U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
Yakima Sub-Office

Hydrologic and water temperature investigation of tributaries to Keechelus Reservoir

Final Report
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Introduction

Keechelus Reservoir is one of five major storage reservoirs for the U.S. Bureau of Reclamation's (Reclamation) Yakima Project located in Central Washington. Situated at an elevation of approximately 2517 feet mean sea level (at full pool), it is the uppermost reservoir in the Yakima River Basin. Originally a natural lake, Keechelus was dammed in 1917 to create storage for the increasing irrigation needs of the Kittitas and Yakima Valleys. Keechelus is a zoned earthfill dam built on glacial moraine. It is 6,550 feet long at the crest, and has a structural height of 128 feet. The reservoir has a capacity of 157,800 acre feet and generally fills each spring as the accumulated snowpack in the Cascade Mountains begins to melt. Runoff water enters the lake from numerous unregulated tributary streams.

A number of fish species are either present, or once were present, in Keechelus Reservoir and the streams which flow into it. The system was once utilized by native anadromous populations of chinook salmon (*Oncorhynchus tshawytscha)*, coho salmon (*O. kisutch)*, sockeye salmon (*O. nerka*), and steelhead trout (*O. mykiss)*. These species are no longer present in the Keechelus Basin (Tuck 1995). Of these species, steelhead were listed by the National Marine Fisheries Service as threatened under the Endangered Species Act (ESA) in March 1999 for the entire Middle Columbia River ESU which includes the Yakima River Basin. A species of special concern which historically and currently inhabits Keechelus Lake is the bull trout (*Salvelinus confluentis*). The only native char species found in the Yakima River Basin, these fish were once ubiquitous and abundant but their populations have declined precipitously. The status of the adfluvial population of bull trout in Keechelus Lake is currently rated as "critical" (WDFW 1998), defined as "a stock of fish experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred". In June1998, the U.S. Fish and Wildlife Service listed bull trout in the Yakima Basin as threatened under the ESA.

While many factors have undoubtedly led to the extirpation and/or decline of salmon, steelhead, and bull trout populations throughout their range (e.g., timber harvest, unscreened diversions, livestock grazing practices, modified flow regimes, overharvest), there can be little doubt that the construction of impassable dams has contributed. Keechelus is one such dam. When the dam was completed anadromous salmonids were permanently excluded from the upper basin and bull trout which had migrated below the dam could never return.

Recently, the issue of fish passage at Keechelus Dam has received heightened interest. This interest was precipitated by the discovery in mid-1998 of structural flaws in a number of locations along the face of the dam. As a result, the structure will require some major repair or perhaps replacement and may present an opportunity to provide fish passage facilities at the dam. In October 1999, Reclamation contacted the FWS Moses Lake Field Office to request that the Service conduct an assessment of the possible fishery benefits which might be derived from providing fish passage at the dam; specifically, the potential spawning and rearing habitat for anadromous salmonids and migratory bull trout in the tributaries flowing into Keechelus

Reservoir. The Moses Lake Field Office contacted the Services' Yakima Sub-Office which agreed to conduct the assessment and a proposal was prepared. The results of the assessment were to be submitted in a Planning Aid Memorandum, pursuant to the Fish and Wildlife Coordination Act, by May 1, 2000.

Subsequent to this, and before a contract was formalized, a document was found which precluded the need to conduct a comprehensive assessment. In 1996-97, Terrapin Environmental (TE) conducted a Fish Habitat Assessment of the Keechelus/Mosquito Creek watershed under contract to the Plum Creek Timber Company. The data acquired by TE satisfied most of the objectives identified by the Yakima Sub-Office Service in the development of the habitat assessment proposal. Two elements missing however, are descriptions of the flow regimes in the major tributaries (i.e., hydrographs) for the period from late-spring to late-fall and stream water temperature data for the same period. After consultation with Reclamation, the original proposal was withdrawn and a second proposal was submitted to acquire these data.

Study Period

Stream discharge and water temperature data were collected from the first week of June through the end of November, 2000. This time period was selected for a number of reasons, both practical and biophysical in nature. Stream discharge and water temperatures would be at their respective lowest and highest levels of the year, and most likely to limit salmonid production, within this period. The spring runoff which generally produces the years highest flows, is diminishing by early June and fall precipitation can be expected to increase streamflow appreciably before the end of November. From a practical standpoint, the manual techniques used to measure stream discharge would have been impossible to employ safely much earlier in the spring due to the magnitude of the runoff flows and most of the study sites would have been very difficult, if not impossible, to access during the winter. With respect to water temperatures, the data presented in this document will validate to the appropriateness of the time period selected for the investigation.

Study Streams

There are numerous tributary streams (creeks) which flow into Keechelus Reservoir. Of those that are perennial, four were chosen for this investigation based on the size of their watersheds and the usable stream length accessible to migratory salmonids: 1) Meadow Creek which enters the reservoir at the southwest end near the dam; 2) Cold Creek which enters from the west; 3) Coal Creek, entering from the north; and 4) Gold Creek, which also flows into the north end of the reservoir. The lower gradient portion of all of these streams is seasonally inundated by the reservoir impoundment. The length of channel inundated is variable ranging from less than 0.5 km on Coal Creek to approximately 3.2 km on Gold Creek. The discharge in all of the creeks is unregulated and none are gaged although Reclamation was in the process of constructing and calibrating a hydromet gaging station on Meadow Creek during the course of data collection.

Meadow Creek is a second-order stream draining approximately 21.8 km^2, with almost all of the watershed located in the Wenatchee National Forest. The absolute length of the creek accessible to migratory salmonids is unknown but a series of falls approximately 6.5 km above the reservoir inlet may prevent any further upstream migration (USFS 1995). Past timber practices, including clear-cutting throughout the watershed, have significantly diminished the riparian overstory and increased the streams exposure to solar radiation.

Cold Creek is a second-order stream draining a watershed of approximately 13.5 km^2, most of which is contained within Forest Service land. The headwaters of the creek flow out of four small lakes on the north slopes of Tinkham Peak into the Twin Lakes. From the outlet of Twin Lakes, Cold Creek flows approximately 3.2 kilometers before entering Keechelus Reservoir. The watershed is relatively undisturbed.

Coal Creek is a third-order stream which drains a watershed of approximately 14.2 km^2 having the lowest mean basin elevation of the four creeks studied. The creek has also been hydrologically and geomorphically modified to a greater extent than the other study streams by timber harvest (i.e., clear-cutting), development of the Snoqualmie ski area, construction of Interstate-90, and residential and commercial development. Approximately 4.2 km of Coal Creek is accessible to migratory salmonids from the mouth to the point where the creek flows through a huge culvert beneath I-90 which is impassible.

Gold Creek drains a watershed of approximately 35.2 km^2 with the headwaters located in the Alpine Lakes Wilderness Area. The creek is the only recorded spawning tributary for the adfluvial population of bull trout which resides in Keechelus Reservoir. Much of the watershed is completely undisturbed and the stream affords the most pristine conditions in the Keechelus Basin. Conditions change drastically in the very lower portion of the watershed around Gold Creek Pond where gravel for the Interstate was excavated from the floodplain in the late 1970s and residential development has occurred. Approximately 11.4 km of Gold Creek is accessible to migratory salmonids from the point where it flows into Keechelus Reservoir (at full pool) to a vertical falls which is impassible. Gold Creek typically goes sub-surface (dewaters) intermittently during August and September in a section of the channel above Gold Creek Pond. Craig (1997) observed the length of the dewatered reach to be 3.3 km in 1996 with the first sub-surface conditions noted on 24 August. In 2000, the creek was first observed to dewater on 16 August from a point 1.0 km upstream of Gold Creek Pond for a length of 0.7 km upstream. Gold Creek was continuously flowing again after a rainfall event on 10 September for a period of 17 days but was again sub-surface for a brief period between 28 September and 6 October. The cause of this phenomenon, or whether it is a natural condition, is unknown at this time.

Study Sites

Five study sites were located on the four streams; one each on Meadow, Cold, and Coal Creeks and two on Gold Creek. The Meadow Creek site was located at the location where Reclamation was constructing the hydromet station about 4.0 km upstream of the Reservoir inlet; the Cold Creek site was about 0.3 km above the Reservoir; and the Coal Creek study site was approximately 0.75 km upstream of the reservoir. Two sites were established on Gold Creek, one below the reach which dewaters and one above, to enable evaluation of the sub-surface flow effects on the flow and water temperature regimes. The lower Gold Creek site was located approximately 0.7 km upstream of Keechelus Reservoir (at full pool) and a few hundred meters downstream of Gold Creek Pond. The upper Gold Creek site was located 6.0 km upstream of the reservoir, about 0.5 km downstream of a primary bull trout spawning area.

The exact locations of study sites were selected based on accessibility to the investigator, channel characteristics which would enable accurate discharge measurements, and limited access to the public. The latter criterion addressed the concern that instruments left on-site (i.e., continuously recording thermographs) would stand the least chance of being stolen or vandalized.

Atmospheric Conditions

As a frame of reference when interpreting the hydrologic and water temperature data which were collected, an understanding of the atmospheric conditions under which those data were collected is helpful. The pattern of precipitation during the study period (Table 1) was erratic with the total at the end of the period considerably below normal at 68 percent. The period began with the last of the runoff from an average snowpack and a wetter than normal June. Conditions became progressively drier in July followed by an entire month with no rain whatsoever. Conversely, September was much wetter than normal which was followed by two months, particularly November, which were considerably below normal precipitation levels

	June	July	August	September	October	November		Totals
2000	3.12	0.9	0	4.62	3.02	4.12		15.78
Normal	2.33	1.23	1.56	2.83	4.97	10.17		23.09
% of Normal	134	73	0	163	61	41		68

Table 1. Precipitation (inches) in the Keechelus watershed during the study period in 2000 and that which would be considered normal. (Data provided by the U.S. Bureau of Reclamation, Yakima Field Office, Hydrology Section)

Air temperatures during the study period were close to normal (Table 2). June was a slightly warmer month than normal, July and August were normal, September slightly below, October slightly above, and November experienced below normal air temperatures.

	June	July	August	September	October	November
Long-Term	11.7	15.3	15.1	11.8	6.0	1.1
Year 2000	12.8	15.2	15.0	11.1	6.2	-0.8

Table 2. Monthly mean air temperatures (Degrees Celsius) for the study period in 2000 and long-term mean air temperatures based on a period of record from 1978-2000. (The data used to construct this table were extracted from records archived by the U.S. Bureau of Reclamation, Yakima Field Office. Monthly averages were calculated in a spreadsheet)

Study Methods

To reduce variability in the discharge data, water depth and velocity were measured at the same location on each site visit. Rebar was driven into the ground above the high water mark on each bank of the stream so that a survey tape strung between would cross the channel perpendicular to the direction of the flow. The rebar remained in place throughout the study period. Depths and velocities were measured on at least 20 evenly spaced verticals across the channel with no more than ten percent of the total discharge passing through any one cell. Measurements were made using a four-foot wading rod equipped with either a Price AA or Pygmy (for low flow conditions) current meter. Water velocities were calculated based on a 40-second count using a current meter digitizer manufactured by the USGS Hydrologic Instrumentation Facility. All data were recorded in a field notebook and subsequently entered into a Quattro Pro® spreadsheet for discharge calculation and graphic display. Data were generally collected weekly with a few exceptions.

Water temperatures were recorded using electronic, programmable Optic Stowaway® thermographs manufactured by the Onset Corporation. These instruments were deployed on 6 June at the study sites in Cold, Coal, and lower Gold Creeks; and 14 June at the Meadow and upper Gold creek Sites. They were placed in the stream in locations that would not be dewatered at low flows and were hidden from view to the greatest extent possible. To avoid damage and theft, the thermographs were encased in a short section of PVC pipe, permanently affixed with 1/8 inch plastic coated steel cable, looped around tree trunks and locked. The instruments were checked on each site visit to confirm their continued operation and downloaded monthly. All of the instruments operated continuously and without malfunction for the entire study period. On each site visit, water temperature was also measured manually and recorded with the time noted.

Downloaded temperature data were transferred into the BoxCar Pro® computer program and then to a Quattro spreadsheet upon returning from the field. All data were compiled, checked for errors, and graphically displayed in Quattro. During this procedure, manually measured temperature data collected on each site visit were compared to that collected by the thermographs to verify the accuracy of the data recorded by the instruments. No appreciable discrepancies were found at any time.

Study Results

Coal Creek

Stream Discharge

Stream discharge was measured in Coal Creek on 23 occasions between 6 June and 30 November (Table 3). The lowest flows measured for the period occurred between 7 August and 5 September, ranging between 0.9 and 1.4 cubic feet per second (cfs). This is not surprising as the watershed received no rain during the month of August (Table 1). A steadily declining hydrograph, which had peaked in mid-June, preceded the low-flow period (Figure 1). The high flow event observed in mid-June was the result of a rainfall event and is evidence of the flashy nature of the stream. It is assumed that a more extended peak flow period associated with snowmelt runoff occurred earlier in the spring. Following the low-flow period and as rainfall increased, Coal Creek responded rapidly. Streamflow varied widely from 2.6 to over 20 cfs with one storm producing a flow of just over 80 cfs, the highest flow measured on the creek.

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
06-Jun	47	02-Aug	2.5	12-Sep	7.7	27-Oct	13.9
14-Jun	80	07-Aug	1.4	28-Sep	2.6	06-Nov	17.1
27-Jun	19	16-Aug	0.9	04-Oct	20.6	14-Nov	9.8
05-Jul	10	23-Aug	1	06-Oct	16.1	20-Nov	6.5
13-Jul	5	29-Aug	0.9	13-Oct	8.2	30-Nov	18
24-Jul	2.7	05-Sep	1	20-Oct	80.9		

Table 3. Measured streamflows in Coal Creek on 23 dates during the study period in 2000.

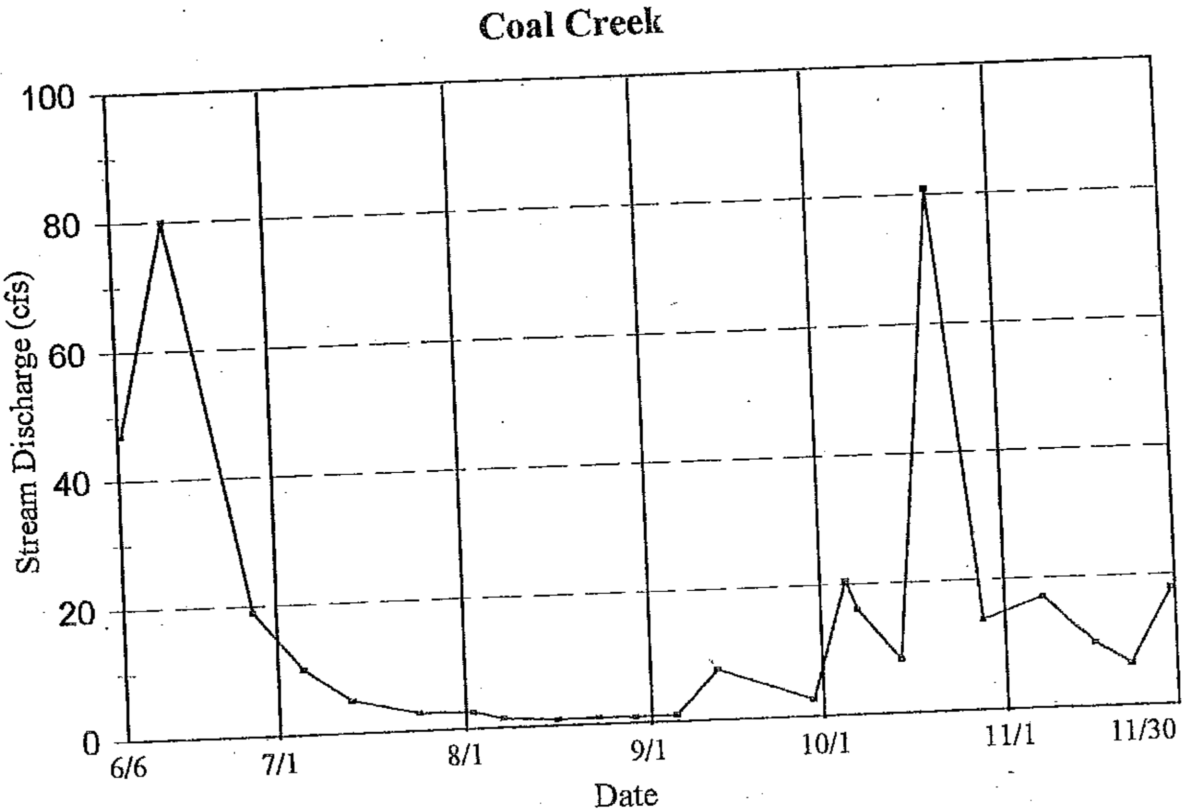

Figure 1. Hydrograph for Coal Creek in the Keechelus Basin for the period between 6 June and 30 November, 2000. Data used to construct this hydrograph were collected on 23 dates and are presented in Table 3.

Water Temperatures

Water temperature preferences and requirements are cited in the literature for various salmonid species and life stages of those species. To simplify the analytical discussion of water temperatures in this report some general temperature criteria will be used as a frame of reference. These criteria are: 1) Water temperatures which reach 20 to 22 °C (Celsius) for extended periods are considered stressful for salmonids, with those in excess of 22 °C potentially lethal; and 2) An average daily summer water temperature of 15 °C is within the range that would be considered optimal for most salmonid species. A third criterion to be considered is more specific and applies to bull trout which are currently present in the watershed and listed as threatened under the ESA. Bull trout are generally considered to have the most stringent temperature requirements of any salmonid species and their distribution is known to be limited in waters where mean summer water temperatures exceed 15 °C.

The thermal regime for Coal Creek during the study period is presented graphically in Figures 2 and 3; tabular data are presented in Appendix A. Overall, water temperatures in Coal Creek were the warmest of any of the streams monitored in this study yet the duration of the period displaying the warmest conditions was relatively brief. During the last week of July through the first week of August, 7-day mean water temperatures were 15.3 and 15.6 ^{0}C. The highest single-day mean water temperature during these two weeks reached 16.9 ^{0}C. Daily maximum water temperatures exceeded 18.0 ^{0}C on 22 of 23 days between 7 July and 9 August with three days displaying maximums between 20.0 and 21.0 ^{0}C. Daily minimum water temperatures during this time period ranged between 10.6 and 14.5 ^{0}C. The daily range of water temperatures observed on Coal Creek during the summer was broad, undoubtedly the result of extensive stream-side development and degraded riparian conditions.

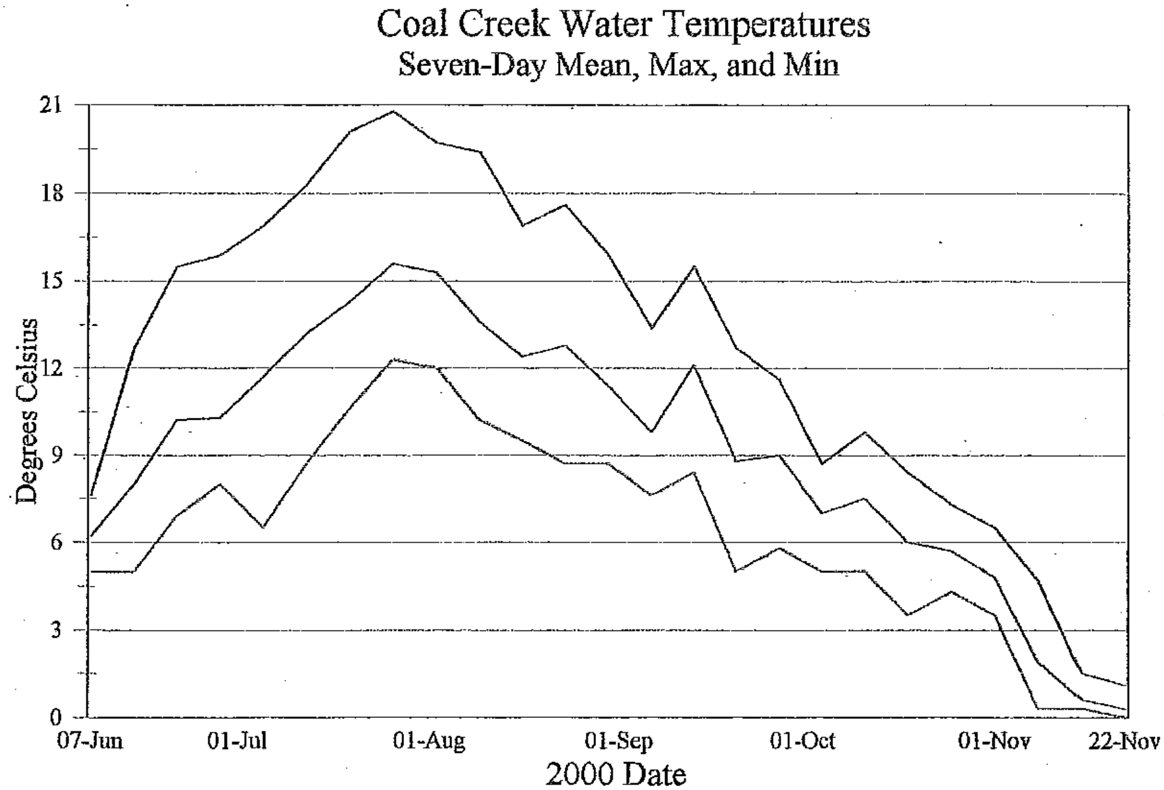

Figure 2. Seven-day mean, maximum, and minimum water temperatures in Coal Creek for the period between 7 June and 1 December, 2000.

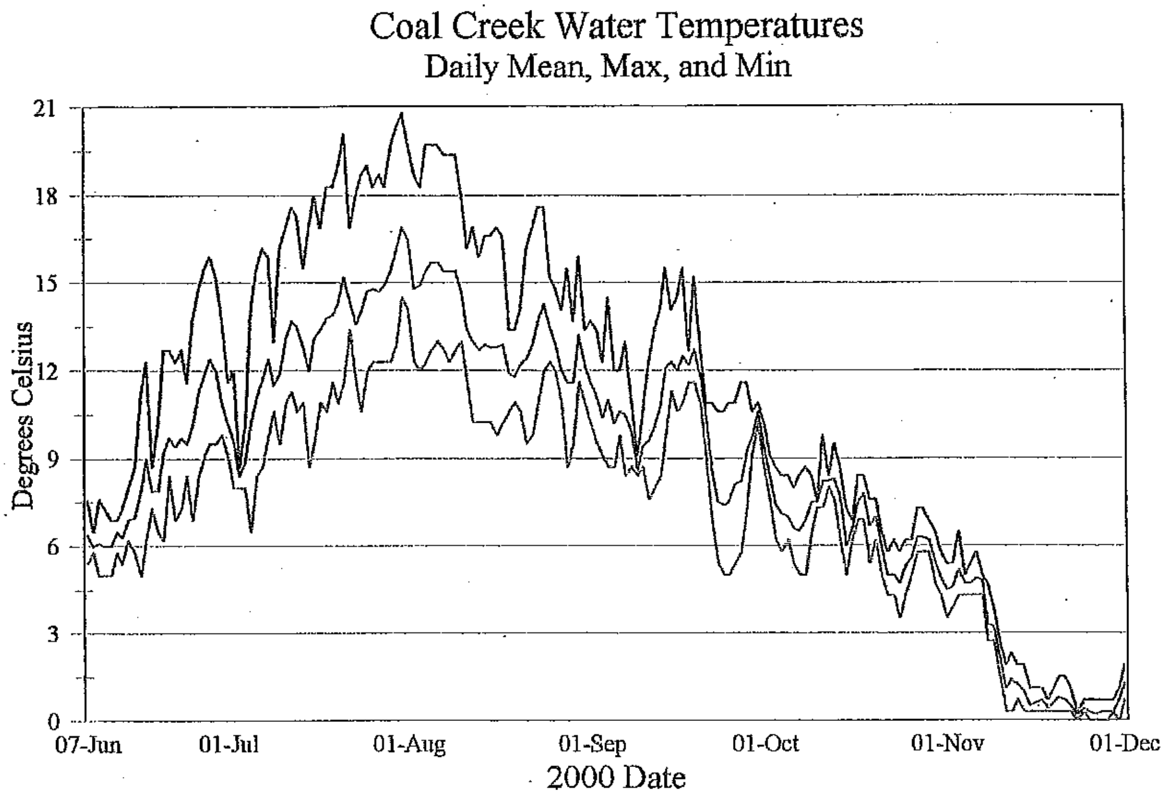

Figure 3. Daily mean, maximum, and minimum water temperatures in Coal Creek for the period between 7 June and 1 December, 2000.

Cold Creek

Stream Discharge

Stream discharge was measured in Cold Creek on 23 occasions between 6 June and 30 November (Table 4). The lowest flows measured occurred between 16 August and 5 September, ranging between 0.6 and 1.0 cfs, again the result of an extremely dry August (Table 1). Preceding the low flow period, streamflows steadily declined after peaking in mid-June at 105 cfs (Figure 4). Following the low-flow period, streamflows in Cold Creek increased significantly. Discharge varied widely from 1.9 cfs on 28 September to 26.3 cfs on 20 October. More stable flows were observed after the latter date with an average discharge of about 7.0 cfs to the end of November.

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
06-Jun	70	02-Aug	4	12-Sep	11.2	27-Oct	7.8
14-Jun	105	07-Aug	2.9	28-Sep	1.9	06-Nov	8.8
27-Jun	47	16-Aug	1	04-Oct	12.6	14-Nov	5
05-Jul	19	23-Aug	1	06-Oct	9.8	20-Nov	4
13-Jul	15	29-Aug	0.6	13-Oct	4	30-Nov	9
24-Jul	8.4	05-Sep	0.6	20-Oct	26.3		

Table 4. Measured streamflows in Cold Creek on 23 dates during the study period in 2000.

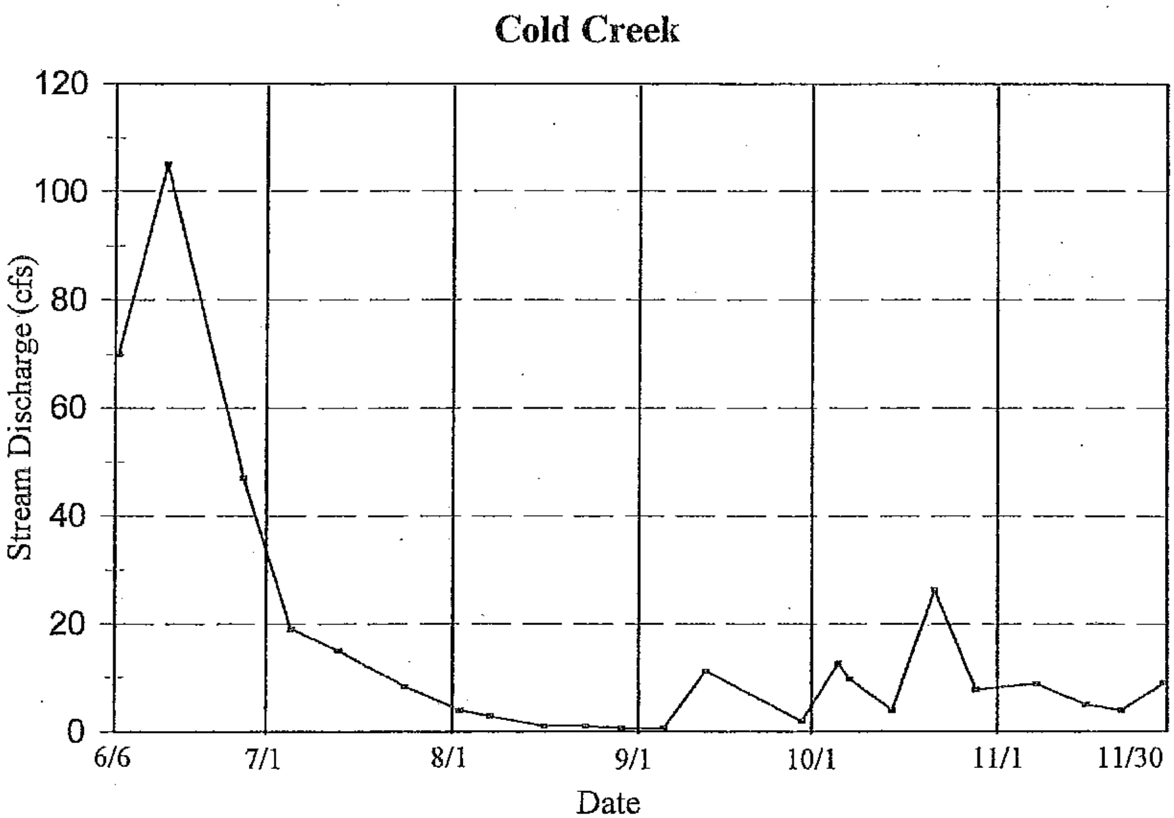

Figure 4. Hydrograph for Cold Creek in the Keechelus Basin for the period between 6 June and 30 November, 2000. Data used to construct this hydrograph were collected on 23 dates and are presented in Table 4.

Water Temperatures

The thermal regime for Cold Creek during the study period is presented graphically in Figures 5 and 6; tabular data are presented in Appendix A . Water temperatures in Cold Creek were highly suitable for all salmonid species throughout the study period. The warmest water temperatures occurred during the last week of July through the first week of August with 7-day mean temperatures of 13.6 and 14.0 ^{0}C. The highest single-day mean water temperature during these two weeks reached 14.9 ^{0}C on two consecutive days. Daily maximum water temperatures exceeded 15.0 ^{0}C on only eleven days during the period with the highest single-day maximum of 16.4 ^{0}C reached on 31 July. Daily minimum water temperatures during this period ranged between 11.5 and 13.8 ^{0}C. The daily range of water temperatures observed in Cold Creek during the summer was very narrow, particularly compared to Coal Creek. This was likely due to the fact that the riparian corridor of Cold Creek is, for the most part, undisturbed.

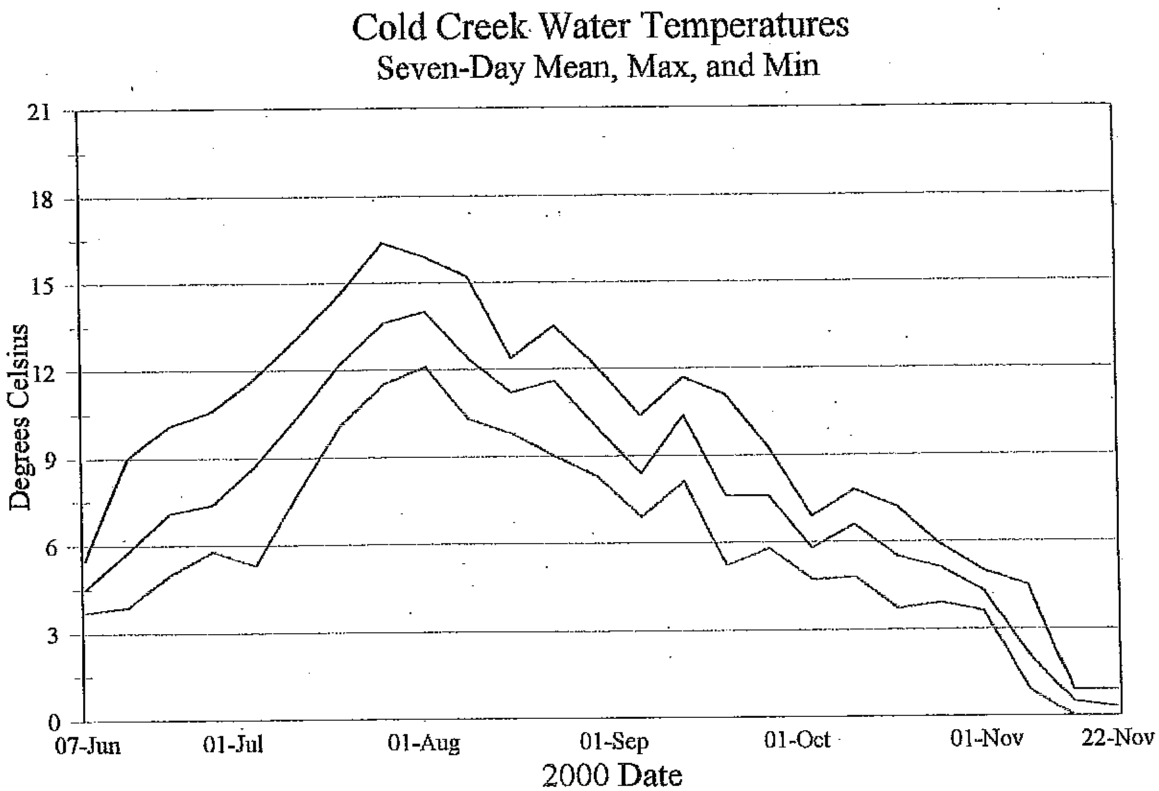

Figure 5. Seven-day mean, maximum, and minimum water temperatures in Cold Creek for the period between 7 June and 1 December, 2000.

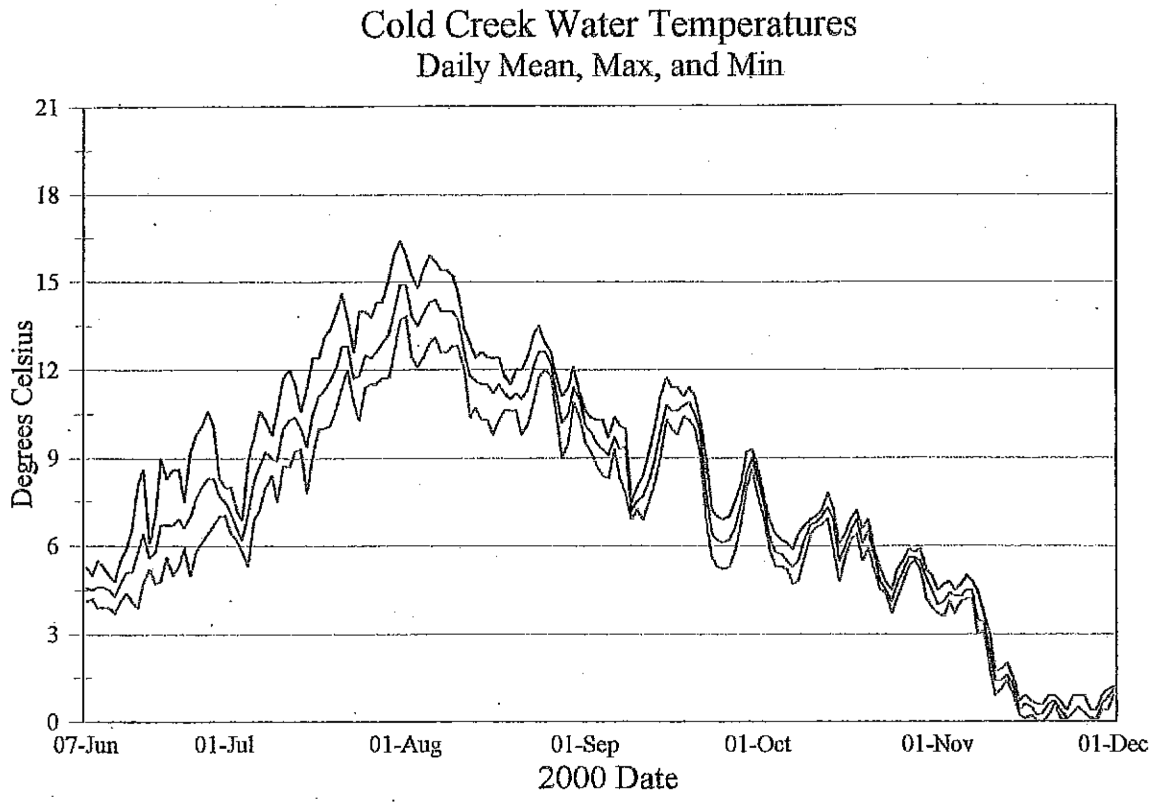

Figure 6. Daily mean, maximum, and minimum water temperatures in Cold Creek for the period between 7 June and 1 December, 2000.

Meadow Creek

Stream Discharge

Stream discharge was measured in Meadow Creek on 23 occasions between 6 June and 30 November (Table 5). Draining a larger watershed than either Coal or Cold Creek, summer base-flows in Meadow Creek were higher than in either of those two streams. The lowest flows measured occurred between 7 August and 28 September, ranging between 2.0 and 3.8 cfs. Preceding the low flow period, flows steadily declined after peaking in mid-June of 108 cfs (Figure 7). Following the low-flow period, streamflows in Meadow Creek increased significantly. Discharge varied widely during the rest of the study period from 9.1 cfs on 28 September and 20 November to 29.7 cfs on 20 October.

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
06-Jun	65	02-Aug	4.3	12-Sep	3.8	27-Oct	19.4
14-Jun	108	07-Aug	3.1	28-Sep	2.3	06-Nov	15
27-Jun	22	16-Aug	2.4	04-Oct	22.6	14-Nov	13.5
05-Jul	12	23-Aug	2.3	06-Oct	17.6	20-Nov	9.1
13-Jul	8	29-Aug	2	13-Oct	9.1	30-Nov	22
24-Jul	5.6	05-Sep	1.8	20-Oct	29.7		

Table 5. Measured streamflows in Meadow Creek on 23 dates during the study period in 2000.

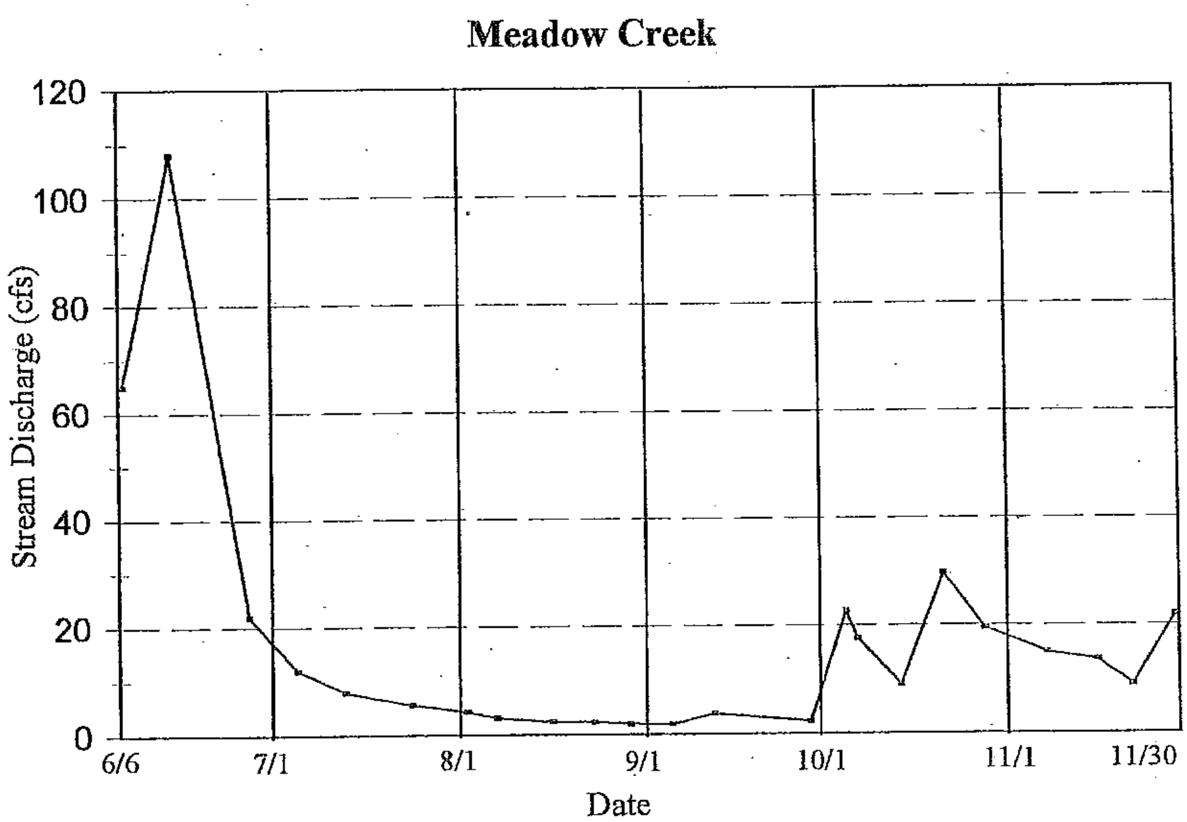

Figure 7. Hydrograph for Meadow Creek in the Keechelus Basin for the period between 6 June and 30 November, 2000. Data used to construct this hydrograph were collected on 23 dates and are presented in Table 5.

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
06-Jun	65	02-Aug	4.3	12-Sep	3.8	27-Oct	19.4
14-Jun	108	07-Aug	3.1	28-Sep	2.3	06-Nov	15
27-Jun	22	16-Aug	2.4	04-Oct	22.6	14-Nov	13.5
05-Jul	12	23-Aug	2.3	06-Oct	17.6	20-Nov	9.1
13-Jul	8	29-Aug	2	13-Oct	9.1	30-Nov	22
24-Jul	5.6	05-Sep	1.8	20-Oct	29.7		

Table 5. Measured streamflows in Meadow Creek on 23 dates during the study period in 2000.

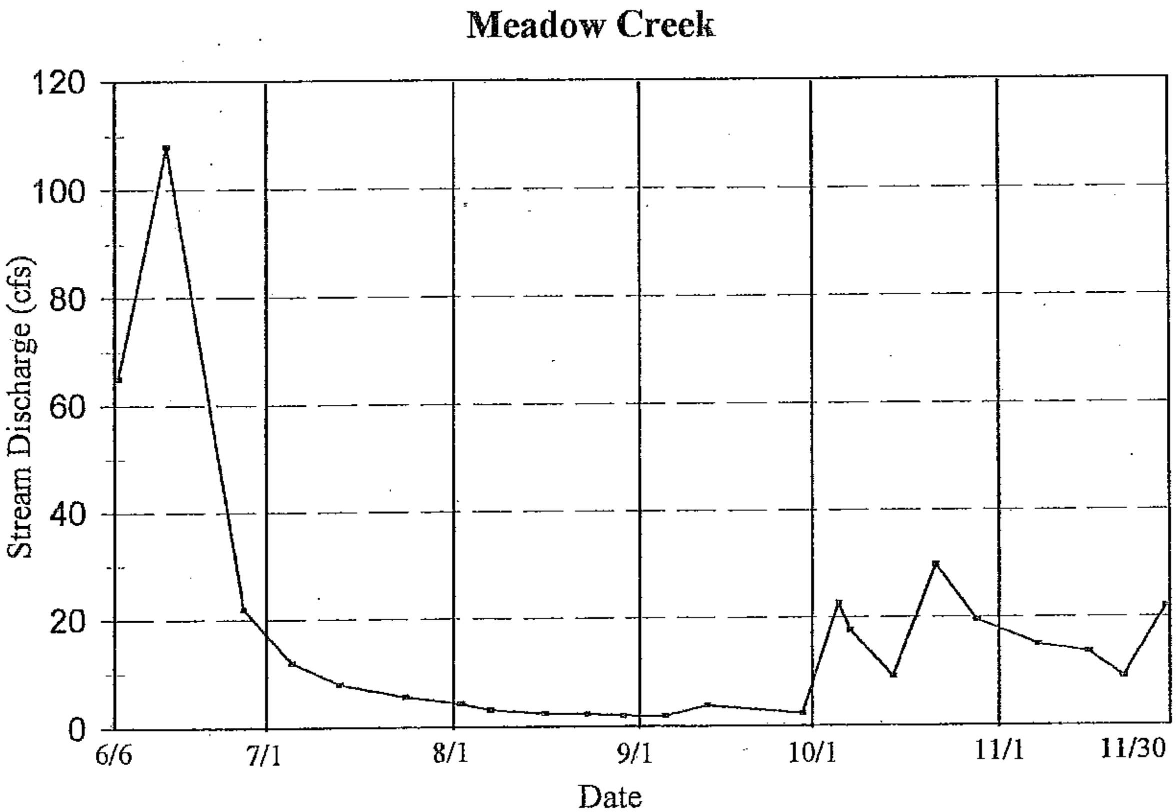

Figure 7. Hydrograph for Meadow Creek in the Keechelus Basin for the period between 6 June and 30 November, 2000. Data used to construct this hydrograph were collected on 23 dates and are presented in Table 5.

Water Temperatures

The thermal regime for Meadow Creek during the study period is presented graphically in Figures 8 and 9; tabular data are presented in Appendix A . Water temperatures in Meadow Creek were suitable for all salmonid species throughout the study period although daily maximums did reach levels which were higher than on all of the study streams except Coal Creek. The warmest water temperatures occurred during the last two weeks of July with 7-day mean temperatures of 13.4 and 13.5 °C. The highest single-day mean water temperature during these two weeks reached 14.7 °C on 31 July. Daily maximum water temperatures exceeded
18.0 °C on four days with six other daily maximums very close to18.0 °C during the period. Daily minimum water temperatures ranged between 9.6 and 12.0 °C. With a watershed that is still recovering from extensive clear-cutting, in some locations down to the stream banks, the daily range of water temperatures observed in Meadow Creek during the summer was broad and very similar to Coal Creek.

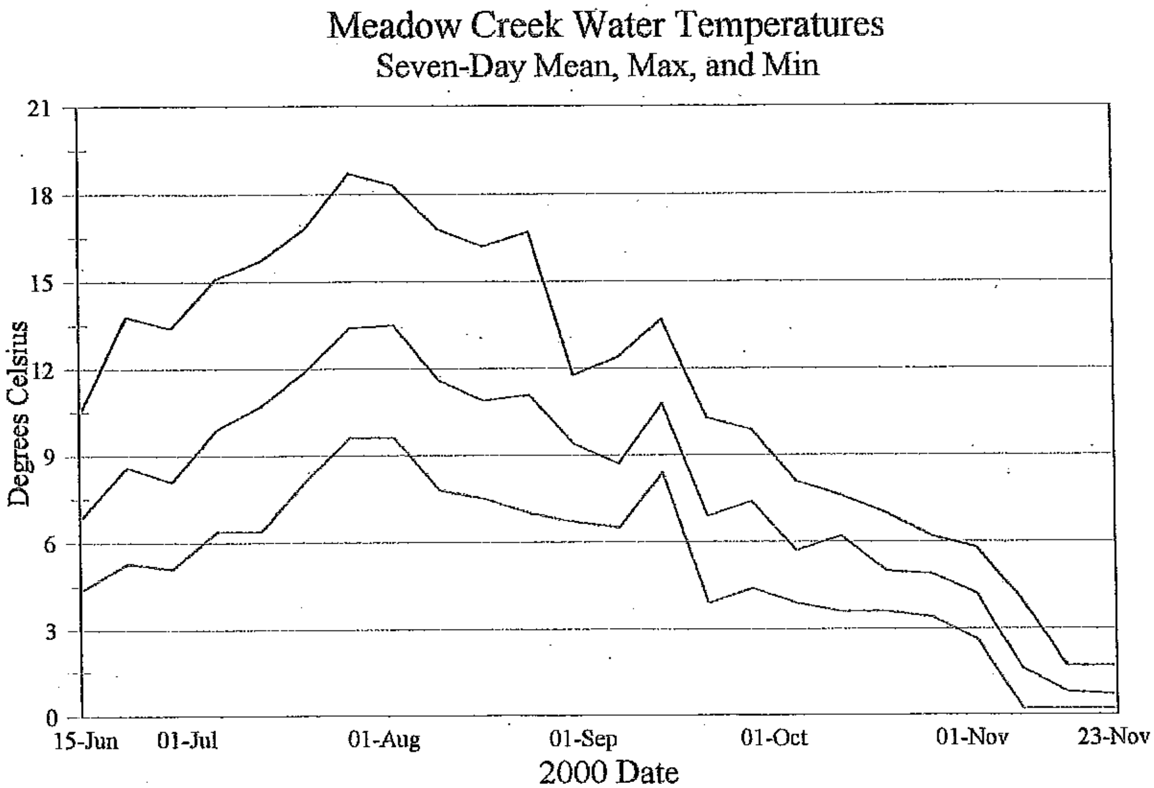

Figure 8. Seven-day mean, maximum, and minimum water temperatures in Meadow Creek for the period between 7 June and 1 December, 2000.

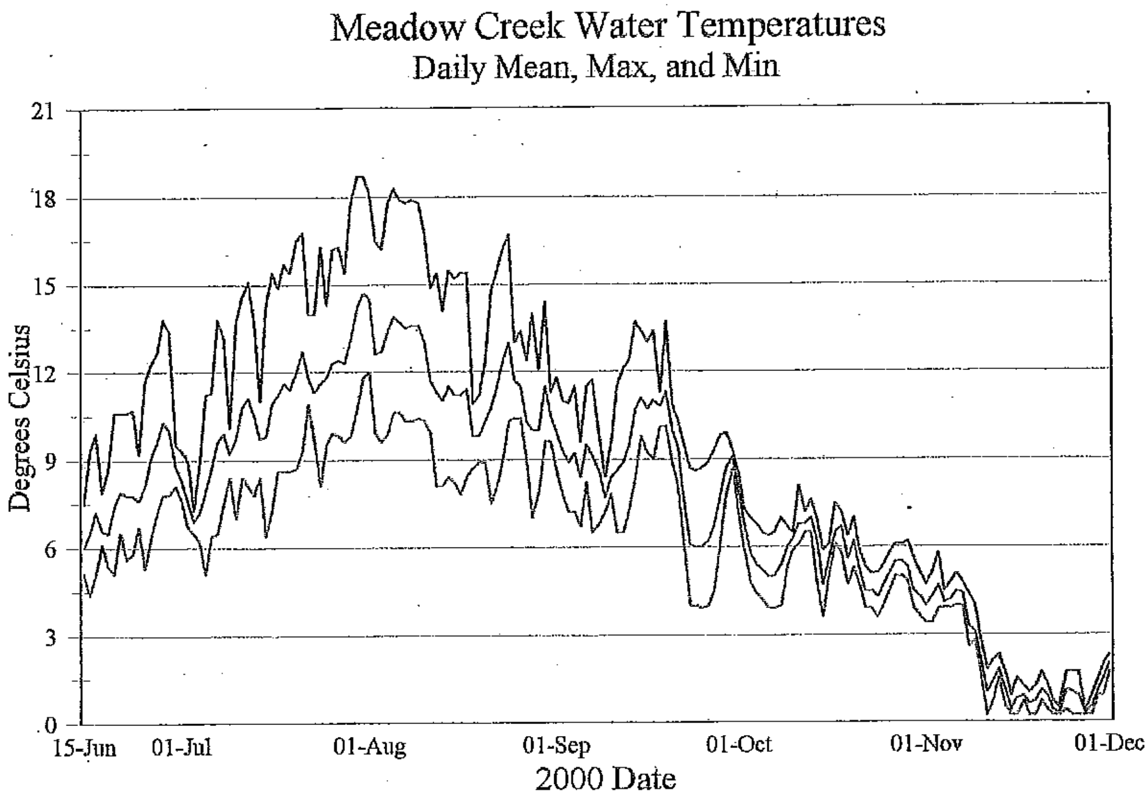

Figure 9. Daily mean, maximum, and minimum water temperatures in Meadow Creek for the period between 7 June and 1 December, 2000.

Gold Creek

Stream Discharge

Stream discharge was measured in upper and lower Gold Creek on 23 occasions between 6 June and 30 November (Table 6). The hydrographs for the two sites display identical flow patterns but different flow magnitudes with the lower site always possessing the higher discharge (Figure 10). There are several small ephemeral tributaries entering the creek between the two sites and also inflow from the outlet of Gold Creek Pond which is perennial. The proportional difference in stream discharge measured at the two sites on specific dates ranged from 8-to-26 percent and does not appear to be correlated with flow magnitude (Table 7). With the largest watershed in the Keechelus Basin, Gold Creek streamflows were higher than those measured in the other study streams throughout the study period.

Date	Upper Flow (cfs)	Lower Flow (cfs)	Date	Upper Flow (cfs)	Lower Flow (cfs)	Date	Upper Flow (cfs)	Lower Flow (cfs)
06-Jun	220	274	16-Aug	15.7	19.9	13-Oct	20	26.4
14-Jun	253	331	23-Aug	14.4	17.6	20-Oct	58	70
27-Jun	195	225	29-Aug	11.5	14.6	27-Oct	35	41.4
05-Jul	92	110	05-Sep	10.3	12.3	06-Nov	39.5	46.3
13-Jul	101	117	12-Sep	23.6	30.8	14-Nov	20	24.8
24-Jul	62	72	28-Sep	11.5	15.6	20-Nov	15	17
02-Aug	37	41	04-Oct	53.5	64	30-Nov	32	37
07-Aug	28	30.5	06-Oct	41.8	49.2			

Table 6. Measured streamflows in Upper and Lower Gold Creek on 23 dates during the study period in 2000.

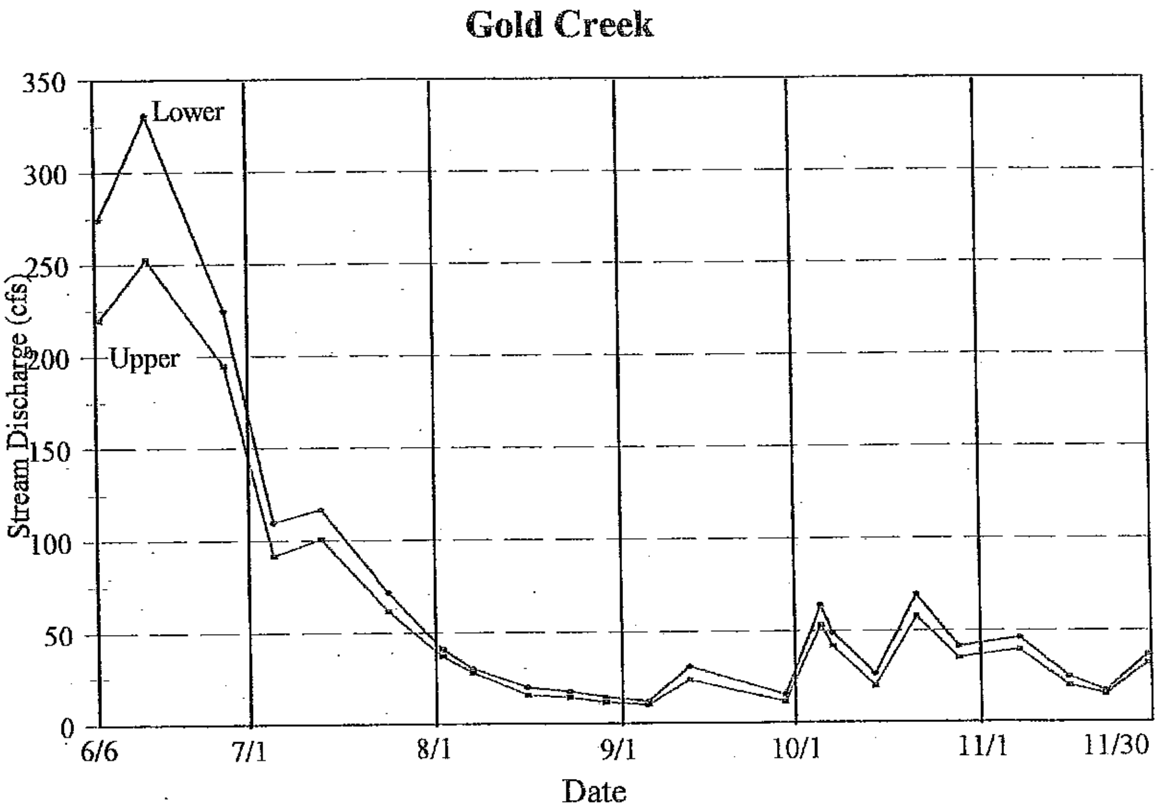

Figure 10. Hydrograph for Gold Creek in the Keechelus Basin for the period between 6 June and 30 November, 2000. Data used to construct this hydrograph were collected on 23 dates and are presented in Table 5.

Upper Flow (cfs)	Lower Flow (cfs)	Percent Difference	Upper Flow (cfs)	Lower Flow (cfs)	Percent Difference	Upper Flow (cfs)	Lower Flow (cfs)	Percent Difference
10.3	12.3	16	23.6	30.8	23	58	70	17
11.5	14.6	21	28	30.5	8	62	72	14
11.5	15.6	26	32	37	14	92	110	16
14.4	17.6	18	35	41.4	15	101	117	14
15	17	12	37	41	10	195	225	13
15.7	19.9	21	39.5	46.3	15	220	274	20
20	24.8	19	41.8	49.2	15	253	331	24
20	26.4	24	53.5	64	16			

Table 7. Percent difference in stream discharge measured at the Upper and Lower Gold Creek study sites on 23 dates between 6 June and 30 November, 2000. Paired discharge data for each measurement date have been sorted in ascending order.

The lowest flows measured occurred from mid-August through the last week of September with a minor flow spike on 12 September following a rainfall event. Excepting that event, stream discharge during the period ranged from 10.3 to 15.7 cfs in upper Gold Creek and 12.3 to 19.9 cfs in the lower segment of the stream. Preceding the low flow period, as was the case on the other creeks studied, flows were generally declining after peaking in mid-June at 253 cfs and 331 cfs in upper and lower Gold Creek, respectively. Following the low-flow period streamflows varied significantly during the rest of the study. Flows measured in upper Gold Creek ranged from 15 cfs on 20 November to 58 cfs on 20 October with those in lower Gold Creek ranging from 17 to 70 cfs on the same dates.

Water Temperatures

The thermal regimes of both upper and lower Gold Creek were cooler than those of the other study streams at all times during the study period. Upper Gold Creek, at a higher elevation and with an undisturbed riparian corridor, had cooler water temperatures than the lower reach of the stream (Figure 11). The temperature difference between the two reaches was greatest between mid-August and the end of the first week in September when differences in mean daily water temperatures exceeded 3.0 ^{0}C with a maximum difference of 3.7 ^{0}C reached on one occasion.

The thermal regime for upper Gold Creek during the study period is presented graphically in Figures 12 and 13; tabular data are presented in Appendix A . Water temperatures in upper Gold Creek were highly suitable for all salmonid species throughout the study period. The warmest water temperatures occurred during two weeks beginning on 27 July and ending on 9 August with 7-day mean temperatures of 10.3 and 10.5 ^{0}C. Single-day mean water temperatures ranged

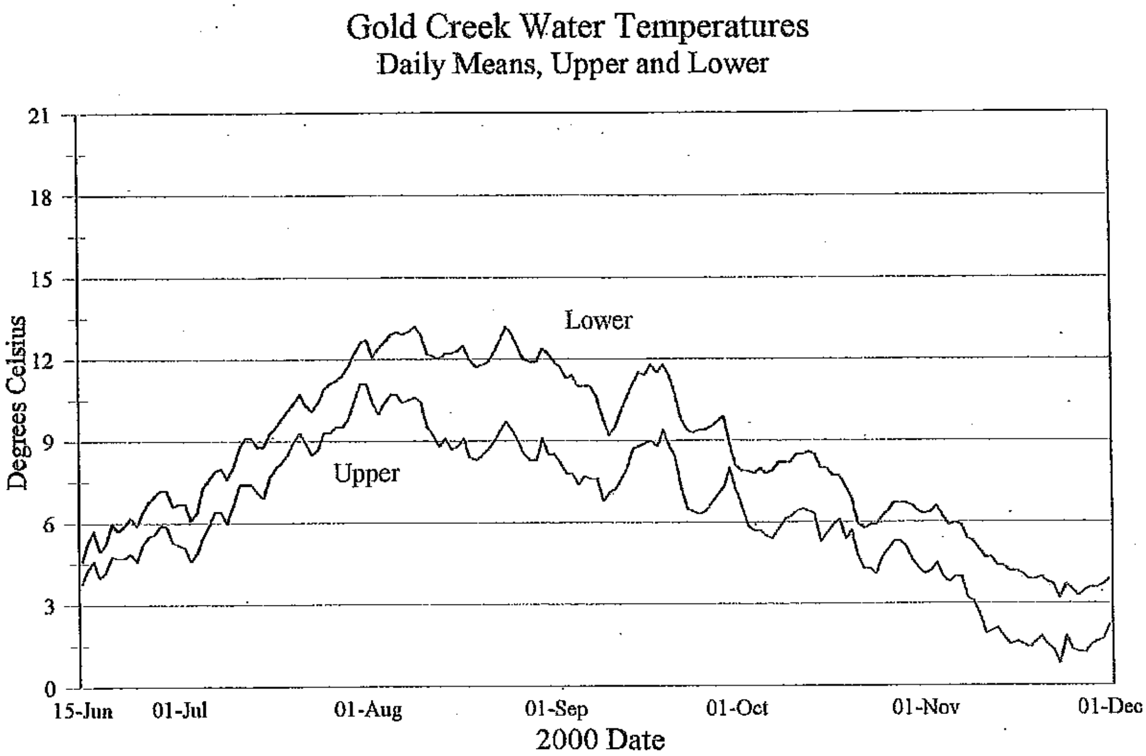

Figure 11. Comparison of mean daily water temperatures in Upper and Lower Gold Creek in the Keechelus Basin for the period between 15 June and 30 November, 2000.

from 9.5 to11.1 °C during the period. Daily maximum water temperatures ranged from 11.3 to13.8 °C, the latter value reached only once. Daily minimum water temperatures during this period were between 8.0 and 9.9 °C. With a totally undisturbed watershed in excellent condition, the daily range of water temperatures observed in upper Gold Creek was narrow.

The thermal regime for lower Gold Creek during the study period is presented graphically in Figures 14 and 15; tabular data are presented in Appendix A . Water temperatures in lower Gold Creek were also highly suitable for all salmonid species throughout the study period. The warmest water temperatures occurred during four weeks in August when 7-day mean temperatures ranged from 12.1 and 12.7 °C. Single-day mean water temperatures ranged from 11.7 to13.2 °C during the period. Daily maximum water temperatures were between 12.3 and 15.1 °C, the latter value reached twice. Daily minimum water temperatures ranged from 10.9 and 12.3 °C. Although the lower Gold Creek watershed has been impacted by development, the daily range of water temperatures observed during the summer was the narrowest of any of the creeks studied. This is possibly the result of groundwater influences in this alluvial reach which would moderate temperatures.

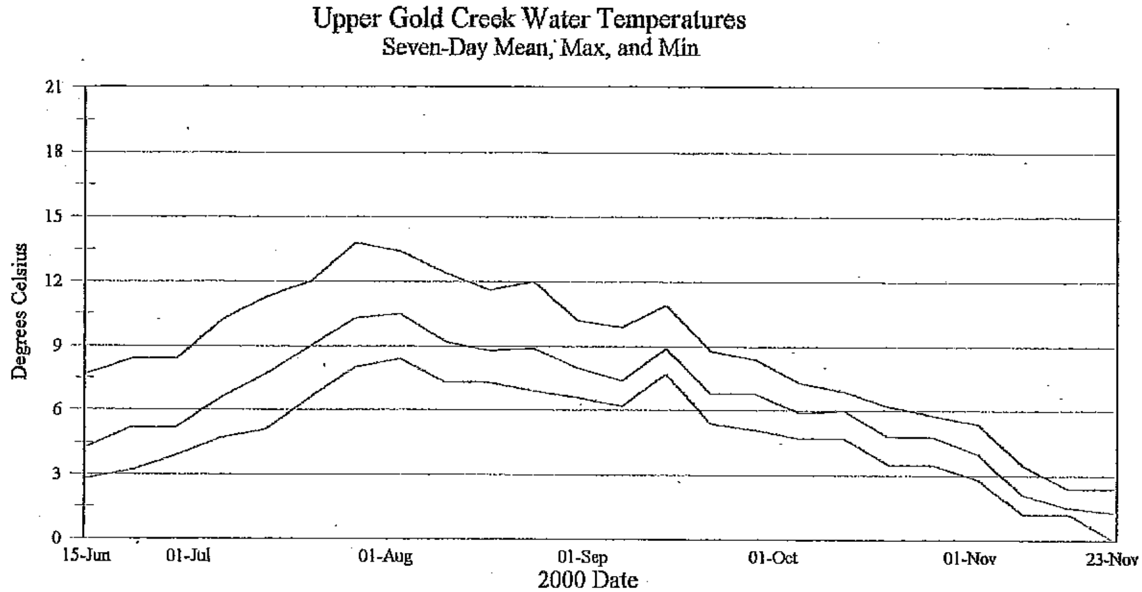

Figure 12. Seven-day mean, maximum, and minimum water temperatures in Upper Gold Creek for the period between 15 June and 1 December, 2000.

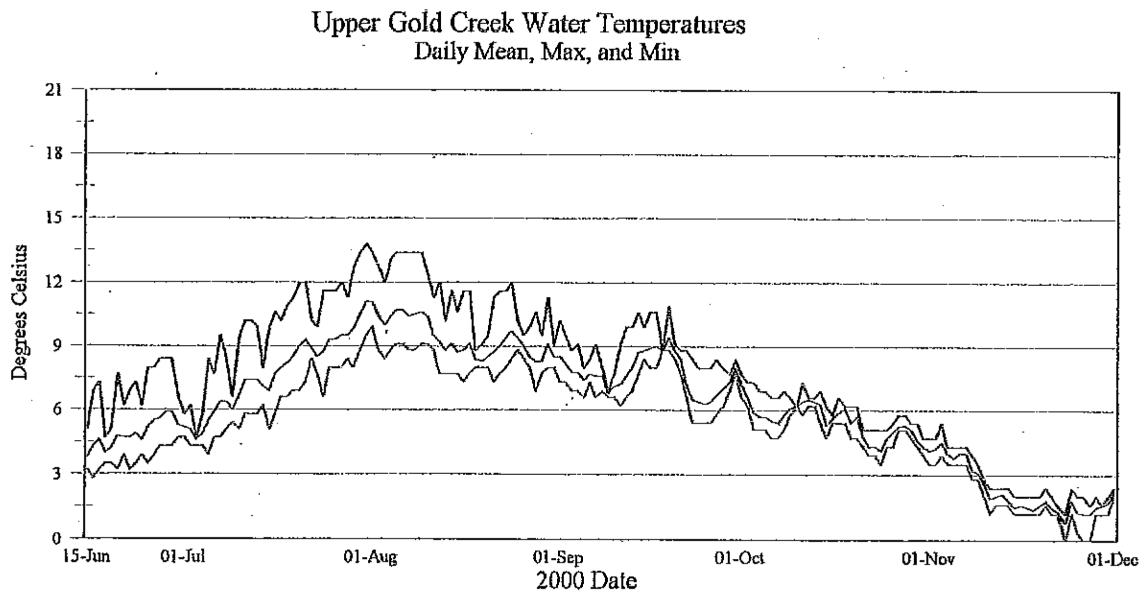

Figure 13. Daily mean, maximum, and minimum water temperatures in Lower Gold Creek for the period between 7 June and 1 December, 2000.

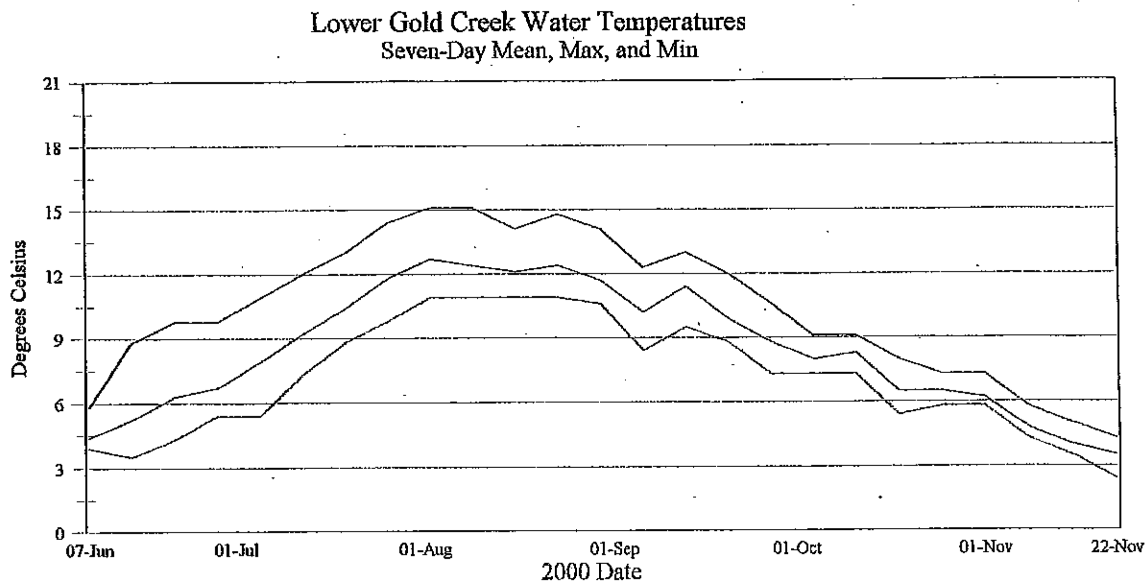

Figure 14. Seven-day mean, maximum, and minimum water temperatures in Lower Gold Creek for the period between 15 June and 1 December, 2000.

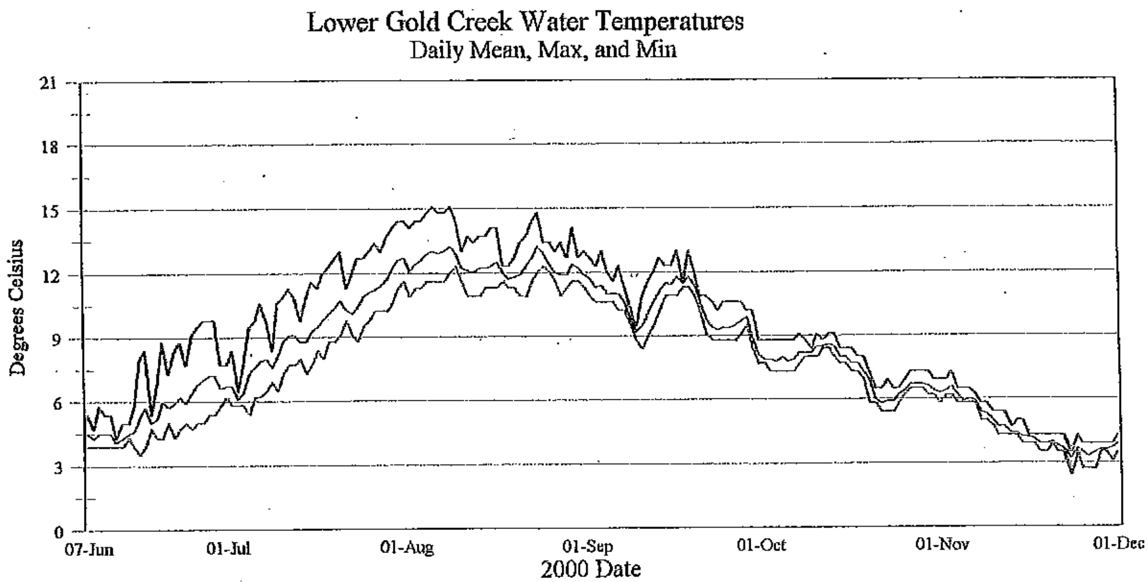

Figure 15. Daily mean, maximum, and minimum water temperatures in Lower Gold Creek for the period between 7 June and 1 December, 2000.

Acknowledgments

I would like to thank Patrick Monk, fishery biologist for the Roza-Suunnyside Board of Joint Control for the loan of three thermographs for use in this study and for lending assistance on a couple of occasions in the collection of field data. I also thank Eric Anderson of the Washington Department of Fish and Wildlife for his assistance on several occasions, two of them in absolutely miserable weather, in collecting field data. Finally, I would like to express my gratitude to the folks at Lake Easton State Park for providing me vehicle access to the John Wayne Trail without which I would have had to hike a lot more than I did.

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APPENDIX A

Tabular display of Seven-day mean, maximum, and minimum water temperatures for streams in the Keechelus Reservoir watershed

Coal Creek

Week	7-Day Mean	7-Day Maximum	7-Day Minimum
1	6.2	7.6	5
2	8	12.7	5
3	10.2	15.5	6.9
4	10.3	15.9	8
5	11.7	16.9	6.5
6	13.2	18.3	8.7
7	14.3	20.1	10.6
8	15.6	20.8	12.3
9	15.3	19.7	12
10	13.6	19.4	10.2
11	12.4	16.9	9.5
12	12.8	17.6	8.7
13	11.4	15.9	8.7
14	9.8	13.4	7.6
15	12.1	15.5	8.4
16	8.8	12.7	5
17	9	11.6	5.8
18	7	8.7	5
19	7.5	9.8	5
20	6	8.4	3.5
21	5.7	7.3	4.3
22	4.8	6.5	3.5
23	1.9	4.7	0.3
24	0.6	1.5	0.3
25	0.3	1.1	0

Table A-1. Seven-day mean, maximum, and minimum water temperatures (^{0}C) in Coal Creek for the period between 7 June and 1 December, 2000.

Cold Creek

Week	7-Day Mean	7-Day Maximum	7-Day Minimum
1	4.5	5.5	3.7
2	5.8	9	3.9
3	7.1	10.1	5
4	7.4	10.6	5.8
5	8.7	11.7	5.3
6	10.4	13.1	7.8
7	12.2	14.6	10.1
8	13.6	16.4	11.5
9	14	15.9	12.1
10	12.4	15.2	10.3
11	11.2	12.4	9.8
12	11.6	13.5	9
13	10	12.1	8.3
14	8.4	10.4	6.9
15	10.4	11.7	8.1
16	7.6	11.1	5.2
17	7.6	9.3	5.8
18	5.8	6.9	4.7
19	6.6	7.8	4.8
20	5.5	7.2	3.7
21	5.1	5.9	3.9
22	4.3	5	3.6
23	2.1	4.5	0.9
24	0.5	0.9	0
25	0.3	0.9	0

Table A-2. Seven-day mean, maximum, and minimum water temperatures (^{0}C) in Cold Creek for the period between 7 June and 1 December, 2000.

Meadow Creek

Week	7-Day Mean	7-Day Maximum	7-Day Minimum
1	6.9	10.6	4.4
2	8.6	13.8	5.3
3	8.1	13.4	5.1
4	9.9	15.1	6.4
5	10.7	15.7	6.4
6	11.9	16.8	8.1
7	13.4	18.7	9.6
8	13.5	18.3	9.6
9	11.6	16.8	7.8
10	10.9	16.2	7.5
11	11.1	16.7	7
12	9.4	11.8	6.7
13	8.7	12.4	6.5
14	10.8	13.7	8.4
15	6.9	10.3	3.9
16	7.4	9.9	4.4
17	5.7	8.1	3.9
18	6.2	7.6	3.6
19	5	7	3.6
20	4.9	6.2	3.4
21	4.2	5.8	2.6
22	1.6	4	0.2
23	0.8	1.7	0.2
24	0.7	1.7	0.2

Table A-3. Seven-day mean, maximum, and minimum water temperatures (^{0}C) in Meadow Creek for the period between 15 June and 1 December, 2000.

Upper Gold Creek

Week	7-Day Mean	7-Day Maximum	7-Day Minimum
1	4.3	7.7	2.8
2	5.2	8.4	3.2
3	5.2	8.4	3.9
4	6.6	10.2	4.7
5	7.7	11.3	5.1
6	9	12	6.6
7	10.3	13.8	8
8	10.5	13.4	8.4
9	9.2	12.4	7.3
10	8.8	11.6	7.3
11	8.9	12	6.9
12	8	10.2	6.6
13	7.4	9.9	6.2
14	8.9	10.9	7.7
15	6.8	8.8	5.4
16	6.8	8.4	5.1
17	5.9	7.3	4.7
18	6	6.9	4.7
19	4.8	6.2	3.5
20	4.8	5.8	3.5
21	4	5.4	2.8
22	2.1	3.5	1.2
23	1.5	2.4	1.2
24	1.3	2.4	0

Table A-4. Seven-day mean, maximum, and minimum water temperatures (^0C) in Upper Gold Creek for the period between 15 June and 1 December, 2000.

Lower Gold Creek

Week	7-Day Mean	7-Day Maximum	7-Day Minimum
1	4.4	5.8	3.9
2	5.2	8.8	3.5
3	6.3	9.8	4.3
4	6.7	9.8	5.4
5	7.9	10.9	5.4
6	9.2	12	7.3
7	10.4	13	8.8
8	11.8	14.4	9.8
9	12.7	15.1	10.9
10	12.4	15.1	10.9
11	12.1	14.1	10.9
12	12.4	14.8	10.9
13	11.7	14.1	10.6
14	10.2	12.3	8.4
15	11.4	13	9.5
16	9.9	12	8.8
17	8.8	10.6	7.3
18	8	9.1	7.3
19	8.3	9.1	7.3
20	6.5	8	5.4
21	6.5	7.3	5.8
22	6.2	7.3	5.8
23	4.8	5.8	4.3
24	4	5	3.5
25	3.5	4.3	2.4

Table A-5. Seven-day mean, maximum, and minimum water temperatures (^0C) in Lower Gold Creek for the period between 7 June and 1 December, 2000.