MONTANA DEPARTMENT OF FISH AND GAME
FISHERIES DIVISION
JOB PROGRESS REPORT

STATE: Montana TITLE: Southwestern Montana Fisheries Investigations.

PROJECT NO.: F-9-R-26 TITLE: Madison River Temperature Study

JOB NO.: II-a

PERIOD COVERED: March 16, 1977 through March 15, 1978

ABSTRACT

Three thermographs were placed on the Madison River aboue and below Ennis Reservoir to study the warming effect of the lake on the lower Madison River trout fisheries. A depth contour map of the reservoir shows its average depth of 9.2 feet. Less than 1% of the reservoir volume exists below the 16 foot depth. A statistical t-test showed a significant warming of the Madison River between the area above the reservoir thermal station (Varney) and the two stations below the reservoir (Ennis Powerhouse and Norris), but no significant difference between the Ennis Powerhouse and Norris stations. A multiple linear regression test shows air temperature explains 80-91% of the variation in weekly water temperatures at all three thermal stations. A t-test shows Ennis Reservoir to be more sensative to air temperatures in 1972-77 than during 1960-66, as at low air temperatures the water is cooler and warmer during high (85°F) air temperatures. Salmonid growth data shows mountain whitefish, rainbow trout and brown trout from above Ennis Reservoir (Varney) are 46.6%, 33.9% and 35.9% heavier at four-years-old than they are below the reservoir (Norris), which is probably due to the higher growth inhibiting water temperatures.

BACKGROUND

In 1900, Madison Dam at Ennis was constructed to provide electrical power for southwestern Montana. Ennis Reservoir is located in a shallow basin, which over the last 75 years, has slowly become more shallow due to sedimentation from upstream sources. This shallowing of Ennis 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 that Ennis Reservoir warmed the Madison River 10-15°F from what it was above the reservoir (Heaton, 1912).

OBJECTIVES AND DEGREE OF ATTAINMENT

1. To obtain fish population data on two sections of the Madison River (Varney and Norris). Data included in this report.

2. To obtain growth rates on rainbow and brown trout for the April through September period from a section above (Varney) and below (Norris) Ennis Reservoir. Data included in this report.

3. To obtain water temperature data above and below Ennis Reservoir in an attempt to correlate water temperature with salmonid growth. Date included in this report.

PROCEDURES

Electrofishing gear was used to sample fish polulations in two sections of the Madison River (Norris and Varney). Electrofishing was carried out while floating through the section in a fiberglas boat. Population estimates were made by 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 10-15 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 computor programmed to use methods described by Vincent (1971a and 1974).

Three thermograph stations were set up on the Madison River as follows: (1) Varney bridge - at U.S.G.S. gaging station near Varney bridge; (2) below Ennis Reservoir - at U.S.G.S. gaging station and (3) at Norris bridge. All thermographs recorded water temperatures from March 1, 1977 through October 31, 1977.

The depth contour map of Ennis Reservoir was completed using a boat, depth rod and two land based transects used to locate the depth points. Two baselines were established along the north and east shores. Using the transects placed at each end of the known baselines, the various depths could be located on a map of Ennis Reservoir by means of triangulation.

Surface areas at various depth were calculated by a Bendix digitized automatic planimeter at Montana State University. All statisical tests were at the 95% level.

FINDINGS

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 (Figure 1). Two major reservoirs are built on the Madison River: (1) Hebgen which is located about 1.5 miles north of Yellowstone National Park and (2) Ennis which is located about 7 miles north of the town of Ennis.

The depth contour map of Ennis Reservoir was finished during August, 1977 when the water level elevation was 4831 feet; 0.6 feet below a full reservoir. A total of 125 depth measurements were taken during August, 1977 in addition to the 256 taken during 1976. These 381 depth points were used to plot a depth contour map of Ennis Reservoir (Figure 2). The depth measurements show Ennis Reservoir to have a large surface area in relation to its total volume. The maximum depth is near the dam site at 35 feet with the average depth being only 9.2 feet at reservoir level of 4831 feet above sea level. The reservoir has no measurable thermocline because of its shallow nature, as the thermoclines in this area of Montana usually are below 30 feet. Since less than 1% of the reservoir is deeper than 16 feet, a thermocline would not be expected (Table 1). This wide-shallow shape tends to create a "heat trap" during the warm summer months (May-September) warming the Madison River below the reservoir. The Madison River below Ennis Reservoir averages 7.5°F higher than the river above

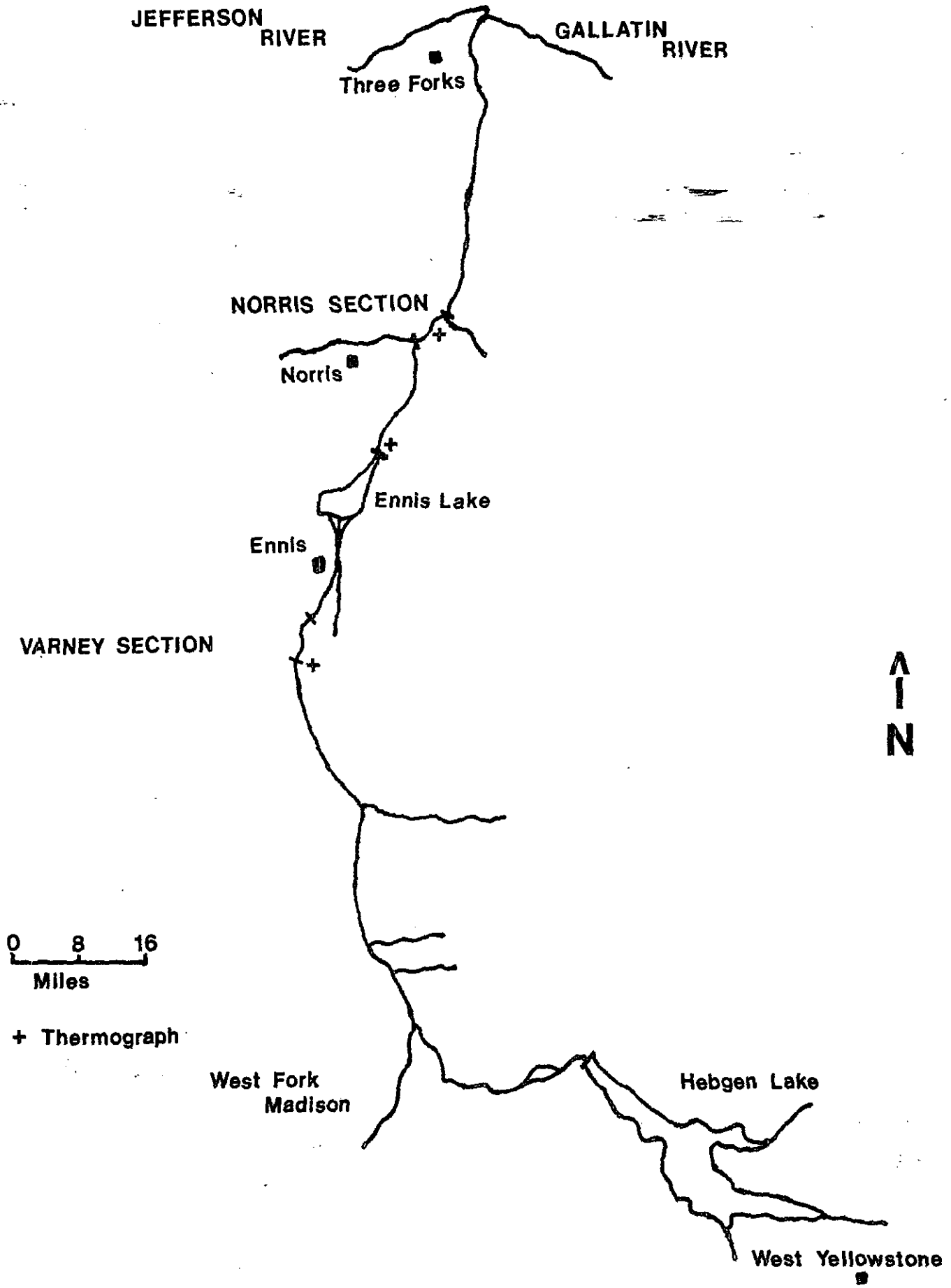

FIGURE 1. Map of the Madison River showing study sections and thermograph stations.

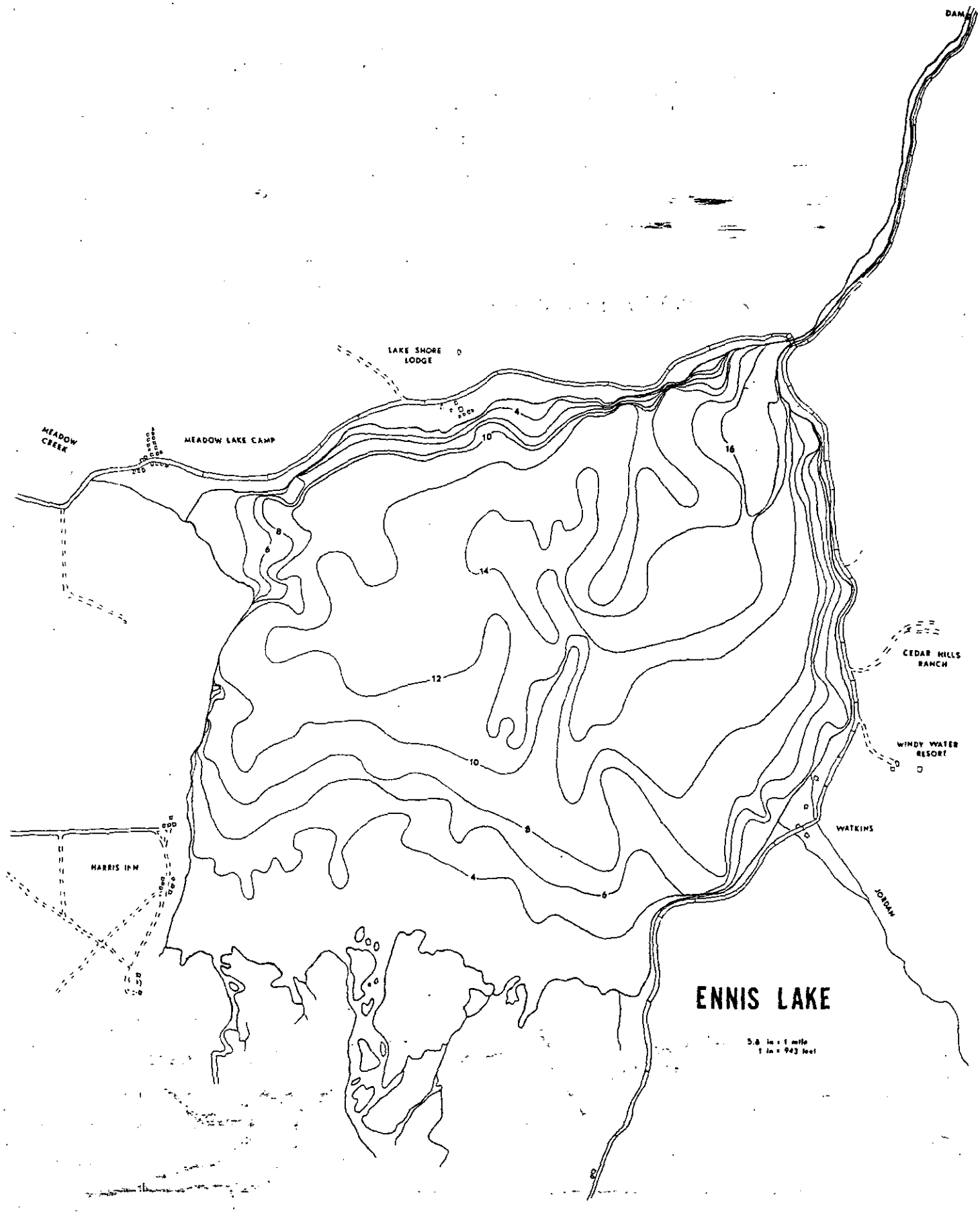

FIGURE 2. Depth contour map of Ennis Reservoir.

TABLE 1. Surface acreage and reservoir volume below various depth contour levels on Ennis Reservoir, August, 1977.

Contour Depth (ft.)	Surface Acres	Volume 1/ (Acre - ft.)
0	3781	34,675
4	3151	20,811
6	2780	14,880
8	2461	9,639
10	1990	5,188
12	1171	2,077
14	359	497
16	69	69

1/ Approximately 1000 acre-feet of water downstream from county bridge not included in figures.

the reservoir (Table 2). Maximum temperatures often differ as much as 12°F. A t-test comparing monthly mean temperatures (1972-77 average) above and below the reservoir shows a significant difference between above (Varney) and below (Ennis Powerhouse or Norris) the reservoir for the months from May through October ($P < .01$), but no significant difference for March and April ($P > 0.5$). For the same period March through October no statistical difference was found between the two stations below Ennis Reservoir-Norris and Ennis Powerhouse ($P > .05$).

TABLE 2. Comparison of average monthly temperatures for the 1972-77 period for Varney (above Ennis Reservoir), Ennis Powerhouse (0.5 mile below Ennis Dam) and Norris (9.0 miles below Ennis Reservoir) thermograph stations.

Month	Varney	Ennis Powerhouse	Norris
March	36.6	38.1	37.4
April	40.6	42.8	42.3
May	46.3	52.6	51.6
June	51.9	59.3	59.1
July	59.8	67.0	66.7
August	59.9	67.4	66.5
September	54.4	57.8	57.4
October 1/	47.2	48.0	48.0

1/ Based on years 1972-1976.

Air temperature was the major factor controlling water temperatures at all three stations, as shown by a linear multiple regression test comparing air temperature versus water temperature, plus water temperature versus discharge rate (Table 3). The test showed air temperatures explained 80-91% of the variation in weekly water temperatures and discharge a negative 10-18%. Since air temperatures accounted for most of the variation in weekly mean water temperatures, a single tailed t-test was run on the Ennis Powerhouse thermal station data to determine if similar air temperatures created similar water temperature for both the 1960-66 and 1972-77 periods (Table 4). The test showed that under

TABLE 3. Linear regression correlation of water temperature vs. air temperature, and water temperature vs. water discharge rates for the Norris, Ennis Powerhouse and Varney thermograph gages.

Station	Water temperature vs. Air temperatures 1/	Water temperature vs. Water discharge rate
	Correlation 2/	Correlation 2/
Norris	0.9558	-0.4215
Ennis Powerhouse	0.9149	-0.3127
Varney	0.8942	-0.4162

1/ Air temperatures from Ennis Powerhouse area (Anonymous, 1960-1977.)
2/ Significant at PC 0.01.

TABLE 4. Comparison of average water temperatures at the Ennis Powerhouse thermal gage between 1960-66 and 1972-77 at various air temperatures.

Air Temperature (F)	Average Water Temperatures (F) 1960-66	1970-75	t 1/ Value	Approx. P Value
35	39.9	35.8	-1.95	0.03
45	46.4	43.6	-1.72	0.06
55	52.9	51.5	-1.12	0.20
65	59.4	59.3	-0.10	>0.5
75	65.9	67.2	1.20	0.22
85	72.5	75.1	1.89	0.04

1/ Single tailed t-test.

similar air temperatures the reservoir water was significantly cooler in 1972-77 for the 35-45°F air temperatures and significantly warmer for high air temperaturees (85°F). This means that the reservoir water has become more sensitive to air temperatures from 1972-77 than during the early 1960s. This could come from depth loss through sedimentation with little or no surface area loss. As the reservoir becomes more shallow due to sediment deposition, the possibility of further warming of reservoir water exists.

Brettetal, 1969, showed that water temperatures did effect growth rates of young sockeye salmon, as temperatures progressed past the optimum (59°F) growth rates slowed until 73°F when growth ceased. This relationship of temperature versus growth existed regardless of the quanity of food available. Monthly temperatures from the Norris section (below Ennis Reservoir) showed that for the 1972-77 period the monthly mean temperature for July and August was 66.6°F (7.6°F above the optimum growth temperature), while for the same period in the Varney section (above Ennis Reservoir) the mean July-August temperature was 59.8°F. The high temperature for the Norris area was 82°F versus 72°F for Varney. These high water temperatures in the Madison River below Ennis Reservoir resulted in slower growth of salmonids, as the average length and weight of all age groups of mountain whitefish, two-year-old and older rainbow trout and three-year-old

and older brown trout were smaller than similar ages above the reservoir (Table 5).

TABLE 5. Comparison of the average length and weights of various age groups of brown trout, rainbow trout and mountain whitefish between the Varney and Norris study sections on the Madison River. Data from September, 1977 population samples.

Age Group	Species					
	Brown Trout		Rainbow Trout		Mtn. Whitefish	
	Norris	Varney	Norris	Varney	Norris	Varney
I	8.8	8.0	8.2	7.9	8.5	8.6
II	12.0	11.7	11.0	11.4	10.3	11.4
III	14.0	15.1	12.3	14.4	12.1	12.6
IV	15.7	17.3	13.9	15.9	12.8	13.9
V	17.2	18.8	15.6	17.1	13.5	15.1
	Average weight (lbs.)					
I	0.28	0.22	0.24	0.21	0.25	0.27
II	0.70	0.67	0.54	0.60	0.40	0.60
III	1.09	1.46	0.77	1.18	0.66	0.85
IV	1.56	2.12	1.15	1.54	0.73	1.07
V	2.05	2.59	1.61	1.84	0.83	1.33

The differences became more pronounced in the older age groups for example in comparing age group IV above and below Ennis dam: (1) mountain whitefish - 8.6% longer and 46.6% heavier; (2) rainbow trout - 14.4% longer and 33.9% heavier; and (3) brown trout - 10.2% longer and 35.9% heavier.

Fall 1977, wild brown and rainbow trout population estimates for both the Varney and Norris sections shows more yearling brown and rainbow trout per mile in the Norris section (3354) than the Varney secton (2635) and total pounds per mile was 1775 (Norris) versus 1501 - Varney (Table 6). Comparing two-year-old and older trout Norris had 1195/mile vs 1182 /mile for Varney.

TABLE 6. Comparison of wild trout populations above (Varney) and below (Norris) Ennis Reservoir on the Madison River for 1977. Confidence intervals at the 80% level are shown in parenthesis.

Age Groups	Sections			
	Norris (4 miles		Varney 1/ (5 miles)	
	Brown Trout	Rainbow Trout	Brown Trout	Rainbow Trout
	April, 1977			
I	2/	2/	-	-
II	1957	3469	-	-
III	716	1350	-	-
IV and older	1752	702	-	-
Total Number	4425 (±894)	5521 (±1447)	-	-
Total Wt. (lbs.)	4025 (±928)	2485 (±491)	-	-
	September, 1977			
I	2909	5726	4332	2920
II	1011	1266	2900	923
III	562	563	1033	279
IV and older	1086	293	569	220
Total Number	5568 (±994)	7848 (±1432)	8834 (±996)	4342 (±932)
Total Wt. (lbs.)	4199 (±1048)	2901 (±541)	5642 (±732)	1863 (±304)

1/ No. April population estimate made for Varney Section.

2/ No. April yearling population estimate made.

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Waters Referred to:

Madison River	13-3440-01
Ennis Reservoir	13-7560-05