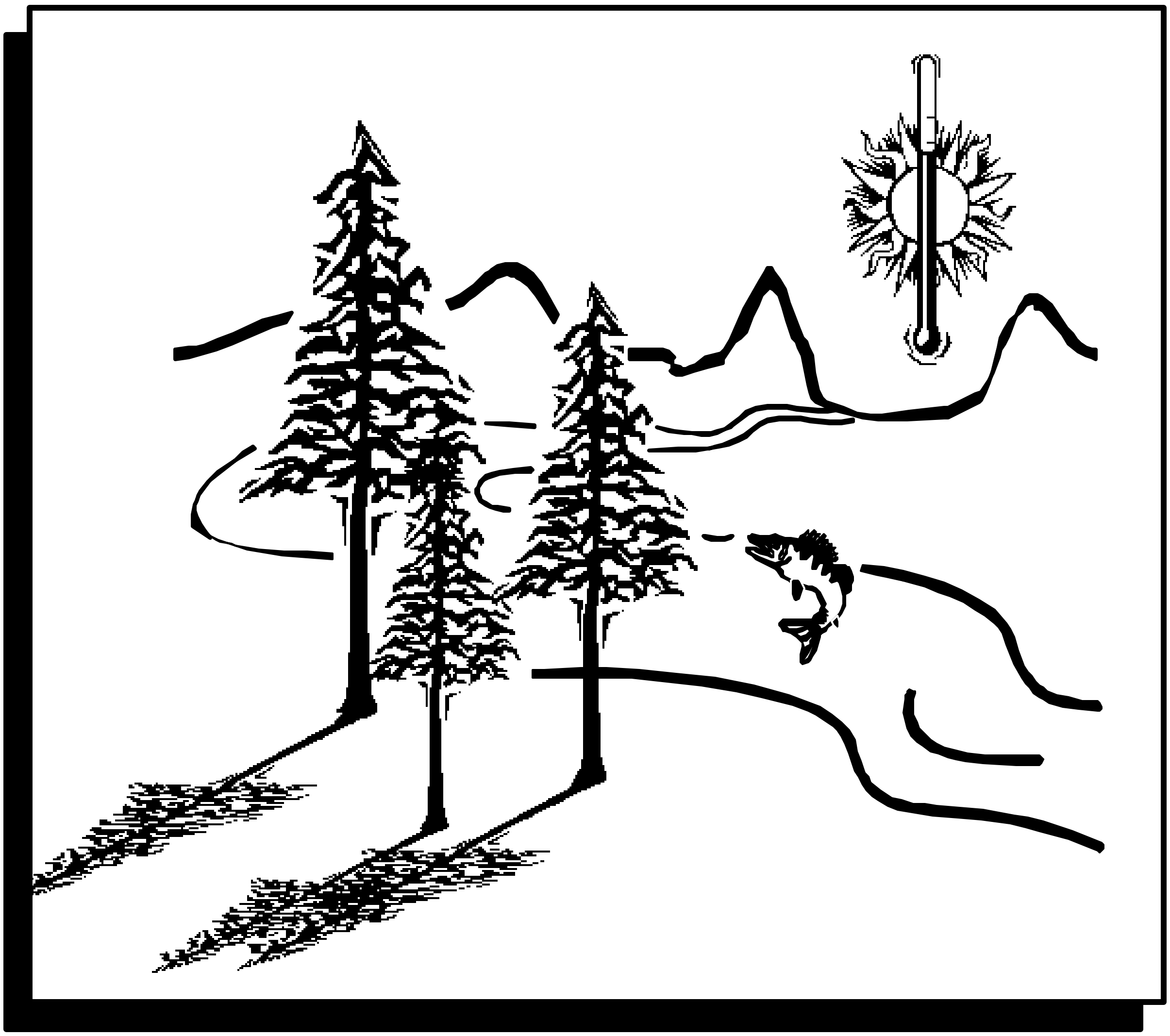
The Dilemma of Applying Uniform Temperature Criteria in a Diverse Environment: An Issue Analysis



Division of Environmental Quality

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The Dilemma of Applying Uniform Temperature Criteria in a Diverse Environment: An Issue Analysis

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Abstract

This issue analysis was undertaken to document apparent inconsistencies between water temperatures that exceed criteria in the Idaho Water Quality Standards and Wastewater Treatment Requirements and fish data that indicate viable, self-sustaining assemblages exist. The climatic and geographic diversity of Idaho was evaluated as a primary factor affecting natural stream temperature regimes. Sources of measurement error are discussed and small-scale heterogeneity and thermal refugia in streams are presented as factors which compound measurement of biologically relevant water temperature. Ninety-eight comparisons of water temperature records and fish data were made with data collected from the Little Lost River drainage, Owyhee County drainages, and the Lochsa River drainage. In over 50% of the comparisons, criteria exceedances were documented and the affected cohorts of salmonids were represented in length frequency distributions. In these instances, salmonid spawning has occurred coincidentally with criteria exceedances. In the instances where fish data were collected more than one year after the temperature was measured, these data also indicate that rearing has occurred.

The current water temperature criteria for Idaho appear to be not working well since they do not comport with biological reality in many instances. We suspect the reasons for this are 1) fixed criteria that do not allow for environmental or species diversity, and 2) the manner in which stream temperatures are measured and summarized. A comprehensive study is needed to further document this issue and to provide a scientific basis for water quality standard revision. A temperature measurement protocol needs to be written to assure the quality and relevance of temperature data.

Idaho Aquatic Life Temperature Criteria

"For too long we have sought some 'magic number' which, if met, would protect all aquatic life. Clear-thinking scientists and engineers have known for some time that the many species of fish and other aquatic animals vary greatly in their individual tolerances and sensitivities. Some of the confusion can be eliminated if we consider the requirements, for example, of the coho salmon, the northern pike, white bass, carp, etc., and stop searching for a single thermal requirement for 'aquatic life' in general." (Mount 1969).

1.0 Introduction

Barthalow (1989) describes the physical factors affecting stream temperatures as used in the Instream Water Temperature Model (SNTEMP) (Theurer and others 1984), and reports the results of a sensitivity analysis of the SNTEMP. When predicting <u>mean</u> daily water temperature, air temperature is the most sensitive input variable. Relative humidity is the next most sensitive input variable, accounting for less than half as much change in stream temperature. Percent shade follows a close third to relative humidity. When predicting <u>maximum</u> daily water temperature, air temperature is just as important, but percent shade, which affects diurnal range, overtakes relative humidity as the second most sensitive variable. For both measures, stream flow is the fourth most sensitive variable and "water temperature is very sensitive to changes in air temperature when stream flow is low."

There is little allowance in Idaho's current aquatic life temperature criteria for the biological and physical diversity that exists in Idaho. Criteria that work in north Idaho mountains may not apply as well to southern valleys and plains. Nor is there allowance for climatic swings which bring periodic drought and heat waves, and normal summertime peaks. Likewise, there is insufficient allowance for the continuum of preferences between species, only the gross categories of cold and warm water species. Water quality standards need to be dynamic enough to incorporate new findings from advances in technology. These gross categories may have served the state well when the water quality standards were first written, but appear to be inadequate today. Abiotic factors often define the natural range of a species, at the limits of that range individuals exist under marginal conditions. It should not be surprising that when we evaluate stream temperature records against current criteria and also look at aquatic life populations we find incongruities.

Below we present an overview of Idaho's climatic variations, the complexities of accurate and biologically relevant stream temperature measurement, and give several examples where stream temperatures sometimes exceed Idaho's current water temperature criteria. In spite of these exceedances, the existing aquatic life appears to be self propagating with juveniles and multiple age classes represented.

In this paper, the reader will find a mix of Fahrenheit (°F) and centigrade (°C) temperatures used. Air temperature records are customarily reported in Fahrenheit (°F), a long standing convention that is maintained herein. To do otherwise would result in unusual conversions, such as number of days above 32.2°C, rather than 90°F. On the other hand stream temperatures and the criteria they are compared to are given in degrees centigrade (°C), largely because those are the units used in Idaho's water quality standards. This use reflects the more recent origin of water temperature criteria. Table 1 gives some equivalent readings on the these two temperature scales.

Table 1. Equivalent readings on the Fahrenheit and centigrade temperature scales.

Fahrenheit (°F)	centigrade (°C)	Fahrenheit (°F)	centigrade (°C)
32	0	55.4	13
41	5	59	15
48.2	9	66.2	19
50	10	71.6	22

2.0 Geography, Climate and Stream Temperature

Spatial variation

Idaho covers a vast and varied geographic range. The state spans seven degrees of latitude from 42°N at its southern border with Nevada to 49°N at its northern border with Canada. Elevations range from 738' where the Snake River leaves Idaho to the 12,662' Borah Peak in east central Idaho, although most of Idaho falls in a narrower band of 2500' to 7500'. With geographic variation comes climatic variation, and a range in climate translates to range in stream temperature.

It is commonly known that climates cool as one heads north. Landsberg (1958) reported that average annual air temperature decreases about 1.5° F (0.8°C) for each 1 degree increase in latitude in the middle latitudes (40-50°N) of the northern hemisphere. Thus, based on latitude alone one would expect it to be several degrees cooler at Idaho's northern extreme than at its southern bound. Similarly a decrease of about 3°F for each 1000' increase in elevation (6°C/1000 m) is a typical mid-latitude environmental lapse rate (Daubenmire 1974). Idaho's valleys are likely 10-20°F warmer than mountain locations at any given time. Furthermore, the uplift created by mountainous terrain leads to more clouds and greater precipitation at higher elevations (Miller and Thompson 1975), reducing the direct solar input that can be expected in mountain streams.

Table 2 documents the range in Idaho's climate at representative reporting stations. In the south, the arid Snake River Plain receives less than 12" of precipitation per year, almost entirely during winter months, and temperatures over 100°F occur each summer (WRCC 1998). To the north, the Panhandle mountains can receive over 80" of precipitation, mostly as snow, and temperatures over 90°F are infrequent. All of Idaho is quite arid during the summer, with many cloudless days, but this pattern intensifies from northeast to southwest, and from mountains to valleys.

Although the above text describes general climate trends across Idaho, there are also important local variations which may affect stream temperatures. The weather reporting stations located at Headquarters and Howe, for example, have the same annual temperature even though separated by about three degrees of latitude and at similar elevation. This occurs because Howe is a sunnier and warmer location in summer, as evidenced by its lower July precipitation and greater growing degree days (Table 2). Elevation and latitude changes can offset one another. For example, Boise, three degrees latitude south of Lewiston and twice the elevation, is similar in degree days.

Table 2. Selected climate data for a range of meteorological stations in Idaho (Abramovich and others 1998).

Station	North Latitude	Elevation (feet)	Mean Annual Temp °F	Average July Precip.		Annual Degree Days[2] (40°F base)
				Total	Days with $0.1"	
Boise WSFO[1]	43:34	2840	50.9	0.36	1	5021
Bonner's Ferry	48:42	1780	46.4	0.89	3	3662
Couer d'Alene	47:41	2160	48.4	0.86	2	4107
Dixie	45:33	5620	36.0	1.20	3	1749
Elk City RS	45:50	4060	41.0	1.46	4	2490
Fenn RS	46:06	1590	48.9	1.08	3	4187
Glenns Ferry	42:56	2510	51.8	0.24	0	5190
Headquarters	46:38	4150	43.3	1.14	2	2667
Howe	43:47	4384	43.3	0.73	1	3621
Idaho Falls	43:31	4457	43.6	0.62	1	3643
Jerome	42:44	3740	49.3	0.25	0	4693
Lewiston WSO	46:23	1440	52.7	0.67	1	5302
Powell	46:31	3630	42.6	1.28	4	2878
Riggins	45:25	1800	54.4	0.82	2	5695
Salmon	45:11	3930	45.5	1.01	3	3949
Stanley	44:13	6720	35.3	0.83	2	1820
Swan Falls PH	43:15	2320	55.3	0.26	0	6266
Wallace WP	47:30	2940	44.5	1.29	3	3211
Yellow Pine 7S	44:47	5100	39.1	1.16	2	2198

[1]Climatic data for **stations in boldface** based on 1961-1990 period (NCDC climatic normals), other stations are based on data of record between 1961-1990.
[2]Degree days are the sum of the differences between daily mean temperature and a base temperature. A day with a high of 80°F and a low of 50°F would have a daily mean temperature of 65°F, and 25 degree days using a 40°F base. Degree days are a measure of cumulative warmth (see text).

Degree days (far right column in Tables 2 & 3) are a means to quantify cumulative warmth in a season or year at a given location. It is a measure that takes into account both magnitude and duration of departure from a chosen threshold temperature. Degree days originated as a way to predict residential heating and cooling needs and are also used to predict an area's suitability for growing certain crops or the day of maturation of a crop in a given year (Trewartha 1968).

The degree day concept provides a single quantity that is better at characterizing station warmth than annual average temperature. As with crops, the concept may be useful in water quality assessment to evaluate the potential of a particular stream to achieve or maintain a temperature below a threshold (criteria). Degree days could be used to account for warm and cold years and the resulting variation in stream temperatures.

When a meaningful threshold temperature is used, degree days are particularly useful. If one’s goal is to maintain stream temperature at or below 50°F (10°C), then degree days based on 50°F (far right column Table 3) seem best for comparing station warmth. Degree days provide one basis for evaluating the feasibility of that goal. By this measure, the valley locations of Boise and Lewiston are nearly five times as warm as Dixie, at 5620' elevation in the mountains.

Table 3. Summer temperatures (°F) for a range of meteorological stations in Idaho (Western Regional Climate Center 1998)[1].

Station	North Latitude	Elevation	Mean July Max	Mean July Min	Ave. # of Days/year with Max >90°F	Annual Degree Days[2] (50°F base[3])
Boise WSFO	43:34	2840	90.1	58.0	44	2805
Bonner’s Ferry	48:42	1780	83.5	49.8	18	1783
Couer d’Alene	47:41	2160	85.2	52.5	25	2074
Dixie	45:33	5620	75.9	36.9	1	564
Elk City RS	45:50	4060	80.7	40.5	12	1020
Fenn RS	46:06	1590	88.5	50.2	41	2249
Glenns Ferry	42:56	2510	95.3	55.4	69	2949
Headquarters	46:38	4150	80.9	44.4	13	1252
Howe	43:47	4384	86.5	50.2	23	1870
Idaho Falls	43:31	4457	85.8	51.0	22	1876
Jerome	42:44	3740	90.8	55.4	48	2597
Lewiston WSO	46:23	1440	88.7	58.6	40	2849
Powell	46:31	3630	82.4	44.3	19	1305
Riggins	45:25	1800	92.3	58.4	58	3229
Salmon	45:11	3930	87.9	50.8	35	2061
Stanley	44:13	6720	77.9	35.8	2	597
Swan Falls PH	43:15	2320	96.1	63.1	77	3793
Wallace WP	47:30	2940	80.1	47.6	12	1445
Yellow Pine 7S	44:47	5100	79.4	39.0	6	816

[1]Climatic data are based on the period of record for each station and were obtained online at *http://www.wrcc.dri.edu* on 9-14-98.
[2]Degree days are the sum of the differences between daily mean temperature and a base temperature. A day with a high of 80°F and a low of 50°F would have a daily mean temperature of 65°F, and 15 degree days using a 50°F base.
[3]Fifty °F equals 10 °C, the Environmental Protection Agency bull trout criterion for Idaho.

Temporal variation

Temporal variation in air temperature can be described in four time scales: daily or diel, between days, seasonal, and between years. Some temporal variations are very predictable in an aggregate or climatic sense. We expect days to be warmer than nights and summers warmer than winters. There is a cycle of temperature driven by solar cycles. There are parallel cycles to stream temperature as well. However, overlying these cycles are weather events which cause departure from the expected or norm. These departures can be extreme (floods, droughts, heat waves etc.), causing havoc in human as well as plant and animal communities.

For example, July 28 is on average the warmest day of the year in Boise, but this is no guarantee the hottest day of any given year will occur on that day. An illustration of variability between days (Figure 1) is the departure of 1998 Boise air temperature from recent climatic normals. An example of air temperature variability between years is provided in Figure 2. Although this example is specific to eastern Idaho, most of the recent decade has been warmer than is normal in Idaho. Later it will be shown many of these warm years have been drier than normal as well. This has undoubtedly had an affect on stream temperatures.

The substantial variation between days and years in weather are unpredictable and can only be addressed in a stochastic sense. With adequate records, the probabilities of crossing certain thresholds can be estimated, e.g., one out of 10 years will have frost before September 15, or as frequencies, e.g., number of days above 90°F. This accepted concept in climatology applies as well to stream temperature. We lack the long term data to apply this concept directly to water temperature. However, meteorological records can provide a useful surrogate for identifying times of extreme natural conditions. Under these conditions, it would be reasonable to expect that fixed temperature criteria would be exceeded and such exceedances could be excused.

Seasonal and diel differences are also apparent among locations. Lewiston is warmer than Boise on an annual average, but its summer days are a bit cooler (see Table 2). While the Lewiston WSO and Fenn RS share a very similar average air temperature maximum for July and nearly the same frequency of 90°F days, Fenn’s nighttime lows average more than 8°F lower in July. This is likely a result of cold air drainage from nearby mountain slopes, an important aspect of the area’s thermal regime. These typically cooler nights may affect that area’s suitability for particular species.

Figure 1. 1998 daily departure from climatic norms of air temperature at Boise.

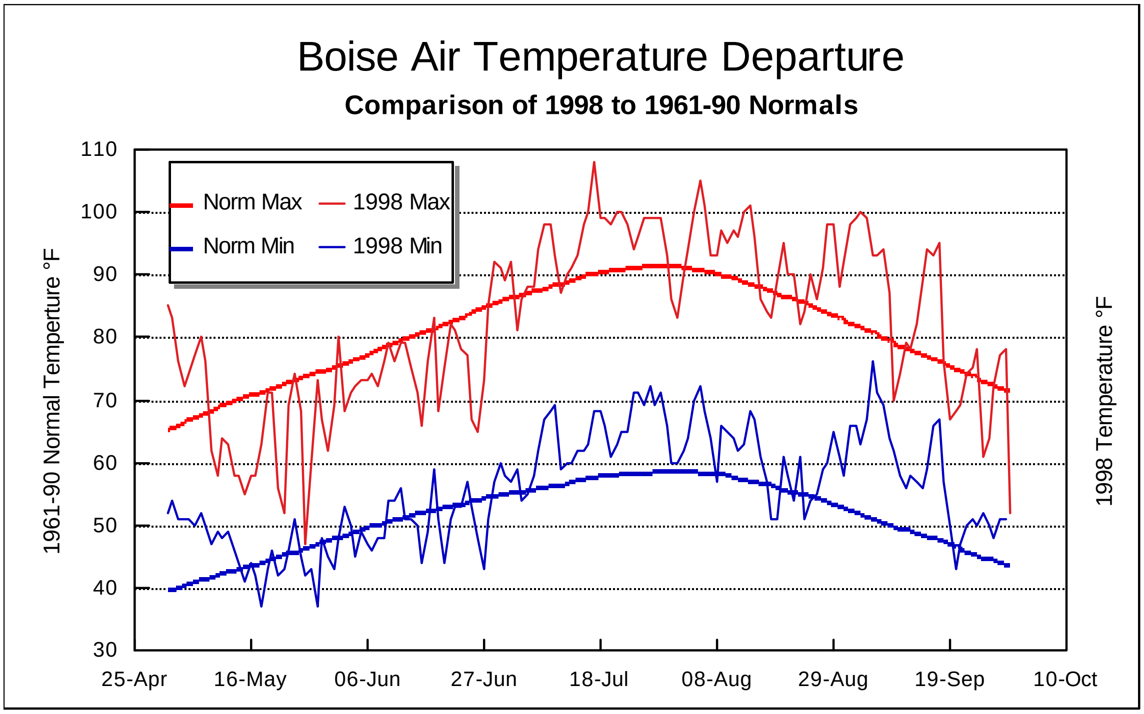
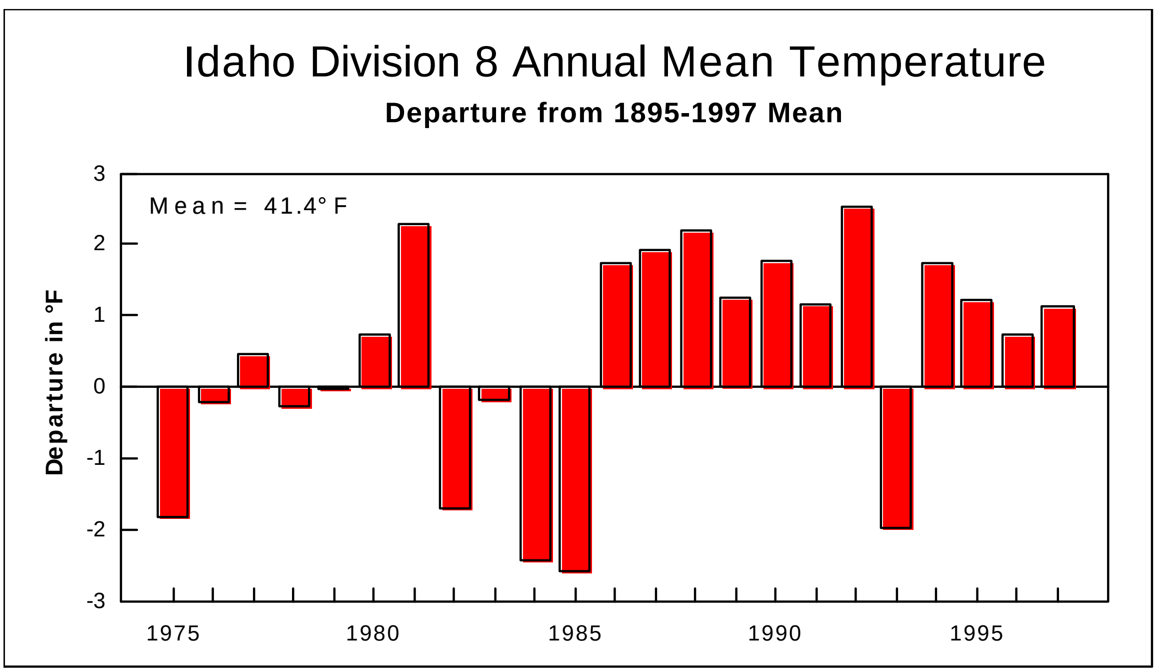


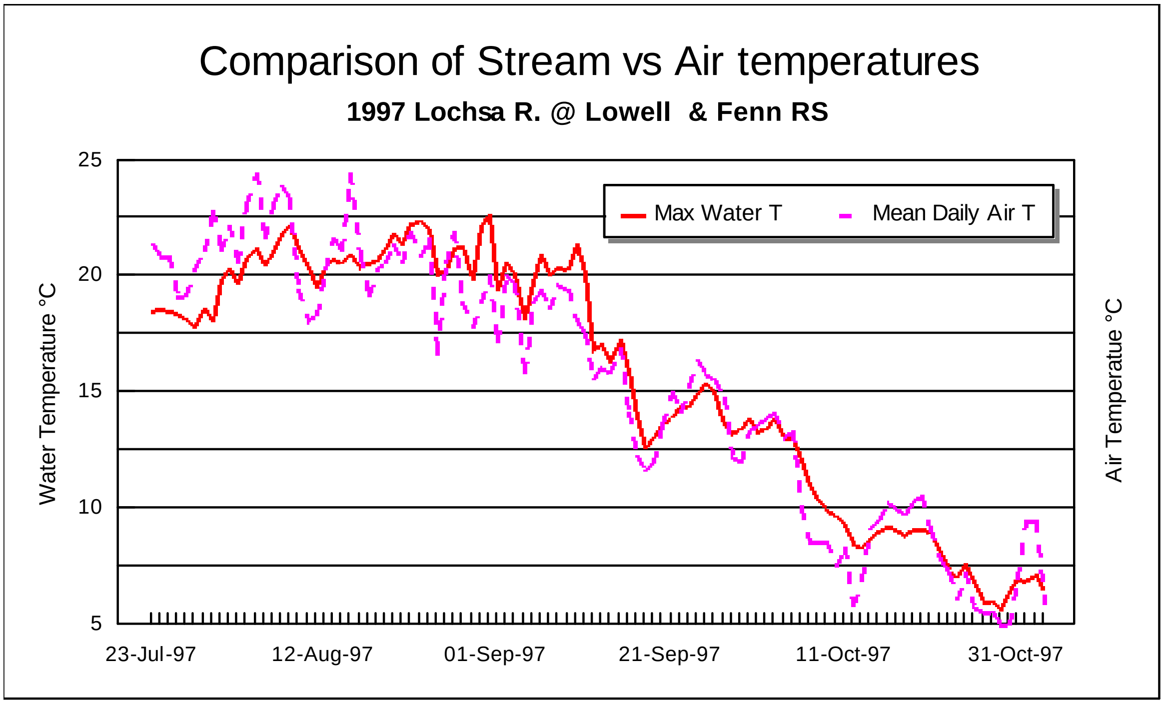
Figure 2. Recent air temperature variability between years in eastern Idaho.



Relation of climate to stream temperature

Several scientists have shown the close relation between air and stream temperature (Collins 1925, Mangan 1946, Moore 1967, Smith and Lavis 1975, Smith 1981, Crisp and Howson 1982, Sinokrot and Stefan 1994). This relation is observed in daily as well as monthly records and appears to be particularly strong in larger rivers. Figure 3 demonstrates the strong relation between air and water temperatures in the Lochsa River drainage. Kothandaraman (1971) constructed an empirical, rather than energy balance, model to predict daily stream temperatures within 1°C of observed data based on meteorological data alone.

Figure 3. Comparison of 1997 stream and air temperatures in the Lochsa River drainage.



Theoretical or energy balance models predict stream temperatures based on physical processes and basic input variables. Barthalow (1989) ranks air temperature as the most influential input variable in the SNTEMP stream temperature model. Sinokrot and Stefan (1994), in a sensitivity analysis of the MNSTREM (Stefan and others 1980), also found air temperature to be most important, followed by solar radiation.

Exposure to direct solar radiation is also important. In a study of Oregon streams, Moore (1967) found east-west oriented streams to be 4-8°F (2.2-4.4°C) warmer than comparable streams with a north-south aspect. In fact, this difference in aspect accounted for the summertime elevation of mean monthly water temperatures above the mean monthly air temperature in east-west streams.

In a classic study of smaller forested streams, Brown (1969) was able to accurately predict the increase in stream temperature as a result of removal of forest canopy shading. In a recent study of small pasture streams in New Zealand, the predominant effect of shade removal was on daily maximum stream temperature (Rutherford and others 1997).

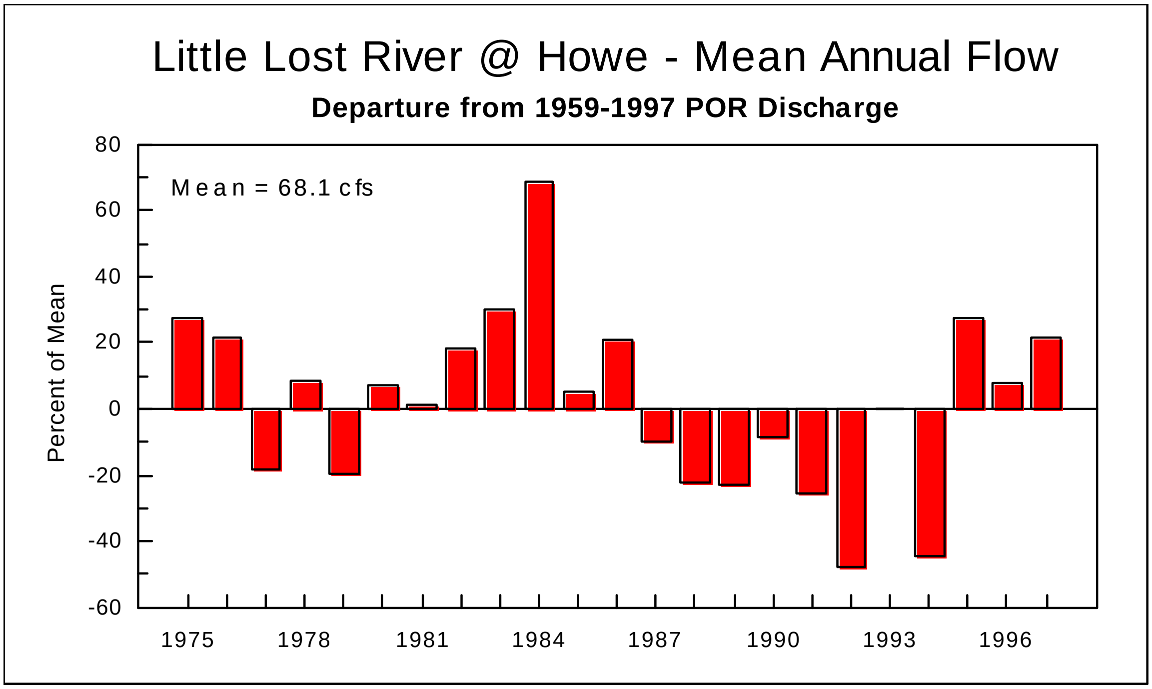
Large streams, because of their width relative to flanking vegetation, naturally have less shade. Most larger streams also receive proportionally less local groundwater inflow; some may even become losing streams (Kjelstrom 1992 and Donato 1998) at certain times of the year. The water they carry has experienced exposure to atmospheric heating proportionate to transit time from its source. These large streams approach and fluctuate around an equilibrium temperature with their surrounding environment (Krajewski and others 1982). As flow drops so does stream velocity, giving more time for water to approach thermal equilibrium with air above it.

Air temperature is largely controlled by solar radiation flux (Miller and Thompson 1975). The rate of heating and eventual maximum or equilibrium temperature is greater in the sun than in the shade for both air and water. However, water warms when air temperature exceeds stream temperature, even without exposure to direct or indirect solar radiation. Some locations in Idaho are so warm that stream heating can occur throughout the night. For example, in Riggins, at the confluence of the Little and main Salmon Rivers, mean July minimum air temperature, 58.4°F (~15°C), exceeds Idaho's salmonid spawning instantaneous maximum temperature (13°C).

For a given stream, flow is also driven by climate (Petts and Foster 1985, Leopold 1994, and Mount 1995). Precipitation in most of Idaho reaches a minimum in summer, but early summer stream flows are boosted by snowpack runoff which generally peaks in June. Still, unregulated stream flows in much of the state decline to baseflow by mid to late July and continue to decline into the early fall (Brennan and others 1998). If the winter snowpack is light, stream flows typically decline quicker, reach baseflow sooner, and have lower late summer minimums.

Idaho's hot, dry summers and normally low mid to late summer stream flow combine to make July, August, and sometimes into early September, a time of high stream temperature. In addition, there is considerable variation between years such that this normally warm time of year is periodically compounded by drought (see Figure 4) as well as above normal temperatures (see Figure 2). This causes departure from normal stream temperatures to occur as well.

Figure 4. Mean annual stream flow variation between years in the Little Lost River drainage.



3.0 Measurement and Expression of Stream Temperature

Until this decade, very few agencies or individuals had the capability to monitor stream temperatures at regular intervals over an extended period of time. The available equipment was expensive, bulky, and required a higher level of effort and expertise to deploy and maintain than is the case today. Diurnal temperature records were largely the province of researchers and the U.S. Geological Survey (USGS).

When monitoring continuous stream temperature, the USGS defines three temperatures of concern: true stream temperature, temperature near sensor, and temperature recorded (Stevens and others 1975). True stream temperature (TST) is defined as an instantaneous measurement obtained in a shaded location in the main flow of the stream outside of the influence of tributaries or groundwater influx with a full immersion thermometer calibrated against an ASTM standard thermometer. It can also be calculated as a weighted average of a cross-section temperature profile.

Sensors for stream temperature recorders, for reasons of safety and convenience, are often placed closer to shore than would represent true stream temperature. The actual temperature of the water surrounding the sensor reflects its location in the channel cross-section. This is known as the temperature near sensor (TNS). Moore (1967) found almost a 2°C range in temperature across the Middle Fork Willamette River near Dexter, Oregon, and notes that in all instances the range could be accounted for by "one or two observations of comparatively high temperatures near the bank where the flow is extremely sluggish." This is often the place temperature measuring and recording devices are located, if not at the time of placement then by the time of retrieval due to streamflow recession.

The temperature recorded, or TRC, is the measurement we record or read. If the thermometer or sensor is calibrated, TRC can and should be adjusted. It will then be the TNS. That still leaves differences between TST and TNS, which are stream specific and likely vary diurnally and seasonally (Stevens and others 1975). If TST is also measured, we can account for these differences under the conditions of the paired measurements. Because of the inherent variability in stream temperature measurement, the USGS recommends recording temperature only to the nearest 0.5°C (Stevens and others 1975).

With the advent of inexpensive electronic temperature recording devices, the number of extended regular interval data records has increased dramatically. Today we have available much more stream temperature data, from all manner of water bodies, than was ever imagined possible when temperature criteria were conceived. Unfortunately most of these data are TRC, maybe TNS if care was taken to calibrate the recording devices[1]. These data provide very little, if any, information about true stream temperature. If recording devices were located in a well mixed portion of a stream, there may be little difference between TNS and TST. In most cases, we simply don't know these differences and should be cautious in evaluation of such temperature records, particularly in a regulatory context.

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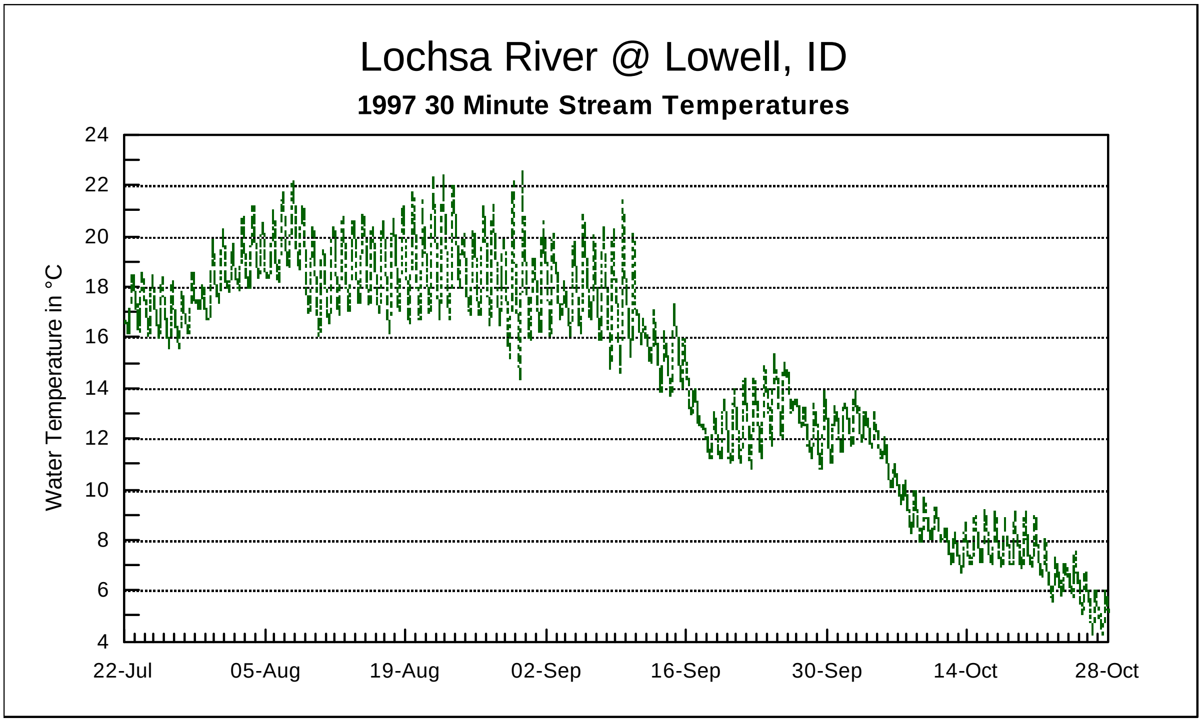
[1] In a recent calibration check in ice water, a series of eight StowAway XTI® electronic thermograph devices varied from true temperature by +0.40°C to -0.44°C (IDEQ 1998).

Water temperature relevant to the biota

Even if we measure true stream temperature, arguably the temperature most characteristic of the basic thermal regime at any moment in time, we may not be measuring a temperature to which the biota respond. Stream temperatures exhibit great temporal variability (Figure 5), and there are many metrics which can be used to summarize and analyze a continuous record, e.g., daily mean, daily maximum, maximum weekly average, maximum weekly maximum, and so on. Each will give a different result which likely relates to support of aquatic life differently.

Figure 5. 30 minute temperature readings from the Lochsa River at Lowell, Idaho, 1997.



In addition, there are questions of small scale heterogeneity and animal behavior. There is variation in stream temperature throughout a stream cross section. Stevens and others (1975) provide an example of a 2.5°C range in temperature measured at intervals of depth and distance from shore in a large river (148' wide by 30' deep). Smaller rivers at low flow may exhibit a 8°C range in temperature across their channel (Bilby 1984). Bilby also identified four distinct types of cool water refugia, averaging 4.7°C lower than nearby stream temperatures on warm summer afternoons. Anyone who has swum in a river knows of cold and warms spots and chooses the latter. Fish also seek thermally favorable areas, balanced with other life needs (Coutant 1987).

4.0 Recent Stream Temperature and Aquatic Life Observations

Fish and temperature data from the Little Lost River, Owyhee County, and Lochsa River drainages were compiled and compared. Fish data were collected through electrofishing and snorkeling surveys, and the number of age classes was estimated from length frequency distributions. The temperature data were collected with temperature data recorders, and criteria exceedances that occurred during salmonid spawning periods[2] were counted. Rows with italic text in the following tables indicate comparisons where the fish data were collected prior to the temperature data, therefore, the time period in which the temperature data were collected is not represented in the fish data. The numbers in the water body index (WBID) number column are the numbers assigned by DEQ for indexing Idaho waters. The estimated number of age classes represented in the length frequency distribution is provided in the Age classes column. Where juveniles appear to be included in the distribution, they are noted with the abbreviation "juv." Tables 4, 5, 6, 7, and 8 contain summaries of these data.

Little Lost River rainbow trout and thermograph data comparison

Table 4 provides a comparison of rainbow trout (*Oncorhynchus mykiss*) age class structure to State of Idaho water temperature criteria in the Little Lost River drainage (USGS cataloging unit 17040217). Criteria that could be assessed with existing data include instantaneous cold water biota (22°C) and salmonid spawning (13°C). Fishery and temperature data were compiled from *The History and Status of Fishes in the Little Lost River Drainage, Idaho*, January 29, 1998 draft (Gamett 1998). The values in the 22°C and 13°C columns are the count of instantaneous criteria exceedances and the percentage of all applicable observations these exceedances represent.

Table 4. Summary of rainbow trout (*Oncorhynchus mykiss*) age class structure and exceedances of Idaho water temperature criteria from the Little Lost River (cataloging unit 17040217). Criteria assessed include instantaneous cold water biota and instantaneous salmonid spawning during the spawning period January 15 to July 15.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC (#/%)	13EC (#/%)
Big Creek #1 - 0.8 km above Wet Creek	*24*	*1994*	*1995*	*3*	*0/0*	*10/18*
Big Creek #1 - 0.8 km above Wet Creek	24	1996	1996	3/juv	0/0	15/100
Little Lost River #1 - 0.8 km below Big Springs Creek	*2*	*1993*	*1994*	*2*	*1/1*	*58/92*
Little Lost River #1 - 0.8 km below Big Springs Creek	*2*	*1993*	*1995*	*2*	*0/0*	*40/70*
Little Lost River #3 - at Clyde campground	*10*	*1993*	*1994*	*5/juv*	*0/0*	*32/59*

[2] Spawning periods used were the default time periods defined in Idaho Water Quality Standards and Wastewater Treatment Requirements (IDAPA 16.02.01.250.02.d.iv)

Table 4. Summary of rainbow trout (*Oncorhynchus mykiss*) age class structure and exceedances of Idaho water temperature criteria from the Little Lost River (cataloging unit 17040217). Criteria assessed include instantaneous cold water biota and instantaneous salmonid spawning during the spawning period January 15 to July 15.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC (#/%)	13EC (#/%)
Little Lost River #3 - at Clyde campground	*10*	*1993*	*1995*	*5/juv*	*0/0*	*55/95*
Little Lost River #11 - below Timber Creek	14	1995	1995	5/juv	0/0	0/0
Little Lost River #11 - below Timber Creek	14	1997	1995	4/juv	0/0	0/0
Summit Creek #4 - 400m below Sawmill Canyon road	19	1995	1995	4/juv	6/4	48/84
Wet Creek - below Pancheri diversion	*22*	*1992*	*1994*	*4*	*2/1*	*12/19*
Wet Creek - below Pancheri diversion	*22*	*1992*	*1995*	*4*	*0/0*	*34/59*
Wet Creek 0 - top end of transect is Big Creek	24	1997	1996	3	0/0	12/100
Wet Creek - 0.6 km above forest boundary	*24*	*1995*	*1996*	*4/juv*	*0/0*	*12/100*
Wet Creek - 0.6 km above forest boundary	24	1996	1996	4/juv	0/0	12/100
Wet Creek - 0.5 km above Hilts Creek	*24*	*1995*	*1996*	*4/juv*	*0/0*	*12/100*
Wet Creek - 0.8 km above Hilts Creek	*24*	*1995*	*1996*	*3/juv*	*0/0*	*0/0*
Wet Creek - 0.8 km above Hilts Creek	24	1996	1996	3	0/0	0/0

Little Lost River bull trout and thermograph data comparison

Table 5 provides a comparison of bull trout (*Salvelinus confluentus*) age class structure to State of Idaho water temperature criteria in the Little Lost River drainage (USGS cataloging unit 17040217). Criteria that could be assessed with existing data include instantaneous cold water biota (22°C) and salmonid spawning (13°). These fish and temperature data were compiled from *The History and Status of Fishes in the Little Lost River Drainage, Idaho*, January 29, 1998 draft (Gamett 1998).The values in the 22°C and 13°C columns are the count of instantaneous criteria exceedances and the percentage of all applicable observations these exceedances represent.

Table 5. Summary of bull trout (*Salvelinus confluentus*) age class structure and exceedances of Idaho water temperature criteria from the Little Lost River (cataloging unit 17040217). Criteria assessed include instantaneous cold water biota and instantaneous salmonid spawning during the spawning period September 1 to April 1.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC (#/%)	13EC (#/%)
Iron Creek - above Iron Creek road	*14*	*1995*	*1996*	*4/juv*	*0/0*	*0/0*
Little Lost River #3 - at Clyde campground	*10*	*1993*	*1994*	*2*	*0/0*	*21/100*
Little Lost River #3 - at Clyde campground	*10*	*1993*	*1995*	*2*	*0/0*	*17/43*
Little Lost River #11 - below Timber Creek	14	1995	1995	3	0/0	**a**
Little Lost River #11 - below Timber Creek	14	1997	1995	3	0/0	**a**
Mill Creek #2 - 0.5 km above trailhead	14	1996	1996	1	0/0	0/0
Wet Creek - below Pancheri diversion	*22*	*1992*	*1994*	*2/juv*	*2/1*	*24/48*
Wet Creek - below Pancheri diversion	*22*	*1992*	*1995*	*2/juv*	*0/0*	*13/33*
Wet Creek 0 - top end of transect is Big Creek	24	1997	1996	1	0/0	9/29
Wet Creek - 0.6 km above forest boundary	24	1996	1996	1	0/0	9/29
Wet Creek - 0.5 km above Hilts Creek	*24*	*1995*	*1996*	*3*	*0/0*	*0/0*
Wet Creek - 0.8 km above Hilts Creek	*24*	*1995*	*1996*	*3*	*0/0*	*0/0*
Wet Creek - 0.8 km above Hilts Creek	24	1996	1996	3	0/0	0/0

Owyhee County redband rainbow trout and thermograph data comparison

Table 6 provides a comparison of redband rainbow trout (*Oncorhynchus mykiss gairdneri*) age class structure to State of Idaho water temperature criteria in Owyhee County drainages (USGS cataloging units 17050103, 17050107, and 17050108). Criteria that could be assessed with existing data include cold water biota (22°C instantaneous and 19°C maximum daily average) and salmonid spawning (13°C instantaneous and 9EC maximum daily average). These fish and temperature data were compiled from Idaho Department of Fish and Game redband trout and stream habitat surveys in Owyhee County (Allen and others 1993, 1995, 1997a, and 1997b) and Idaho DEQ Boise Regional Office (Steed and Horsburgh 1997). The values in the 22°C, 19°C, 13°C, and 9°C columns are the count of instantaneous criteria exceedances and the percentage of all applicable observations these exceedances represent.

Table 6. Summary of rainbow trout (*Oncorhynchus mykiss gairdneri*) age class structure and exceedances of Idaho water temperature criteria from Owyhee County streams (cataloging units 17050103, 17050107, and 17050108). Criteria assessed include instantaneous and daily average cold water biota and salmonid spawning during the spawning period March 1 to July 15.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC #/%	19EC #/%	13EC #/%	9EC #/%
Snake River - cataloging unit 17050103								
McBride Creek - T2S, R5W, S22	4	1996	1996	0	2/2	1/1	26/96	27/100
NF Castle Creek - T7S, R2W, S15	29	1996	1996	5/juv	17/16	2/2	26/96	27/100
North Fork Owyhee River - cataloging unit 17050107								
Cabin Creek - T9S, R5W, S15	12	1996	1995	3/juv	39/44	0/0	7/100	7/100
Juniper Creek - T9S, R5W, S21	13	1996	1995	4/juv	45/70	0/0	10/100	10/100
Juniper Creek - T9S, R5W, S21	13	1996	1995	4/juv	28/31	1/1	10/100	10/100
Juniper Creek - T9S, R5W, S21	13	1996	1995	4/juv	28/31	0/0	10/100	10/100
Juniper Creek - T9S, R5W, S21	13	1996	1995	4/juv	40/45	2/2	7/100	7/100
NF Owyhee River - T9S, R5W, S32	9	1996	1996	3/juv	69/73	51/54	27/100	27/100
Jordan Creek - cataloging unit 17050108								
Jordan Creek - T5S, R3W, S7	35	1996	1995	4/juv	0/0	0/0	15/41	11/30

Lochsa River cutthroat trout and thermograph data comparison

Table 7 provides a comparison of cutthroat trout (*Oncorhynchus clarki*) age class structure to State of Idaho water temperature criteria in the Lochsa River drainage (USGS cataloging unit 17060303). Criteria that could be assessed using existing data include cold water biota (22°C instantaneous and 19°C maximum daily average) and salmonid spawning (13°C instantaneous and 9°C maximum daily average). These fish and temperature data were compiled from habitat and salmonid abundance studies (Clearwater Biostudies Inc.1992a, 1992b, 1994a, 1996, 1998a, and 1998b) and Idaho Department of Fish and Game data (Tim Cochnauer personal communication). The values in the 22°C, 19°C, 13°C, and 9°C columns are the count of instantaneous criteria exceedances and the percentage of all applicable observations these exceedances represent.

Table 7. Summary of cutthroat trout (*Oncorhynchus clarki*) age class structure and exceedances of Idaho water temperature criteria from the Lochsa River (cataloging unit 17060303). Criteria assessed include instantaneous and daily average cold water biota and salmonid spawning during the spawning period April 1 to August 1.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC #/%	19EC #/%	13EC #/%	9EC #/%
Canyon Creek - lower	*62*	*1991*	*1993*	*2*	*0/0*	*0/0*	*6/35*	*17/100*
Canyon Creek - lower	*62*	*1991*	*1994*	*2*	*0/0*	*0/0*	*32/84*	*38/100*
Canyon Creek - lower	62	1997	1993	2	0/0	0/0	6/35	17/100
Canyon Creek - lower	62	1997	1994	2	0/0	0/0	32/84	38/100
Colt Creek - mouth	26	1995	1993	4/juv	0/0	0/0	2/22	9/100
Glade Creek - lower	*1*	*1991*	*1993*	*3/juv*	*0/0*	*0/0*	*7/23*	*31/100*
Glade Creek - lower	*1*	*1991*	*1994*	*3/juv*	*0/0*	*0/0*	*31/82*	*38/100*
Nut Creek - mouth	*63*	*1991*	*1993*	*1*	*0/0*	*0/0*	*10/40*	*25/100*
Nut Creek - mouth	*63*	*1991*	*1994*	*1*	*0/0*	*0/0*	*32/84*	*38/100*
Nut Creek - mouth	63	1997	1993	1	0/0	0/0	10/40	25/100
Nut Creek - mouth	63	1997	1994	1	0/0	0/0	32/84	38/100
Placer Creek - mouth	*63*	*1991*	*1993*	*3*	*0/0*	*0/0*	*16/64*	*25/100*
Placer Creek - mouth	*63*	*1991*	*1994*	*3*	*0/0*	*0/0*	*34/89*	*38/100*
Placer Creek - mouth	63	1997	1993	0	0/0	0/0	16/64	25/100
Placer Creek - mouth	63	1997	1994	0	0/0	0/0	34/89	38/100
Polar Creek - mouth	*64*	*1991*	*1993*	*1/juv*	*0/0*	*0/0*	*2/7*	*30/100*
Polar Creek - mouth	*64*	*1991*	*1994*	*1/juv*	*0/0*	*0/0*	*19/49*	*39/100*
Polar Creek - mouth	64	1997	1993	1/juv	0/0	0/0	2/7	30/100
Polar Creek - mouth	64	1997	1994	1/juv	0/0	0/0	19/49	39/100
South Fork Canyon Creek - mouth	*62*	*1991*	*1993*	*2*	*0/0*	*0/0*	*3/12*	*25/100*
South Fork Canyon Creek - mouth	*62*	*1991*	*1994*	*2*	*0/0*	*0/0*	*26/68*	*38/100*
South Fork Canyon Creek - mouth	62	1997	1993	2	0/0	0/0	3/12	25/100
South Fork Canyon Creek - mouth	62	1997	1994	2	0/0	0/0	26/68	38/100
Storm Creek - lower	32	1994	1993	4/juv	0/0	0/0	4/44	8/89

Table 7. Summary of cutthroat trout (*Oncorhynchus clarki*) age class structure and exceedances of Idaho water temperature criteria from the Lochsa River (cataloging unit 17060303). Criteria assessed include instantaneous and daily average cold water biota and salmonid spawning during the spawning period April 1 to August 1.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC #/%	19EC #/%	13EC #/%	9EC #/%
Storm Creek - lower	32	1994	1994	4/juv	0/0	0/0	25/93	26/96
Walde Creek - mouth	*64*	*1991*	*1993*	*3/juv*	*0/0*	*0/0*	*7/23*	*30/100*
Walde Creek - mouth	*64*	*1991*	*1994*	*3/juv*	*0/0*	*0/0*	*33/85*	*39/100*
Walde Creek - mouth	64	1997	1993	3/juv	0/0	0/0	7/23	30/100
Walde Creek - mouth	64	1997	1994	3/juv	0/0	0/0	33/85	39/100
West Fork Deadman Creek - mouth	61	1993	1993	1	0/0	0/0	3/9	32/100
West Fork Deadman Creek - mouth	*61*	*1993*	*1994*	*1*	*0/0*	*0/0*	*25/76*	*33/100*

Lochsa River rainbow trout and thermograph data comparison

Table 8 provides a comparison of rainbow trout (*Oncorhynchus mykiss*) age class structure to State of Idaho water temperature criteria in the Lochsa River drainage (USGS cataloging unit 17060303). Criteria that could be assessed using existing data include cold water biota (22°C instantaneous and 19°C maximum daily average) and salmonid spawning (13°C instantaneous and 9°C maximum daily average). These fish and temperature data were compiled from habitat and salmonid abundance studies (Clearwater Biostudies Inc.1992a, 1992b, 1992c, 1994b, 1996, and 1998a) and Idaho Department of Fish and Game data (Tim Cochnauer personal communication). The values in the 22°C, 19°C, 13°C, and 9°C columns are the count of instantaneous criteria exceedances and the percentage of all applicable observations these exceedances represent.

Table 8. Summary of rainbow trout (*Oncorhynchus mykiss*) age class structure and exceedances of Idaho water temperature criteria from the Lochsa River (cataloging unit 17060303). Criteria assessed include instantaneous and daily average cold water biota and salmonid spawning during the spawning period January 15 to July 15.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC #/%	19EC #/%	13EC #/%	9EC #/%
Boulder Creek - lower	40	1993	1993	3/juv	0/0	0/0	4/29	13/93
Boulder Creek - lower	*40*	*1993*	*1994*	*3/juv*	*11/13*	*13/15*	*13/93*	*14/100*
Canyon Creek - lower	*62*	*1991*	*1993*	*4/juv*	*0/0*	*0/0*	*0/0*	*0/0*
Canyon Creek - lower	*62*	*1991*	*1994*	*4/juv*	*0/0*	*0/0*	*15/71*	*21/100*
Canyon Creek - lower	62	1997	1993	4/juv	0/0	0/0	0/0	0/0

Table 8. Summary of rainbow trout (*Oncorhynchus mykiss*) age class structure and exceedances of Idaho water temperature criteria from the Lochsa River (cataloging unit 17060303). Criteria assessed include instantaneous and daily average cold water biota and salmonid spawning during the spawning period January 15 to July 15.

Stream	WBID no.	Fish year	Temp year	Age classes	22EC #/%	19EC #/%	13EC #/%	9EC #/%
Canyon Creek - lower	62	1997	1994	4/juv	0/0	0/0	15/71	21/100
Fish Creek - lower	57	1993	1993	4/juv	0/0	0/0	7/50	14/100
Fish Creek - lower	57	1994	1993	4/juv	0/0	0/0	7/50	14/100
Fish Creek - lower	57	1995	1993	4/juv	0/0	0/0	7/50	14/100
Fish Creek - lower	57	1996	1993	4/juv	0/0	0/0	7/50	14/100
Fish Creek - lower	57	1994	1994	4/juv	14/16	17/20	13/93	14/100
Fish Creek - lower	57	1995	1994	4/juv	14/16	17/20	13/93	14/100
Fish Creek - lower	57	1996	1994	4/juv	14/16	17/20	13/93	14/100
Fish Creek - lower	57	1997	1994	4/juv	14/16	17/20	13/93	14/100
Glade Creek - lower	*1*	*1991*	*1993*	*3*	*0/0*	*0/0*	*1/7*	*14/100*
Glade Creek - lower	*1*	*1991*	*1994*	*3*	*0/0*	*0/0*	*14/67*	*21/100*
Nut Creek - lower	*63*	*1991*	*1993*	*1*	*0/0*	*0/0*	*2/25*	*8/100*
Nut Creek - lower	*63*	*1991*	*1994*	*1*	*0/0*	*0/0*	*15/71*	*21/100*
Placer Creek - mouth	*63*	*1991*	*1993*	*0*	*0/0*	*0/0*	*5/63*	*8/100*
Placer Creek - mouth	*63*	*1991*	*1994*	*0*	*0/0*	*0/0*	*17/81*	*21/100*
South Fork Canyon Creek - mouth	*62*	*1991*	*1993*	*3*	*0/0*	*0/0*	*0/0*	*8/100*
South Fork Canyon Creek - mouth	*62*	*1991*	*1994*	*3*	*0/0*	*0/0*	*9/43*	*21/100*
South Fork Canyon Creek - mouth	*62*	*1997*	*1993*	*2*	*0/0*	*0/0*	*0/0*	*8/100*
South Fork Canyon Creek - mouth	62	1997	1994	2	0/0	0/0	9/43	21/100
Storm Creek - lower	32	1994	1993	2	0/0	0/0	0/0	0/0
Storm Creek - lower	32	1994	1994	2	0/0	0/0	8/80	9/90
West Fork Deadman Creek - mouth	61	1993	1993	3/juv	0/0	0/0	0/0	15/100
West Fork Deadman Creek - mouth	61	1993	1994	3/juv	0/0	0/0	8/50	16/100

Summary of stream temperature and fish population data

Ninety-eight comparisons of fish and temperature data were made. Temperature criteria were exceeded in 29 instances where salmonid spawning had occurred and the affected cohort of salmonids were present. These instances occurred primarily in Owyhee County and the Lochsa drainage. Temperature criteria were exceeded in 25 instances where the affected salmonid cohorts were not represented in the length frequency distributions. In 44 instances, no comparison was made since the time period in which the temperature was measured was not represented in the fish data.

These data indicate that more than 50% of the time where Idaho temperature criteria exceedances occur, the affected age classes of fish are present. In other words, salmonid spawning (and incubation) has occurred coincidentally with measured temperature criteria exceedances. In the instances where fish data were collected more than one year after the temperature was measured, these data also indicate that rearing has occurred. In contrast, nearly half the time, the affected cohort of fish was not represented in the length frequency distribution. This may be due to the observed temperature exceedances, or may be due to other factors not considered here.

5.0 Discussion and Conclusions

The National Academy of Science's (NAS 1973) analysis of temperature criteria concluded:

> *The general difficulty in developing suitable criteria for temperature (which would limit the addition of heat) lies in determining the deviation from 'natural' temperature a particular body of water can experience without suffering adverse effects on its biota. … In view of the many variables, it seems obvious that no single temperature requirement can be applied to continental or large regional areas; the requirements must be closely related to each body of water and to its particular community of organisms, especially the important species found in it.*

These words ring as true today as they were in 1973, but we are still far from realizing this truth.

Present Idaho water quality standards contain surface water temperature criteria for aquatic life, salmonid spawning, and bull trout beneficial uses. The aquatic life and salmonid spawning criteria are uniform statewide. The salmonid spawning criteria (Idaho and EPA) are applied during default spawning (and bull trout rearing) periods of individual species, and the numeric criteria are uniform. Application of essentially uniform criteria to waters in a highly variable environmental setting is problematic. Fixed or single value criteria applied uniformly (all places, all times, or pre-defined time periods) do not reflect the range in stream temperatures one would expect, based on climatic variability in Idaho. Single value criteria also do not account for environmental preference or tolerance differences between species, or within species throughout its range.

There are a number of variables that need to be accounted for in the application of surface water temperature criteria. These variables include natural spatial and temporal climate variation, organism response, and temperature measurement variation. It has been shown that the climate of Idaho varies considerably primarily due to latitude, elevation, and season. In addition, weather introduces significant day-to-day and year-to-year departures from climatic normals. These variations affect water temperature through influences on air temperature and stream flow. Gradients of normal stream temperatures exist across Idaho, but, one cannot expect to go out and always encounter normal temperatures. As the National Academy of Sciences stated in 1973
"The agents that affect the natural temperature are so numerous that it is unlikely that two bodies of water, even in the same latitude, would have exactly the same thermal characteristics. Moreover, a single aquatic habitat typically does not have uniform or consistent thermal characteristics" (NAS 1973).

It is largely, laboratory studies on fish which demonstrate their tolerance limits and the effects of certain temperatures. In their natural setting, individual organisms experience daily, seasonal, and annual cycles of environmental change which break the continuity of exposure to extremes. When environmental conditions become intolerable, fish move to refugia habitats that are more favorable. The behavioral response of aquatic animals needs to be accounted for in temperature metrics and criteria and in how stream temperatures are measured and assessed. True stream temperature, an aggregate property, likely is not the temperature aquatic life experiences. This may be why laboratory derived temperature tolerances appear to be exceeded in the field, but no biological response is measured.

The process of collecting and analyzing water temperature data introduces additional variability. Current stream temperature data may not reflect true stream temperatures due to calibration and sensor placement. The way we, as humans, compile our data may or may not adequately describe environmental conditions that fish and macroinvertebrates respond to in their natural setting. Such inadequacies in the data are primarily due to spatial, temporal, and geographic scale issues.

Available empirical fish and temperature data from selected drainages have been compiled which demonstrate the problems with application of uniform surface water temperature criteria in Idaho. More than half of the data where comparisons were possible show criteria exceedances and yet the affected salmonid cohort is represented. These data also indicate that nearly half the time the affected salmonid cohort is not present. This incongruity is likely due to a combination of human-induced temperature criteria exceedances compounded by other factors, poorly understood natural conditions, inappropriate criteria, and inadequate data collection. The current state of affairs is that we cannot reliably distinguish management caused temperature exceedances from natural conditions.

Given the influence of the variables described above, several questions arise concerning the spatial and temporal heterogeneity in streams. How can we collect temperature data to accurately reflect the conditions the fish are exposed to? Which temperature metric best relates to support of aquatic life and salmonid spawning? How much refugia from prevailing warmer water temperatures is needed by a given species to maintain a viable population and assemblage? If adequate refugia are present, how important are temperatures outside the refugia? Do spawning temperature requirements matter other than when and where fish do or could spawn? How much of a stream drainage must be suitable for how long to maintain integrity of the fish assemblage? How much of a species range must be protected in terms of space and time? These questions can serve as a starting point for the development of a project to address the temperature criteria dilemma.

6.0 Recommendations

It is proposed that an aquatic life, salmonid spawning, and temperature regime study be developed and conducted. The data from such a study would be used to: 1) comprehensively document the uniform criteria issue and 2) support development of water quality criteria to protect salmonid spawning which take into account natural environmental diversity. Some factors that need to be considered in such a study include the use of refugia by aquatic life, incubation and rearing temperature requirements of each species, and appropriate temperature metrics.

In addition, a protocol for measuring, reporting, and evaluating stream temperatures for evaluation of water quality temperature criteria is needed. This protocol needs to be specific and detailed as to 1) placement of sensors, 2) sensor calibration, 3) other quality assurance and control issues, 4) expression of results, and 5) the documentation needed to establish a temperature record acceptable for comparison to criteria. The data need to be consistent so that all can benefit from the collection and comparisons may be made between years and sites.

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