Some limnological effects of Tiber Reservoir on the Marias River
by Quentin J Stober

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:
Abstract Temperatures, turbidity, and plankton were measured in the river above the reservoir, in the reservoir proper, and in the river below during the summers of 1960 and 1961 to observe effects of the reservoir on the river below. Water temperatures below the reservoir were found to be influenced by the level and volume of release as well as by atmospheric conditions. Average daily water temperatures below the reservoir averaged 12° F cooler than those above in 1961. The reservoir had a marked effect on temperatures for at least 24 miles below the dam. The upper end of the reservoir which was most affected by the inflowing river had the highest average turbidity readings and lowest average transparency. Average turbidity immediately below the reservoir was 14.1 ppm less than above in 1960 and 10.3 ppm less in 1961. Runoff from a severe storm increased turbidity in the river below the dam to the maximum 465 ppm. Plankton productivity was found extremely low in the reservoir as well as in the river. Diatoms comprised over 90 and 85 per cent of the total phytoplankton population at each river station above and below the reservoir during 1960 and 1961, respectively. Cladobhora grew in very dense mats in the riffle areas in the first six miles of river below the dam. The plankton in the river below the reservoir was largely indigenous and not a contribution from the reservoir. Following high water and increased turbidity in 1961, the average total phytoplankton population was lower at all stations below the reservoir than in 1960.

SOME LIMNOLOGICAL EFFECTS OF TIBER RESERVOIR ON THE MARIAS RIVER

by

QUENTIN J. STOBER

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Fish and Wildlife Management

at

Montana State College

Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

Bozeman, Montana
March, 1962

The Author

I was born in Billings, Montana on March 25, 1938 and I attended public schools in Belt, Montana where I graduated from Belt Valley High School in June 1956. In September, 1956 I entered Washington State University and was in attendance during my freshman year. In 1957 I transferred to Montana State College and completed the requirements for the degree of Bachelor of Science in Fish and Wildlife Management by June, 1960. I was employed by the Montana Fish and Game Department for four summers as an assistant fisheries biologist. In October, 1960 I was accepted to the Graduate Division at Montana State College.

Table of Contents

Abstract

Temperatures, turbidity, and plankton were measured in the river above the reservoir, in the reservoir proper, and in the river below during the summers of 1960 and 1961 to observe effects of the reservoir on the river below. Water temperatures below the reservoir were found to be influenced by the level and volume of release as well as by atmospheric conditions. Average daily water temperatures below the reservoir averaged 12° F cooler than those above in 1961. The reservoir had a marked effect on temperatures for at least 24 miles below the dam. The upper end of the reservoir which was most affected by the inflowing river had the highest average turbidity readings and lowest average transparency. Average turbidity immediately below the reservoir was 14.1 ppm less than above in 1960 and 10.3 ppm less in 1961. Runoff from a severe storm increased turbidity in the river below the dam to the maximum 465 ppm. Plankton productivity was found extremely low in the reservoir as well as in the river. Diatoms comprised over 90 and 85 per cent of the total phytoplankton population at each river station above and below the reservoir during 1960 and 1961, respectively. Cladophora grew in very dense mats in the riffle areas in the first six miles of river below the dam. The plankton in the river below the reservoir was largely indigenous and not a contribution from the reservoir. Following high water and increased turbidity in 1961, the average total phytoplankton population was lower at all stations below the reservoir than in 1960.

Introduction

The present study was initiated to determine certain physical and biological effects of an impoundment on a river. Observations were made from June to September of both 1960 and 1961. Temperature, turbidity, and plankton were measured in the river above the reservoir, in the reservoir proper, and in the river below. The effects of large impoundments on the temperature of outflowing water have been reported on TVA mainstream reservoirs by Dendy and Stroud (1949), Pfitzer (1954), and Churchill (1956) and on Tenkiller Reservoir in Oklahoma by Finnell (1953). The action of large impoundments in reducing stream turbidity is well known. Descriptions are given by Ellis (1940) for Elephant Butte Reservoir, New Mexico, and for several other impoundments (1942). Turbidities, as measured by secchi disc readings, are reported on Lake Mead by Anderson and Pritchard (1951) and on Atwood Lake in Ohio by Wright (1954). The effects of impoundments on river plankton have received very little attention. Damann (1951) presented general information on the plankton of reservoirs across the Missouri River and its tributaries. Galstoff (1924) studied plankton above and below impoundments and in slow water areas of the upper Mississippi River, while Hartman and Himes (1961) analyzed the phytoplankton downstream from Pymatuning Reservoir in Pennsylvania. Brook and Rzóska (1954) studied the plankton in and below a reservoir on the White Nile River in Sudan.

<u>Description of Study Area</u>: Tiber Reservoir and the Marias River were selected for study because of their relatively small size and lack of

tributaries. These are located in north central Montana and are tributary to the Missouri River. Tiber dam is 196 feet high and was completed by the U. S. Bureau of Reclamation in 1956 for irrigation purposes, however, the resulting reservoir has been used only for flood control and recreation. Tiber Reservoir is the only impoundment on the Marias River. During the study period, constant water levels were maintained at elevation 2983 feet m.s.l. in 1960 and at 2984 feet m.s.l. in 1961, but during the intervening time the level of the reservoir was lowered about 10 feet to provide for storage of spring runoff. The approximate surface area was 15,000 acres. Some morphometric characteristics of Tiber Reservoir are given in Table 1.

Observations were made on 10 miles of the Marias River above the reservoir and on approximately 80 miles below the dam extending to the mouth of the Teton River. The river both above and below the reservoir is relatively sluggish. It had a gradient ranging from 2.8 to 3.4 feet per mile and an average width of about 200 feet. The river meanders through a flood plain and is flanked by steep eroding banks. Sagebrush, cottonwood, and willow are common adjacent to the stream channel. The only rooted vegetation found in the river channel was sparse growths of *Potamogeton pectinatus*. Some debris was present in the channel but nowhere did it obstruct the flow of the river.

Chemical analyses of these waters found the pH to range from 7.5 in the river above to 7.6 below the reservoir on August 2, 1960. Dissolved oxygen in the lower depths of the reservoir as well as in the outlet water

Table 1. Morphometric characteristics of Tiber Reservoir.

Water surface at	Elevation* (feet m.s.l.)	Area* (acres)	Capacity* (acre feet)	Max. length (miles)	Max. width (miles)	Max. depth (feet)	Shore-line** (miles)	Shore-line devel-opment
Maximum operating level	3012.5	22,180	1,337,000	25	4	182	91	4.37
Spillway crest	2980	14,400	741,000	23	4	150	75	4.48
Minimum operating level	2967	11,300	575,000	20	3	137	51	3.42
River outlet	2870	1,480	24,000	5	0.5	40		

* Tiber Reservoir Area — Capacity Curves, Drawing No. 84-604-193, U. S. Bureau of Reclamation, Missouri River Basin Project, Marias Division, Lower Marias Unit, Montana, 1951.

** From a Preliminary Evaluation Report on Fish and Wildlife Resources in Relation to the Water Development Plan for the Lower Marias Unit, Missouri River Basin Project, U. S. Department of Interior, Administrative Report, November, 1951.

immediately below the dam was never found to be lower than 7.8 ppm during July and August of both years. Total dissolved solids averaged 395 ppm 10 miles above the reservoir, 350 ppm in the reservoir, 429 ppm one mile below the reservoir, and 392 ppm 80 miles below. Total hardness was 300 ppm above the reservoir and 320 ppm immediately below. These data suggest Tiber Reservoir caused an increase in total dissolved solids in the river immediately below.

Acknowledgements: The writer extends thanks to those individuals and agencies that assisted in this investigation. Nels A. Thoreson of the Montana Fish and Game Department suggested the problem and gave advice during the study. Dr. C. J. D. Brown directed the study and assisted in the preparation of the manuscript. Dr. John C. Wright aided in the identification of plankton. Eugene B. Welch, James A. Posewitz, and William J. Hill aided in the field work. The U. S. Bureau of Reclamation supplied maps, flow data and other information. The Water Pollution Branch of the State Board of Health made the chemical water analysis. The Montana Fish and Game Department provided equipment and financial support under Federal Aid Projects F-5-R-10,11.

Temperatures

One station was established approximately 10 miles above the reservoir and eight stations below at approximate distances of 1, 5, 11, 24, 42, 48, 54, and 80 river miles (Fig. 1). Dickson Minicorder thermographs (seven-day type) were used at stations 1 and 5. In 1960 these were enclosed in heavy metal cases and external atmospheric temperatures in-

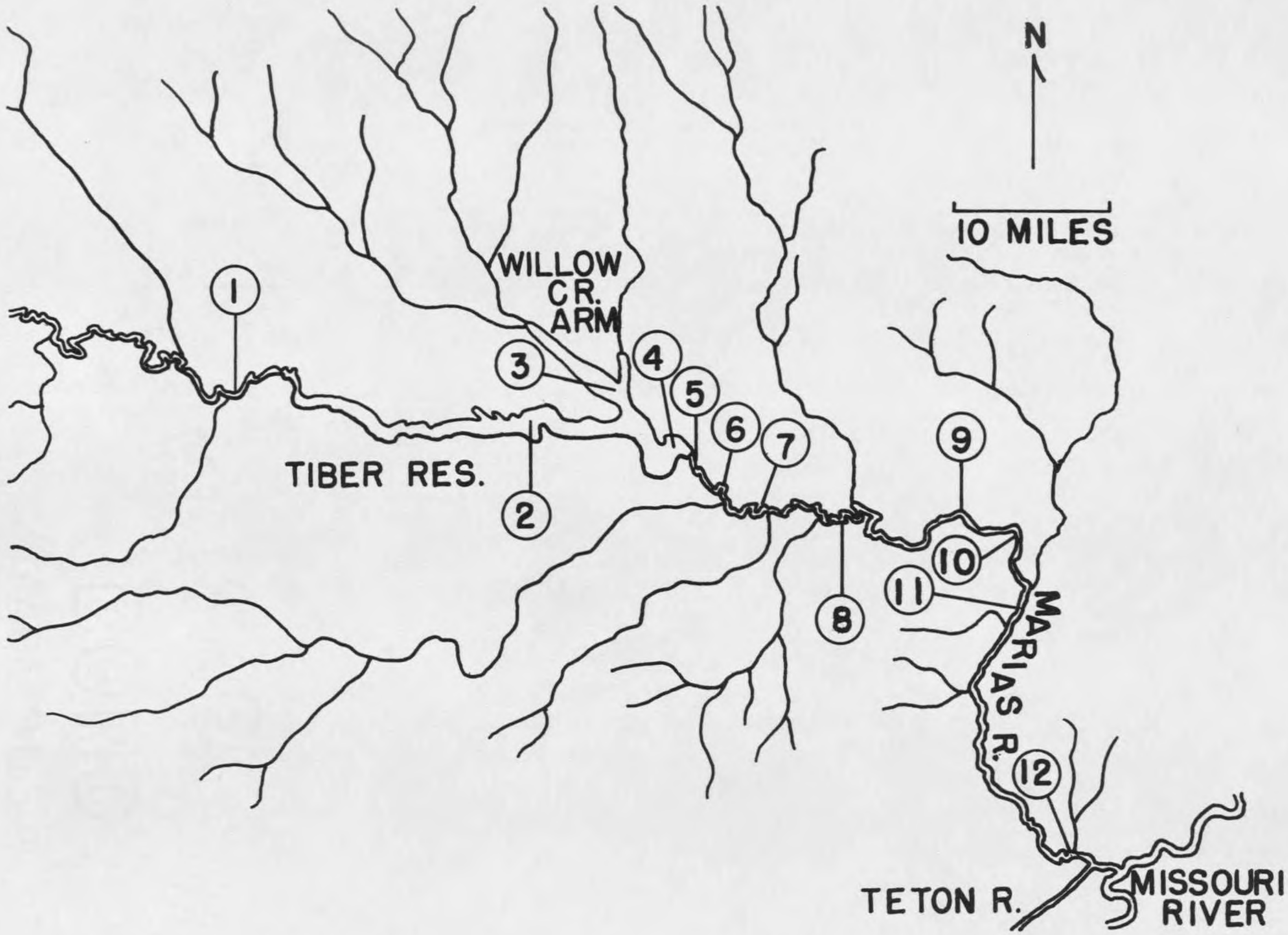

Fig. 1. Tiber Reservoir and Lower Marias River Drainage sampling stations.

fluenced the recording device so that water temperatures were inaccurate. Temperature data for these stations are excluded. However, during 1961 these thermographs were enclosed in light colored insulated wooden boxes and satisfactory results were obtained. Taylor thermographs were used in place of Minicorder thermographs during the latter part of the study in 1961.

Surface and vertical water temperatures were regularly taken at three stations on Tiber Reservoir (Fig. 1), in addition, they were also taken at 2.5 mile intervals from the head of the reservoir to the dam during 1961. Surface and air temperatures were secured with a pocket thermometer and vertical temperatures with an electrical resistance thermometer. The latter were taken at five-foot intervals except in the thermocline where they were measured at one-foot intervals. Samples were collected as follows: 1960 — July 8, August 12, 18, September 8; 1961 — June 14, July 11, August 2, 30, September 7, 19.

Temperatures were taken at the remaining stations below the dam with Taylor maximum-minimum thermometers mounted on wooden frames and bolted to steel posts that were driven into the river bed. They were placed approximately 18 inches below the surface of the water to allow for fluctuations in the river level. Maximum and minimum temperature data were secured for both 1960 and 1961 but there are fewer data for 1960 because extreme fluctuations in river flow made it difficult to maintain thermometers below the water surface. River water temperatures were taken semi-weekly or weekly. All temperatures are given in degrees Fahrenheit.

Above Reservoir: A continuous record of the water temperature was secured between June 5 and September 20, 1961. Fluctuations generally followed changes in air temperatures (Fig. 2). The maximum and minimum water temperatures for each month are as follows: June and July — 81°, 53°; August — 84°, 55°; September — 65°, 46°. The average maximum and minimum temperatures are given in Table 2.

Table 2. Maximum, minimum, and average maximum and minimum water temperatures taken in the Marias River during 1960-61.

	Stations								
	1	5	6	7	8	9	10	11	12
June 12 to September 20, 1960									
Maximum		63	71	70	78	84	83	82	86
Average maximum		61	67	66	71	78	73	72	77
Minimum		52	47	45	47	53	46	42	53
Average minimum		53	51	52	53	60	56	55	60
June 5 to September 20, 1961									
Maximum	84	76	76	80	79	84	84	87	86
Average maximum	71	60	66	72	70	74	75	77	76
Minimum	46	41	48	47	45	47	34	45	47
Average minimum	63	51	54	56	59	60	58	59	62

Reservoir: The maximum surface temperature of Tiber Reservoir was 70° (August) in 1960 and 74° (August) in 1961. Surface temperatures taken from the head of the reservoir to the dam ranged as follows: June 14, 60-72°; July 11, 67-71°; August 2, 71-73°; August 30, 70-74°; and September 19, 54-59°.

Thermal stratification existed on the first sampling date each year

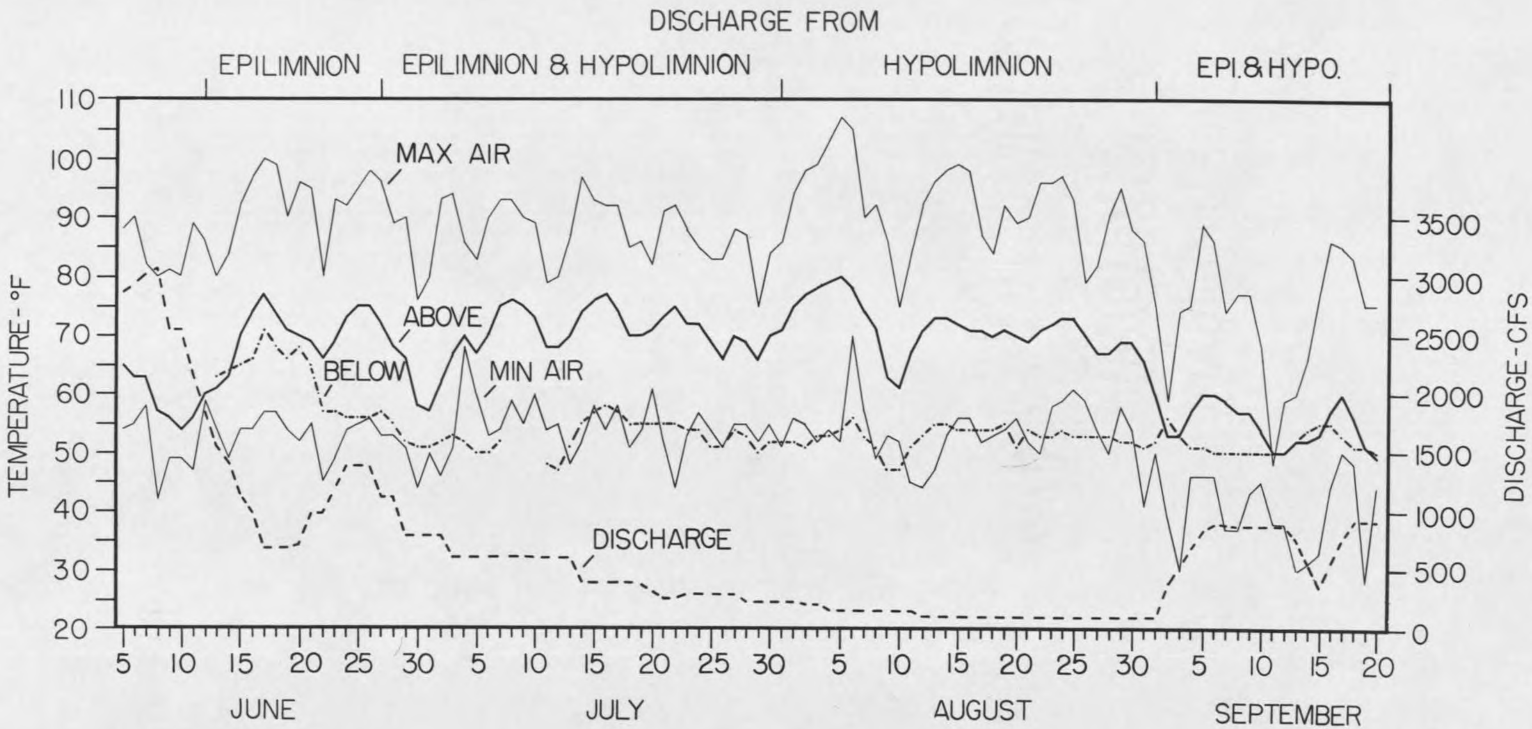

Fig. 2. Average daily water temperatures in the Marias River above and below Tiber Reservoir (stations 1 and 5). Daily maximum and minimum air temperatures at Tiber Dam (Climatological Data, U.S.D.A., Weather Bureau, Vol. 64, Nos. 6, 7, 8, 9, 1961). Discharge (c.f.s.) and level of release from Tiber Dam during 1961.

(July 8, 1960; June 14, 1961). Tiber Reservoir temperature profiles taken in 1960 and 1961 (Fig. 3) illustrate the downward depression of the metalimnion throughout both years. Data obtained in 1960 show greater variation in the depth of the metalimnion on any given sampling date than for 1961. This may be due to generally cooler atmospheric temperatures, wind action and inflow of cool water into the reservoir. On June 14, 1961 a large inflow of cold water was passing through the reservoir as a density current. The temperature profile near the head of the reservoir (station 2) averaged 4.5° cooler than the temperature profile near the dam (station 4). Isotherms for June 14 (Fig. 4) show a metalimnion between the surface and 10 foot levels in addition to the presence of a density current flowing down the old river channel and seeking a level between 40 and 50 feet at the dam. The density current extended approximately 20 miles through the lower part of the reservoir. It had disappeared from the upper end at the time of sampling. Temperatures in the river above the reservoir averaged 58° one week prior to sampling the reservoir, the temperature of the density current was identical with this. The temperature gradient through the metalimnion at the surface averaged 4° while that through the density current averaged 7.5°. The temperature of the outflow on June 14 averaged 64° and there was no indication of density current water in the outflow. By July 11, only one metalimnion existed and its location between 50 and 55 feet suggests that it originated from the density current. During September of both years the volume of the epilimnion was found to be greatly increased and nearly homo-

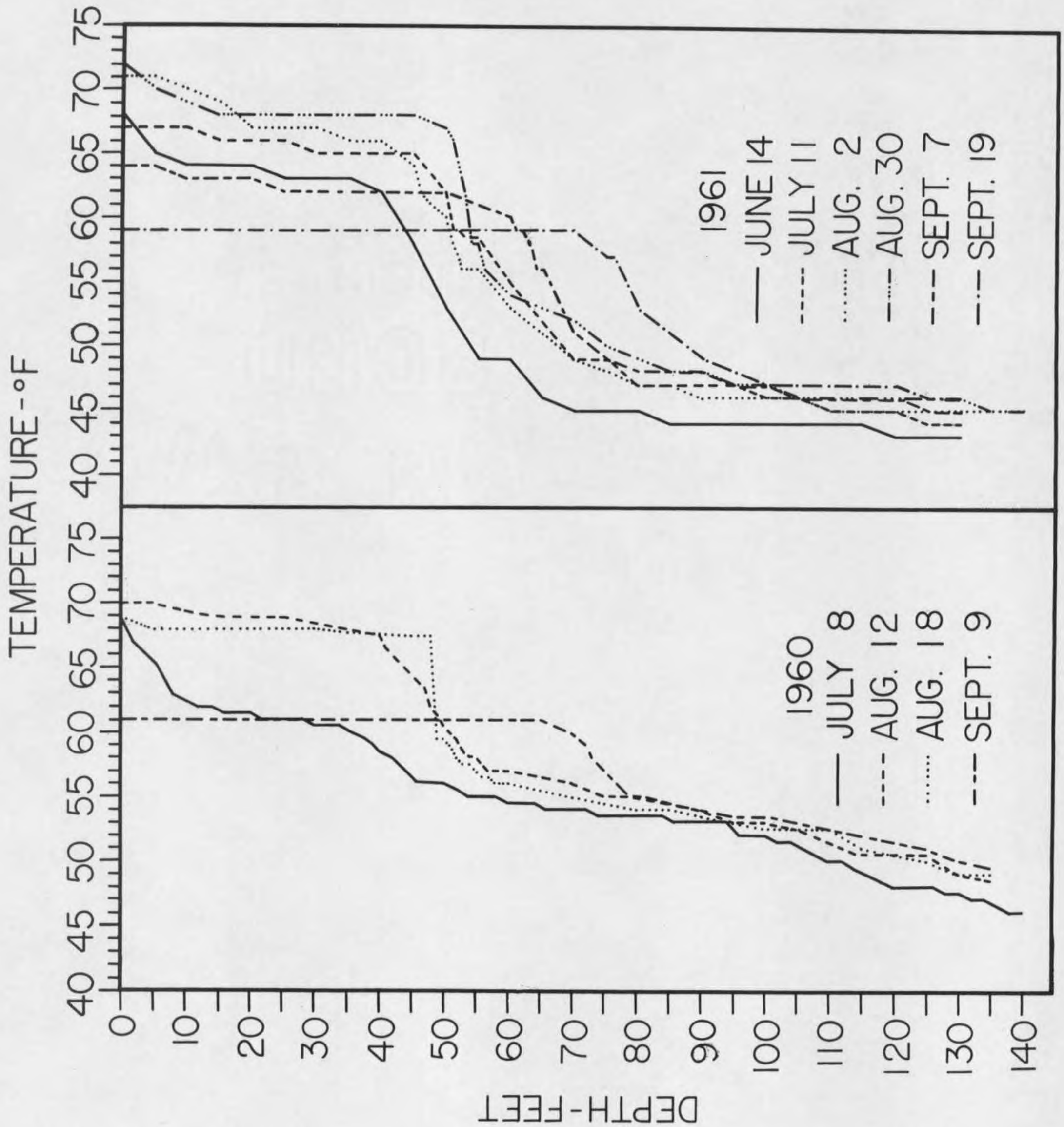

Fig. 3. Tiber Reservoir temperature profiles at station 4 1960 and 1961.

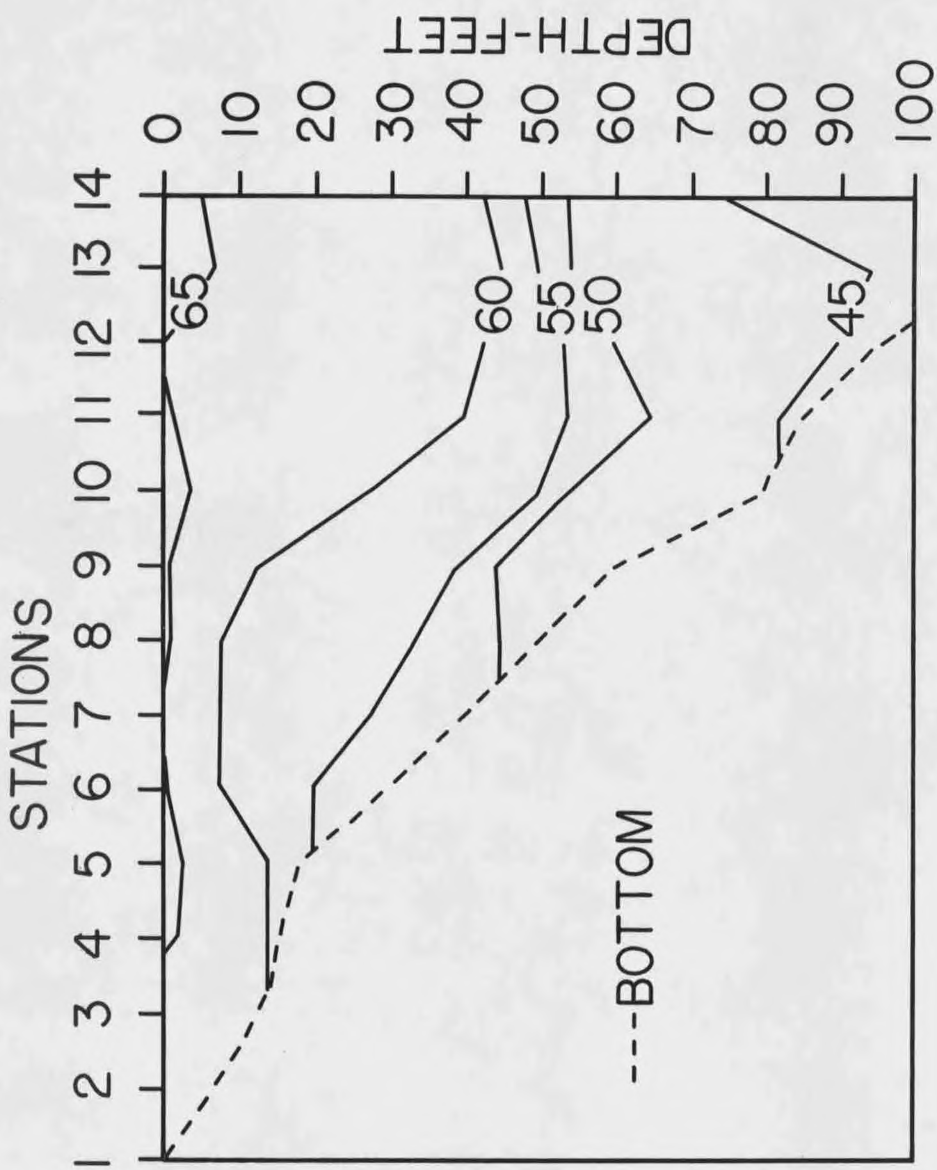

Fig. 4. Isotherms in Tiber Reservoir showing a surface metalimnion and density current June 14, 1961.

thermous and the thickness of the metalimnion was reduced due to cooler atmospheric temperatures and increasing winds. The metalimnion no longer existed at stations 2 and 3 on September 8, 1960 or on September 19, 1961, however, it was observed at stations nearer the dam on these dates. On September 19, 1961 the metalimnion was not horizontal. It ranged from 75-80 feet near the dam to 60-65 feet approximately 10 miles up the reservoir. There may have been a seiche resulting from persistent winds which blew from the head of the reservoir toward the dam the day before sampling.

River Below Reservoir: Water temperatures below the reservoir were found to be influenced by the level of release, by the volume of the release, and by atmospheric conditions.

In 1960, water releases from Tiber Reservoir were exclusively from the hypolimnion between June 12 and September 1. After this time some water was released from the epilimnion. The average maximum and minimum temperatures recorded at each station show a general increase from the dam to the mouth of the river (Table 2). Most of the temperatures at station 9 were taken during the hottest part of the summer thus the high average water temperatures. The maximums shown for all stations in 1960 (Table 2) occurred during late July and early August, when highest atmospheric temperatures existed, the minimums generally during June when atmospheric temperatures were lowest.

In 1961, water temperatures were recorded continuously from June 13 to September 20 (station 5) except on July 8, 9, and 10 when the thermograph was molested. Daily temperatures below the reservoir averaged 12° cooler (Fig. 2) than those above. This was primarily due to the release of water from the hypolimnion throughout most of this period. Moffett (1949) found temperatures averaging about 13° lower downstream from Shasta Dam, California, (June-September) than before the dam became operational. Churchill (1956) reported a drop in temperatures of approximately 25° after releases were started below Watauga Reservoir, Tennessee, during August. A drop of 8° at station 5 on June 22 below Tiber Reservoir resulted from an increase in flow on June 21 (Fig. 2). Even though water was drawn entirely from the upper surface of the epilimnion the increased flow probably pulled cooler water from below the surface causing the drop in temperature. Due to the discharge of water from the epilimnion (Fig. 2) daily temperatures in the river below were warmer than the river above on June 13-14, 2°; September 2-3, 3°; and September 13-15, 2°.

Diurnal fluctuation of river temperatures was measured above (station 1) and below (station 5) the reservoir during 1961. The average from June 13 to September 20 was about the same above the reservoir (8.1°) as below (7.9°) and was identical for the months of June and July. The greatest variations occurred during August (10° above and 13° below) and September (7° above and 3° below).

Water releases were from various levels during 1961 and observations were divided into four periods. The first period, between June 12 and June 27, water was released from the epilimnion. Average maximum and minimum temperatures for all stations were highest below the reservoir

(Table 3). The maximum temperatures for the entire summer also occurred during this period and reached 76°, 76°, and 80° at stations 5, 6, and 7, respectively. The second period, between June 28 and July 31, water was released from the epilimnion and hypolimnion. There was a drop in the average maximums of 4.1° and in the average minimums of 5.7° for all stations during this period (Table 3). Sometime between July 19 and 24 a temperature of 34° was recorded at station 10 (Table 2). The temperatures at stations 7, 8, and 11 were 48°, 52° and 45°, respectively. These low temperatures followed a storm (hail and rain) on July 21 which caused a sudden increase in flow. The third period, between August 1 and August 31, water was released from the hypolimnion. The average maximums rose 1.9° and the average minimums 0.6° (Table 3). Summer maximums occurred at stations 8, 9, 10, 11, and 12 (Table 2) even though water was being released from the hypolimnion. However, summer maximums at stations 5, 6, and 7 were not reached during this period. The most pronounced gradient occurred in the temperatures downstream from the reservoir to the mouth of the river. The maximum and minimum temperature for each station was as follows: 5—65°, 41°; 6—67°, 55°; 7—76°, 63°. This represents an average of about 1.2° rise in temperature per mile for 11 miles downstream. The minimum at station 5 was the lowest recorded for the summer. Finnell (1953) reported a rise of about 3° per mile for seven miles of stream below Tenkiller Reservoir (Oklahoma). Tiber Reservoir had a marked effect on river temperatures at least 24 miles below. At stations below this point temperatures were approaching those of the river above. Tempera-

Table 3. Average maximum and minimum water temperatures for 1961 in the Marias River in relation to water releases from Tiber Dam.

	Stations								
Release Periods	5	6	7	8	9	10	11	12	Average
Average maximum	66	71	77	73	76	78	80	80	72.6
June 12-27									
Average minimum	59	61	60	62	63	62	63	67	61.1
Average maximum	57	68	72	72	77	78	80	79	68.5
June 28-July 31									
Average minimum	49	54	55	60	62	58	61	65	55.4
Average maximum	61	65	74	76	78	78	81	79	70.4
Aug. 1-31									
Average minimum	47	52	60	63	63	62	62	64	56.0
Average maximum	54	58	62	58	62	63	63	63	58.7
Sept. 1-20									
Average minimum	50	50	49	49	49	47	48	49	49.4

tures would have been higher had water not been drawn from the hypolimnion. The fourth period, between September 1 and September 20, water was released from the epilimnion and hypolimnion. The average maximums and minimums including all stations showed a decrease of 11.7° and 6.6° when compared to the preceding release period (Table 3). This was not entirely due to the release itself but to the drop in atmospheric temperatures (Fig. 2). Minimum temperatures occurred during this period at stations 6, 7, 8, 9, and 12 (Table 2). The average maximum and minimum temperatures for each station show similar trends for both 1960 and 1961 (Table 2).

Flows had an influence on the maximum and minimum temperatures for 1961. Maximum and minimum temperatures occurred above the reservoir in August, during the period of lowest flow (110 cfs). No appreciable rise in temperature was found below the reservoir (station 5) during the period of lowest flow (120 cfs) which occurred between August 12 and September 1. This was primarily due to release of water from the hypolimnion and the proximity of station 5 to the dam. However, stations at greater distances below the dam showed an increasing correlation between low flow and high maximum and minimum temperatures.

Turbidity

Turbidity samples were collected at the same river stations as temperatures. Reservoir samples were collected on transects at 2.5 mile intervals from the head to the dam at each 10 foot contour (stations 1 to 13) and some were taken in the Willow Creek Arm (station 3). Surface samples were secured directly with dark bottles and sub-surface samples with a Kemmerer Water Sampler. All determinations were with a Hellige Turbidimeter.

Transparency was measured with a standard Secchi disc (20 cm in diameter). Most readings were made in conjunction with turbidity samples.

Above Reservoir: Turbidity ranged from 1.8 ppm to 75 ppm during 1960 and from 4 ppm to 63 ppm during 1961. Maximums occurred both years during spring runoff. Turbidity averaged 16.6 ppm in 1960 and 16.5 ppm in 1961 (Table 4).

Reservoir: The shores of Tiber Reservoir are steep and soft. During periods of vigorous wave action the water was observed to change from a blue-green to a milky-brown color within a few hours. A few samples collected near shore in the zone of highest turbidity (1 to 3 feet in depth) during heavy wave action showed a range from 127 ppm to 158 ppm.

Table 4. Maximum, minimum, and average turbidity (ppm) in the Marias River during 1960 and 1961.

	Stations								
	1	5	6	7	8	9	10	11	12
					1960				
Maximum	75.0	6.0	6.5	10.4	12.0	8.7	13.5	12.0	28.5
Minimum	1.8	0.06	0.3	0.43	0.35	0.35	0.35	0.28	0.59
Average	16.6	2.5	3.1	3.8	4.0	3.8	4.2	5.3	8.8
					1961				
Maximum	63.0	33.0	69.0	72.0	89.0	158.0	180.0	276.0	465.0
Minimum	4.0	0.11	0.06	0.06	1.5	2.2	1.5	2.7	3.1
Average	16.5	6.2	11.9	14.5	16.1	24.4	32.6	37.9	69.4

The average turbidity for samples taken on each transect from the head of the reservoir to the dam are as follows: 1960 — June 23, 28 ppm; July 21, 10 ppm; August 30, 12 ppm; 1961 — June 14, 20 ppm; July 7, 11 ppm; August 2, 8 ppm; August 30, 11 ppm; September 19, 17 ppm. Highest averages were reached during June of both years coinciding with spring runoff. The increase found in September 1961 was due to wave action and shore erosion which occurred just prior to sampling. The range of turbidity at the regular sampling stations was from 0.7 ppm to 185 ppm during 1960 and from 0.06 ppm to 110 ppm during 1961 (Table 5). Highest average turbidity readings were obtained in the upper end of the reservoir which was most affected by the inflowing river. Ellis (1940) reported a decrease in turbidity from the upper end of Elephant Butte Reservoir (New Mexico) toward the dam.

Secchi disc readings ranged from 0.8 to 15.5 feet during 1960 and from 1.0 to 13.4 during 1961 (Table 6). Transparency was lowest near the head of the reservoir and increased progressively toward the dam. The average values were greater in 1961 for all stations except 6, 8, and 9.

Table 5. Maximum, minimum, and average turbidity (ppm) for Tiber Reservoir during 1960 and 1961. Stations are arranged in order from the upper end toward the dam.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	WCA*
							1960							
Maximum	95.0	28.5	27.0	60.0	75.0	17.0	20.0	25.0	11.0	12.5	32.0	75.0	185.0	20.0
Minimum	15.0	21.5	8.5	11.0	6.0	4.5	5.0	2.2	2.6	2.6	3.1	2.7	0.7	4.5
Average	46.8	25.0	23.5	26.2	28.2	12.3	10.6	7.0	6.1	7.4	7.2	7.9	8.2	8.7
							1961							
Maximum	69.0	82.0	51.0	60.0	110.0	33.0	24.0	22.0	22.0	9.2	10.4	25.5	30.0	7.5
Minimum	14.0	4.5	13.0	3.1	5.0	4.0	2.3	1.5	0.9	1.1	1.1	0.06	0.45	0.6
Average	32.5	30.5	25.0	26.3	26.0	15.6	10.0	7.0	6.2	4.4	4.0	4.5	3.3	4.1

* Station 3 (Fig. 1).

Table 6. Maximum, minimum, and average secchi disc readings (in feet) for Tiber Reservoir during 1960 and 1961.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	WCA*
							1960							
Maximum	1.8	1.0	1.5	3.5	8.0	9.2	7.5	15.5	5.5	6.3	3.0	6.5	12.0	7.5
Minimum	1.0	1.0	1.3	0.8	1.0	1.1	1.6	2.4	2.4	3.5	2.5	3.0	4.6	4.7
Average	1.4	1.0	1.4	2.2	4.5	5.2	4.6	8.8	4.0	4.9	2.8	4.8	8.0	5.7
							1961							
Maximum	2.1	3.6	3.5	4.7	5.6	5.6	7.0	9.7	10.3	11.0	11.8	13.4	12.8	6.8
Minimum	1.0	1.1	1.1	1.0	1.0	1.3	1.5	2.0	2.5	3.7	4.7	5.0	6.4	5.8
Average	1.8	2.1	2.1	3.0	3.8	4.1	4.7	6.6	6.2	6.6	7.4	7.8	9.0	6.2

* Station 3 (Fig. 1).

Wright (1954) and Anderson and Pritchard (1951) reported transparency lowest at the head of the reservoir and increasing toward the dam on Atwood Lake and Lake Mead, respectively.

<u>River Below Reservoir</u>: Turbidity was found to be affected by settling of suspended material in the reservoir, by the volume of water released from the dam, and by runoff.

The average turbidity was 14.1 ppm less at station 5 than at station 1 in 1960 and 10.3 ppm less in 1961 (Table 4). The range of turbidity at station 5 was also less during both years. The reservoir reduced turbidity immediately below the dam (station 5), however, stations farther downstream became influenced by other factors.

The daily volume of water released from Tiber Dam was generally the same both years. However, releases were much smaller during the peak of spring runoff (2170 cfs) in June 1960 than they were in June (3071 cfs) 1961. The period of low flow occurred during August of both years. The smallest release in 1960 was 216 cfs and that in 1961 was 122 cfs. An increase in release volume occurred both years during the first eight days of September. There were no extreme releases in 1960. However, on June 5, 1961, when 2862 cfs were being discharged from the dam turbidity ranged from 3.5 ppm at station 5 to 152.0 ppm at station 12. The average turbidity for all stations was 49.6 ppm. On June 12 turbidity ranged from 0.11 ppm (station 5) to 20.0 ppm (station 12) and averaged 5.1 ppm after flows began to decrease (Fig. 2). No corresponding rise in turbidity was found on June 24, 25, and 26 when the discharge was increased to 1378 cfs (Fig.

2). The lack of a corresponding rise in turbidity was due to the larger flows just prior to this which scoured the river channel so that subsequent flows had little effect. The volume of release affected turbidity on September 5, 8, and 12. The flow on these dates had risen to 845, 887, and 892 cfs, respectively (Fig. 2). Although these were much lower than any observed during June they were high enough to agitate materials deposited in the river by a previous flood. Turbidity on September 5 ranged from 12.3 ppm (station 5) to 127.0 ppm (station 12) and averaged 56.9 ppm for all stations. On September 8 it ranged from 7.0 ppm (station 5) to 100.0 ppm (station 12) and averaged 34.1 ppm for all stations. By September 12 turbidity ranged from 3.1 ppm (station 5) to 395.0 ppm (station 12) and averaged 59.7 ppm for all stations. The average for all stations on September 18 was 13.0 ppm and on September 21 was 18.8 ppm.

The effect of runoff on the turbidity below the reservoir was first observed on July 6, 1961. Samples on this date taken progressively from stations 5 to 12 were as follows: 1.9, 2.6, 3.1, 3.5, 5.9, 54.0, 73.0, and 6.0 ppm, respectively. The high readings (stations 10, 11) were due to runoff from a heavy rain the previous night. It should also be noted that turbid water had not reached station 12 at the time of sampling. Another example of runoff effect on turbidity occurred on July 24 following a severe storm (rain and hail) which caused a sudden increase in flow and at the same time washed large quantities of soil and debris into the river. The turbidity taken at stations 5 to 12 progressively downstream, after the flood had subsided, were as follows: 33.0, 69.0, 72.0, 89.0, 158.0, 180.0, 276.0, and 465.0 ppm, respectively. The average for this date was 167.7 ppm for all stations. Following this flood turbidity samples remained higher the rest of the summer averaging 51.6 ppm on July 27, 44.3 ppm on July 31, with the lowest average for the rest of the summer (7.0 ppm) occurring August 10.

In 1960, Tiber Reservoir had a marked depressing effect on the turbidity in the river below the dam (Table 4). Ellis (1942) reports the general reduction effects reservoirs have on the turbidity below. During 1961, the effect of Tiber Reservoir was much less, however, these were obvious at the stations immediately below the dam and slight downstream. Runoff created unstable conditions in the river as well as along its banks and large releases subsequently carried away loose materials which resulted in rising turbidities. River turbidity may have been affected by the activity of numerous carp and suckers particularly during the period of lowest flow (August), however, this was probably minor to the other causes.

Plankton

Plankton samples were collected at the same stations as temperatures (Fig. 1). All samples were taken with a No. 20 silk bolting cloth plankton net. The original volume of each river sample was 100 liters of water. In 1960, each reservoir sample consisted of 100 liters of surface water, however, in 1961 composite samples of 400 liters were taken at the 10, 20, 30, and 40 foot depths. Collections were made with a pump and hose. A funnel was attached to the distal end of the hose to insure against the loss of plankters resulting from rheotactic reactions. The