INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

PROGRESS REPORT

No. 27

PART I

TEMPERATURE CONTROL DURING SOCKEYE SPAWNING PERIOD IN McKINLEY CREEK IN 1969

BY

A. C. COOPER

PART II

INVESTIGATION OF THE PRESPAWNING MORTALITY OF SOCKEYE IN HORSEFLY RIVER AND McKINLEY CREEK IN 1969

BY

I. V. WILLIAMS

NEW WESTMINSTER, B. C.
CANADA
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INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

Appointed under a Convention
Between Canada and the United States for the
Protection, Preservation and Extension of
the Sockeye and Pink Salmon Fisheries
in the Fraser River System

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ABSTRACT

A pilot project was constructed to control water temperature in McKinley Creek during the period of spawning of the 1969 sockeye run to the creek. The background, design and operation of the project are described. The release of cold water from the bottom of McKinley Lake lowered the maximum daily temperature of McKinley Creek at the lake outlet an average of 10°F below what would have occurred without the temperature control.

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TEMPERATURE CONTROL DURING SOCKEYE SPAWNING PERIOD IN McKINLEY CREEK IN 1969

INTRODUCTION

Investigations into the causes of substantial prespawning mortality of sockeye salmon in the Horsefly River and a tributary, McKinley Creek (FIGURE 1), led to consideration of lowering of water temperature as a means of preventing the mortality which was associated with warm water and the myxobacterium *Chondrococcus columnaris* (Internat. Pacific Salmon Fish. Comm. 1966). Experimental evidence obtained at Horsefly River in 1965 indicated that outbreak of *C. columnaris* in infected sockeye spawners could be controlled at water temperatures averaging 55°F, with maximum daily temperatures not exceeding 57 to 58°F (Colgrove and Wood 1966). Extensive study showed that control of water temperature in Horsefly River and part of McKinley Creek to the prescribed limit of 57°F maximum during the period August 10 to September 5 was feasible. Temperatures in the Horsefly River at the spawning grounds near McKinley Creek would be controlled by holding back the warm surface outflow from Crooked Lake and substituting releases of cold subsurface water. Temperatures at the upper part of the spawning grounds in McKinley Creek below McKinley Lake would also be controlled in a similar manner at McKinley Lake. It was estimated that the storage and discharge facilities at Crooked Lake would cost $1,756,000, and the facilities at McKinley Lake would cost $272,000.

While the available information indicated the temperature control would eliminate serious prespawning mortality attributable to *C. columnaris*, conclusive verification of the experimental evidence could only be obtained from actual experience with full scale operation. In view of the relative costs of the facilities required at Crooked Lake and McKinley Lake, the Commission recommended construction of the facilities at McKinley Lake as an initial step.

This report describes the method of temperature control in McKinley Creek and the facilities required, and also describes the temperature changes produced during the 1969 spawning of sockeye in McKinley Creek.

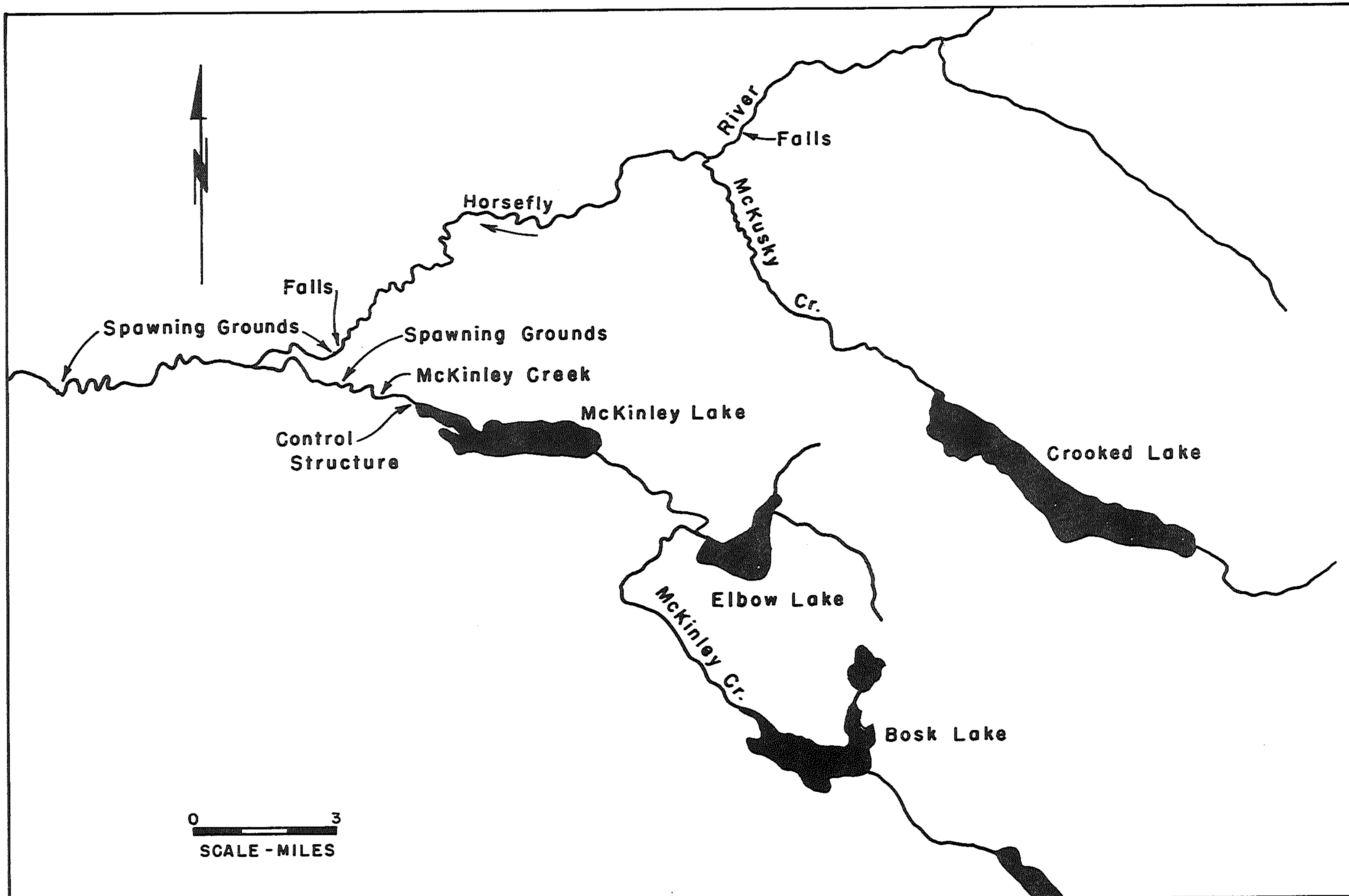

FIGURE 1 - Vicinity map, Horsefly River and McKinley Creek.

METHOD OF TEMPERATURE CONTROL

Background

The temperature control facilities at the outlet of McKinley Lake were planned as an integral part of the plan to control temperature in Horsefly River. While the release of cold water from Crooked Lake would provide the principal means of temperature control in the Horsefly River, the facilities at McKinley Lake were planned to reduce the quantity of cooling water required from Crooked Lake by reducing the heat input to Horsefly River from McKinley Creek. This objective was to be accomplished by reducing the discharge in McKinley Creek to the range from 30 cfs minimum to 60 cfs maximum. By blending the warm surface outflow from McKinley Lake with cold water obtained from the bottom of the lake, water temperatures in the upper half of McKinley Creek below McKinley Lake could also be controlled to the specified 57°F maximum and would thereby benefit the sockeye spawning in this part of the creek. It was this latter feature that was utilized for the test in 1969.

Volume and Temperature of Lake Water Supply

The source of water for the temperature control was the cold water in the lower layers of the outlet arm of McKinley Lake. From echo sounder surveys made in 1962, it was determined that McKinley Lake has an area of 1,266.9 acres with a maximum depth of 210 ft. However, the outflow from McKinley Lake is through an outlet arm about 1.5 miles long which is separated from the main part of the lake by a shallow sill 3 to 4 ft below the lake surface. This sill makes it impractical to make use of the large volume of cold water in the main part of the lake. The outlet arm of the lake has an area of 170.8 acres and a maximum depth of 62 ft (FIGURE 2). The maximum depth of 62 ft is a local depression, but a depth of 50 ft is more representative of the general bottom of the lake. The volume of water in the outlet arm above the 50 ft depth was calculated for 5 ft increments in depth (TABLE 1) from which a curve of depth vs volume was obtained (FIGURE 3).

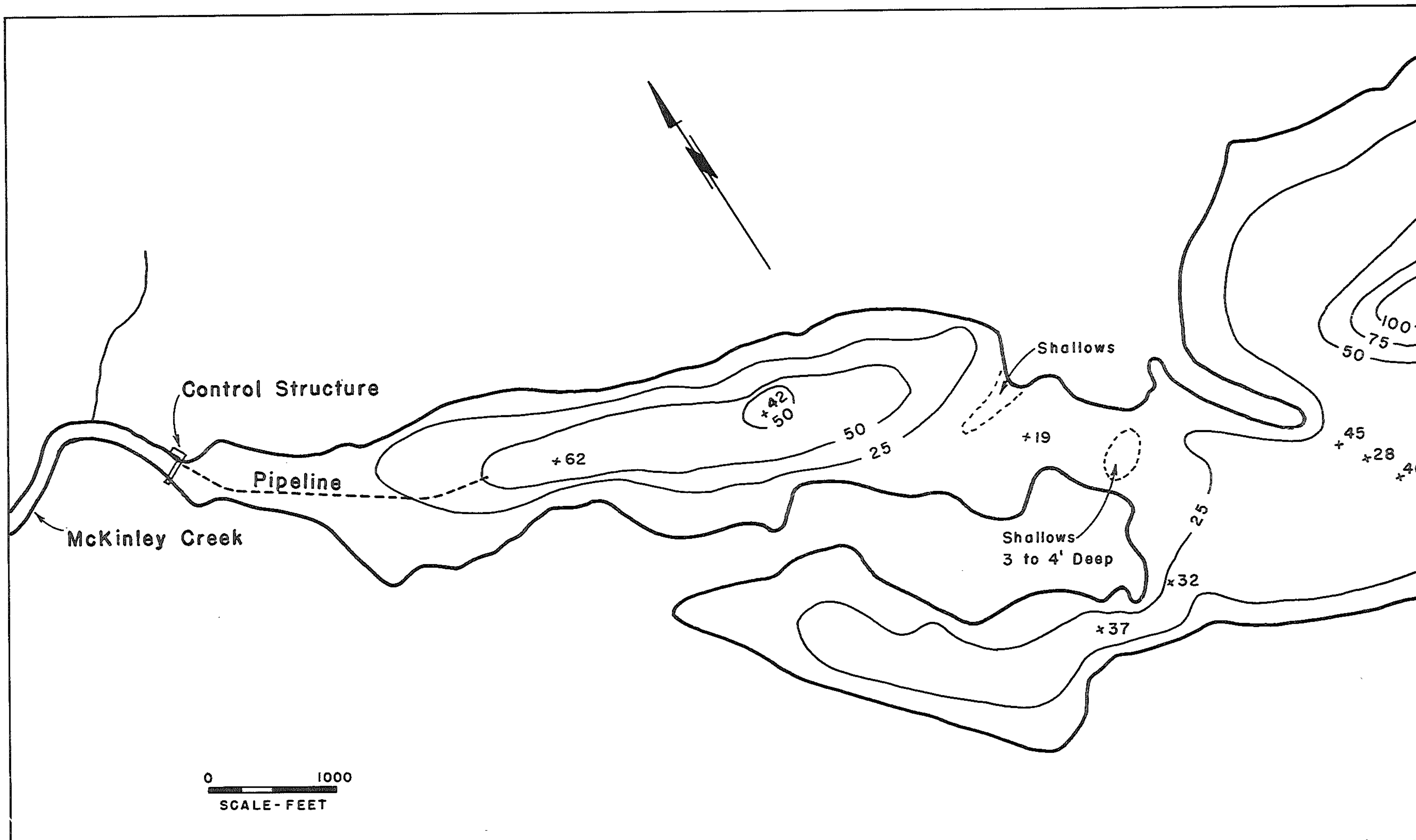

FIGURE 2 - Outlet arm of McKinley Lake.

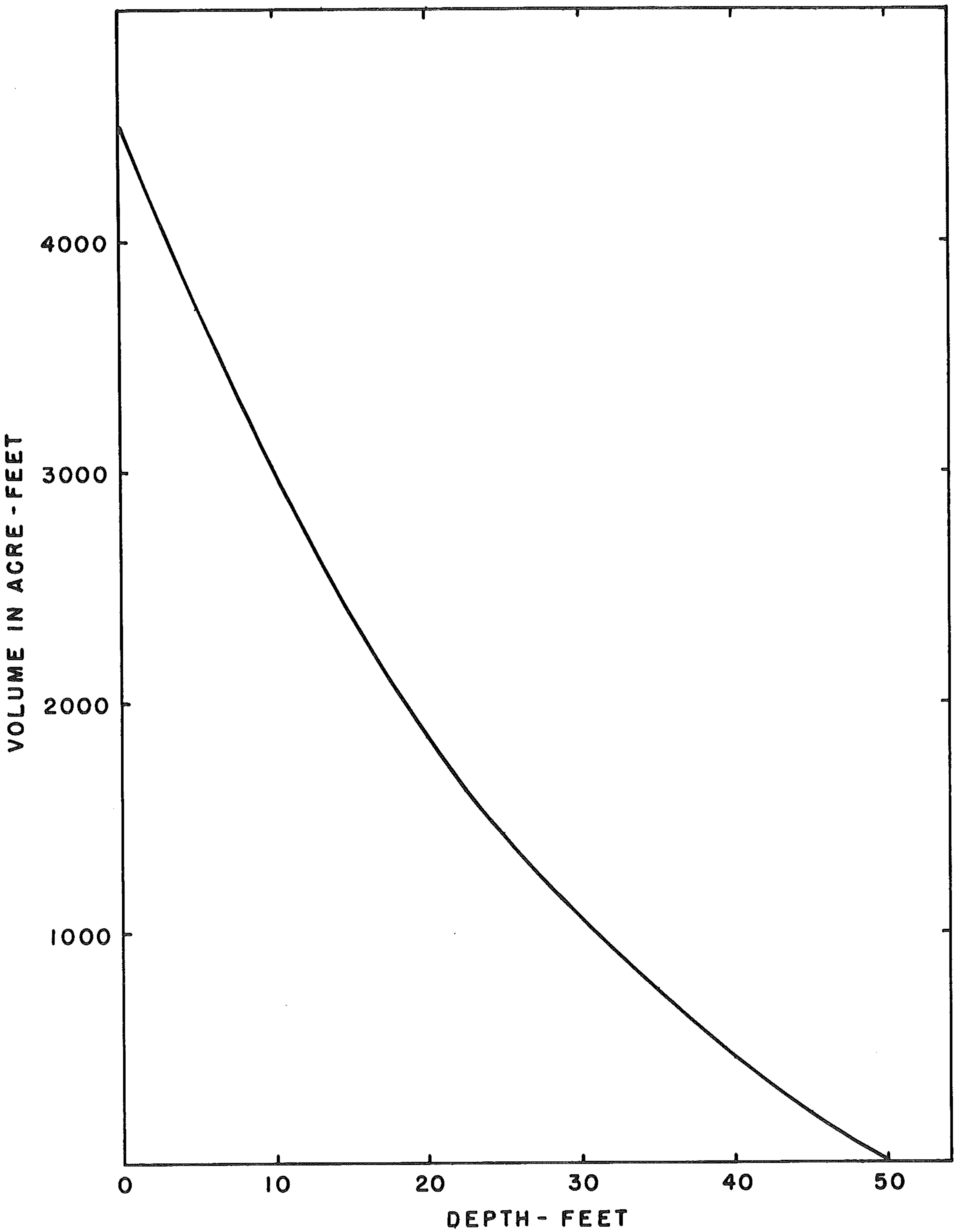

FIGURE 3 – Volume of outlet arm of McKinley Lake above 50 ft depth, acre-ft.

TABLE 1 - Volume of outlet arm of McKinley Lake in acre-ft.

Depth Increment ft	Volume acre-ft
0-5	807.35
5-10	714.05
10-15	620.75
15-20	527.45
20-25	434.15
25-30	366.90
30-35	325.70
35-40	284.50
40-45	243.30
45-50	202.10
Total 0-50	4,526.25

Since it was desired to maintain temperatures in the range from 52 to 57°F at the spawning grounds in the upper half of McKinley Creek, it was estimated that the water to be released at the outlet of McKinley Lake should have a temperature of approximately 50°F, subject to field adjustment. Bathythermographs taken in the lake outlet arm near the end of July in 1962, 1967 and 1968 indicated it would be possible to obtain water with a temperature of 50°F or less at depths of 32 ft or more (FIGURE 4). The lake has an estimated volume of 925 acre-ft (463 cfs-days) between the 32 and 50 ft depths. Since the water temperature decreases to as low as 44.5°F at 50 ft depth, the water could be blended with warmer surface water to produce a temperature of 50°F. The effective volume of 50°F water available when mixed with lake surface water at 60, 65 and 70°F would range from 1,105 to 1,285 acre-ft (TABLE 2). These volumes would provide flows from 20 to 23 cfs for the entire 27 day period (August 10 to September 5) for which temperature control was required. An additional volume of 931.33 acre-ft (466 cfs-days) would be available at temperatures between 50 and 57°F. This volume would provide an additional 17 cfs flow for the

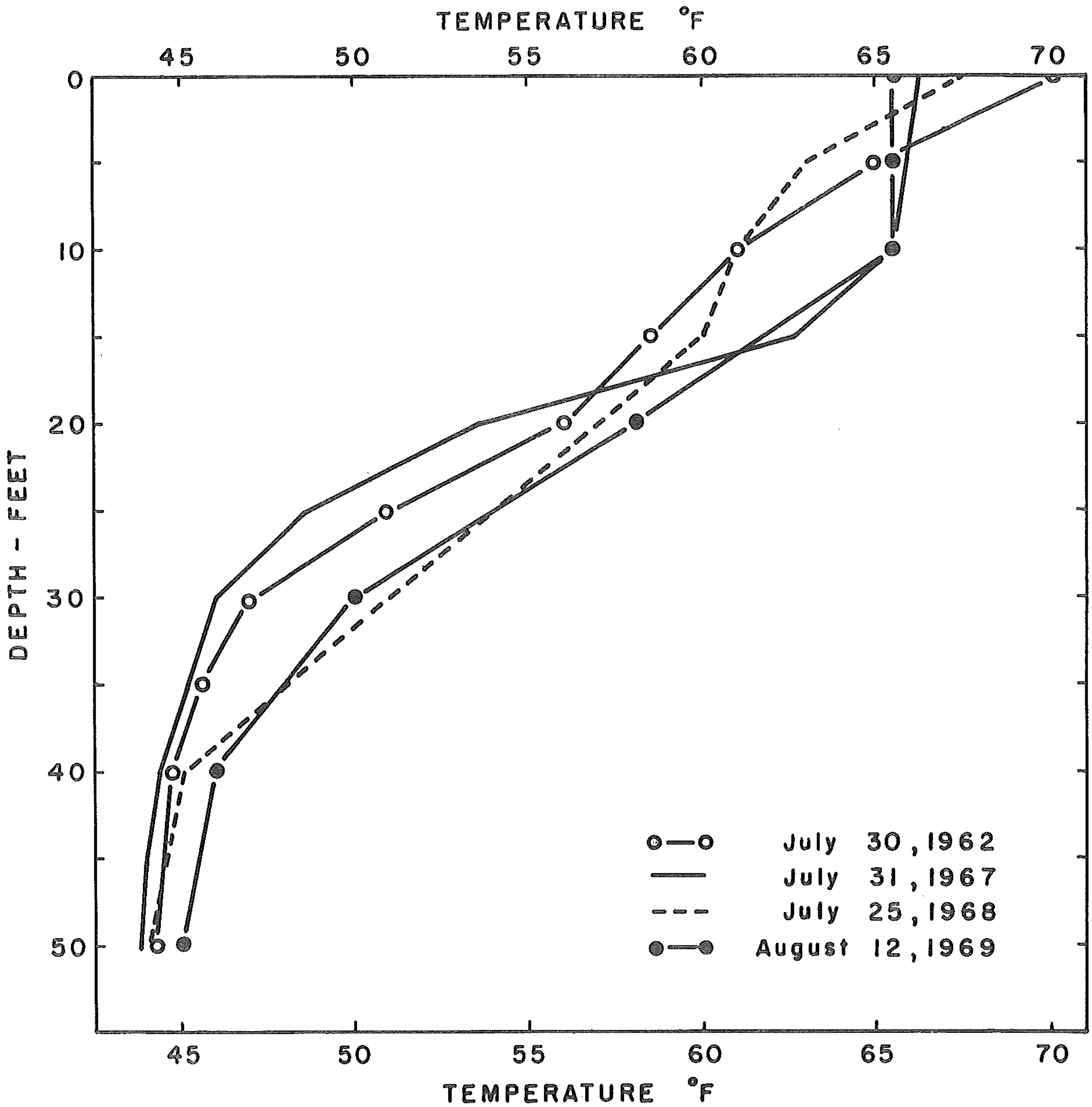

FIGURE 4 - Comparative temperatures, McKinley Lake for 1962, 1967, 1968 and 1969.

TABLE 2 - Effective volume of 50°F water available from outlet arm of McKinley Lake when mixed with lake surface water.

Lake Surface Water Temperature °F	Effective Volume of 50°F Water acre-ft	cfs-days*
60	1,284.5	632
65	1,164.6	582
70	1,104.9	552

*1 cfs = 2 acre-ft per day, approximately.

above period, but the length of creek for which the temperature control would be effective might be reduced depending on the water temperature and weather conditions. The total flow available for temperature control for the 27 day period thus was 37 to 40 cfs.

Lake Outflow and Storage

The recorded and estimated discharges of McKinley Creek for the period August 10 to September 5 in the years 1947 to 1968 (TABLE 3) indicated flows as low as 14 cfs and as high as 585 cfs. The average discharge in eight of these years was less than 40 cfs. Under such conditions it would not be possible to use all the available cold water unless water was stored in advance, since very little drawdown of the lake would be possible. Under the conditions indicated by the other 14 years of records, regulation of the flow to 40 cfs or less would require storage of surplus inflow in McKinley Lake. Under the plan for temperature control for the Horsefly River, it was proposed that the discharge from McKinley Lake would be regulated to not more than 60 cfs. However, for the pilot temperature control test planned in 1969 it might not be possible to discharge more than 40 cfs if temperature control was needed for the entire 27 day period. If the weather permitted, it might be possible to discharge water from McKinley Lake at a temperature between 50 and 57°F and still attain the objective of 57°F maximum in the upper half of the creek.

TABLE 3 - Recorded and estimated daily discharge of McKinley Creek at McKinley Lake outlet during August and September.

Day	Discharge - cfs																						
	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965*	1966*	1967*	1968*	1969*
Aug. 10	24	177	90	31	23	37	48	85	115	51	95	29	82	132	23	200	92	212	76	150	63	92	164
11	23	149	74	29	25	35	43	110	109	50	100	28	75	112	23	199	83	210	73	142	61	88	154
12	27	134	79	28	26	34	40	114	104	50	105	25	70	77	23	199	135	203	73	137	59	66	123
13	25	142	85	28	24	33	37	128	97	50	110	23	66	100	28	197	123	183	79	137	57	52	80
14	27	153	90	28	25	31	33	132	93	50	114	23	58	123	27	196	123	167	88	137	54	52	93
15	24	133	83	28	22	30	32	138	87	50	118	23	55	142	28	191	123	146	93	133	52	52	95
16	21	122	75	27	23	28	32	141	84	51	121	23	47	167	32	191	95	133	92	128	50	54	101
17	23	97	68	26	23	26	33	148	96	53	124	20	40	172	33	196	163	121	88	122	48	52	95
18	26	130	61	28	22	25	29	154	94	56	120	20	35	200	38	199	103	98	88	117	44	52	95
19	24	138	57	25	20	24	28	155	93	50	116	20	30	208	35	202	95	80	88	114	43	52	85
20	23	161	58	28	18	22	27	178	86	47	113	20	27	118	33	202	117	65	84	108	41	52	73
21	20	206	54	25	18	22	32	129	78	44	112	19	135	125	30	204	160*	36	81	104	40	56	69
22	18	217	54	26	18	21	31	121	75	47	102	19	157	142	27	206	175*	44	78	99	39	66	73
23	18	163	61	25	20	21	31	161	72	50	99	18	177	155	25	199	175*	73	79	95	37	71	73
24	19	230	70	25	17	21	31	193	68	56	95	17	185	152	25	183	185*	95	76	92	36	75	73
25	20	274	79	26	17	20	31	199	67	66	92	17	194	142	25	174	185*	121	85	87	34	76	73
26	19	449	75	26	16	21	32	209	69	102	88	17	197	137	25	154	180*	146	97	84	33	84	76
27	19	470	70	28	15	21	32	204	70	74	87	16	198	155	25	146	210*	167	112	83	32	88	73
28	19	585	62	29	15	21	32	138	71	50	82	16	182	162	25	125	226*	183	122	83	31	92	73
29	18	578	58	29	16	23	31	132	67	57	78	16	172	190	32	117	230*	178	137	81	30	94	71
30	17	463	53	31	16	24	37	120	63	67	87	17	135	182	33	95	230*	167	154	78	29	96	85
31	17	445	50	31	15	26	48	136	60	62	95	25	115	156	44	83	225*	153	163	75	28	96	103
Sept. 1	22	315	45	30	15	28	65	136	58	54	93	30	95	150	55	74	140*	150	165	74	27	98	137
2	22	220	43	25	15	27	66	122	56	53	92	30	115	142	44	66	240*	117	171	71	25	100	139
3	22	205	42	25	15	25	58	130	55	52	91	25	135	112	33	43	245*	98	171	69	24	98	139
4	22	210	40	25	14	25	48	128	55	50	92	22	115	105	73	36	245*	80	171	68	23	98	139
5	22	200	38	23	14	25	48	132	53	47	93	20	142	146	44	27	245*	58	167	63	22	98	139
Average	21.5	250.6	63.5	27.2	18.8	26.5	38.3	143.4	77.6	55.1	100.5	21.4	112.4	136.1	32.9	152.0	168.4	129.0	109.3	101.1	38.2	75.9	99.7

*discharge measured

The depth of storage needed in McKinley Lake for regulated outflows of 30, 40, 50 and 60 cfs are given in TABLE 4. To avoid any detrimental effect on recreational sites around the lake, the stipulation was made that the water level should not rise above the normal high water level of 102.9 ft (arbitrary datum). The storage depths available to that elevation on August 10 are also shown in TABLE 4. These data are for the structure as built, with all gates out except the bottom sill gates in the two low flow bays (FIGURE 5). In 9 of the 22 years, the storage requirement to maintain a flow of 40 cfs exceeded the storage space available. Under these circumstances the duration of the period of temperature control would have to be reduced.

Temperature Rise in McKinley Creek

McKinley Creek has a length of 4.4 miles between McKinley Lake and its confluence with Horsefly River. Cold water discharged to the creek at the lake outlet would be heated as it flowed downstream, and estimates of the amount of heating were prepared. Limited data on mean depth and velocity at the discharge measuring station 0.5 miles downstream from the lake were used to determine the relation between discharge and mean depth and travel time (FIGURE 6). Methods previously described (Internat. Pacific Salmon Fish. Comm. 1966) were then used to make hourly estimates of the temperature change. The starting hour was selected so that the water would arrive at the mouth of McKinley Creek, just after the normal time for daily maximum temperature. Estimates were made with a starting temperature of 45 and 50°F, assuming clear skies, but with only 75% insolation received on August 5 and 46% on August 29 because of shade from the forest bordering the creek. The results for a discharge of 30 cfs and a starting temperature of 50°F, shown in FIGURE 7 represent the maximum expected temperature rise. The broken lines in the FIGURE are interpolations for intervening dates. At higher discharges, the temperature rise would be reduced because of greater water depth and shorter travel time. The temperature rise would also be less for more moderate weather with overcast skies. The estimates indicated that a temperature less than 57°F could be obtained at least in the first 1.4 to 2.4 miles of the creek downstream from McKinley Lake, depending on the date. This upper part of the creek contains the best spawning grounds for sockeye and is utilized more by the fish than the lower half of the creek. Spawning in the lower half of the creek is more scattered.

TABLE 4 - Storage required in McKinley Lake in feet for specified outflows in cfs, and storage available on August 10, in feet.

Outflow Year	30 cfs	40 cfs	50 cfs	60 cfs	Available Storage
1947	-0.36	-0.79	-1.21	-1.64	3.03
1948	9.40*	8.98*	8.56*	8.13*	2.50
1949	1.43	1.00	0.64	0.26	2.78
1950	-0.12	-0.55	-0.97	-1.35	3.00
1951	-0.48	-0.90	-1.33	-1.76	3.04
1952	-0.15	-0.57	-1.00	-1.43	2.97
1953	0.35	-0.07	-0.50	-0.92	2.92
1954	4.84*	4.41*	3.98*	3.56*	2.80
1955	2.03	1.60	1.18	0.79	2.70
1956	1.07	0.64	0.21	-0.21	2.90
1957	3.00*	2.58	2.15	1.73	2.75
1958	-0.37	-0.79	-1.22	-1.65	3.0
1959	3.51*	3.09*	2.66	2.23	2.80
1960	4.52*	4.09*	3.67*	3.24*	2.65
1961	0.12	-0.30	-0.73	-1.16	3.04
1962	5.20*	4.77*	4.35*	3.92*	2.45
1963	5.90*	5.47*	5.05*	4.62*	2.76
1964	4.22*	3.79*	3.37*	2.94*	2.40
1965	3.38*	2.95*	2.53	2.10	2.82
1966	3.03*	2.60*	2.18	1.75	2.59
1967	0.45	-0.08	-0.50	-0.93	2.85
1968	1.96	1.53	1.10	0.68	2.78

*Storage requirement exceeds storage available.

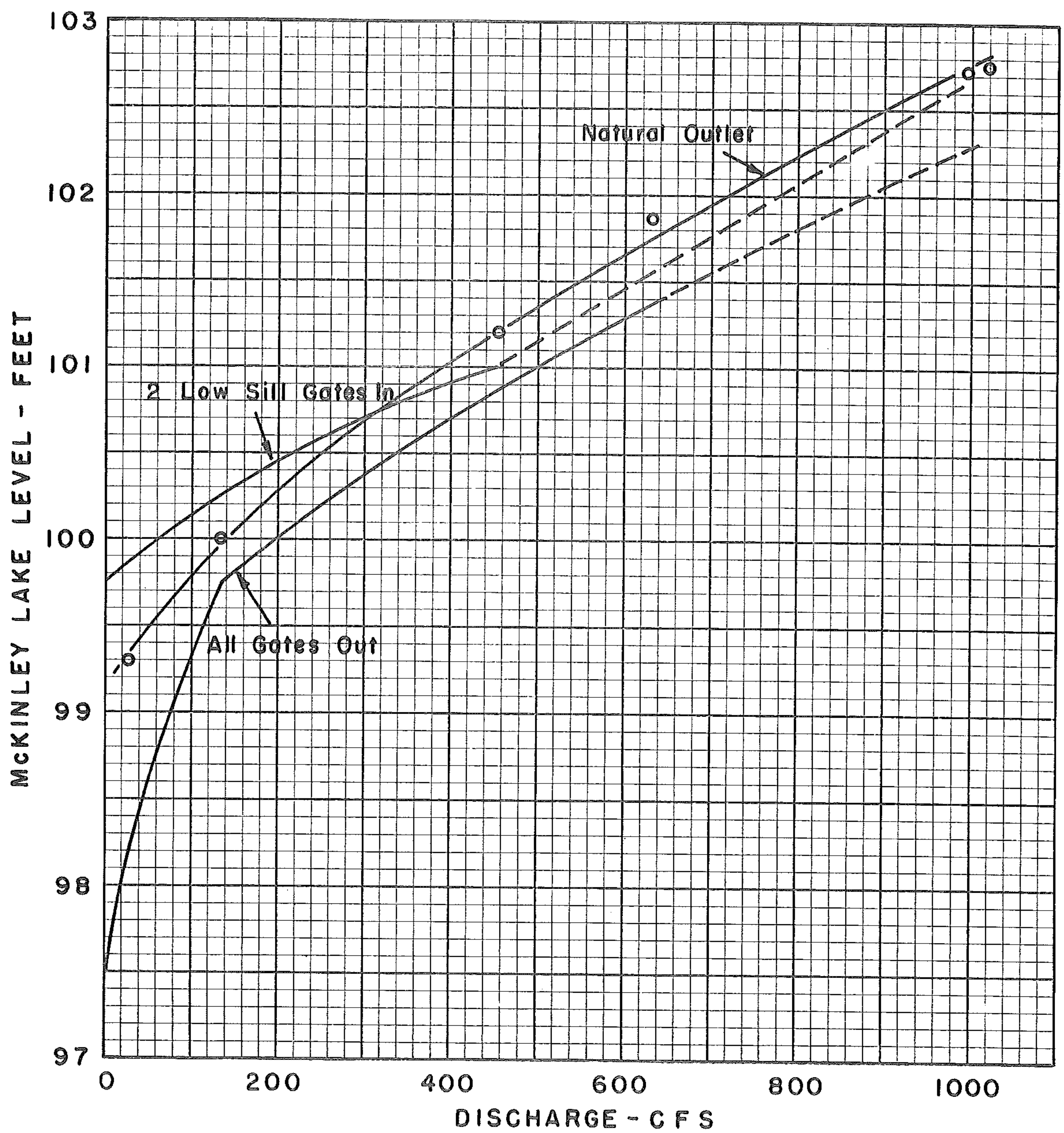

FIGURE 5 - Effect of lake level on discharge from McKinley Lake before and after construction of control structure.

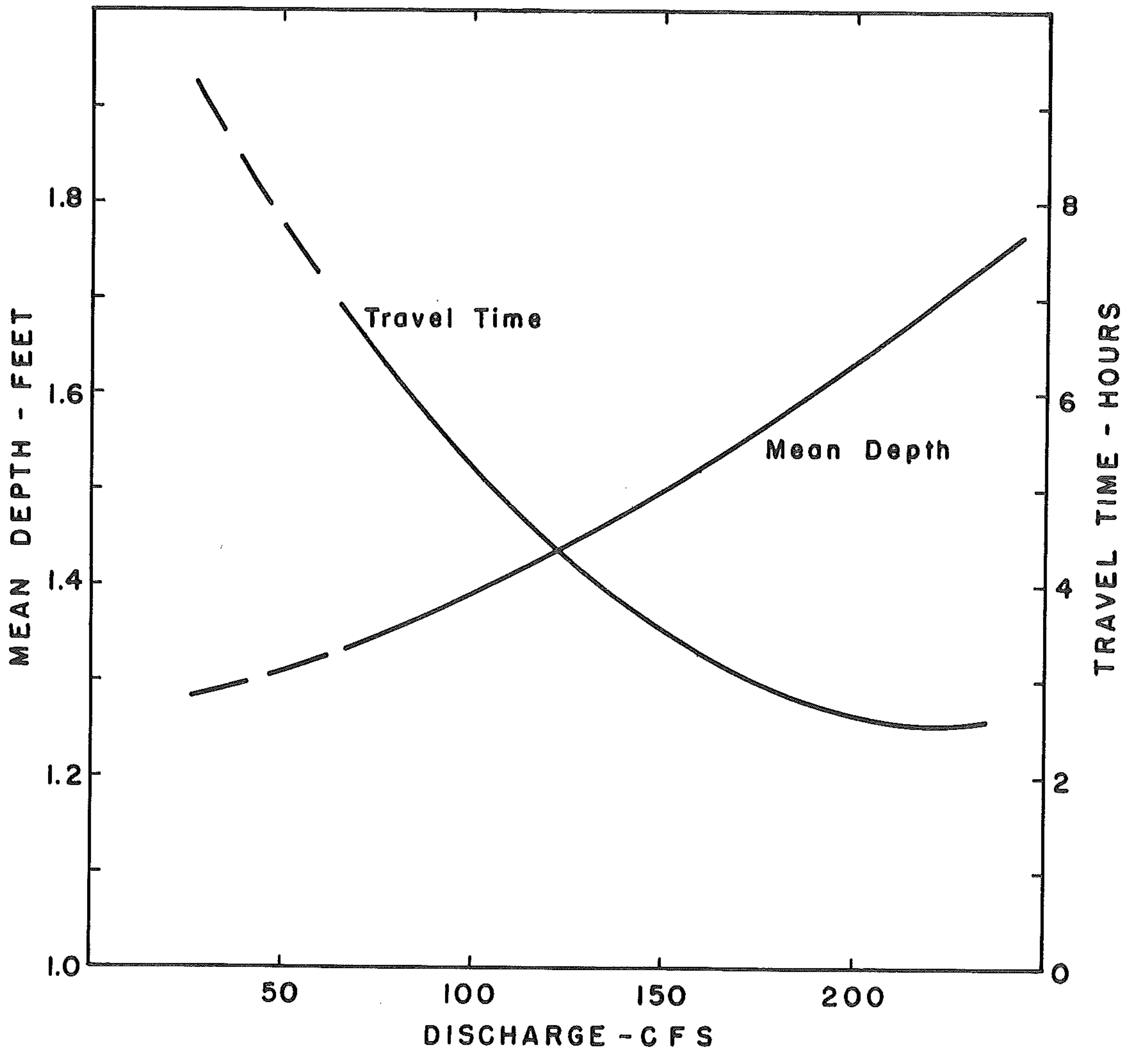

FIGURE 6 – McKinley Creek mean depth and travel time.

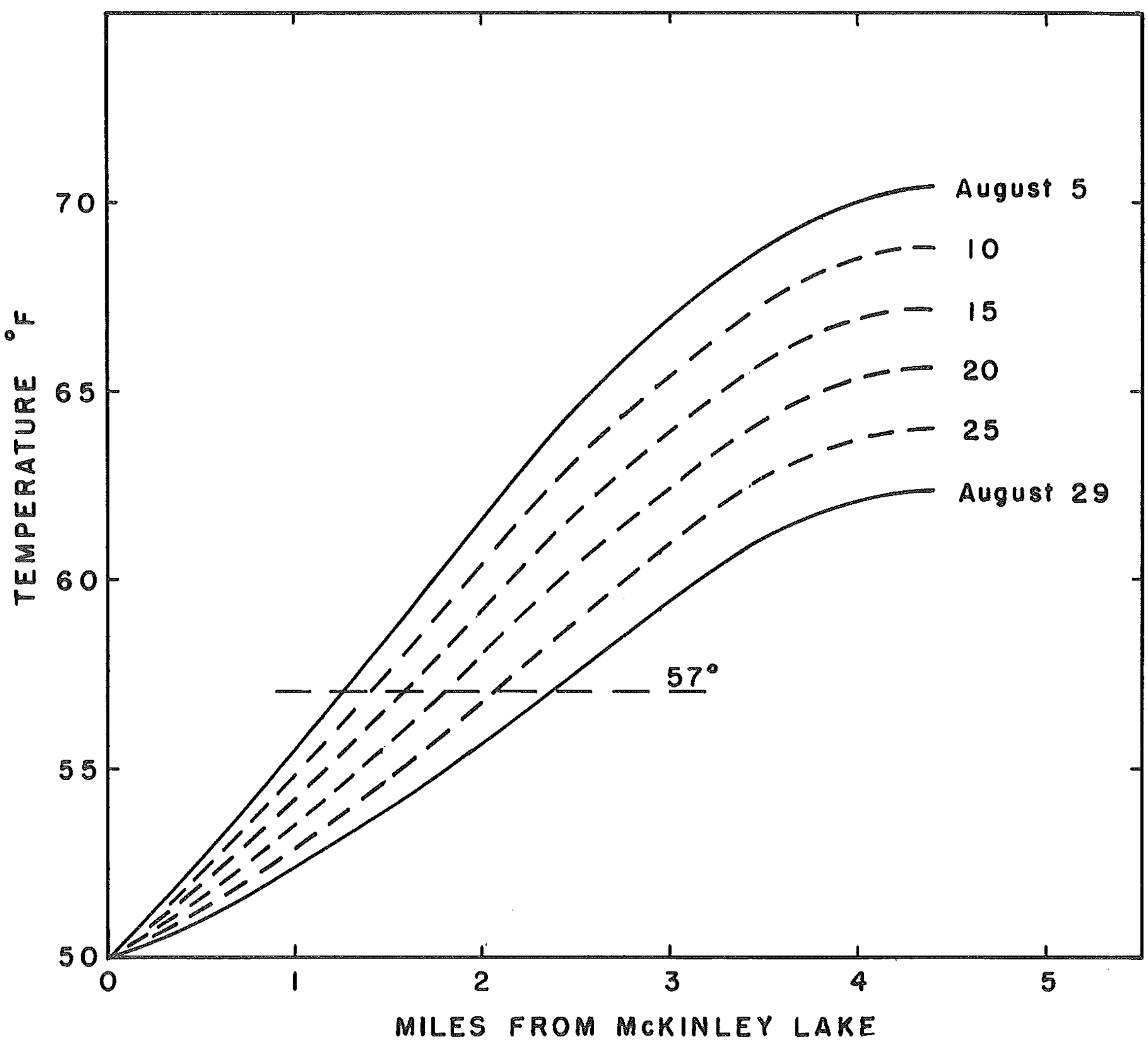

FIGURE 7 - Calculated temperatures between McKinley Lake and mouth of McKinley Creek for a discharge of 30 cfs.

Oxygen and Nitrogen in Lake Water Supply

On the basis of data for Cultus Lake (Harvey 1967) the water obtained from McKinley Lake below a depth of 30 ft was expected to be supersaturated with nitrogen, possibly as high as 112%. Initially, the water withdrawn from the bottom of the lake would have 107% of saturation of nitrogen. Later, as the colder water was withdrawn, it was expected the nitrogen saturation would increase to 112%, and then decrease to 100% when the water originally at the 20 ft depth was displaced down to the pipe intake. As the water flowed down McKinley Creek there would be a tendency for supersaturation to increase as the water temperature increased, but there would be an opposing tendency to equilibrate with the air, due to turbulence in the creek. Mixing with surface water from the lake might also reduce the supersaturation in the water below the control structure.

Because of the potential detrimental effect of nitrogen supersaturation on fish in McKinley Creek, a test was made on July 14 and 15, 1969 to assess the problem. On July 14 at 10 a.m., the surface outflow from McKinley Lake was shut off and a flow of 40 cfs of cold water was released from the pipe. This flow was allowed to run all day and overnight, and on July 15 measurements of dissolved oxygen and nitrogen were made. The results (TABLE 5) indicated the possibility of moderately high supersaturation of nitrogen, and preparations were made for aeration in the diffusion chamber at the control structure if found to be necessary after start of the actual operation.

TABLE 5 - Dissolved nitrogen and oxygen in cold water released from McKinley Lake on July 15, 1969.

Location	Time PST	Temp. °F	Oxygen		Nitrogen	
			ppm	% Saturation	ppm	% Saturation
At pipe outlet	0830	43.5	7.3	67	20.2	113
2¼ miles downstream	0930	48.9	10.5	102	20.2	121.2
	1430	55.0	9.8	102	18.0	116
4 miles downstream	1300	53.0	9.6	98	17.8	112

Temperature Control Facilities

The facilities constructed to control temperature in McKinley Creek consisted of a 66 inch diameter pipeline extending 2,420 ft into the outlet arm of McKinley Lake to a depth of 50 ft, and a control structure at the outlet of McKinley Lake (FIGURE 8). These were constructed during the summer of 1968 and the spring of 1969 at a total cost of $318,000. The increase above the estimate of $272,000 was largely due to inclusion of additional materials and extra work ordered to minimize the effect of construction activity on resident fish populations in the creek. The first 1,200 ft of McKinley Creek below the lake had to be lowered up to 1 ft to enable discharge of water through the pipeline at low lake level. The bed of this portion of the creek was restored at the new slope with 15 inches of gravel in a channel 30 ft wide. The gravel had the same size grading as used in spawning channels for sockeye, and it was anticipated this improvement would increase production of sockeye in McKinley Creek.

The control structure (FIGURE 9) was used to shut off most or all of the warm surface outflow from the lake and to provide the head difference of 1 ft or more needed to force water through the pipe. The structure also stored the lake inflow in excess of the discharge to McKinley Creek during the period of temperature control, and regulated the release of stored water after the period of temperature control.

The pipe is used to draw cold water from the lake and discharge it into McKinley Creek. It has a capacity of 50 cfs at 1 ft head, increasing to 80 cfs at 2.56 ft of head. A large screen structure was placed over the intake end of the pipe to prevent resident fish from being drawn out of the lake. The structure provided 625 sq ft of screened area, covered with a brass screen with 5 mesh per inch of 0.047 inch wire. Steel gratings were placed over the mixing and diffusion chambers at the discharge end of the pipe to prevent adult sockeye from entering the pipe. A fishway at the control structure provides for passage of salmon, trout, and other migratory fish when the structure is being operated. At other times of the year, the control gate on the pipeline is closed and the gates on the control structure are fully open so that there is unrestricted passage for fish into or out of the lake.

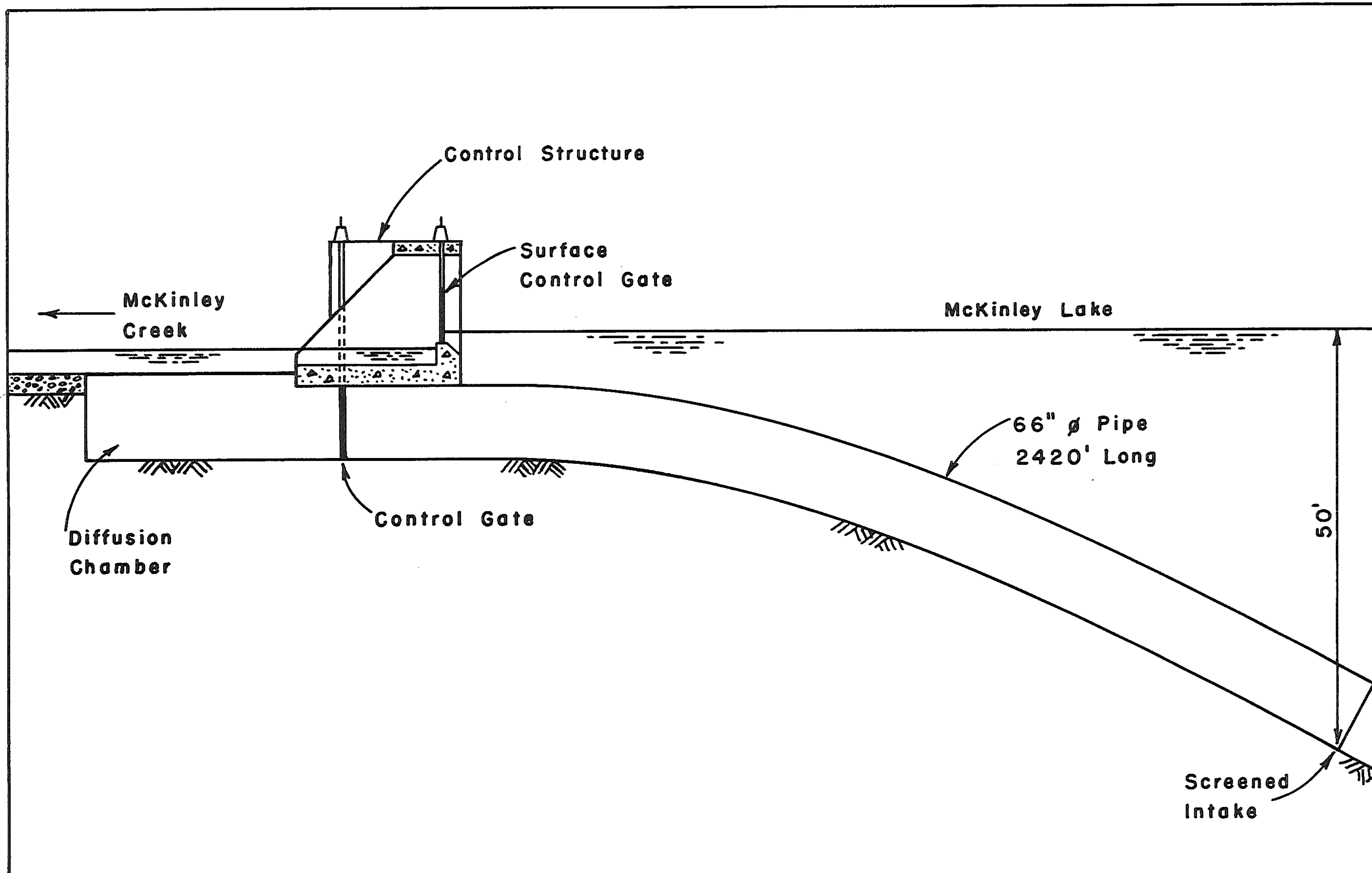

FIGURE 8 - Schematic profile of temperature control works.

FIGURE 9 - Control structure at outlet of McKinley Lake.

Operating Plan

In the design of the investigation, it had been determined that the temperature of the flow below the control structure would not be less than 50°F, partly to conserve the supply of cold water and partly to maintain suitable temperature for spawning in this part of the creek which contained the best spawning grounds. The temperatures of the cold water from the pipe and warm water from the lake surface were measured and the required flows from each source were calculated and then set by regulation of control gates to obtain the theoretical temperature blend desired. The temperature of the blend would be adjusted daily, on the basis of observed results, to obtain the 57°F maximum at a point 2.5 miles downstream. A thermograph was installed at this location (FIGURE 10) to monitor the operation. A thermograph was also placed 0.5 miles downstream from the lake, below two bends in the river, to record the blended water temperature, and another thermograph was placed a short distance upstream from the mouth of the creek.

Because of the limited supply of cold water available in the outlet arm of McKinley Lake, the date for starting the temperature control would not necessarily be August 10, but would be determined in the field by the time of arrival of the first fish at the mouth of McKinley Creek. Also, because of the limited storage available in McKinley Lake, the daily rate of storage would be regulated so that it would not exceed the average rate determined by the storage available at the start of the operation and the expected duration of the test. The temperature control would be required until the peak of spawning, after which temperatures would be restored to normal immediately.

RESULTS

Operation of Project

Sockeye started to arrive at the mouth of McKinley Creek on August 12, and the temperature control was put into operation. A bathythermograph taken at the end of the pipe in the lake (FIGURE 4) indicated a water volume of 1,762.35 acre-ft (881 cfs-days) at a temperature less than 57°F, compared to 929 cfs-days indicated in previous years.

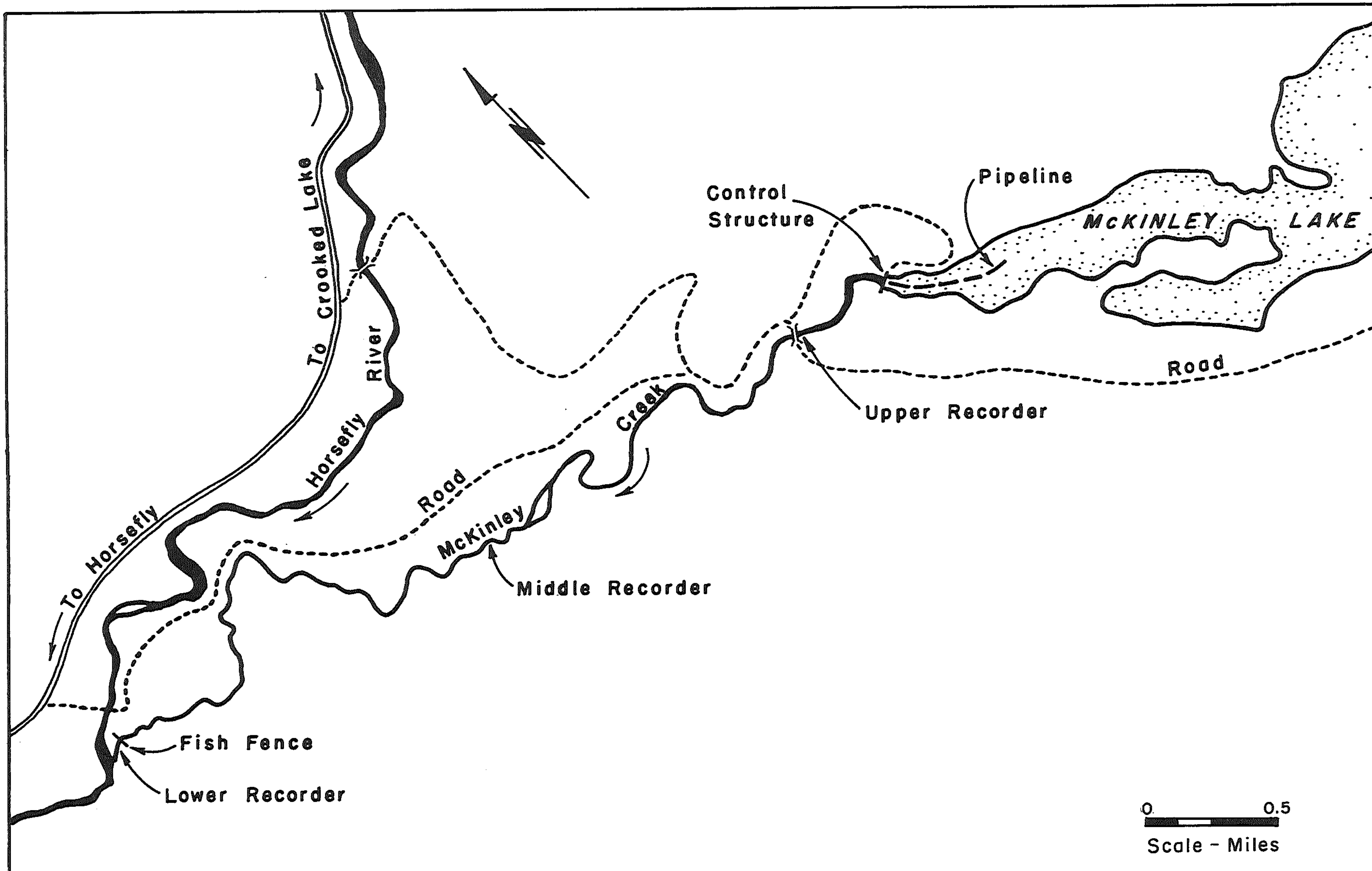

FIGURE 10 - Vicinity map.

At 1 p.m. PST the surface flow from McKinley Lake was shut off except for the flow through the fishway, and the cold water was turned on. The flow in McKinley Creek was reduced from 160 to 65 cfs, and the temperature was reduced from 65.5°F to a theoretical blend of 53°F. The temperature of the mixed flows at the upper recorder dropped to 56°F within 1 hr but did not reach 53°F until 7 p.m. The fish fence at the mouth of McKinley Creek was opened in the afternoon also, and the first sockeye were seen at the outlet of McKinley Lake in the evening. These fish passed through the short fishway into the lake, to continue their migration to spawning grounds in McKinley Creek above McKinley Lake.

On August 12, the level of McKinley Lake was 100.34 ft, indicating 2.56 ft of storage available up to the normal high water in the lake. The discharge of 160 cfs was close to the highest flows recorded or estimated for that date and on the basis of the inclement weather it was anticipated that careful planning of the use of the storage would be necessary.

During the initial 11 days of operation, the inflow to McKinley Lake was very high (TABLE 6) and the flows of warm and cold water were adjusted twice daily to take advantage of the lower cooling requirement at night (TABLE 7). During the entire test period the flows in McKinley Creek ranged from 52 to 115 cfs.

At 8 p.m. on August 31, the flow of cold water was shut off, and a surface flow of 125 cfs was established, with a temperature of 62°F. At that date, the level of McKinley Lake had risen 1.06 ft above the level on August 12.

During the first 10 days of operation the temperature of the cold water from the pipeline varied between 44 and 46°F (TABLE 8). In the final nine days of operation the temperature gradually increased, until on August 31 when the flow was turned off, the temperature was 56.5°F. The flow of cold water ranged from 32 to 78 cfs, increasing as its temperature increased. The total volume of cold water discharged with a temperature less than 56.5°F was 842 cfs-days. The theoretical volume of water above the 50 ft depth with a temperature less than 56.5°F was 836 cfs-days.

TABLE 6 - McKinley Lake inflow in CFS during August 1969.

Date	Inflow, cfs
August 12	372
13	210
14	189
15	199
16	163
17	142
18	139
19	138
20	114
21	178
22	145
23	101
24	179
25	74
26	151
27	28
28	97
29	128
30	121
31	121

Note: Inflow calculated from measured outflow and change in lake level.

TABLE 7 - Discharge from pipeline and in McKinley Creek in CFS during temperature control in August 1969.

Date	Time, hr PST	Pipe Flow cfs	McKinley Creek Total Flow cfs
August 12	13-20	43	65
12-13	20-08	43	90
13	08-20	32	52
13-14	20-08	32	84
14	08-20	43	66
14-15	20-08	43	110
15	08-18	43	63
15-16	18-09	32	115
16	09-12	32	100
16	12-18	32	55
16-17	18-09	32	102
17	09-18	32	71
17-18	18-08	32	96
18	08-19	32	56
18-19	19-08	32	115
19	08-19	32	55
19-20	19-08	32	96
20	08-19	32	53
20-21	19-07	32	64
21	07-19	45	64
21-22	19-07	45	70
22	07-19	45	62
22-23	19-08	45	67
23	08-20	45	62
23-24	20-08	45	57
24	08-19	45	62
24-25	19-07	50	62
25	07-19	45	61
25-26	19-08	50	62
26	08-19	50	63
26-27	19-07	50	55
27	07-19	50	55
27-28	19-07	50	62
28	07-19	50	55
28-29	19-08	50	55
29-30	08-08	50	55
30-31	08-08	70	85
31	08-19	78	88

TABLE 8 - Temperature of cooling water, and calculated temperature of mixed flow below the control structure during August 1969.

Date	Time, hr PST	Cooling Water °F	Calculated Temperature °F of Mixed Flow
August 12	13	46	53
	20	45	56
13	08	44	53
	20	44	57
14	08	44	53
	20	44	58
15	08	46	53
	18	45	58
16	09	45	58
	12	45	53
	18	45	58
17	09	44	53
	18	46	58
18	08	45	53
	19	45	58
19	08	45	53
	19	45	58
20	0745	45	53
	1910	44	53
21	0730	44.5	50
	19	44	50
22	0730	45	50
	19	45	50
23	08	44.5	50
	1930	47.5	50
24	08	45	50
	19	47.5	50
25	0730	46	50
	19	47.5	50
26	08	48	50
	19	49	50
27	0730	50	51
	19	47.5	50
28	0730	49	50
	19	51	51
29	08	52	53
30	08	52	54
31	08	55	56
	19	56.5	-

After September 1 the gates on the control structure were set to discharge 125 cfs. This flow was selected to maintain a stable flow over the spawning grounds in McKinley Creek and at the same time gradually withdraw the 1.06 ft of water accumulated in the lake. However, because of heavy rainfall and resulting increase in lake levels, the discharge increased to 180 cfs by September 20, to 400 cfs by October 6 and about 700 cfs by October 8, and dropped to 620 cfs on October 10. By October 6, the lake level had increased to the high water level usually associated with the spring freshet. Between October 6 and 10, the gates were gradually raised to lower the lake and by October 10, the gates were fully withdrawn, but the discharge of 620 cfs was still very high for the time of year.

Temperatures in McKinley Creek

The daily maximum and minimum temperatures obtained in McKinley Creek during the period of control are shown in FIGURE 11. At the upper end of the natural spawning ground (upper recorder station), a temperature of 57°F maximum was obtained from August 13 to 30. At the middle temperature recorder the 57°F criterion was exceeded by 1 to 4° in the first seven days of operation because of the necessity to discharge as much water as possible without excessive use of the available cold water. Starting on August 20, after the lake inflow reduced, a maximum temperature less than 57°F was maintained until August 29. It had been estimated that the temperature in McKinley Creek at its mouth (lower recorder) could be as high as 62 to 69°F on a clear day depending on flow and date. Because of the cool weather and high discharge, the recorded temperatures did not exceed 61°F from August 13 to 30.

Water temperature at the surface of McKinley Lake ranged from 61 to 68°F maximum daily during the period of control in McKinley Creek. These represent the temperatures that would have occurred in McKinley Creek at the upper station if there had been no control of temperature. During the period of temperature control from August 13 to 31, actual daily maximum temperatures in McKinley Creek at the upper station averaged 10°F lower than the lake surface temperature.

Water temperature data for August 23, one of the few clear warm days during the test, illustrate the changes in temperature as the water flowed down McKinley Creek (FIGURE 12). It is estimated that at the prevailing discharge of 62 cfs water would take about 7 hr to travel the length of

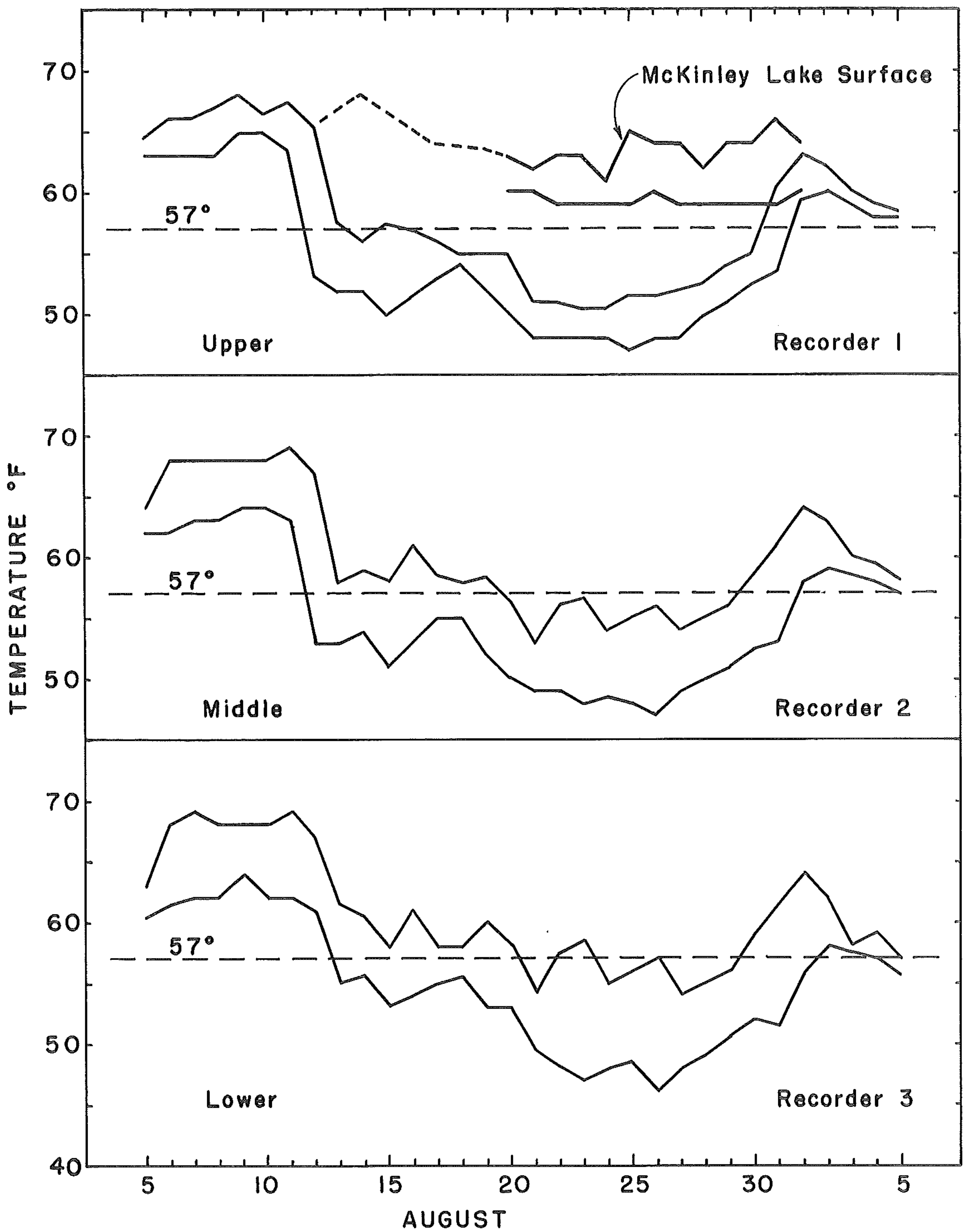

FIGURE 11 - Daily max-min temperature, McKinley Creek and McKinley Lake, August 1969.

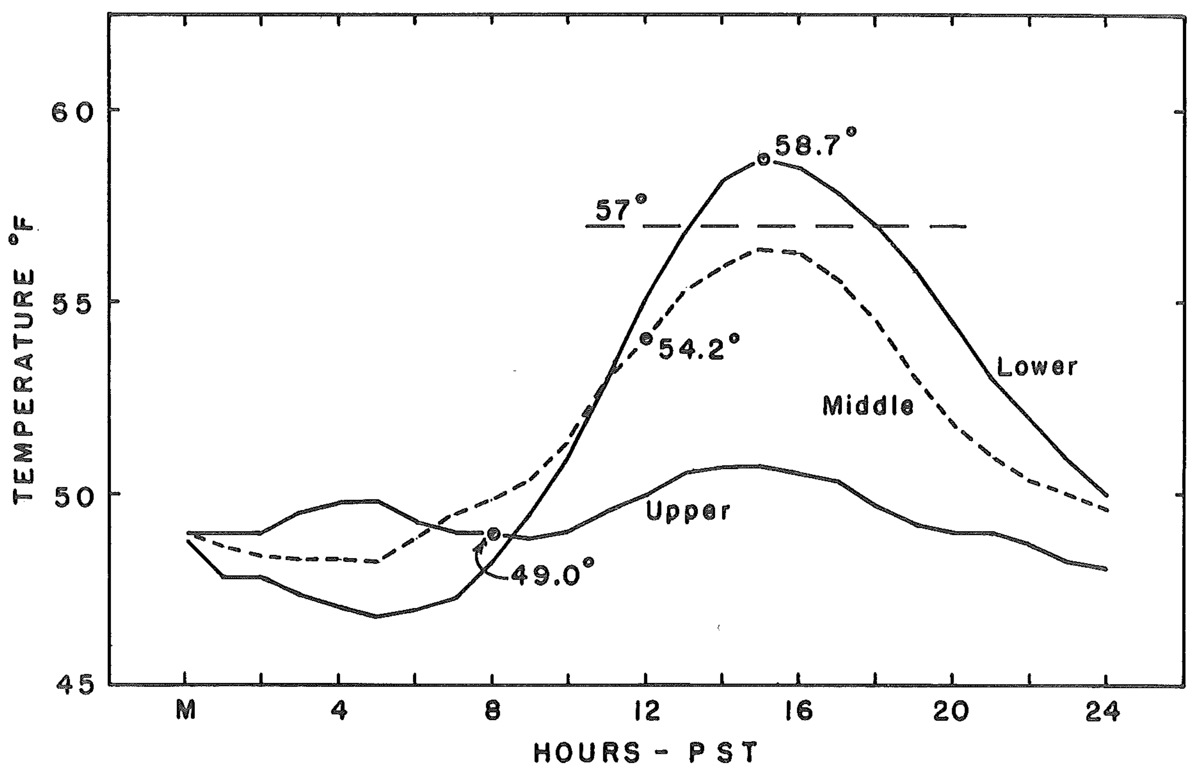

FIGURE 12 - McKinley Creek temperatures, August 23, 1969.

the creek. The temperature of a body of water passing the upper station at 8 a.m. rose 5.2°F at the middle station 4 hr later and another 4.3°F at the mouth 7 hr later. The daily average temperature at the upper station was 49.4°F, compared to 51.6°F at the middle station and 52.1°F at the lower station.

Estimates of the temperature rise at a flow of 62 cfs with a starting temperature of 48.9°F at 9 a.m. for August 23, indicated a rise of 8.3°F at the middle station, and another 4.8°F at the mouth 7 hr later. The estimates indicate a greater increase than actually occurred on August 23. The differences are most probably attributable to a greater amount of shade cover than used in the estimates, which were based on shade factors determined for the Horsefly River. The original estimates for a flow of only 30 cfs were made to determine the maximum expected temperature rise, for planning purposes. The actual results indicate that the criterion of 57°F maximum could be sustained over a greater length of McKinley Creek than anticipated.

During the period August 13 to 30, the daily maximum temperature at the surface of McKinley Lake averaged 64.0°F, at the upper recorder it averaged 54°F, at the middle recorder it averaged 56.8°F and at the lower recorder it averaged 57.6°F.

Dissolved Oxygen and Nitrogen

Measurements of dissolved oxygen and nitrogen were made to check the possibility of nitrogen supersaturation in the cold water released from McKinley Lake as it warmed up while flowing down McKinley Creek. The results (Martens 1969) summarized in TABLE 9, confirm the existence of nitrogen supersaturation, although at much lower levels than indicated by the test on July 15, using only the cooling water. The nitrogen supersaturation in McKinley Creek was lower than measured in the Horsefly River (Williams 1972).

TABLE 9 - Dissolved nitrogen and oxygen in McKinley Creek on August 13, 1969.

Location	Time PST	Temp. °F	Oxygen		Nitrogen	
			ppm	% Saturation	ppm	% Saturation
At control structure	1030	50.1	6.8	66.6	16.5	101.3
	1300	50.1	6.8	66.6	16.7	102.5
$2\frac{1}{4}$ miles downstream	1200	57.0	8.9	95.8	15.8	104.0
	1530	59.0	8.85	97.4	15.6	105.3
	1615	59.0	8.9	98.0	15.8	106.9

The contact between water and air in the riffles increased the concentration of dissolved oxygen by approximately 2 ppm in the $2\frac{1}{4}$ miles of travel, and reduced the concentration of nitrogen by approximately 1 ppm.

Available evidence from Corbold Creek, a tributary of the Upper Pitt River (Internat. Pacific Salmon Fish. Comm. Unpub. data) and from the McNary spawning channel,(Chambers) indicated that adult salmon would not be affected by these relatively low levels of nitrogen supersaturation and no remedial action was considered necessary. No evidence was seen of any detrimental effect on the sockeye in McKinley Creek.

Temperatures in McKinley Lake

The withdrawal of cold water from McKinley Lake resulted in progressive lowering of the thermocline until by September 1, the top 40 ft was nearly isothermal at 61°F (FIGURE 13). After that the lake continued to cool and by October 8 it was isothermal down to 50 ft or more. The cooling sequence was quite similar to the natural sequence illustrated by data for 1968 (FIGURE 14), except the isothermal conditions extended about 10 ft deeper in 1969. The withdrawal of cold water from the outlet basin had no effect on temperatures in the main part of the lake because of the shallow sill between the two parts of the lake which prevented withdrawal of cold water from the main basin. A check was made at this sill on August 25 and it was found that the temperature ranged between 62°F at the surface and 61°F at the bottom, indicating that only the warm surface water was moving across the sill.

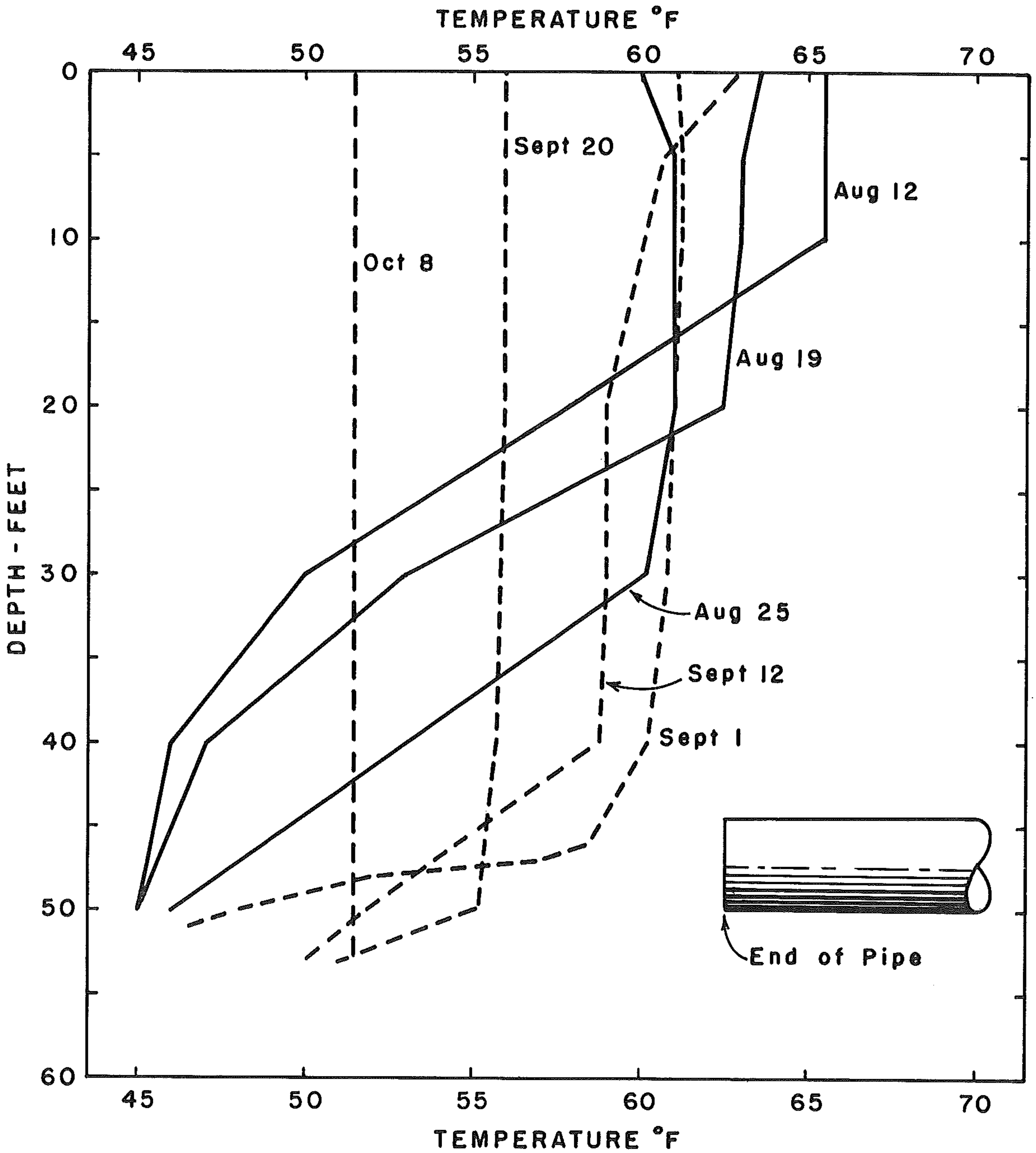

FIGURE 13 - McKinley Lake temperatures, before, during and after withdrawal of cold water, 1969.

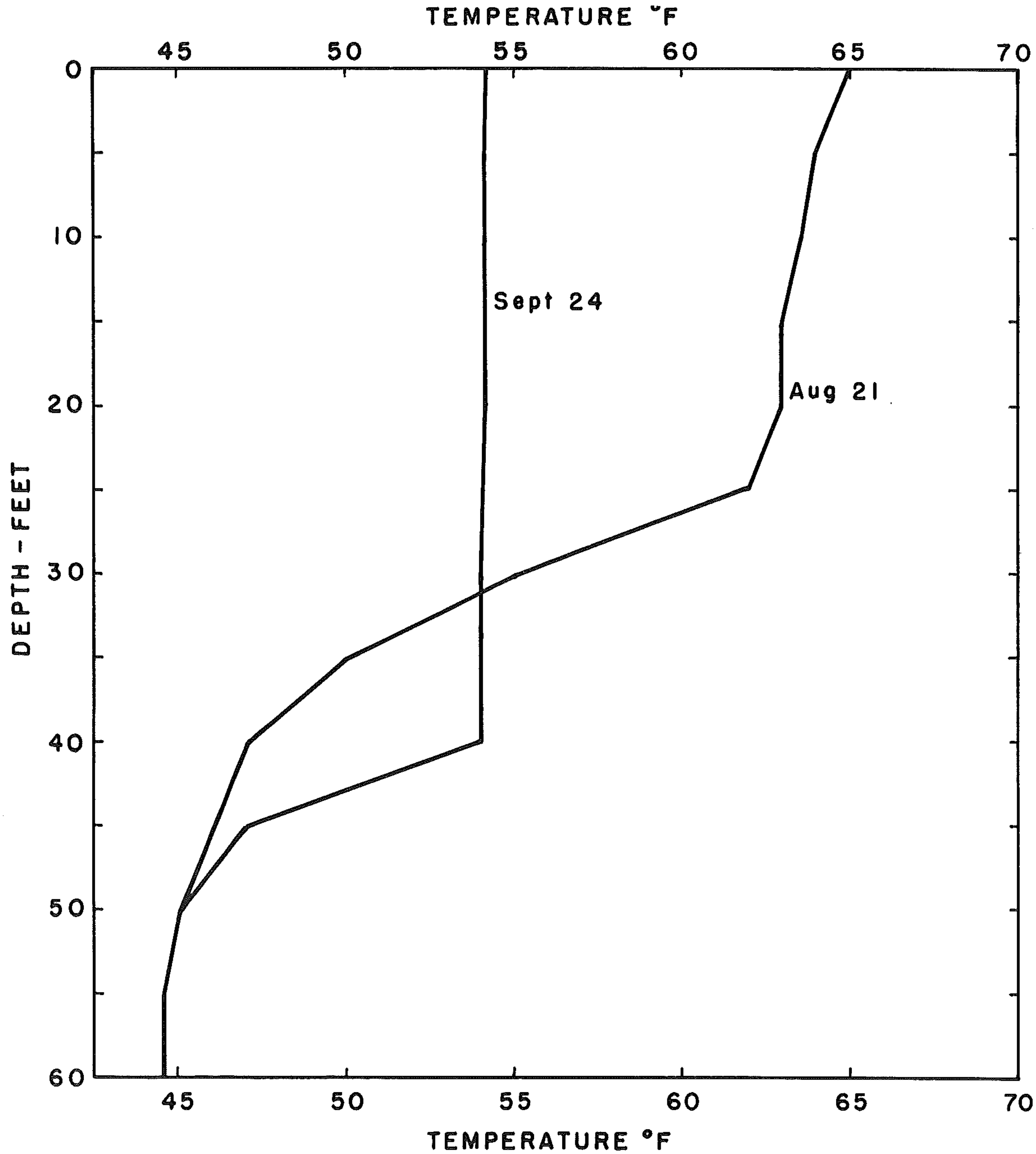

FIGURE 14 - McKinley Lake temperatures, August 21 and September 24, 1968.

Spawning Distribution in McKinley Creek

From live counts and dead recovery it was estimated that 19,512 sockeye spawners were in McKinley Creek between the temperature control structure and the confluence with Horsefly River. At the peak of spawning (August 27 to 30), 63% of the fish were in the upper section of the creek, upstream from the middle recorder site, and 37% were below this point. In the upper half, numerous schools of sockeye migrated up to the control structure through the 1,200 ft section of reconstructed stream channel. The fish roamed up and down this channel, but none were seen spawning, and there was no evidence of nests. Spawning did occur in McKinley Creek immediately downstream from this channel in the undisturbed stream bed. Since the gravel in the reconstructed channel had been in place for a full year, it had been expected that any foreign odors in the gravel would have had opportunity to be washed away. However, it appears that the fish must have detected some artificiality in the gravel. In this respect the behavior is similar to that observed at the Weaver Creek spawning channel when it was first put in operation in 1965. On that occasion the sockeye were reluctant to enter the spawning channel and had to be diverted into it by a fence and had to be prevented from leaving once they had entered the channel. In subsequent years, however, the sockeye entered the channel readily, and entry had to be controlled. Therefore it is expected that the reconstructed portion of McKinley Creek will be used by sockeye in subsequent years when there are sufficient spawners to fully utilize the natural spawning grounds and the additional area provided in the reconstructed creek bed.

CONCLUSIONS

1. The estimated volume of cooling water available in the outlet arm of McKinley Lake, which was determined from an echo sounder survey of the lake bottom and a bathythermograph taken at the end of the pipe in the lake, agreed closely with the actual volume obtained during the test operation.

2. The rise in temperature of water as it flowed down McKinley Creek was less than estimated for a clear sky condition, probably because of a greater than estimated amount of shading of McKinley Creek by the bordering forest.

3. The concentration of dissolved oxygen in the cooling water increased to near saturation after $2\frac{1}{4}$ miles of travel down McKinley Creek. The concentration of dissolved nitrogen decreased, but not quite sufficient to offset the effect of the rise in temperature, resulting in approximately a 2 to 5% increase in per cent saturation to a high of 106.9%. This amount of supersaturation of nitrogen was not considered sufficient to have serious detrimental effect on the adult sockeye and no evidence was seen of harmful effects.

4. The release of cold water from the bottom of McKinley Lake lowered the maximum daily temperature of McKinley Creek below the control structure an average of 10°F below what would have occurred without the temperature control. The desired control of water temperature to 57°F maximum in the upper part of McKinley Creek was obtained for a period of 9 days at the middle recorder and 17 days at the upper recorder. The period of temperature control was shortened by the need to regulate storage in McKinley Lake. If accurate forecasts of the inflow to McKinley Lake could be made, more precise use of the available cold water would be possible, and the temperature control could be obtained for a longer period.

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