MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS

FISHERIES DIVISION

JOB PROGRESS REPORT

State: Montana Title: Southwestern Montana Fisheries Investigation

Project No.: F-9-R-30 Title: Madison River Temperature Study

Job No.: IIb

Period Covered: April 1, 1981 through March 31, 1982

ABSTRACT

Three thermographs were placed in the Madison River above and below Ennis Reservoir to study the effects of warmer water from Ennis Reservoir on the wild trout fishery of the lower Madison River. Wild brown trout population estimates made in 1980 and 1981 show total biomass estimates to be 8 to 29% higher below Ennis Reservoir (Norris) than found above the reservoir (Varney). Comparison of spring (April) wild rainbow trout estimates for the Norris section and fall (September) estimates for the Varney section show the biomass in 1980 and 1981 to be 69 to 81% higher in the lower river. Most of the rainbow trout biomass in the Norris section is concentrated in fish under 13 inches, whereas in the section above Ennis Reservoir (Varney) only 50% of the fish are under 13 inches. Comparison of growth rates of three-year-old and older brown trout between the years 1978 and 1981 show the best growth rate occurred during the year with the coolest June-to-August water temperatures, and the poorer growth rate occurred in the summers with the warmest June-to-August water temperatures. In comparing the amount of hours the water was in the trout growth temperature range (39 to 67°F), the Norris section had 621 fewer hours than did Varney on an annual basis. Using water temperature data from the July 16th to August 16th period for the years 1972-1982 there was an average rise of 8.1°F in the average maximum and 7.9°F in the minimum water temperature from the Varney station to the Norris station. Predictions of changes in water temperature in the lower Madison River with removal of Ennis Reservoir show possible declines in the minimum water temperatures of 2.5 to 8.6°F at the Norris station, depending upon volume of flow and climatic conditions.

BACKGROUND

The Madison River is formed by the Gibbon and Firehole rivers in Yellowstone National Park and flows in a northerly direction to join the Jefferson and Gallatin rivers, forming the Missouri River at Three Forks. Two major reservoirs were built on the Madison River--Hebgen, which is located about 1.5 miles west of Yellowstone National Park, and Ennis, which is located seven miles north of the town of Ennis.

In 1900, Madison Dam at Ennis was constructed to provide electrical power for southwestern Montana. Since Ennis Reservoir is located in a naturally shallow basin with a small dam, the reservoir itself is very shallow with an average depth of less than nine feet. This shallow reservoir has led to a warming of the Madison River below the dam which endangers the "blue ribbon" trout fisheries in the last 35 miles of the river. There has been periodic fish kills in this area in the last 25 years which may have been caused by the warmer water. In 1961 a Montana Department of Fish and Game study showed Ennis Reservoir warmed the Madison River 10 to 15°F from what it was above the reservoir (Heaton, 1962).

OBJECTIVES AND DEGREE OF ATTAINMENT

1. To determine if higher water temperatures below Ennis Reservoir are having detrimental effects on wild trout populations through changes in age structure, size composition, species composition and growth rates. Data included in this report.

2. To obtain wild trout population estimates to include age structure, size composition, species composition and condition factors. Data included in this report.

3. To gather water temperature data above and below Ennis Reservoir from April through September. Data included in this report.

4. To determine if a correlation exists between water temperatures and growth rates from the April through September period. Data included in this report.

PROCEDURES

Electrofishing gear was used to sample fish populations in two sections of the Madison River (Norris and Varney). Electrofishing was carried out while floating through the section in a fiberglass boat. Population estimates were made using the Peterson-type mark-and-recapture method. Two or more "marking" and/or recapture trips were necessary where sample sizes were small and/or efficiencies were low. Usually, a 10- to 15-day period was allowed between marking and recapture trips. Scales were taken to determine age and growth rates. Actual mathematical computations were made by a computer programmed to use methods described by Vincent (1971 and 1974).

Three thermographs are set up on the Madison River as follows: (1) Varney Bridge, at USGS guaging station near Varney Bridge; (2) below Ennis Reservoir in USGS guaging station and operated by the USGS; and (3) at Norris Bridge (see Figure 1). All thermographs recorded water temperatures from Marh 1, 1980 through October 31, 1981.

FINDINGS

Wild brown trout population estimates were made during the spring (April) in both the Varney and Norris sections of the Madison River (Table 1). Wild rainbow trout population estimates were made during the spring period (April) for the Norris section, but only during the fall (September) for the Varney section due to spring (April to May) migration runs of spawning rainbow trout from Ennis Reservoir (Table 2). Comparison of spring estimates of brown trout numbers and biomass between the Varney and Norris sections show Norris to have a slightly higher biomass (29% in 1980 and 8% in 1981). Even when fall rainbow trout estimates for the Varney section are compared with spring rainbow estimates in the Norris section, the Norris rainbow biomass is 81% higher in 1980 and 69% higher in 1981. These trout estimates indicate the Norris section has a higher carrying capacity or productivity than the Varney section. Fraley (1978) found invertebrate numbers in the lower river (Norris) to be two or three times greater than above the reservoir (Varney). Much of the Norris wild trout biomass is concentrated in younger, smaller trout; 93.4% of the rainbow trout biomass was smaller than 13 inches in 1980 and 1981. This compares with 50% in 1980 and 57% in 1981 for the Varney section. In comparing total pounds of 13-inch and larger rainbow trout, the Varney section had 175 lbs/mile versus 122 lbs/mile for Norris during 1980, and 254 lbs/mile versus 82 lbs/mile in 1981. The percentage of brown trout exceeding 13 inches was comparable between the two sections, amounting to 57 to 61% of the total biomass estimates, but the Varney section had 14 to 27% fewer 13-inch and larger brown trout on a per-mile basis. Brown trout population estimates for the September period in the Varney section are shown in Table 3.

Brett, et al. (1967) found that young sockeye salmon experienced optimum growth rates at water temperature 59°F, but growth slowed as temperatures exceeded 59°F until growth ceased at 73°F. Brett (1956) also found that sockeye salmon kept at temperatures below 45°F showed poorer growth rates. Elliot (1975) found that brown trout fed maximum rations had optimum growth rates at 55.4°F with growth rates declining at cooler and warmer water temperatures and ceasing below 39°F and above 67°F. Hokanson, et al. (1977) found that the optimum water temperature for rainbow trout growth was 62.5°F where water temperatures were constant, but declined to 59°F where water temperatures fluctuated daily up to 6.8°F. They also found increased mortality of rainbow trout where daily water temperatures exceeded 66° to 69°F.

Using the amount of hours the water temperatures were between 39° and 67°F as the optimum growth potential for brown trout, April-to-October water temperature data for the years 1972-1975 and 1979 for the Norris station showed an average of 621 fewer hours for growth than the Varney section (Table 4).

Ninety-three percent of this difference lies in the months of July and August. During the months of April, May, September and October there are little differences in the water temperature regimes at Varney and Norris stations. The Norris station also had 500% more hours above 67°F than did the Varney station. During 1980 and 1981 the average water temperature for the months of July and August were 6.4°F to 10.2°F warmer at the Norris station than the upper Varney station (Table 5).

Summer growth rates of brown and rainbow trout in the Norris section were compared between the years 1978 through 1981 (Table 6). There appears to be some relationship between the average water temperature for the June-August period and growth of the brown and rainbow trout (Table 7). Three years old and older brown trout have the most noticeable relationship with the average June-August water temperatures with the best growth rate occurring in the coolest year (1978) followed by declining growth rates in the warmer years of 1979, 1980 and 1981. The years 1979 and 1980 had the warmest June-August period. Two year old brown trout appeared to grow slightly better in the warm years of 1979 and 1980. There was little visible variation in growth rates of two or three year old and older rainbow trout between any of the four years with three year old and older rainbow showing the poorest summer growth rates of all categories for both trout species.

The higher summer water temperatures in the Norris section appear to have the potential of reducing catch rates of the wild trout. A creel census on the Madison River (US Fish and Wildlife Service, 1954) noted that when maximum water temperatures at 8 a.m. reached 60 to 70°F the average catch rate of wild trout decreased. Elliot (1975) stated that brown trout were reluctant to feed when water temperatures exceeded 70 to 71°F. The Norris section had an average of 446 hours exceeding 70°F for the 1972-1979 period with most of these hours occurring during the prime angling hours of 10 a.m. and 7 p.m., which is the warmest period of the day (Table 8). The Varney section had only an average of 15 hours annually above the 70°F temperature. Vincent, et al. (1980) found that 62% of the annual angling pressure on the Pine Butte section of the upper Madison River occurred during July and August. Most of the time during the summer months of July and August the Norris section is too warm for good trout fishing.

Water temperatures in the Madison River below Ennis Reservoir often reach levels near the lethal point for brown and rainbow trout. Lee, et al. (1980) found that where brown and rainbow trout were acclimated to 68°F water, the critical thermal maximum temperature was 85.7°F (±1.04°F) for brown trout and 84.8°F (±0.34°F) for rainbow trout. Since maximum temperatures in the Norris section often reach into the lower 80°'s F and maximums of 82°F were measured in 1972, 1973, 1979 and 1980, possible thermal trout kills are only 2.8 to 3.7°F away. Given the right combination of water flows and climatic conditions a wild trout kill could occur.

A comparison of water temperatures for the July 16th to August 15th period is shown for five thermograph stations on the Madison River for the 1972 to 1982 period (Table 9). Of the two stations above Ennis Reservoir, only the Varney station was operated for the entire period, with the Ennis Bridge station only during 1977. Of the three stations below Ennis Reservoir, only the Three Forks station is incomplete with data only available in 1976 and 1977. The

Ennis Powerhouse and Norris stations were operated for the entire period. Using the July 16th to August 15th, 1972-1982 water temperatures, the above reservoir station (Varney) had the coolest water temperatures with an average maximum of 66.4°F and a average minimum of 56.4°F compared to a 69.1°F average maximum and a 67.4°F average minimum at the Ennis Powerhouse station. The Norris station showed an additional 5.4°F rise in the maximum, but a 3.1°F drop in minimum from the Powerhouse. Mean temperature comparisons show that there was an average 7.9°F rise in water temperature from the Varney station to the Ennis Powerhouse station (immediately below Ennis Dam). Most of this warming occurred in the reservoir, but some warming does occur in the reach of river between the Varney station and the river's entrance into the reservoir. Data from the Ennis Bridge station (67% of this reach) shows about a 1.4°F rise in mean temperature for the July 16th to August 15th period. The degree of "warming" of the river from Varney Bridge to the Ennis Powerhouse varies fom year to year depending on water flow volume and climatic variations.

Water temperatures at the Varney station for the July 16th to August 15th period appear to have an inverse relationship with water flows (Table 10). It appears that the highest maximum, minimum and mean water temperatures occur in low flow years versus the lowest water temperatures occuring in the high flow years. This inverse relationship between volume of flow and water temperature is not apparent for the Ennis Powerhouse and Norris stations (Table 11). The highest mean and minimum water temperatures for the two stations below Ennis Reservoir actually occur in the high flow years.

Several attempts have been made to predict water temperature regimes below Ennis Dam assuming the Ennis Dam were to be removed or its thermal effect was removed by channeling water around the reservoir. Goodman (1982), using existing thermograph data from 1977, made these predictions for the Ennis Powerhouse, Norris and Three Forks stations for July 15th to August 15th (1977 period only): (1) Ennis Powerhouse--no change in the maximum, a 7.5°F decrease in the average minimum and a 3.75°F drop in the mean; (2) Norris--a 4.0°F drop in the average maximum, a 2.0°F drop in the average minimum, and a 2.0°F in the mean; and (3) Three Forks--no appreciable change from existing temperatures. Dooley, et al. (1981) also made some thermal predictions for the Madison River below Ennis Dam using the river temperature and travel time simulation model-Green. These predictions assumed Ennis Dam removed or the river to be channeled around the reseroir reducing reservoir thermal effect. Using the July 16th to August 15th period, predictions for the Norris station showed a 6.1°F drop in mean temperatures for 1977 and a 10.6°F drop in 1973. Table 12 summarizes an attempt to make water temperature predictions for the Norris station for years other than 1973 and 1977 for the July 16th to August 15th period. The predictions for the years 1972-1982 were derived by using the known water temperature and flow measurements from the Varney and Norris stations coupled with the 1977 water temperature predictions for the Norris station. The annual July 16th to August 15th water temperature prediction assumed that the average warming of the minimum temperature would not exceed 2.5°F, which occurred during 1977 when river flow levels were low and air temperatures were slightly above average. If this assumption is correct, there could be up to 8.6°F cooling of the Norris station's minimum water temperatures during the hottest period of the summer. The greatest cooling from existing water temperatures appears to be in medium or high flow years.

The degree of heating or cooling of the Madison River between Ennis Dam and the Norris station varies considerably from year-to-year depending on the volume of flow and the annual variations in climatic conditions. The degree of heating or cooling is defined as the change in water temperature from the Ennis powerhouse station to the Norris station. Mean water temperatures were used for the Ennis powerhouse figures, while either mean maximum (heating) or mean minimums (cooling) were used for the Norris figures. During high and medium flow years (July 16th to August 15th), the river warms 4.4°F to 6.7°F versus low flow years where the river warms 7.8°F (Table 13). The degree of cooling varied from 3.0°F to 4.7°F. Thermograph records from the Madison River show the daily warming period ranges from six to eight hours and the cooling period ranges from 16 to 18 hours. During lower flow years the average flow time from Ennis Dam to the Norris Bridge was estimated to be about six hours. A similar six-hour flow time was estimated for the Varney Bridge-Ennis Bridge reach in 1977. Comparing the Varney Bridge-Ennis Bridge and Ennis Dam-Norris Bridge reaches for the July 16th to August 15, 1977 period, the latter reach had a 40% lower daily heat rise. This may indicate that if the thermal affects of Ennis Reservoir were removed from the lower Madison River there may be a smaller diurnal fluctuation in the water temperature at the mouth of the Beartrap Canyon (Norris) than found above the reservoir at Varney or downstream at Three Forks. This lower rate of warming between Ennis Dam and the Norris Bridge is probably related to the narrow 11 mile north-south Beartrap Canyon which limits solar heating of the river. Other rivers in western Montana flowing through narrow north-south oriented canyons such as Beartrap show a depressed diurnal temperature fluctuation (Table 14). The Big Hole River has two adjacent north-south canyons (Divide; Maiden Rock) approximately 11 miles in total length with thermograph stations above (Wise River) and below (Melrose and Twin Bridges) the canyon. Using the July 16th to August 15th period, the diurnal fluctuation were 45% lower in 1980 and 39% lower in 1981 at the canyon mouth (Melrose) than above the canyon (Wise River). This happened due to the lowering of the maximum temperature coupled with a rise in the minimum water temperature. The greatest variations in the diurnal water temperature fluctuation occurred during the low flow, high air temperature months of July and August (Table 15).

Since there is a potential to decrease present maximum and minimum water temperatures in the Madison River from Ennis Dam to the Norris Bridge area, there are three main benefits to the wild trout fisheries in this zone: (1) improved growth rates for the June-to-August period; (2) an improved catchability of wild trout during the summer months; and (3) a wider margin of safety from possible fish kills due to lethal high temperatures.

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Waters referred to: Madison River 13-3440-01
Ennis Reservoir

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Brown trout
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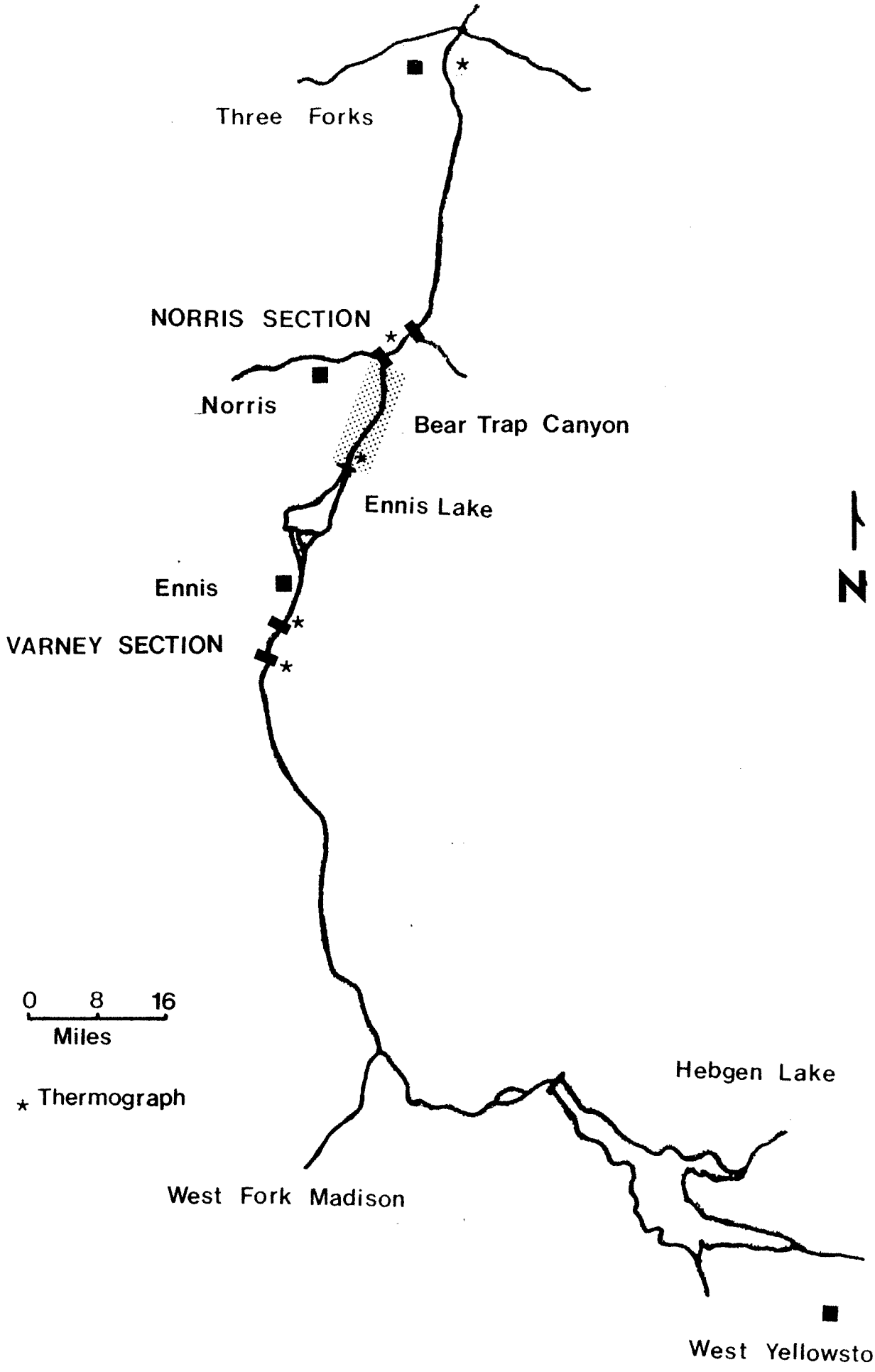

FIGURE 1. Map of the Madison River showing study sections and thermograph stations.

Table 1. Comparison of wild brown trout population and mortality rate estimates for April 1980 and 1981 in the Norris and Varney study sections (80% confidence levels shown in parentheses).

Age Group	April 1980	Brown Trout Age Group	April 1981	Mortality Rate (%)
	-- NORRIS SECTION (4.0 MILES) --			
I	--[1]	II	2 661	--
II	2 051	III	1 448	29
III	2 321	IV	953	59
IV	1 663	V	495	70
V+	576	VI+	202	65
Total No.	6 611 (±1078)		5 759 (±1190)	53[2]
Total Lbs.	5 131 (± 958)		3 589 (± 589)	
	-- VARNEY SECTION (4.2 MILES) --			
I	--[1]	II	2 376	--
II	3 687	III	1 939	49
III	1 150	IV	709	38
IV	1 075	V	487	55
V+	791	VI+	198	75
Total No.	6 703 (±927)		5 709 (±588)	50[2]
Total Lbs.	3 810 (±414)		3 465 (±356)	

[1] No estimates made for yearling trout.

[2] Total mortality includes all II year old and older trout for 1980, and III year old and older trout for 1981.

Table 2. Wild rainbow trout population estimates for the Varney and Norris study sections, 1980 and 1981 (Varney rainbow estimates made in September and Norris estimates made in April; 80% confidence intervals shown in parentheses).

Age Group	1980	Age Group	1981	Mortality Rate (%)
	-- NORRIS SECTION (APRIL) --			
I	--[1]	II	7 233	--
II	13 409	III	7 368	45
III	5 003	IV	2 373	53
IV+	1 413	V+	339	76
Total No.	19 825 (±2 897)		17 313 (±2 366)	49[2]
Total Lbs.	7 348 (± 942)		7 555 (±1 031)	
	-- VARNEY SECTION (SEPTEMBER) --			
0	--[3]	I	4 340	--
I	1 710	II	1 020	40
II	518	III	526	--
III	650	IV	530	18
IV+	414	V+	348	16
Total No.	3 292 (±658)		6 764 (±1048)	26[4]
Total Lbs.	1 467 (±314)		2 484 (±384)	

[1] No estimate made for yearling rainbow trout in Norris section.

[2] Total mortality for II+ trout in 1980 to III+ trout in 1981.

[3] No estimate made for young-of-the-year trout in the Varney section.

[4] Total mortality for yearling and older trout in 1980 to II+ trout in 1981.

Table 3. Wild brown trout population estimates for the Varney section during September 1980 and 1981 (80% confidence intervals shown in parentheses).

Age Group	September 1980	Age Group	September 1981	Mortality Rate (%)
0	--	I	4 870	--
I	3 197	II	2 169	32
II	2 172	III	1 490	31
III	949	IV	724	24
IV	717	V	559	22
V+	724	VI+	335	54
Total No.	7 759 (±798)		10 147 (±848)	32[2]
Total Lbs.	4 705 (±556)		6 186 (±610)	

[1] No young-of-the-year population estimates made.

[2] Total mortality rates include yearling and older trout for 1980 and II+ trout for 1981.

Table 4. Comparison of water temperatures between the Varney and Norris stations on the Madison River during the April 1st through October 31st period for the years 1972-1975, 1977 and 1979.

Numbers are average number of hours between 39-67°F (entire range acceptable for brown trout growth); 42-64°F (range where growth potential exceeds 25% of optimum); and 67°F+ (temperatures above which no growth potential exists).

	TOTAL HOURS					
	39-67°F		42-64°F		67°F+	
Month	Varney	Norris	Varney	Norris	Varney	Norris
April	479	538	267	360	0	0
May	723	736	632	705	0	2
June	714	647	691	559	10	73
July	671	357	554	171	73	387
August	703	439	599	213	41	305
September	720	684	711	626	0	36
October	726	714	687	688	0	0
TOTAL	4 736	4 115	4 141	3 322	134	803

Table 5. Comparison of the 1980 and 1981 average monthly water temperatures for the March 1st through October 31st period at the Varney, Ennis Powerhouse and Norris thermograph stations (degrees in Farenheit).

Month	Varney		Ennis Powerhouse		Norris	
	1980	1981	1980	1981	1980	1981
March	37.1	39.7[1]	37.0	40.5	39.4	41.8
April	44.2	44.1	44.6	45.5	48.8	47.3
May	49.1	48.1	54.9	52.5	57.8	53.7
June	53.6	52.8	59.2	57.4	62.4	58.9
July	60.0	61.4	66.5	67.4	70.2	69.3
August	59.1	62.4	64.4	67.6	67.0	68.8
September	55.7	58.6[2]	57.0	59.5	59.7	60.6
October	49.1	46.2	48.9	44.4	49.7	45.4

[1] No data for March 1-3.
[2] No data for September 23-30.

Table 6. Comparison of growth rates (length and weight) for brown and rainbow trout for the Norris study section, 1978 through 1981 (growth is shown in inches or pounds per day for the summer period; period covered shown in parentheses).

Age Groups	AVERAGE GROWTH (3/22 - 8/31) 1978	(4/4 - 10/15) 1979	(4/3 - 9/3) 1980	(4/17 - 10/7) 1981
		BROWN TROUT--LENGTH		
II	.009	.013	.013	.013
III+	.011	.004	.005	.009
		BROWN TROUT--WEIGHT		
II	.0012	.0017	.0019	.0011
III+	.0035	.0016	.0017	.0032
		RAINBOW TROUT--LENGTH		
II	.007	.006	.008	.007
III+	.004	.002	.004	.003
		RAINBOW TROUT--WEIGHT		
II	.0007	.0009	.0008	.0006
III+	.0007	.0007[1]	.0006	.0006

[1] Includes only three year old trout.

Table 7. Comparison of average monthly water temperatures for March 1st through October 31st for 1978-1981 at the Norris station (degrees in Farenheit).

Month	AVERAGE MONTHLY TEMPERATURE 1978	1979	1980	1981
March	38.8	36.8	39.4	41.8
April	47.5	42.3	48.8	47.3
May	51.9	53.9	57.6	53.7
June	60.7	61.5	62.4	58.9
July	66.8	69.0	70.2	69.3
August	64.0	69.2	67.0	68.8
September	59.6	63.7	59.7	60.6
October	46.6	52.2	49.7	45.4
Avg. June-August:	63.9	66.6	66.5	65.7

Table 8. Comparison of water temperatures over 70°F between the Varney, Ennis Powerhouse and Norris stations for the April 1st through October 31st period for 1972-75, 1977 and 1979 (numbers shown in total hours).

Month	TOTAL HOURS Varney	Ennis Powerhouse[1]	Norris
April	0	0	0
May	0	0	0
June	0	24	61
July	12	147	200
August	3	101	177
September	0	0	8
October	0	0	0
TOTAL	15	272	446

[1] 1979 data not included.

Table 9. Comparison of water temperatures measured at five thermograph stations on the Madison River for years 1972-1982 for the period July 16th through August 15th (temperatures shown in degrees Farenheit; station locations in river miles from mouth shown in parentheses).

	Varney Bridge (59.7)	Ennis Bridge[1] (50.6)	Ennis PH (38.9)	Norris Bridge (28.0)	Three Forks[2] (3.0)
		1972			
Av. Max.	66.3	--	66.5	71.8	--
Av. Min.	55.8	--	64.5	63.2	--
Mean	60.9	--	65.5	67.5	--
		1973			
Av. Max.	67.1	--	70.5	74.9	--
Av. Min.	56.2	--	68.5	66.0	--
Mean	61.7	--	69.5	70.5	--
		1974			
Av. Max.	65.9	--	71.1	74.0	--
Av. Min.	55.5	--	69.6	65.3	--
Mean	61.8	--	70.4	69.7	--
		1975			
Av. Max.	66.5	--	70.9	75.5	--
Av. Min.	55.6	--	69.0	64.0	--
Mean	62.2	--	70.0	69.8	--
		1976			
Av. Max.	65.7	--	67.6	72.9	72.6
Av. Min.	55.6	--	65.6	64.1	62.6
Mean	60.7	--	66.6	68.5	67.6
		1977			
Av. Max.	68.1	69.3	69.3	75.7	74.7
Av. Min.	57.7	59.4	68.2	62.2	64.9
Mean	62.9	64.4	68.8	69.0	69.7
		1978			
Av. Max.	65.5	--	68.6	73.2	--
Av. Min.	55.9	--	66.5	63.8	--
Mean	60.7	--	67.6	68.5	--

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Table 9. Comparison of water temperatures measured at five thermograph stations on the Madison River for years 1972-1982 for the period July 16th through August 15th (temperatures shown in degrees Farenheit; station locations in river miles from mouth shown in parentheses) (concluded).

	Varney Bridge (59.7)	Ennis Bridge[1] (50.6)	Ennis PH (38.9)	Norris Bridge (28.0)	Three Forks[2] (3.0)
		1979			
Av. Max.	68.5	--	70.5	77.2	--
Av. Min.	58.2	--	69.1	65.3	--
Mean	63.3	--	69.8	71.3	--
		1980			
Av. Max.	66.8	--	68.4	76.5	--
Av. Min.	57.8	--	66.8	65.4	--
Mean	61.3	--	67.6	71.0	--
		1981			
Av. Max.	66.5	--	68.0	75.2	--
Av. Min.	57.6	--	66.6	62.6	--
Mean	62.1	--	67.3	68.9	--
		1982			
Av. Max.	63.3	--	69.0	72.4	--
Av. Min.	54.3	--	67.4	65.1	--
Mean	58.8	--	68.2	68.8	--

[1] Data only available for 1977.

[2] Data only available for 1976-1977.

[3] Data based on July 23rd to August 14th period.

Table 10. Comparison of average minimum and maximum water temperatures and mean water discharges at the Varney Bridge thermograph station for the July 16th through August 15th period, 1972 through 1982.

Year	Flow (cfs)[1]	Avg. Maximum Water Temperature (°F)	Avg. Minimum Water Temperature (°F)	Avg. Air Temperature At Ennis Powerhouse (°F)
		Low Flow Years		
1977	1147	68.1	57.7	69.7
1979	1117	68.5	58.2	70.4
1980	1345	66.8	57.8	69.1
1981	1231	66.5	57.6	69.3
Avg.	1209	67.5	57.8	69.6
		Medium Flow Years		
1972	1694	66.3	55.8	68.3
1973	1651	67.1	56.2	69.8
1976	1752	65.7	55.6	67.9
1978	1579	65.5	55.9	68.8
Avg.	1669	66.2	55.9	68.7
		High Flow Years		
1974	1818	65.9	55.5	69.9
1975	2001	66.5	55.6	67.9
1982	2163	63.3	54.3	71.2
Avg.	1994	65.2	55.1	69.7

[1] Madison River flows measured at USGS guaging station near Ennis Powerhouse (McAllister, Montana).

Table 11. Comparison of average minimum and mean water temperatures versus water discharges for the Varney, Ennis Powerhouse and Norris thermograph stations for the July 16th through August 15th period, 1972 through 1982 (mean water discharge and air temperature shown in parentheses).

Average Water Temperature (°F)			Average Minimum Water Temperature (°F)		
Varney	Ennis PH	Norris	Varney	Ennis PH	Norris
		Low Flow Years (1209 cfs - 69.6°F)[1]			
62.7	68.4	70.0	57.8	67.7	63.9
		Medium Flow Years (1669 cfs - 68.7°F)			
61.1	67.3	68.8	55.9	66.3	64.2
		High Flow Years (1994 cfs - 69.7°F)			
60.2	69.5	69.4	55.1	68.7	64.8

[1] Madison River flows measured at USGS guaging station near Ennis Powerhouse (McAllister, Montana) and mean air temperatures taken at Ennis Powerhouse.

Table 12. Predictions of Madison River water temperatures below Ennis Reservoir at the Norris Bridge if dam were removed or river channeled around the reservoir (temperatures shown are average minimums for the July 15th through August 15th period in degrees Farenheit).

Year	Varney (Actual)	Norris (Actual)	Varney +2.5°F Norris Prediction	Degrees Cooling (°F)
		Low Flow Years (1209 cfs)		
1977	57.7	62.2	60.2	2.0
1979	58.2	65.3	60.7	4.6
1980	57.8	65.4	60.3	5.1
1981	57.6	62.6	60.1	2.5
		Medium Flow Years (1669 cfs)		
1972	55.8	63.2	58.3	4.9
1973	56.2	66.0	58.7	7.3
1976	55.6	64.1	58.1	6.0
1978	55.9	63.8	58.4	5.4
		High Flow Years (1994 cfs)		
1974	55.5	65.3	58.0	7.3
1975	55.6	64.0	58.1	5.9
1982	54.3	65.1	56.5	8.6

Table 13. Comparison of changes in water temperature from the Ennis Powerhouse station to the Norris Bridge station between low, medium and high flow years for the July 16th through August 15th period.

Only mean water temperatures were used at the Ennis Powerhouse station versus average maximum or minimum temperatures for the Norris station. Temperature shown in °F.

	Low Flow Years (1209 cfs) 1977, 79, 80 & 81	Medium Flow Years (1669 cfs) 1972, 73, 76 & 78	High Flow Years (1994 cfs) 1974, 75 & 82
Degrees "Warming"	+ 7.8	+ 6.7	+ 4.4
Degrees "Cooling"	- 4.5	- 3.0	- 4.7

Table 14. Comparison of diurnal water temperatures above and/or below north-south canyons located on the Big Hole, Clark Fork and Gallatin rivers, July 16th through August 15th (temperatures shown in degrees Farenheit).

Location	Avg. Max. Temp (F)	Avg. Minimum Temp (F)	Mean Daily Water Temp Change (F)	Mean Flow for Period (cfs)
		GALLATIN RIVER (1975)[1]		
Canyon Mouth	57.3	50.2	7.1	1550
10 mi. below mouth	68.0	56.4	11.6	--[2]
		BIG HOLE RIVER (1980)[4]		
Wise River (above canyon)	69.3	57.7	11.6	511
11 mi. below canyon	67.5	59.8	7.7	810
39 mi. below canyon	71.1	62.3	8.8	533
		BIG HOLE RIVER (1981)[5]		
Wise River (above canyon)	71.0	56.3	14.7	405
11 mi. below canyon	67.5	58.6	8.9	659
39 mi. below canyon	72.2	61.7	10.5	487
		CLARK FORK RIVER (1980)[4]		
Deer Lodge (above canyon)	68.1	58.9	9.2	197
Clinton (10-15 mi. below canyon entrance)	69.7	62.7	7.0	618
At Canyon Mouth (near Missoula)	65.5[3]	62.3	3.2	2246
12 mi. behind canyon mouth (behind Mssla)	67.2	60.7	6.5	3296

(continued on next page)

Table 14. Comparison of diurnal water temperatures above and/or below north-south canyons located on the Big Hole, Clark Fork and Gallatin rivers, July 16th through August 15th (temperatures shown in degrees Farenheit) (concluded).

Location	Avg. Max. Temp (F)	Avg. Minimum Temp (F)	Mean Daily Water Temp Change (F)	Mean Flow for Period (cfs)
		CLARK FORK RIVER (1981)[5]		
Deerlodge (above canyon)	68.3	58.8	9.5	154
Clinton (10-15 mi. below canyon entrance)	70.1	63.1	7.0	515
At canyon mouth (near Missoula)	66.9	62.1	4.7	2103
12 mi. below canyon mouth (below Missoula)	65.9	60.2	5.7	3154

[1] Data available only for July 25th through August 15th period.

[2] No flow data available.

[3] Data available only for July 15th through August 12th period.

[4] USGS, 1980.

[5] USGS, 1981.

Table 15. Comparison of monthly mean diurnal water temperatures with river flow (cfs) for three stations on the Big Hole River, one above and two below a north-south canyon area (Divide-Maiden Rock).

Month	Mean Diurnal Water Temperature Change (F)			Mean Discharge (cfs)		
	1980					
	Wise River	Melrose	Twin Bridges	Wise River	Melrose	Twin Bridges
May	4.9	3.5	4.7	3 073	4 414	4 200
June	5.8	4.3	6.2	3 489	5 483	5 129
July	12.7	7.8	8.7	798	1 251	1 028
August	15.5	8.3	10.5	214	372	202
September	14.4	6.4	13.8	136	251	107
	1981					
May	5.7	3.0[1]	5.3	3 352	4 500	4 790
June	6.8	4.6[2]	5.2	3 080	4 463	4 736
July	8.7[3]	6.3	7.5	1 088	1 628	1 348
August[4]	13.5	8.2	10.0	386	584	348

[1] Only 23 days of temperature data available.

[2] Only 29 days of temperature data available.

[3] Only 28 days of water temperature data available.

[4] Data available only for August 1-11, 1981.