparisons to the other temperature recording devices in place.

Pre-season calibration and quality control of thermometers and thermographs consisted of simultaneous immersion in a water bath for approximately one hour to ensure that all devices were registering the same temperatures ±0.2°C (manufacturer's maximum total error standard). Two water baths were used, one warm (76-98°F) and one cold (60-64°F). Post-season calibrations were not performed. Prior to deployment, thermographs were set to record at 30 to 36-minute intervals. The 30 to 36-minute record interval allowed a maximum deployment of 165 to 192 days before these data loggers needed to be downloaded.

Results: A total of **7195** stream-days of water temperature monitoring were accomplished in 2003 compared with 5913 stream-days in 2002. Data from the USFWS Entiat Hatchery location contributed an additional ?? stream-days to our temperature monitoring database in 2003. For weekly temperature summaries, including weekly maximum, minimum and 7-day average temperatures see Appendix A.

Table 1. Water Temperature Data Summary for the Entiat and Mad Rivers and Lake Chelan Tributaries (2003)

Location	**Monitoring Period**	**# of Days Monitored**	**# Days exceeding 64.4ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
Entiat River Locations				
RM 1.4, Keystone	1/1-12/31	365	60	N/A
RM 3.2, Fire Station	4/16-10/29	197	58	N/A
RM 5.8, Knapp Wham Bridge	5/18-10/29	165	61	N/A
RM 7.1, USFWS Hatchery				N/A
RM 8.5, Rinstead Canyon	5/18-10/30	166	55	N/A
RM 10.2, Cooper's Store	5/17-10/29	166	42	N/A
RM 10.8, Near Milepost 10	6/21-10/29	131	51	N/A
RM 12.5, below Medsker Canyon	Broken Cable	0		N/A
RM 15.0, Near Roundy Cr.	5/18-10/30	166	25	N/A
RM 18, near Stormy Cr. Gage	1/1-12/31	365	31	N/A
Total		**1721**	**383**	N/A
	Monitoring Period	**# of Days Monitored**	**# Days exceeding 61ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
RM 21.1, Near Dill Cr.	5/18-10/29	165	40	N/A
RM 24.1, near Brennegan Cr.	4/16-10/29	197	40	N/A
RM 26, Near Forest Boundary	1/1-12/31	365	18	35
RM 30.5, Silver Falls C.G.	5/20-10/29	163	0	20
RM 34.1 ^ N.F. Entiat	8/7-10/29	184	0	0
RM 38.2, Cottonwood C.G.	6/26-10/29	126	0	0
Total		**1200**	**98**	**165**
Entiat River Tributaries	**Monitoring Period**	**# of Days Monitored**	**# Days exceeding 61ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
North Fork Entiat River	Broken Cable	0		
Upper Roaring Creek	4/16-8/9	116	35	51
Lower Roaring Creek	5/1-9/23	146	54	87
Mud Creek	4/24-9/23	153	0	18
Potato Creek	5/1-9/23	146	70	93
Stormy Creek	8/10-1/24	167	3	22
Preston Creek	4/24-9/23	153	12	49
Lake Creek	Broken Cable	0		
Total		**881**	**174**	**320**

Table 1 (continued). Water Temperature Data Summary for the Entiat and Mad Rivers and Lake Chelan Tributaries (2003)

Lake Chelan Drainages	**Monitoring Period**	**# of Days Monitored**	**# Days exceeding 61ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
First Creek	7/7-10/6	92	0	0
25 Mile Creek	7/7-10/6	92	4	39
North Fork 25 Mile Creek	7/7-10/6	92	0	0
South Fork 25 Mile Creek	7/7-10/6	92	0	0
Lower Mitchell Cr	6/3-9/24	114	64	89
Gold Creek	7/11-10/21	103	0	0
Poison Cr	7/11-10/21	103	8	45
Grade Creek	7/11-10/21	103	0	13
Coyote Creek	7/11-10/21	103	0	0
Falls Creek	Broken Cable	0		
Safety Harbor Creek	7/11-10/8	90	0	0
Prince Creek	6/3-7/18	46	6	10
Fish Creek	6/3-11/6	157	54	74
Total		**1187**	**136**	**270**
Mad River	**Monitoring Period**	**# of Days Monitored**	**# Days exceeding 61ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
Mad River @ mouth	4/10-12/3	238	58	75
Mad ^ Tillicum	1/1-12/31	365	62	74
Mad ^ Pine Flats C.G.	4/8-10/30	206	59	74
Mad ^ Hornet Cr	4/10-10/30	204	56	73
Mad ^ Windy Cr	5/22-10/24	156	57	64
Mad ^ Young	5/22-10/23	155	1	14
Mad ^ Cougar Cr	7/23-10/28	98	0	0
Mad ^ Berg Cr	7/23-10/9	79	0	0
Mad ^ Jimmy Cr	7/28-10/9	74	2	3
Mad ^ Blue Cr	8/12-10/20	70	0	1
Mad Lake Outlet	7/21-10/21	93	51	65
Total		**1738**	**346**	**443**
Mad River Tributaries	**Monitoring Period**	**# of Days Monitored**	**# Days exceeding 61ºF**	**# Days Average 7-Day Max of 58ºF was exceeded**
Tillicum Creek	4/8-12/3	240	0	0
Young Creek	5/22-10/23	155	0	0
Cougar Creek	7/23-10/3	73	0	0
Total		**468**	**0**	**0**
Total Stream-Days		**7195**	**754**	**1877**

Discussion and Conclusions

Climate Factors

Climate data from the Entiat National Fish Hatchery indicated that the lower Entiat basin experienced warmer than average air temperatures and below average levels of snowfall (2002-2003 winter) in comparison to the thirteen-year average (1989-2002). Climate data from Entiat RM 18, recorded 17.6 inches of precipitation during the 2002-2003 water year, which is slightly below the 8-yr average of 18.98 inches of precipitation (1996-2003). The Entiat Cooperative River Basin Study (1979) estimated that this area recieves 20 to 25 inches of precipitation per year.

Climate data from the Pope Ridge Weather Station, in the upper Entiat Valley (approx. RM 34) recorded mean maximum air temperatures that were warmer (1.0ºF to 2.5ºF) than average during the winter of 2002-2003 (November to February). From March to May, air temperatures cooled to below average (0.8ºF to 3.9ºF) and June through August were again warmer than average (2.9ºF to 5.8ºF). For the 2003 water year, 27.7 inches of precipitation accumulated at the Pope Ridge site which is 22% less than the 22-year average of 35.6 inches. The majority of precipitation accumulated from December (2002) to March (2003), mostly as snow. From June to September, only trace amounts of preciptiation were recorded. The combined effects of lower than average precipitation during the winter, an extremely dry summer and warmer than average summer air temperatures (June to August), resulted in low streamflows during the summer months (see Figure 1) and elevated water temperatures. Initial peaks in stream temperatures occurred two to three weeks earlier and were of longer duration than those observed in 2002 and maximum stream temperatures within the Entiat River were also higher (up to 10°F) than those observed in 2002.

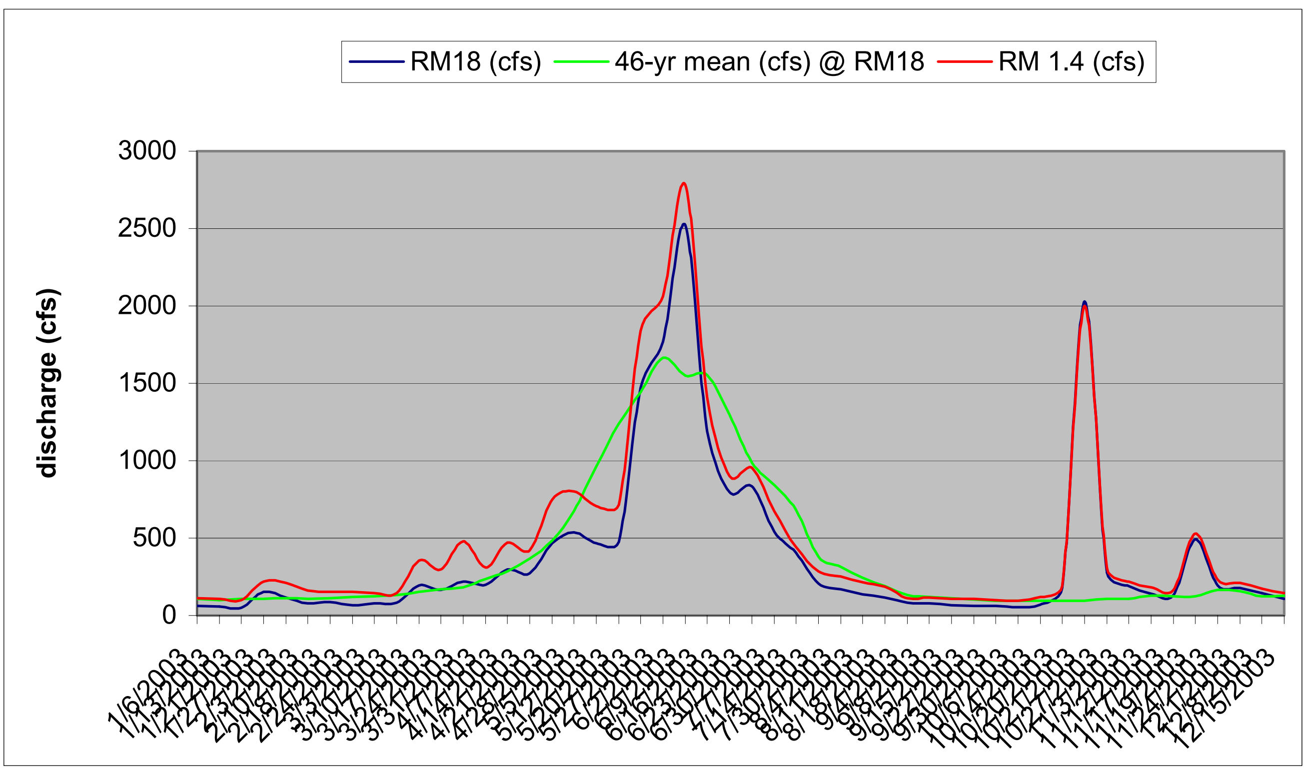

Figure 1. 2003 Entiat River hydrograph and mean annual hydrograph, USGS gage @ RM18 and Entiat River hydrograph @ RM 1.4.

Elevational Influences
Exceedances of the Forest Plan water temperature standard (61°F; State Class AA = 60.8°F) most frequently occur in streams at or below 2000 feet in elevation (see Table 1; see Appendix A). Four locations above 2000 feet in elevation exceeded Forest Plan standards: the Mad River above Windy Creek (2440 feet in elevation; 57 days), the Mad River above Young Creek (3000 feet in elevation; 1 day), the Mad River above Jimmy Creek (4600 feet in elevation; 2 days) and the Mad River at the Mad Lake Outlet (5900 feet in elevation; 51 days). Five monitored locations below 2000 feet in elevation did not exceed the Forest Plan Standard for daily maximum stream temperatures, including: the Entiat River at RM 31, Tillicum Creek, First Creek, and the North and South Forks of Twenty-Five Mile Creek. Factors such as topography, geology, groundwater storage landforms, riparian conditions and orientation of the drainages with respect to the surrounding landscape are most likely very influential in maintaining lower water temperatures in these streams.

Exceedances and the Thermal Regime in the Entiat River
The following discussion incorporates analysis from multiple sources, including; historical stream temperature data and current stream temperature data collected and analyzed by USFS personnel (USFS 1993-2003); Stream Network Temperature Model Analysis (SNTEMP; Hendrick and Monahan 2002) for the Entiat Watershed Planning Unit (EWPU) Draft WRIA 46 Management Plan (2004), the Thermal Infrared Aerial Remote Sensing Survey (Watershed Sciences, LLC 2001), stream temperature data from WDOE gaging stations, Entiat River Gain/Loss Study (CCCD 2002), the Entiat valley aquifer depth study (Dixon 2003) and information about the Entiat geology and alluvial valley.

Temperature exceedances in the Entiat River occur during mid to late summer when low flows, high air temperatures and high insolation rates coincide. They are usually of short duration and diurnal in nature. A 1994 review of ambient monitoring results by WDOE for Water Years (WY) 1978 - 1991 noted that high water temperature in the afternoon during late-summer and fall was the major water quality standard not met (Ehinger 1994). Ambient water quality data collected at the Keystone site from July 1959 to September 2003 also show a pattern of late summer temperature exceedances occurring during the months of July, August and September. The lower Entiat River was included on the 1996 303(d) list of impaired or threatened waters for temperature and instream flows, and is currently listed on the draft 2002 303(d) list for temperature.

The following trend in summer stream temperatures is based on data collected by the USFS (1993-2003) and confirmed by the TIR Flight (2001) and SNTEMP model:

- The North Fork of the Entiat River near its confluence with the Entiat River tends to be warmer than the mainstem from the middle of July until early September;
- Substantial warming tends to occur between RM 38 (Cottonwood campground) and RM 21 (Dill Creek Bridge);
- A "moderating zone" extends from RM 18 (USGS gage) downstream to RM 15 (Roundy Creek confluence) during the hottest part of the summer, with maximum stream temperatures differing by only tenths of a degree from late July to early October;
- Between RM 10.8 and RM 10.2, where the Mad River flows into the Entiat River, stream temperatures tend to be equivalent indicating that the Mad River does not have a great influence on Entiat River water temperatures;
- In 2003, another "moderating zone" extended from RM 8.5 downstream to RM 5.3;
- Stream temperatures gradually warm from RM 5.3 to RM 1.4, with maximum temperatures recorded near the Keystone bridge;
- Exceedances about RM 20 generally occur from early August to early September; from RM 21 downstream, exceedances are of progressively longer duration, beginning in late July and continuing until mid-September.

Table 2. 2003 Entiat River longitudinal stream temperature monitoring results by week and elevation. Shown are weekly **maximums** in degrees F. *Exceedances are noted within shaded boxes*

Elev. (ft.)	RM	6/10 6/16	6/17 6/23	6/24 6/30	7/1 7/7	7/8 7/14	7/15 7/21	7/22 7/28	7/29 8/4	8/5 8/11	8/12 8/18	8/19 8/25	8/26 9/1	9/2 9/8	9/9 9/15	9/16 9/22	9/23 9/29	9/30 10/6	10/7 10/13
3100	RM 38.2				50.8	53.1	54.2	55.3	56.1	55.6	55.3	54.2	53.6	539	49.4	48	51.1	55.8	56.6
2650	RM 34.1										57.7	58.3	56.9	56.6	56.3	51.9	49.9	53	50.2
1950	RM 30.5	48.2	48.8	51.8	52.7	55.2	57.4	59.4	60.5	59.7	60.2	59.1	58.5	58.8	52.9	52.1	54.3	51.8	50.7
1750	RM 26	49.6	49.8	53.5	55.1	57.9	60.5	**62.8**	**63.9**	**62.2**	**62.5**	**61.3**	55.7	55.7	53.2	52.6	52.4	51.8	51.8
1710	RM 24.1	50.1	50.4	54.3	55.9	58.7	**61.6**	**63.9**	**65.3**	**63.9**	**65.3**	**64.4**	**63.3**	**63.3**	57.8	56.2	58.4	55.9	53.1
1640	RM 21.1	49.3	49.6	52.9	53.5	57.1	59.9	**61.9**	**62.5**	**66.2**	**66.8**	**65.4**	**64.5**	**64.5**	58.5	56.5	59.1	56.5	53.5
1580	RM 18	52.2	52.7	56.9	58.3	61.7	**64.9**	**66.9**	**68.4**	**66.6**	**66.9**	**66.1**	**64.9**	**64.6**	57.7	57.2	58.6	56.3	54.4
1480	RM 15	51.7	52.5	57.3	59.5	**65.5**	*	*	*	*	**67.3**	**67.9**	**67.3**	**66.1**	**65.5**	58.7	57.8	59.5	57.3
1365	RM 12.5																		
1265	RM 10.8			58.1	60	63.5	**66.4**	**69**	**71.1**	**70.5**	**71.4**	**69.9**	**69.6**	**69.9**	61.8	62.3	64	60.9	55.6
1250	RM 10.2	52.4	53.2	58.2	57.7	60.2	63.1	**65.4**	**67.4**	**70.4**	**71.6**	**70.4**	**69.5**	**69.5**	61.1	61.4	63.1	60	55.7
1150	RM 8.5	52.7	53.8	58.8	60.8	**64.9**	**67.5**	**70.4**	**72.2**	**71**	**71.9**	**70.4**	**69.2**	**69.8**	62.3	61.7	**64.6**	59.7	55.7
1150	RM 7.1																		
950	RM 5.3	52.9	53.8	59.4	60.5	**64.5**	**67.7**	**71.9**	**75.2**	**73.4**	**74.6**	**72.2**	**72.2**	**73.4**	63.4	**65.1**	**68.9**	**65.7**	58.5
820	RM 3.2	53.5	54.3	60.2	62.5	**66.2**	**69.4**	**71.8**	**73.6**	**71.8**	**72.7**	**71.2**	**69.7**	**70**	62.7	61	64.2	59.6	56.5
744	RM 1.4	54.3	55.2	61.1	63.1	**66.6**	**69.8**	**72.5**	**74.3**	**72.5**	**73.1**	**71.6**	**70.1**	**70.1**	63.1	61.4	**64.5**	60.5	56.6

Differences in stream temperatures near the confluence of the North Fork with the Entiat River mainstem are likely related to several factors. First, the mainstem and the North Fork of the Entiat have different primary sources of summer flows. The Entiat mainstem receives summer flows from snowmelt, glaciers and perennial snowfields within the Glacier Peak Wilderness area located farther west and at higher elevation (7000-8000 feet) than the headwaters of the North Fork. In contrast, the North Fork receives summer flows from yearly snow melt and runoff not associated with glaciers or perennial snowfields and the headwaters are at a lower elevation (6000 feet).

Other factors that may have a large influence on North Fork stream temperatures include the aspect of the stream (north-south versus the east-west orientation of the mainstem) and the presence of massive rock outcrops that constrain the channel from RM 0.5 to RM 1 potentially serving as heat sinks during the summer. Additionally, aquifer depth near the mouth of the North Fork Entiat River was modeled at 40 feet and approximately 47 acres in size (Dixon 2003), indicating that the volume of cooler groundwater input to this reach during the months of June through September, which showed a decreasing trend in aquifer storage, would not likely be substantial enough to provide a moderating influence on warmer water temperatures.

In the mainstem Entiat from the North Fork confluence at RM 34 to the USFS monitoring site at RM 26 (Forest Service boundary, near McCrea Creek confluence), stream temperatures would be expected to rise naturally due to the warmer North Fork contributions, an elevational decline of about 900 feet and the presence of the Box Canyon near RM 29 which confines the channel to a narrow bedrock gorge that likely serves as a heat sink/source as well. Modeled aquifer depth from the North Fork confluence downstream to Box Canyon ranged from 45 to 65 feet, which is still relatively shallow given the range of aquifer thickness estimated in the valley (25 to 197 feet) (Dixon 2003). Although aquifer storage was shown to decrease between July and September, indicating that baseflows are supporting overall stream flow during this period, gain loss data showed an overall net loss of 12.85 cfs per mile for the 4.67 mile reach between the North Fork confluence and the top of Box Canyon (CCCD 2002). Almost all of the loss recorded in the September gain/loss analysis occurred in the 0.4 miles between the North Fork confluence and Entiat Falls (-12.85 cfs per mile). This significant decrease in surface flow may also be contributing to warmer water temperatures in the reach from the North Fork to Box Canyon; however, DNR surficial geology data indicate a pocket of alluvium here, which confounds interpretation of surface/ground water exchange in this area.

From the USFS boundary at RM 26 downstream to RM 18, the river flows through an increasingly wider U-shaped valley where it exhibits increased sinuosity and a lower gradient compared to all other areas of the Entiat River. In this "still waters" reach where stream temperatures would be naturally expected to increase as well, a temperature moderating influence was observed in 1999-2003 and was also seen from the TIR flight data. The moderating zone lies between RM 21 and RM 16, and is most likely related to a ground aquifer created by glacial till. Much of the landform in the upper and mid-Entiat Valley was shaped by a glacier that extended from the west towards the Columbia River ending at about RM 16. The area at RM 16 is a terminal moraine, with a broad U-shaped valley present above this point and a more confined V-shaped valley downstream. However, movement of the cooling zone downstream during late fall indicates that the area of glacial till serving as groundwater storage may actually extend downstream further than RM 16.

Model data show that alluvial aquifer depth and aquifer polygon size increase significantly in the stillwaters reach from RM 26 downstream to the Stormy Creek confluence near RM 18, with the majority of aquifer polygons estimated to be 100 feet or more deep (Dixon 2003). The deepest aquifer polygon (197 feet), and five aquifer areas estimated at over 100 acres in size and ranging in depth from 129 to 180 feet, are found within this portion of the valley. This supports the hypothesis that the large volume of groundwater stored in this area may provide a moderating influence on stream temperatures. DNR data indicate a large fault between RM 19 and RM 20, which may also contribute cooler subsurface water to this reach.

Predicted aquifer depth begins to decrease around RM 17 although tends to remain between 60 and 80 feet until about RM 14. Two modeled areas of approximately 50 acres and 70 feet deep fell between RM 16 and 15, with a larger polygon of approximately 100 acres in size and 79 feet in depth between RM 14 and 15. Gain/loss data show a gain of 10.09 cfs per mile between RM 16 and approximately RM 14.3, which may be explained by groundwater contributions from these larger, moderately deep aquifer areas (CCCD 2002). Their presence also contributes to the idea that areas of deeper alluvium and groundwater storage do exist downstream of the terminal moraine at RM 16.

Stream temperatures in the Mad River near the confluence with the Entiat River were somewhat cooler than those observed at the Entiat RM 10.8 or RM 10.2 during the 18 weeks of data collected during the 2003 Mad River monitoring period. Overall the Mad River appeared to have a slight (mean = 0.8°F, range = 0.0ºF to 3.9°F) cooling influence on mainstem Entiat stream temperatures although the Mad River in August and September generally contributes 10-20% of the Entiat River flow. Gain/loss data collected in September above and below the Mad River confluence showed a loss of 7.02 cfs per mile in this area (CCCD 2002), which may also help explain why the Mad has very little moderating influence on temperatures of the mainstem Entiat River in this reach.

The thermal moderating zone that lies between RM 8.5 and RM 5.3 may be related to groundwater aquifers created by glacial Lake Missoula flood deposits located at the mouth of Roaring Creek (Claudia Narcisco, USFS Geomorphologist, personal communication). Aquifer model data show an area approximately 92 feet deep near the mouth of Roaring Creek, which supports the notion of a deeper deposit and the potential influence of groundwater in that area. Gain/loss data also indicated a net gain of 0.02 cfs over the 0.9mi stretch from just above the Roaring Creek alluvial fan to its mouth. "In addition to the glacial outwash gravels there are geologic controls, both bedrock and structural that likely contribute to the occurrence of groundwater in the area. A wedge of the Mad River schist extends from the headwaters of the Mad River down to the Columbia. It begins to thicken in plan view near Dinkelman Canyon, and mid to lower Roaring Creek is largely underlain by this rock type. It weathers to a finer textured soil than is common with the granitic or gneissic bedrock in the area with potential for clay intergrades. This rock is the same as that seen on the southwest slope of the Mad River, where the large and seepy slumps occur. Additionally, there is a (thrust) fault contact within this unit and the Swakane biotite gniess which crosses the mid-drainage of Roaring Creek and near the mouth of Mills Canyon" (C. Narcisco, personal communication). DNR data also show three normal faults oriented towards the mainstem Entiat contacting a Napeequa unit and Entiat Pluton in the Saunders Canyon area (between RM 5 and RM 4). Fault zones can serve as conduits which transmit increased groundwater; gain/loss data show a tremendous increase in flow (30.51 cfs per mile) between Dissmore and Dinkleman Canyons (approximately RM 5.2 to 4.3) (CCCD 2002). Another potential factor is that the foliation plane in both the Mad River schist and the Swakane gneiss (in this area) dips toward the Entiat valley and could provide for some recharge of groundwater to the aquifer" (C. Narcisco, personal communication).

Thermal Infrared (TIR) imagery data for the Entiat River collected during a flight on August 11th, 2001 (Watershed Sciences, LLC 2001) showed thermal cooling from two outflows from the Entiat National Fish Hatchery. The hatchery is located upstream from Roaring Creek at RM 7.1 and pumps hatchery well water into the Entiat River daily. Six pumps continuously delivered approximately 4.1 cfs of cold (51ºF) groundwater to the Entiat River during August 2003, which is approximately 2% of the average monthly river flow based on the USGS gaging station at Keystone (218 cfs). This influx of cold groundwater may be another potential factor for the moderating influence located within this zone.

From RM 5.3 to the river mouth, warming continued at a rate similar to that between RM 21 and RM 31. This is likely related to changes in channel morphology and reduced riparian cover in the most populated segment of the river.

Two implications of the above described thermal regime come to mind. Due to <u>natural conditions</u> created by the Box Canyon and still waters areas, some monitoring sites above RM 15 may be naturally prone to exceeding water quality standards. From a fisheries standpoint, the zones of warming and cooling are both important and are utilized by spawning chinook salmon from September through November. Chinook spawning survey maps indicate that the majority of the spring chinook spawning typically encompasses RM 28 to RM 16 while the summer chinook spawning generally occurs from RM 20 to RM 16 and from RM 0.5 to RM 4.5. Because summer chinook spawn later in the season when water temperatures are declining, they may be drawn to areas nearer to ground aquifers that would provide appropriate stream temperatures for spawning success.

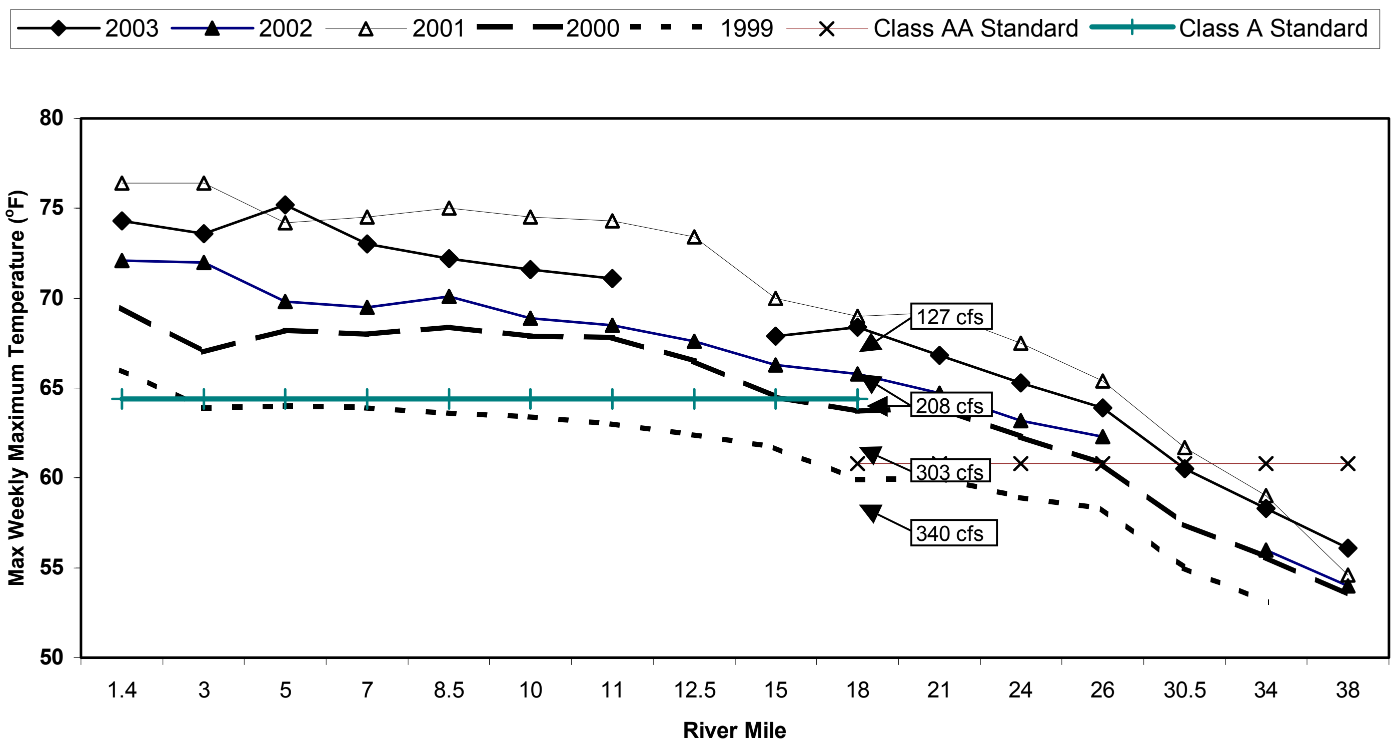

Figure 2. Entiat River longitudinal temperature profile (RM 1-38) 1999-2003.

Exceedances in the Mad River and Tributaries

The Mad River temperature data set spans 63 years, making it the longest-term record available for the Entiat subbasin. As the Mad River is essentially unaffected by direct management of riparian and valley bottom vegetation from RM 4.0 to the headwaters, a distance of nearly 20 miles, it represents a possible "reference" stream useful for assessing "natural variability" and may provide an important piece of information for natural water temperature regimes in similar land type associations.

Thermograph data collected by the USFS Entiat RD from 1993-2003 indicate that maximum water temperatures in excess of 61°F in the lower Mad River occur consistently. The following trend in Mad River summer water temperatures has been identified:

- At Mad Lake where the river originates, stream temperatures are substantially warmer at the outlet of this high elevation (5900 feet) shallow lake;
- Stream temperatures gradually cool going downstream until reaching the Cougar Creek area (3400 feet);
- Re-warming progressively occurs from Cougar Creek downstream to Tillicum Creek (1400 feet);
- Tillicum Creek then provides a cooling influence evidenced by lower stream temperatures at the confluence with the Entiat River than those observed just above the Tillicum confluence.

Three historic sources of Mad River water temperature data (stream surveys from 1935-36 (Bureau of Fisheries), 1972 (Holtby WNF), and 1990 (Haskins WNF*)*, were reviewed to provide context and support for the observed trend; all historic data coincided with and reinforced the trend hypothesized in 1997. Thermal Infrared (TIR) imagery data for the Mad River collected during a flight on August 12th, 2001 helped to explain observed trends (Watershed Sciences, LLC 2001). The TIR imagery showed that cold water inputs from springs and tributaries contributed to the observed spatial temperature variations in the Mad River, and analysis revealed that reach-scale patterns may influence downstream heating in five identified "response" reaches (Faux and Archibald 2002).

The Mad River originates relatively warmer at the small (5 acres) and shallow (<20 feet deep) Mad Lake. It then flows through high elevation meadows with little shading from vegetation or topography. TIR imagery revealed that the temperature pattern in this reach (Reach 1, RM 26 to RM 20.5) is characterized by rapid increases in temperature over relatively short spatial scales due to direct solar radiation; however, stream temperatures in this reach also respond dramatically to tributary and spring inputs as a result of relatively low flow conditions, (Faux and Archibald 2002). Thus, a high degree of spatial thermal variability exists from Mad Lake downstream to this point.

Reach 2 (RM 20.5 to RM 17.4) showed an overall cooling trend. A spring was detected near RM 20.5, and vegetative shading also increases. Most importantly, the valley bottom consists of deep glacial till which stores and cools groundwater that contributes to Mad River streamflow. The combination of ground water influx, topographic and vegetative shading reduces the warming effects of direct solar radiation in this reach (Faux and Archibald 2002).

Reach 3 (RM 17.4 to 14.3) temperatures remained consistently cool, although no longer showed a general cooling trend. Deposits of glacial till are also present in this reach indicating the continued contribution of ground water as a buffer to stream warming; however, cooling influences decrease as the glacial till ends below Cougar Creek. The river also has an easterly aspect through this reach, which may also increase the amount of solar radiation. Downstream of this reach, Mad River temperature begins to increase again.

In Reach 4 (RM 14.3 to RM 10), from below Cougar Creek to around Camp Nine, a rapid increase in the heating rate was observed that accounted for most of the warming observed over the full length of the profile (Faux and Archibald 2002). The likely explanation is the transition from glacial till and associated groundwater inputs to more exposed steep bedrock along the north side of the Mad River valley. Riparian vegetation is also less dense in this reach due in part to the 1994 Tyee Fire. It is tempting to attribute some of the warming to the 1994 Tyee Fire which killed most overstory riparian vegetation in the vicinity of Young Creek and Camp Nine. Although the magnitude of temperature increases may be a result of the Tyee Fire, the warming trend was observed in the 1930's, 1972, and 1990, when the riparian canopy was intact. The visible band color images also showed both vegetative and topographic shading at the time of the August 2001 survey (Faux and Archibald 2002), indicating that the mass of bedrock outcroppings likely acts as a heat sink which warms the Mad River by conduction and possibly by reflection as the sun declines from its zenith in the months of July and August.

Reach 5 (RM10 to mouth) showed a slight warming trend with some local spatial variability at several points. A marked cooling in temperature was noted at around RM 8.7 where the channel gradient increases over the next two miles, suggesting possible groundwater upwelling in this area. Tillicum Creek (about RM 2) has also been identified as a cooling source to the Mad River.

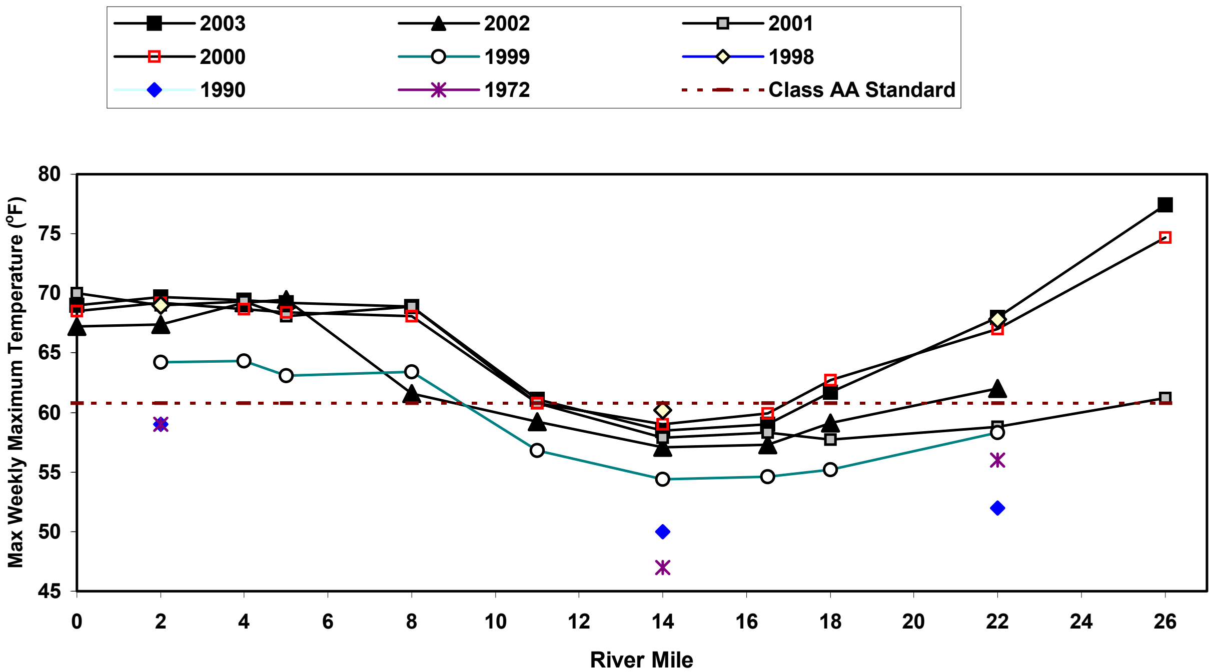

Figure 3. Mad River longitudinal temperature profile RM 0-26.

Two major implications of the Mad River temperature regime come to mind. The first is that the **cooling zone**, Jimmy Creek to Cougar Creek is also **the primary bull trout spawning zone** of the Mad River and of the entire Entiat subbasin. A log jam formed downstream of Cougar Creek in 1999, forcing the bull trout to spawn in the **warming zone**. This log jam has persisted as an upstream migration barrier from 1999 to 2003. Consequences of spawning in the warming zone (or lack of) will not be detectable for several years. The second implication is that the Mad River is essentially unaffected by direct management of riparian and valley bottom vegetation from rivermile 4.0 to the headwaters, a distance of nearly 20 miles. As such, it represents a possible "reference" stream useful for assessing "natural variability" and may serve as a basis for revising Forest Plan temperature standards. We are not proposing that Forest-wide temperature standards be based solely on the Mad River but rather that the Mad River profile may provide an important piece of information for natural water temperature regimes in similar landtype associations.

Exceedances in Lake Chelan Tributaries

Tributaries on the North Shore of Lake Chelan have experienced intense wildfires over the past two years. Portions of Safety Harbor Creek, Fish Creek and Falls Creek were burned during the 2001 Rex Creek fire and portions of Falls Creek, Grade Creek, Poison Creek, Gold Creek and Mitchell Creek burned during the 2002 Deer Point fire. Temperature monitoring sites were placed in these streams to monitor effects related to these wildfires.

Fish Creek appears to have been the most severly affected by the Rex Creek fire and exceeded Forest Plan temperature standards for 7 weeks during the late summer of 2003 (July to September). When monitored in 1998 and 1999, the summer maximums of Fish Creek did not exceed Forest Plan Standards, therefore high temperatures in recent years are most likely a response to the fire. Safety Harbor Creek had no temperature exceedances in 2003.

Poison Creek, which burned severly in the 2002 Deer Point fire, exceeded 61ºF on eight days in 2003. When monitored in 1999, Poison Creek had a maximum stream temperature of 54.9ºF. Lower Mitchell Creek exceeded Forest Plan standards for approximately 9 weeks during the summer of 2003, however, this is typical for Mithchell Creek which also exceeded the 61ºF standard when it was monitored prior to 2002 and the Deer Point Fire. Prince Creek exceeded Forest Plan Standards for six monitored days in 2003, however the thermograph was dewatered on July 18th and the extent of exceedances are not known. Prince Creek was monitored during the summer of 2000, during which time stream temperatures exceeded 61ºF on one day .

On the South shore, exceedances to the daily maximum temperature limit occurred and were of short duration (4 days) at the mouth of Twenty-Five Mile Creek. The highest daily maximum stream temperature observed was 63.4°F. Additional temperature monitoring sites were added in the South Fork and North Fork of Twenty-Five Mile Creek in 1999 to monitor effects related to a major wildfire in this area in 1998. Neither location has exhibited unstable thermal regimes or exceeded Forest Plan standards since monitoring began. Stream temperatures in the South Fork have been consistently higher than those observed in the North Fork even though the 1998 fire primarily affected the North Fork drainage. First Creek, located downlake of Twenty-Five Mile Creek, did not exceed stream temperature standards and continued to exhibit stable summer maximum temperatures despite influences of the 1994 Tyee Fire on that drainage.

Overall Conclusions

Based on all water temperature data compiled for the Mad River drainage, we believe that the thermal regime described again in this report is firmly established. Longitudinal profile data from the Entiat River indicate that the Entiat River has its own unique thermal regime, which has been confirmed by the WADOE using the SNTEMP model and TIR Flight imagery (see Figure 2). In the Chelan Subbasin, clear differences exist in stream temperature regimes between the North and South shore tributaries at lower elevation sites and within the upper and lower monitoring sites of the North shore tributaries. We also conclude, based on several years of stream temperature monitoring results (1994-2003), that present WNF LRMP Standards are simply not attainable in all Entiat/Chelan waters in all years. Future iterations of Watershed Analyses and Forest Plan revisions should take into consideration deviations from current water temperature standards that appear to be related to natural conditions within watersheds.

Recommendations: In order to meet the objectives outlined on page 1, we expect to implement the following:

- Repeat the expanded longitudinal monitoring network in Mad River and major tributaries in 2004.
- Reestablish the expanded monitoring network in the Lake Chelan drainages in 2004.
- Repeat the longitudinal monitoring network in the Entiat River (10 stations approximately 2 miles apart on the lower River) with the cooperation of private landowners, Chelan County Conservation District, USFWS, WADOE and USEPA to provide on-loan monitoring devices in 2004.
- At three locations on the Entiat River (RM 1.4, RM26 and RM 18) monitor water temperatures over winter to further assess effects of water temperature on chinook salmon egg incubation and to predict times to emergence of fry.
- Cooperate with USGS to install temperature monitoring devices at gage stations (Keystone, Ardenvoir).
- Use the **triggered-start** mode for Optic StowAway Temperature Loggers. The **delayed-start** mode used for some devices in 1998 resulted in immediate shutdown of some older devices.

- Continue to emphasize quality control of all temperature measuring devices prior to deployment to assure accurate results. More frequent field checks will be performed for timely detection of improperly functioning devices.
- Water temperatures in the drainages burned by the 1994 Tyee Fire, 1998 Twenty-Five Mile Creek Fire, 2001 Rex Creek Fire and 2002 Deer Point Fires should be monitored to assess cumulative effects and recovery.
- Coordinate with other agencies (USFWS, YIN, WADOE, USEPA) to exchange water temperature data and expand baseline temperature data base.
- Review historical records (USGS, STORET data @EPA, FS Experimental Forest research data) to expand baseline temperature data base in preparation for next iteration of Watershed Analysis and Forest Plan revision.

Cost Analysis: The following costs were incurred on this monitoring project during 2001:
- GS-11 supervision, data analysis, and reporting ....5 days @$278/day =1390
- GS-9 data reduction, data analysis and report writitng................................25 days @$208/day =5200
- GS-9 calibration, set-up, deployment, retrieval, data collection...........…...25 days @ $208/day =5200
- vehicle mileage..…......3000 miles @ .30/mile= 900
- Data Logger (3 @$60)) and Optic Shuttle (2@$80) refurbishment............................………….. =340
- Cable, Cases and Hardware for temperature monitoring…………............................…………=100

Total $13,130

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