SUMMER REAERATION AND WINTER ICE REMOVAL FROM LAKES AND RESERVOIRS

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ABSTRACT

This report has three parts. Part one concerns an experiment conducted on Lake Texoma with an eight-foot propeller. Outflows ranged from 50 to 600 cubic feet per second. Maximum improvement for the various parameters occurred at different release rates. Maximum improvements observed were a 83-percent reduction in turbidity, a 68-percent reduction in sulfides, a 49-percent reduction in manganese, and a 53-percent reduction in phosphorus.

Part two concerns experiments conducted at Pine Creek Reservoir near Valliant, Oklahoma. These experiments were with outflows ranging from 30 to 90. Experiments were conducted with various sizes of propellers pumping surface water downward to the vicinity of the outlet. Reductions of the levels of iron and manganese in the outlet releases of 60 to 70 percent have been achieved with less than 2 horsepower input.

Part three concerned winter ice removal on a 100-acre lake with a six-foot propeller pumping water upward. During a severe winter for Oklahoma when ice thickness was approximately nine inches, an open area of approximately one acre was maintained. This should be of benefit to waterfowl and should prevent winter fish kills under snow covered lakes.

PART I

LOCALIZED DESTRATIFICATION AT LAKE TEXOMA

PART I

LOCALIZED DESTRATIFICATION AT LAKE TEXOMA

By James E. Garton,[1] Kerry M. Robinson,[2] and Richard E. Punnett[3]

INTRODUCTION

As water changes from a flowing environment to an essentially standing environment, the effects on water quality can be dramatic. Smalley and Novak (9) stated that one of the most significant changes is in water temperature or heat distribution within the impoundment. More than any other environmental change, this one factor determines what takes place biologically, chemically, and physically in the reservoir.

Many temperate reservoirs stratify into three zones in summer, Birge and Juday (1). The surface zone or epilimnion has waters which are warm, well mixed, and relatively high in dissolved oxygen. The lower zone of water within the reservoir, the hypolimnion, is generally at a much lower temperature and essentially isolated from mixing. Chemical reduction and biological respiration reduce and often deplete dissolved oxygen supplies. Hydrogen sulfide, ammonia nitrogen, iron, manganese, and phosphorous can occur at high concentrations. When reservoir outlets are located within the hypolimnion, released waters can cause potable water supply problems, reduce downstream assimilative capacity, and stress if not kill certain aqua-

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tic biota. The zone of rapid changes in temperature and dissolved oxygen between the epilimnion and hypolimnion is the metalimnion. The density gradient within the metalimnion suppresses wind induced circulation of hypolimnetic waters. The depth of the metalimnion is mainly determined by the wind stress applied to the water surface, Hutchinson (4).

An axial flow pump was developed by Quintero and Garton (7) to pump oxygen rich surface waters down into the hypolimnion. Additional work conducted by Steichen (10), Strecker (11), and Punnett (6) demonstrated the system could be used to destratify large bodies of water and improve overall water quality. These studies suggested the possibility of using a Garton Pump to improve release water quality without destratifying the entire reservoir. Field tests performed by Garton and Jarrell (3) and Dortch and Wilhelms (2) demonstrated the applicability of localized destratification at Lake Okatibbee, Mississippi (Figure 1). Hydraulic modeling investigations were also conducted by Moon, McLaughlin, and Moretti (5). Continued study of the Garton Pump as a means of improving release water quality is reported by Robinson (8) and herein.

OBJECTIVE

The objective was to measure the effectiveness of the pump in reducing undesirable constituents in the downstream water as a function of reservoir release rate to pumping rate ratio.

STUDY LOCATION

Release water quality improvement tests were conducted at Lake Texoma during the summer of 1980. Lake Texoma is on the southern Oklahoma - northern Texas border. The dam is located on the Red River in Bryan County,

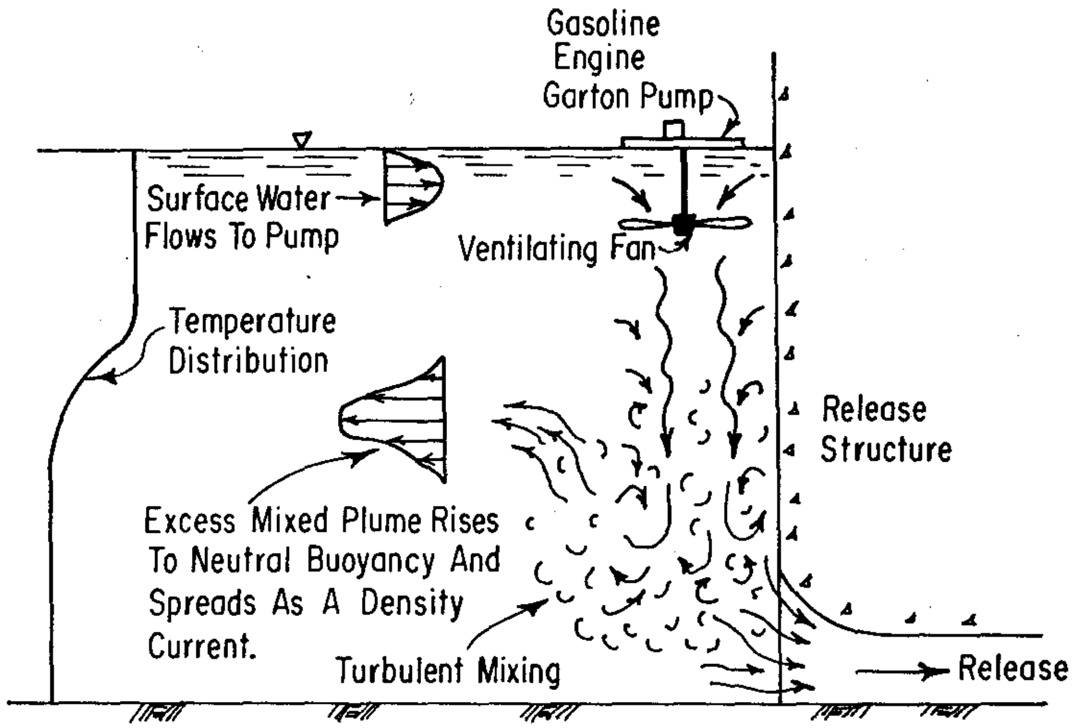

Figure 1-1. Localized Mixing (After Dortch, M.S. and Wilhelms, S. C. (2))

Oklahoma, and Grayson County, Texas. The dam site is approximately 5 mi. (8 km) northwest of Denison, Texas and 15 mi. (24 km) southwest of Durant, Oklahoma. The dam is a rolled earthfill structure with an impervious fill in the upstream portion of the embankment and a pervious fill on the downstream portion. Total length of the dam is 17,200 ft. (5244 m), and maximum height above the streambed is 165 ft. (50.3 m) (Tulsa District Corps of Engineers (12)).

The project was approved for construction in 1938 for flood control and power generation and was completed by 1944. At flood control elevation, 640 ft. (195.1 m) above sea level, the impoundment surface area is 143,410 acres (58,036 ha) with a total storage capacity of 5.27×10^6 ac. ft. (6.63×10^9 m^3) of water. At the power pool elevation of 617 ft. (188.1 m) above sea level, the surface area is 89,000 ac. (36,045 ha), and the storage capacity is 1.67×10^6 ac. ft. (2.06×10^9 m^3). The drainage area controlled by Lake Texoma is 39,700 mi^2 (102,828 km^2).

EXPERIMENTAL EQUIPMENT

The Garton Pump consisted of an 8-foot (2.44 m) propeller, orifice shroud, a support platform, and a gasoline engine operating through a right angle reduction gearbox (Figure 2). The propeller was an aluminum ventilation fan manufactured by Aerovent, and the six propeller blades were set at a pitch of 22° measured at two-thirds of the propeller radius.

A redwood raft filled with gasoline resistant expanded foam supported the pump in the water. The support platform was 6.6 ft. (2 m) wide, 7.9 ft. (2.4 m) long, and 1 ft. (0.3 m) thick.

For these relatively short duration tests, the 16 hp (11.9 kW) gasoline engine used, allowed rapid pump installation and variable speed capability.

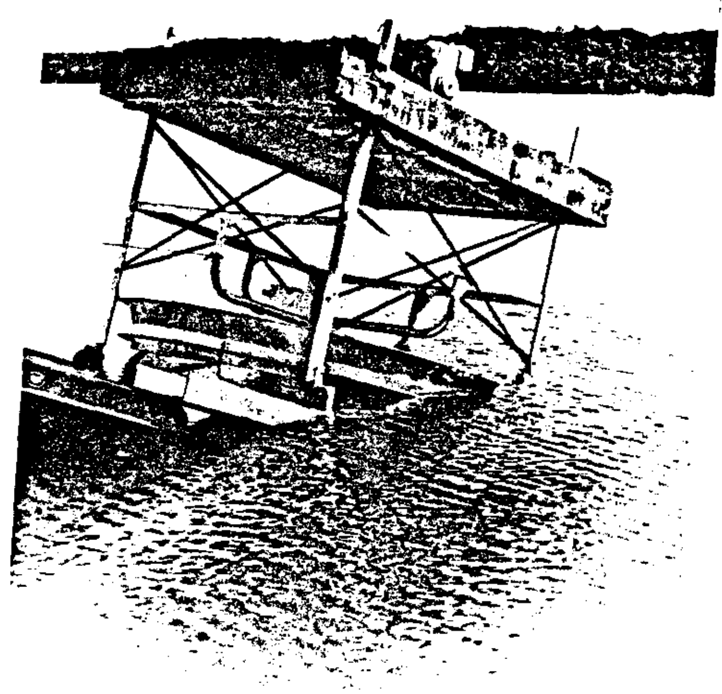

Figure 1-2. The Wheel-Mounted Pump Being Unloaded From the Trailer

The pump was powered through a 29.5:1 Falk gearbox. During these tests the pumping rate was calculated to be 143 cfs (4.06 m^3/sec), the velocity 2.85 ft/sec (0.87 m/sec), and the propeller power 3.9 hp (2.9 kW). The 46.7 rpm output was obtained by adjusting the speed of the engine.

A Kenmerer water sampler was used to collect water samples from different depths. A Hydrolab #4041 meter was used to measure temperature, dissolved oxygen, pH, and conductivity. Turbidity was measured with a Hach turbidimeter. Total iron, manganese, ammonia nitrogen, pH, reactive phosphorous, and sulfide concentrations were determined on site using Hach chemicals and a Hach DR/2 spectrophotometer. All measuring equipment was standardized/calibrated according to manufacturer's specifications. Water samples were analyzed on site in a mobile laboratory.

METHODS AND PROCEDURES

Release water quality improvement tests were conducted at Lake Texoma on 17-18 August 1980. Lake water quality profiles were obtained prior to pump operation. Depth of penetration tests were also conducted prior to release improvement tests to insure that the plume of pumped water penetrated to outlet depth. These preliminary profiles and tests were conducted at the buoy line just upstream from the intake structure to insure that the probe would not be drawn into the intake.

Permission was granted by the Corps of Engineers to change the release rates through the dam. The pump was positioned above the outlet works and operated for 30 minutes at each release rate. Samples were taken at the downstream outlet before, during, and after the pump tests. Samples were analyzed as soon as possible after collection. Comparison of various water quality parameters, with and without pumping, was then possible.

The pump discharge rate was calculated using the fan laws and the manufacturer's stated performance in air for the propeller as reported by Strecker (11).

Changes in temperature or enthalpy of release waters were used to determine the amount of surface water pumped down to and released from the outlet at each test discharge. From preservation of continuity the enthalpy tracer was determined from the equation:

$$h_0 Q_0 = h_1 Q_1 + h_2 Q_2 \qquad (1)$$

in which h_0 = enthalpy of release water while pumping; Q_0 = release rate through outlet while pumping; h_1 = enthalpy of release water without pumping; Q_1 = release rate through outlet without pumping; h_2 = enthalphy of surface waters above propeller; Q_2 = release rate of surface waters above propeller. However, for conservation of flow:

$$Q_0 = Q_1 + Q_2 \qquad (2)$$

therefore,

$$Q_1 = Q_0 - Q_2 \qquad (3)$$

Substituting equation (3) into equation (1) and simplifying provides the following equation:

$$\text{Dilution Factor} = \frac{Q_2}{Q_0} = \frac{h_0 - h_1}{h_2 - h_1} \qquad (4)$$

PRESENTATION AND ANALYSIS OF DATA

Profiles

Release improvement tests were conducted at Lake Texoma on 18 August 1980 using the 8-foot (2.44 m) pump. The water surface elevation was 90.9 ft. (27.7 m) above the invert of the 20-foot (6.1 m) diameter flood control conduits. The epilimnion extended from the surface to a depth of approximately 52.5 ft. (16.0 m), and the metalimnion extended from 52.5 ft. to 65.5 ft. (16.0 to 20.0 m) (Figure 3). The reservoir was anoxic below a depth of 59 ft.

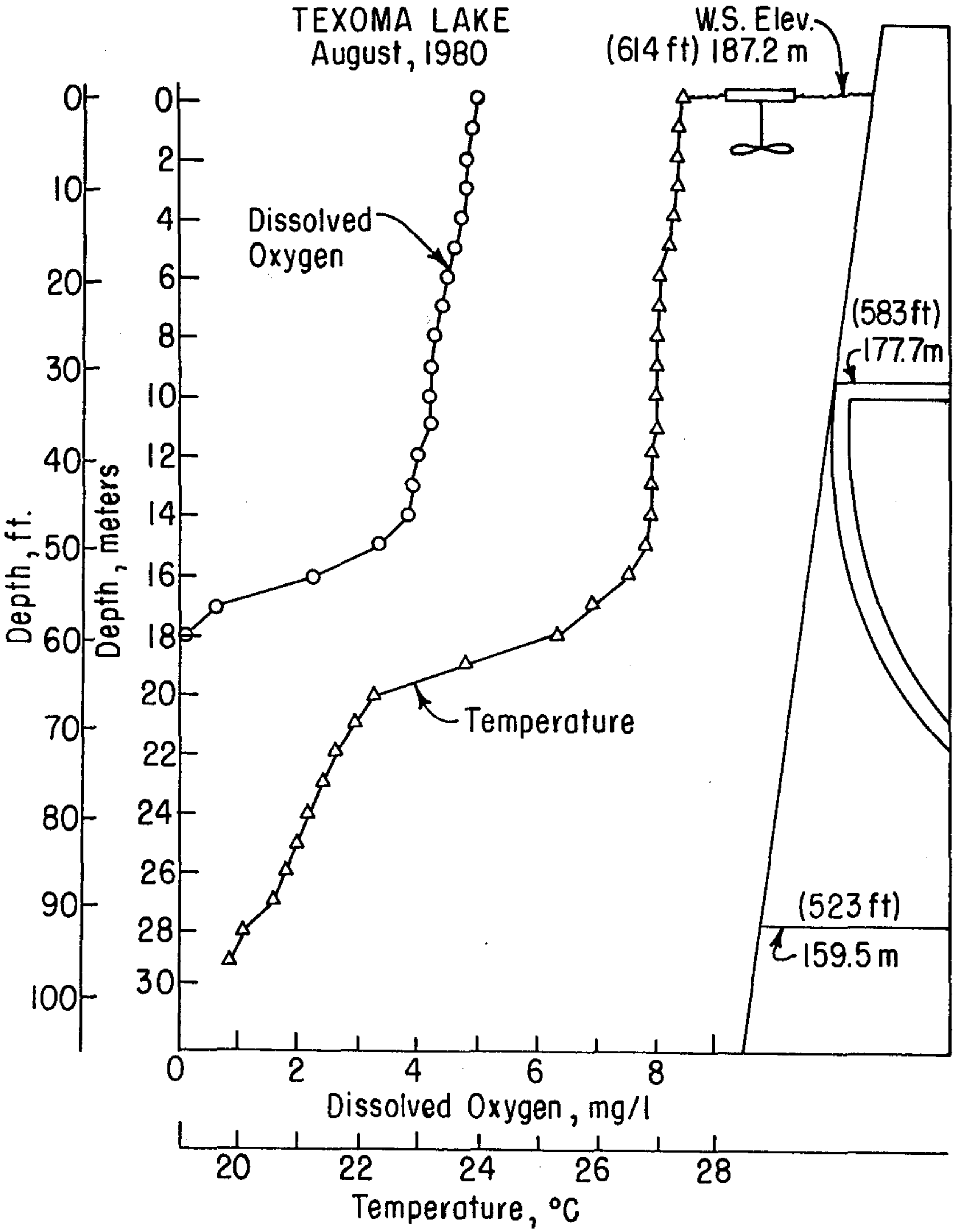

Figure 1-3. Temperature and Dissolved Oxygen Profiles at Lake Texoma on 18 August 1980

(18.0 m). The 20-foot (6.1 m) diameter outlet was located entirely in the hypolimnion. The water quality profiles within the lake are shown in Figures 4 and 5. Turbidity, ammonia nitrogen, phosphorus, sulfides and manganese were relatively uniform from the surface to a depth of 50 feet. Below 50 feet they were stratified, with the higher concentrations being at the level of the intake opening. The pH and total iron concentrations were fairly uniform with depth, and obviously could not be greatly affected by localized mixing. A strong hydraulic jump within the release structure increased oxygen levels at the outlet; therefore, dissolved oxygen was not a reliable indicator of the effects of pumping.

Release Water Quality

The 8-foot (2.44 m) diameter pump was operated at a pumping rate of 143 ft^3/sec (4.06 m^3/sec), which required 46.7 propeller revolutions per minute. The calculated discharge velocity was 2.85 ft/sec (0.87 m/sec). A depth of penetration test was conducted at this pumping rate prior to the dilution test, and the plume of pumped water penetrated to the reservoir bottom.

The pump was operated for approximately 30 minutes at release rates of 50, 150, 300, 450, and 600 cfs (1.4, 4.2, 8.4, 12.6, and 16.8 m^3/sec). Samples of release water without pumping were collected at release rates of 50 cfs (1.4 m^3/sec), 300 cfs (8.4 m^3/sec), and 600 cfs (16.8 m^3/sec). Tests were conducted from low to high release rates. The effect of pumping on release water temperature, turbidity, total iron, manganese, sulfide, phosphorous, and ammonia nitrogen is shown in Figures 6 through 12, respectively.

Figure 6 shows that the temperature of the released water with the pump operating was higher than the temperature with the pump not operating at

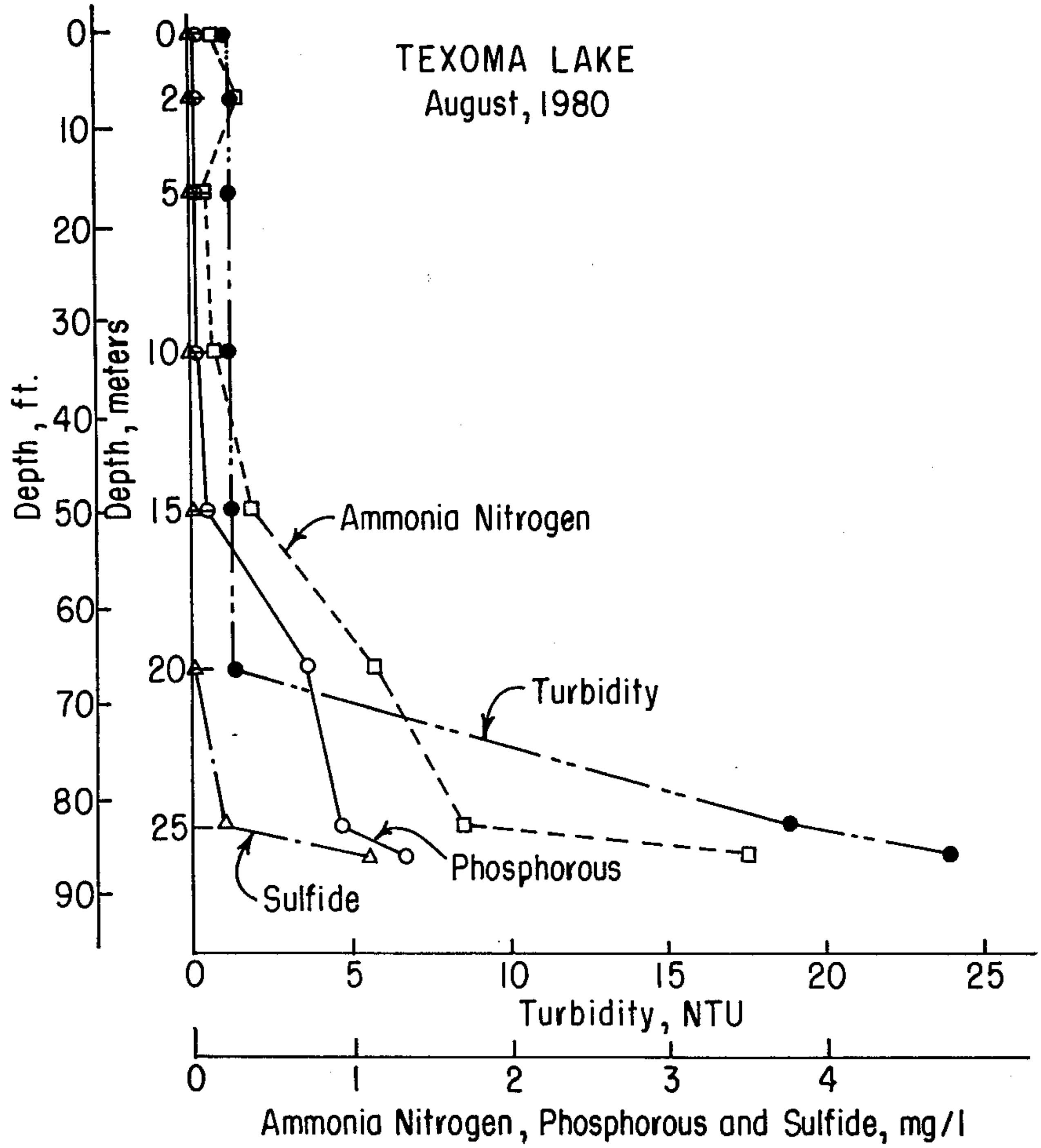

Figure 1-4. Ammonia Nitrogen, Phosphorous, and Sulfide Profiles at Lake Texoma, 18 August 1980

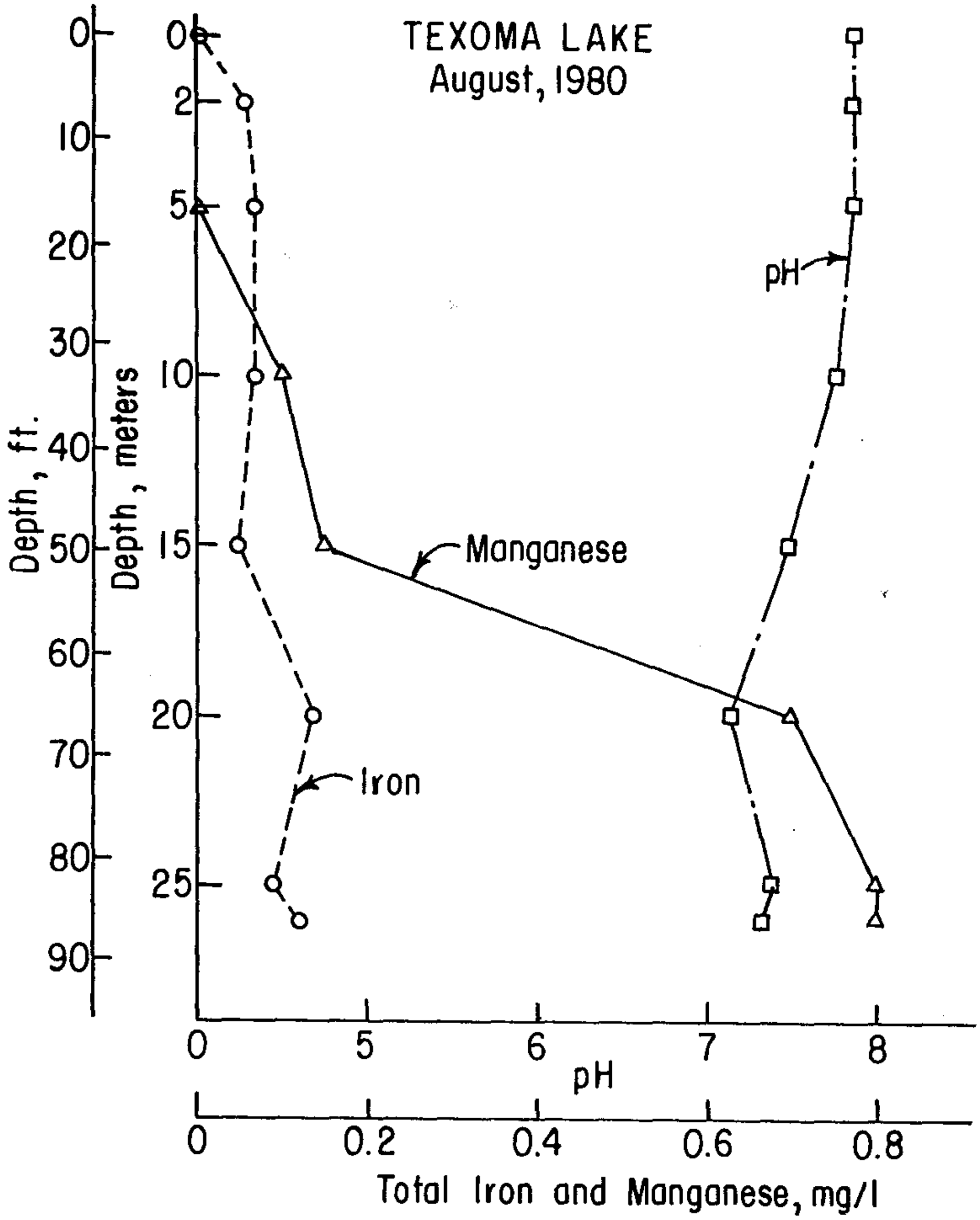

Figure 1-5. Iron and Manganese Profiles at Lake Texoma, 18 August 1980

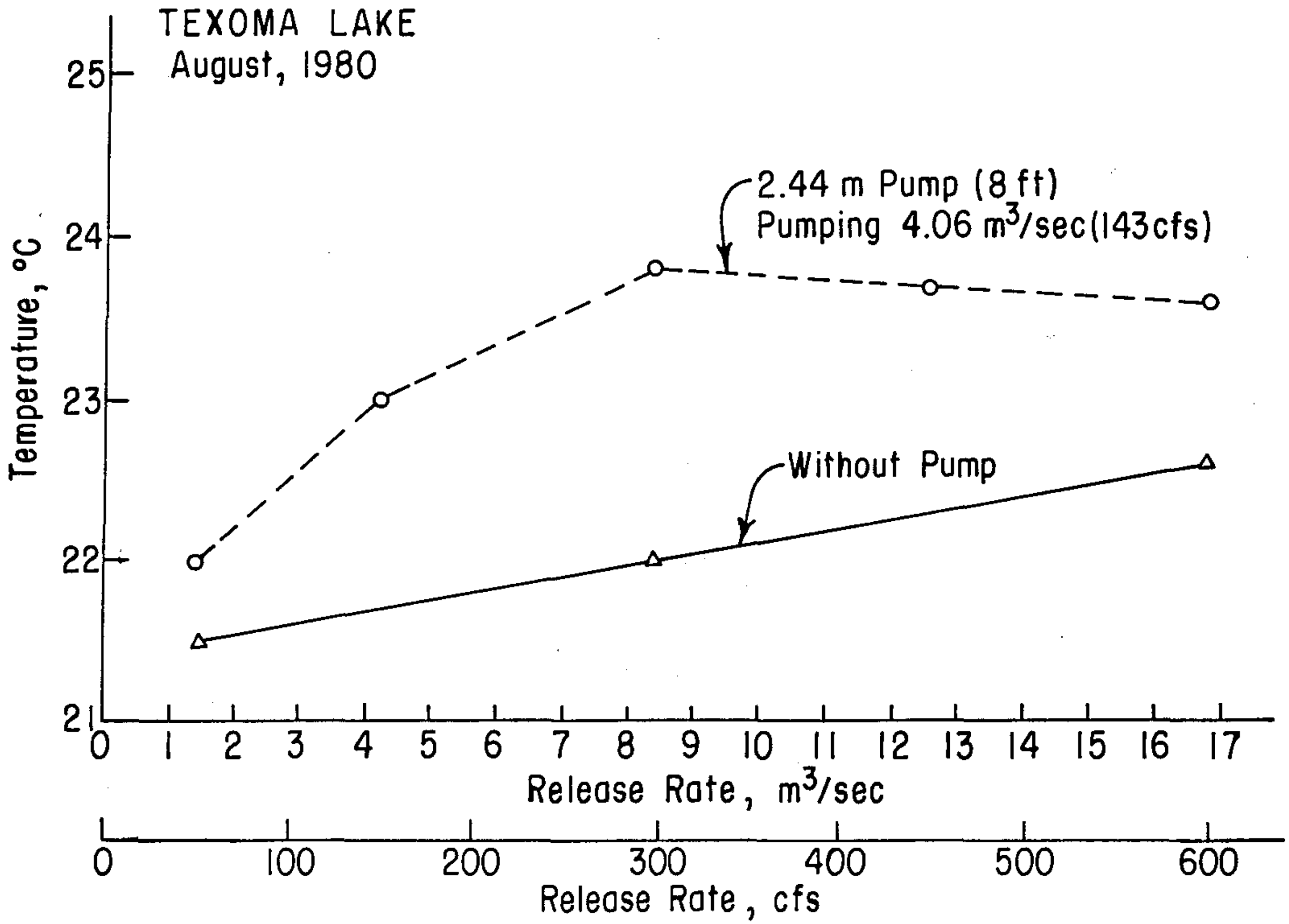

Figure 1-6. Temperature as a Function of Release Rate at Lake Texoma

each of the release rates studied. The maximum temperature increase observed was 3.24^{O}F (1.8^{O}C) at 300 cfs (8.4 m^3/sec). Downstream temperature increase may not be desirable if there is a cold-water fishery downstream.

Figure 7 indicates the greatest effect of any of the parameters. At a flow of 300 cfs (8.4 m^3/sec), the improvement in turbidity was 83 percent. A considerable improvement was observed over a wide range of flows.

In Figure 8, no difference is observed in the level of total iron. As Figure 5 showed, total iron was not strongly stratified, so pumping was not expected to affect the released water.

A 49-percent reduction in manganese is indicated in Figure 9 at a release rate of 150 cfs (4.2 m^3/sec); at a release rate of 600 cfs (16.8 m^3/sec) there was no benefit from pumping.

Sulfide was reduced 68 percent at a flow of 50 cfs (1.4 m^3/sec) as shown in Figure 10. As was true with manganese, the effect disappeared at a release rate of 600 cfs (16.8 m^3/sec). This may have been due to the increasingly strong hydraulic jump developed within the outlet tube which would tend to more fully aerate and oxidize the outflow.

Phosphorus behaved almost opposite to the two previous substances as shown in Figure 11. There was no effect at low release rates; but at the maximum rate of 600 cfs (16.8 m^3/sec), there was a 53-percent reduction in phosphorus. Whether this effect would be maintained over a long period is unknown.

Ammonia nitrogen was improved a moderate amount by pumping. A 37-percent improvement is indicated in Figure 12. An improvement was observed at each rate studied.

All release water quality parameters measured were improved by pump operation. Table I lists the maximum percentage improvement for selected

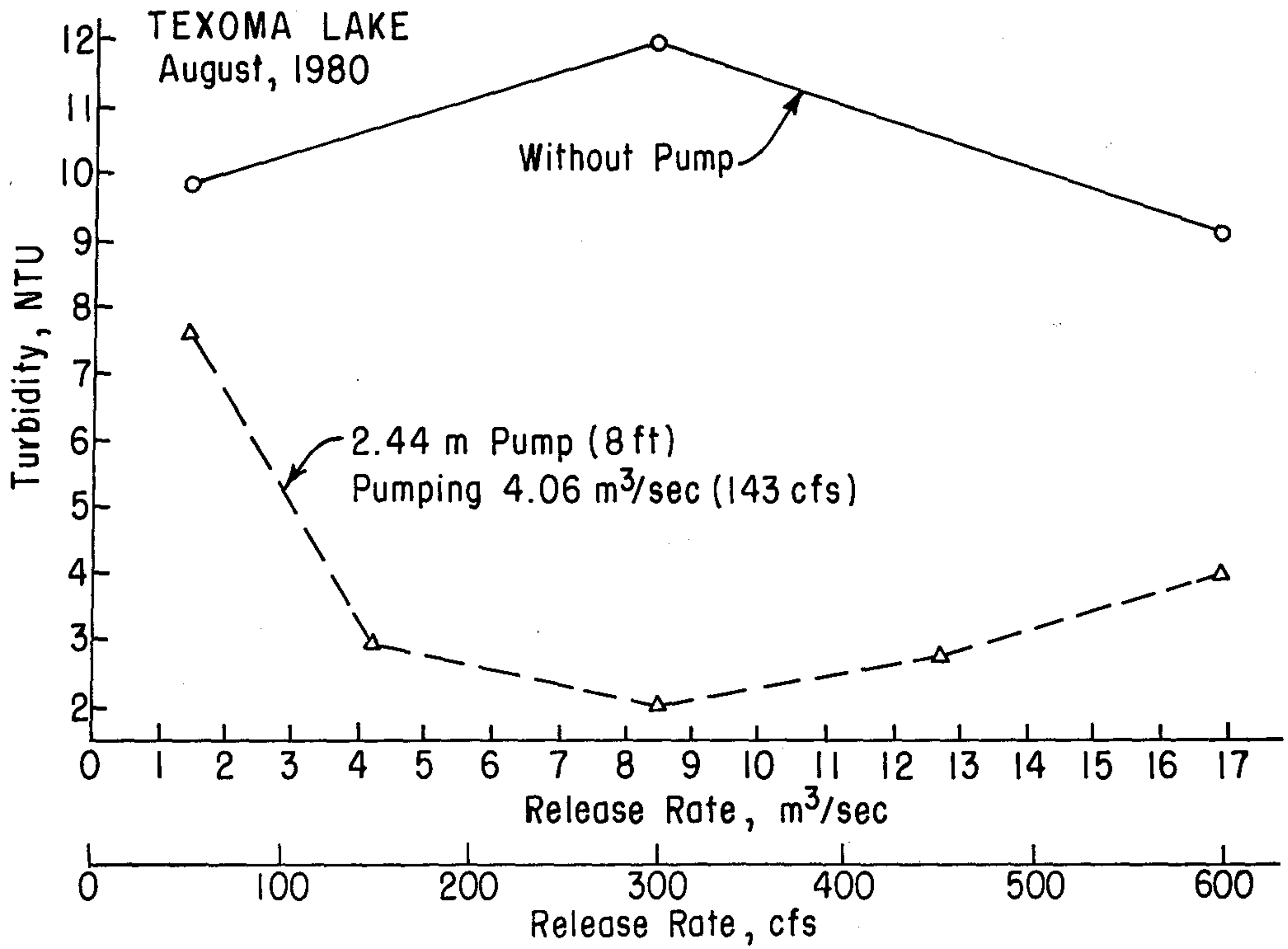

Figure 1-7. Turbidity as a Function of Release Rate at Lake Texoma

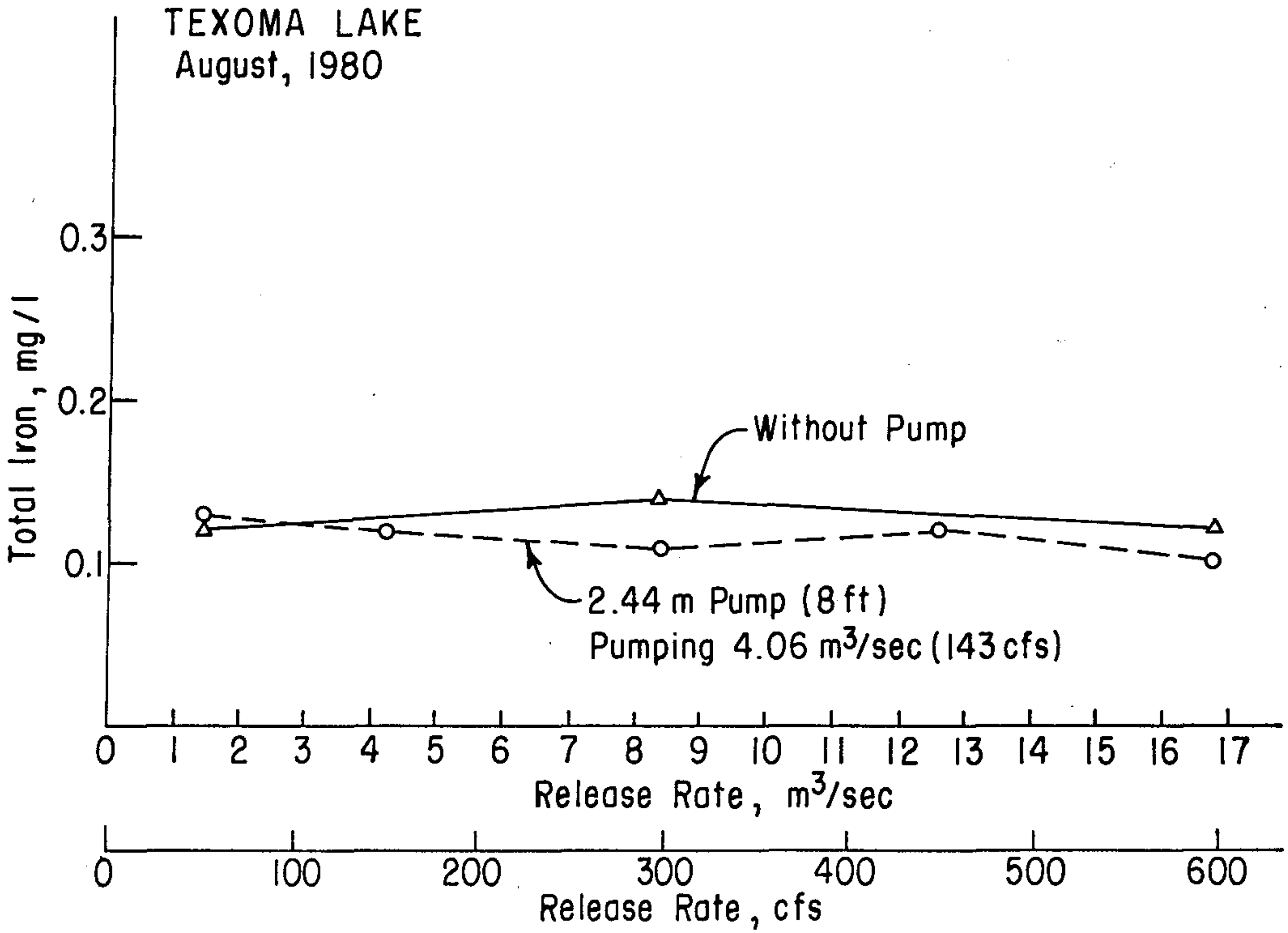

Figure 1-8. Total Iron Concentration as a Function of Release Rate at Lake Texoma

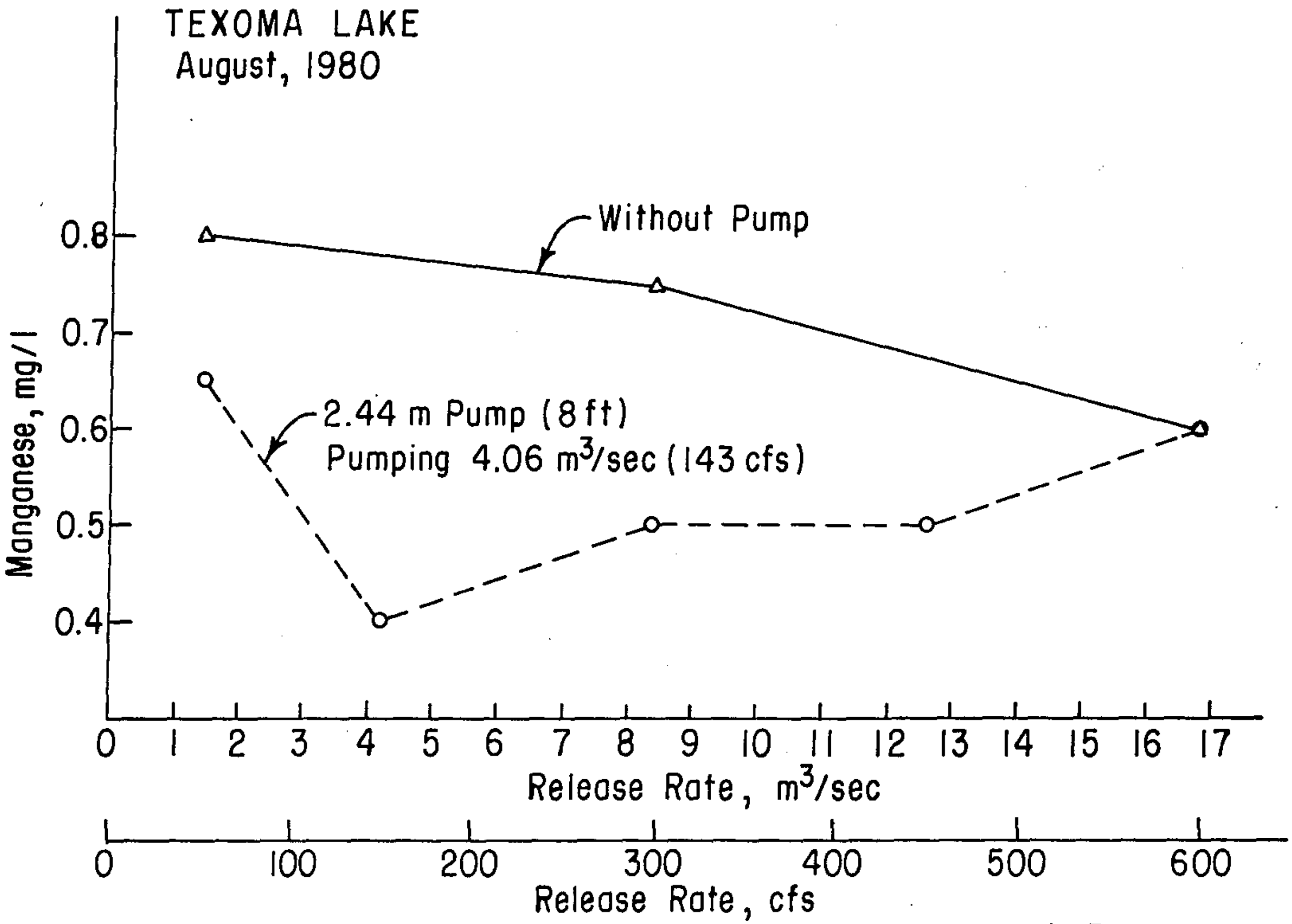

Figure 1-9. Manganese Concentration as a Function of Release Rate at Lake Texoma

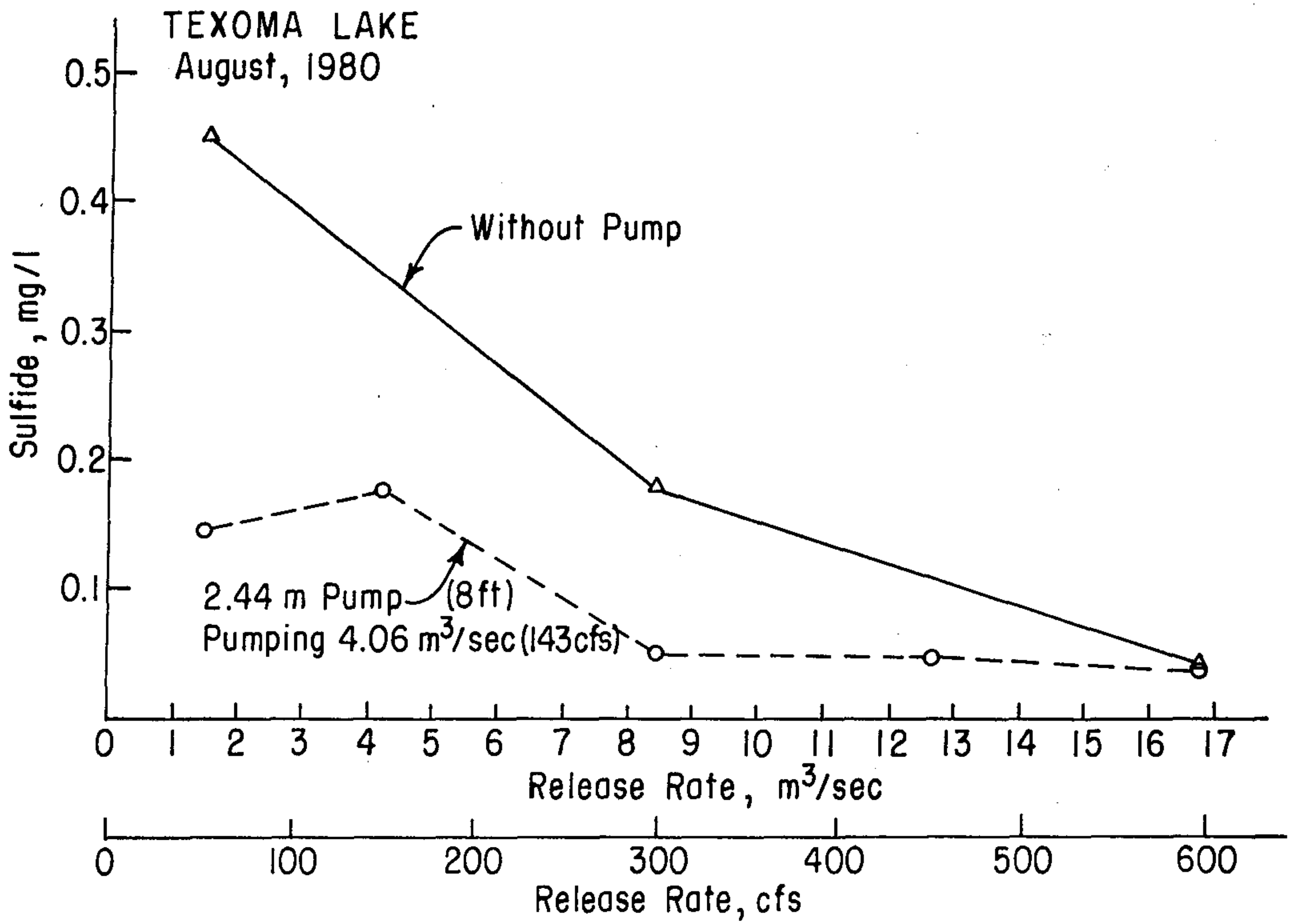

Figure 1-10. Sulfide Concentration as a Function of Release Rate at Lake Texoma

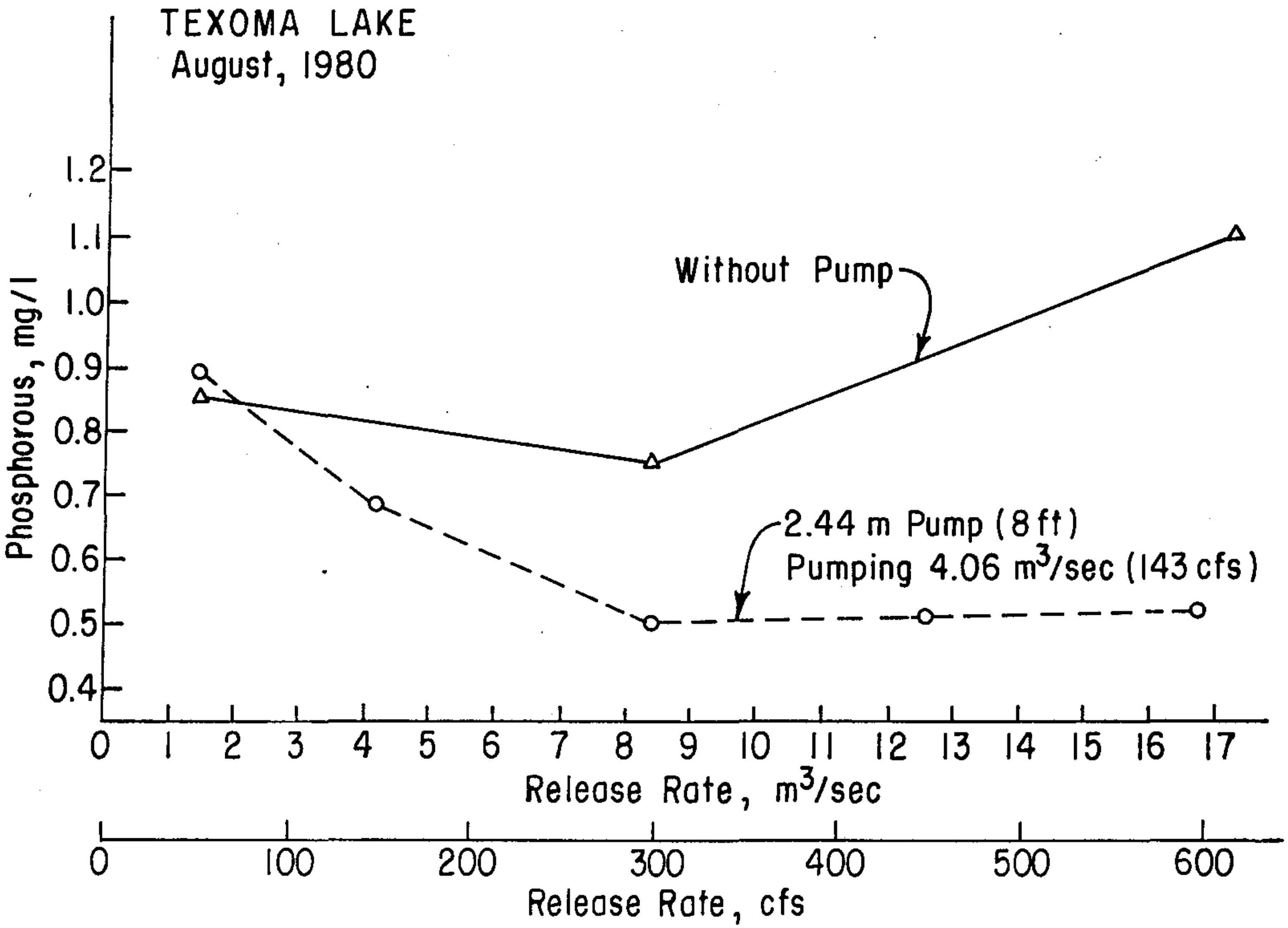

Figure 1-11. Phosphorous Concentration as a Function of Release Rate at Lake Texoma

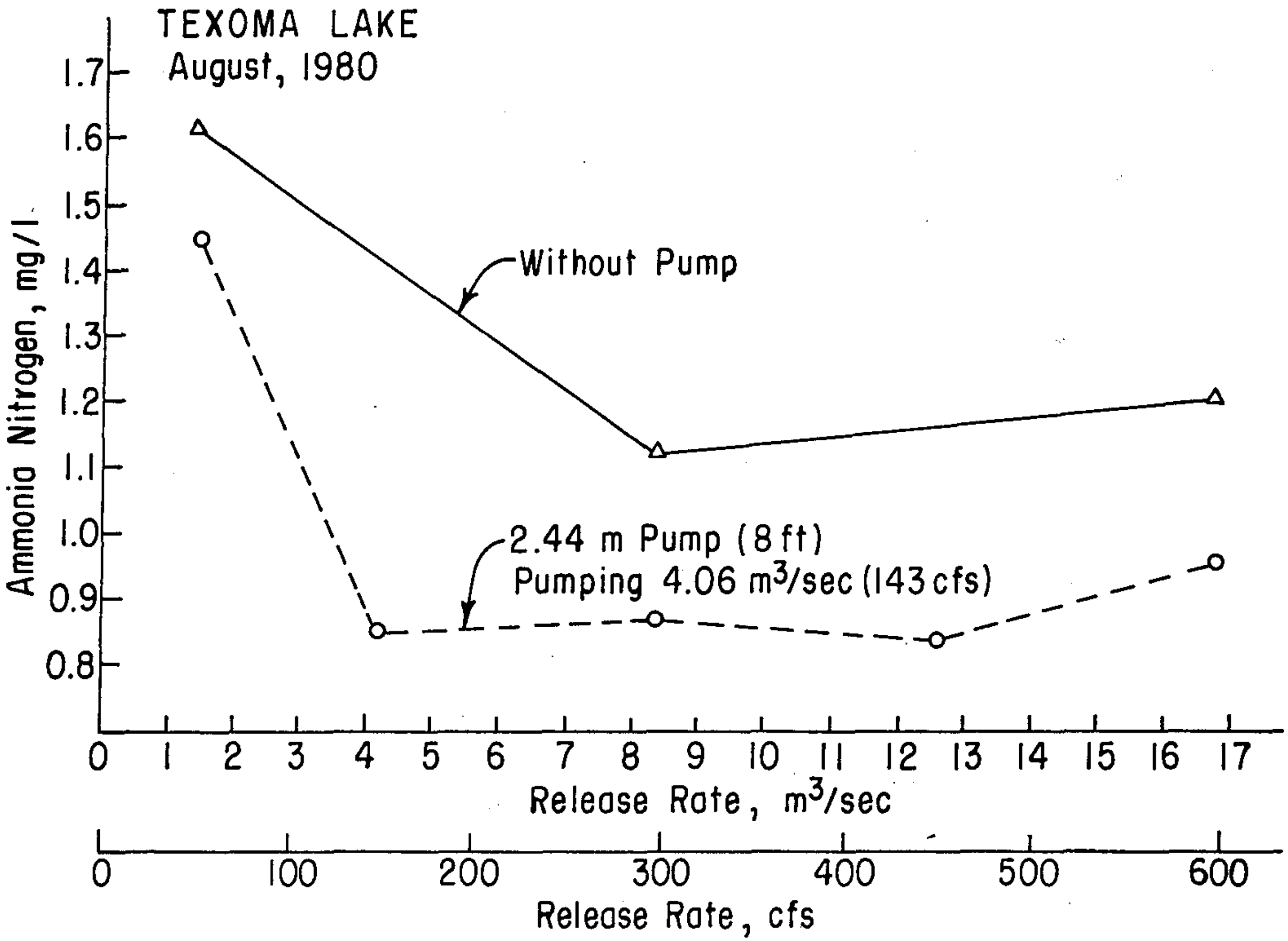

Figure 1-12. Ammonia Nitrogen Concentration as a Function of Release Rate at Lake Texoma

Table 1-1. Maximum Improvement at Texoma Lake - 2.44 m Pump

Parameter	% Improvement	Release Rate cfs (m^3/sec)
Turbidity	83	300 (8.4)
Ammonia Nitrogen	37	150 (4.2)
Sulfide	68	50 (1.4)
Manganese	49	150 (4.2)
Phosphorous	53	600 (16.8)
Total Iron	21	300 (8.4)

parameters and their corresponding release rates. Ammonia nitrogen and mangaese concentrations without pumping at a release rate of 150 cfs (4.2 m^3/sec) were determined by assuming a linear relationship between concentrations at release rates of 50 and 300 cfs (1.4 and 8.4 m^3/sec). Table II shows the magnitude of the concentration changes for each parameter.

Dilution Factor

The change in enthalpy of release waters with and without pumping was used to calculate the dilution factor. Water temperatures without pumping at release rates of 150 and 450 cfs (4.2 and 12.6 m^3/sec) were determined by assuming a linear relationship between adjacent data points. Surface water enthalpy was obtained by averaging the surface, 3.3 ft. and 6.5 ft (1 m, and 2 m) values.

The Garton Pump discharging a calculated 143 cfs (4.06 m^3/sec) at the surface attained a maximum dilution factor of 32.5% at a release rate of 300 cfs (8.4 m^3/sec) (Figure 13). That is, 95 cfs (2.7 m^3/sec) of surface water was pumped through the outlet when the release gate discharged 300 cfs (8.4 m^3/sec). The ratio of pump discharge to release water discharge at the maximum dilution factor was 0.48. Two-thirds of the water pumped by the propeller appeared as surface water in the outlet. This ratio will probably vary with each outlet configuration.

Table 1-2. Release Improvement Test for Texoma Lake. 18 August 1980.

Q_p (m^3/sec) cfs	Q_{rel} (m^3/sec) cfs	Temperature (°C)	Dissolved Oxygen (mg/l)	Total Iron (mg/l)	Manganese (mg/l)	Ammonia Nitrogen (mg/l)	Phosphorous (mg/l)	Hydrogen Sulfide (mg/l)	pH	Turbidity (NTU)	Conductivity (μmhos/cm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(0) 0	(1.41) 50	21.5	6.6	0.12	0.80	1.62	0.85	0.45	7.7	9.8	2200
(4.06) 143	(1.41) 50	22.0	6.5	0.13	0.65	1.45	0.89	0.145	7.7	7.6	2200
(4.06) 143	(4.21) 150	23.0	6.1	0.12	0.40	0.85	0.68	0.175	7.6	2.9	2300
(0) 0	(8.41) 300	22.0	5.6	0.14	0.75	1.12	0.75	0.18	7.5	12.0	2300
(4.06) 143	(8.41) 300	23.8	5.6	0.11	0.50	0.87	0.50	0.05	7.6	2.0	2300
(4.06) 143	(12.61) 450	23.7	6.0	0.12	0.50	0.83	0.51	0.045	7.7	2.75	2250
(4.06) 143	(16.81) 600	23.6	5.6	0.10	0.60	0.95	0.52	0.036	7.6	4.0	2200
(0) 0	(16.81) 600	22.6	5.6	0.12	0.60	1.20	1.10	0.04	7.5	9.2	2200

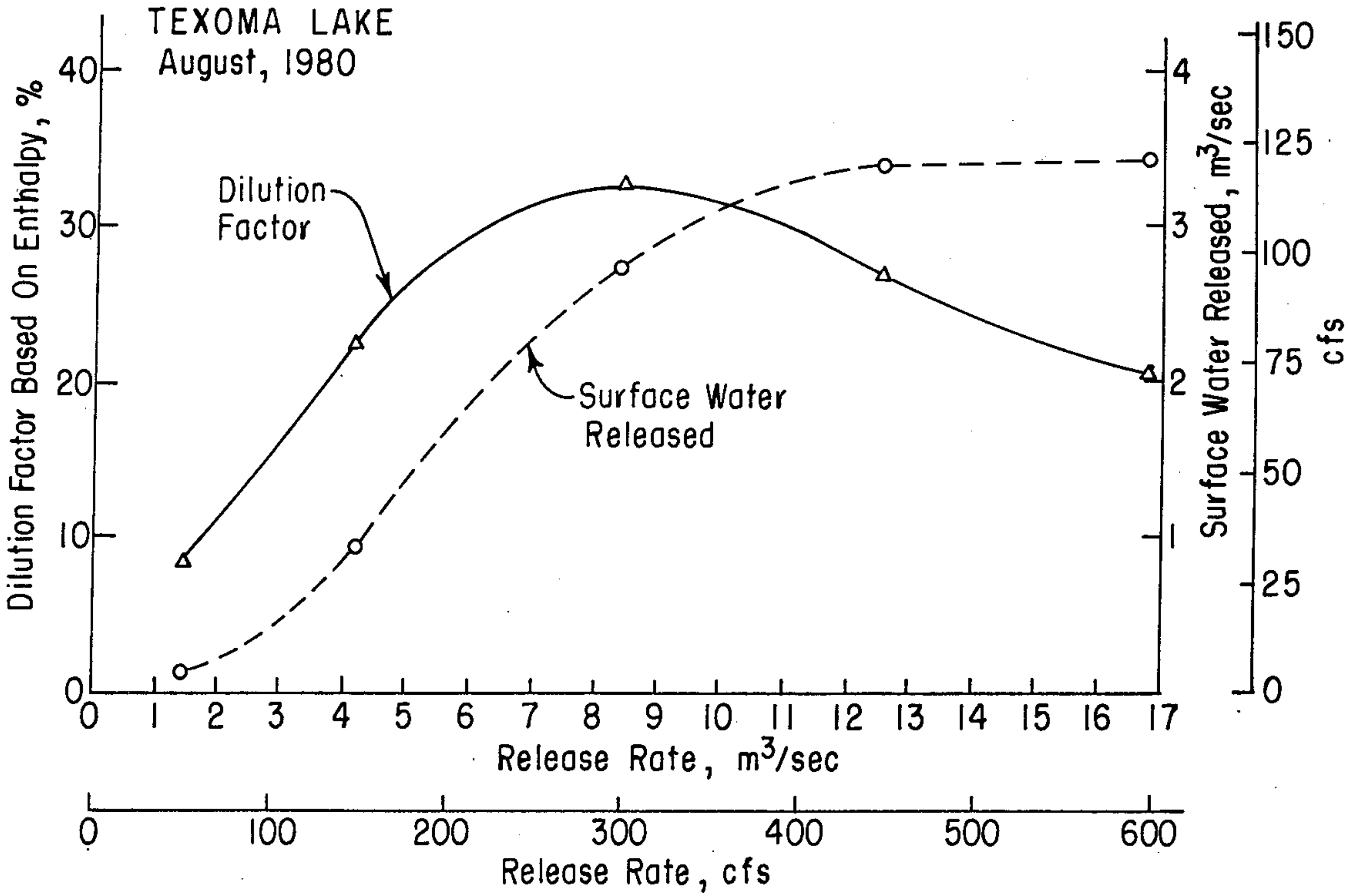

Figure 1-13. Dilution Factor and Surface Water Release Rate as a Function of Reservoir Release at Lake Texoma

CONCLUSIONS

1. Operating an axial flow Garton Pump over a low level intake gate in the hypolimnion of a stratified impoundment will increase release water temperature and improve release water quality provided the plume of pumped water reaches outlet depth.
2. Localized destratification will affect only those water quality parameters which display a concentration increase with depth above the release outlet.
3. The dilution factor resulting from pump operation can best be determined by using temperature or enthalpy changes in release waters as a base.
4. Optimum release water quality improvements were obtained at a specific pumping rate to release rate ratio. At Lake Texoma a pumping to release rate ratio of 0.48 for the 8-foot (2.44 m) diameter pump resulted in the greatest dilution factor.
5. The calculated 3.9 blade horsepower required to accomplish these results would result in a low annual power cost if the device were used continuously on an operational basis. The construction cost should compete favorably with any other system designed to improve downstream water quality.
6. The operation of such a device might be expected to reduce treatment costs for potable water if the system intake is located in the hypolimnion.

APPENDEX 1.--REFERENCES

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PART II

LOCALIZED MIXING AT PINE CREEK RESERVOIR

PART II

LOCALIZED MIXING AT PINE CREEK RESERVOIR

Operation of different pumps over the outlet to Pine Creek Reservoir near Valliant, Oklahoma has been conducted. During the summer of 1978 two pumps were used. One was a 6-foot ventilating fan with orifice ring made by Acme Manufacturing Co., Muskogee, Oklahoma. The other was a 3.5-foot cast aluminum propeller made by Aerovent.

The outlet structure at Pine Creek Reservoir was rectangular shaped with one side open. The outlets were located on one face of the rectangle. Figure 2-1 shows the devices in place inside the structure directly over the outlets.

The structure had two 4-foot outlets which were located 13.4 and 30.4 feet below the water surface during the summer of 1978. The flow from the structure was 68 cfs. The data in Table 2-I were obtained from samples from the discharge channel immediately downstream from the dam with both pumps operating (64 cfs).

Table 2-1

EFFECT OF LOCALIZED MIXING ON WATER QUALITY PARAMETERS
PINE CREEK - 1978

Parameter	Value Before Pumping	Value with Both Pumps Operating
Temperature	22.85^{0}C	23.50
Conductivity	35μ mhos/cm	32
Manganese	1.4 mg/l	0.60
Sulfide	0.06 mg/l	0.03
N as NH	1.18 mg/l	1.10
Total Fe	2.1 mg/l	0.55
D. O.	6.8 mg/1	7.10

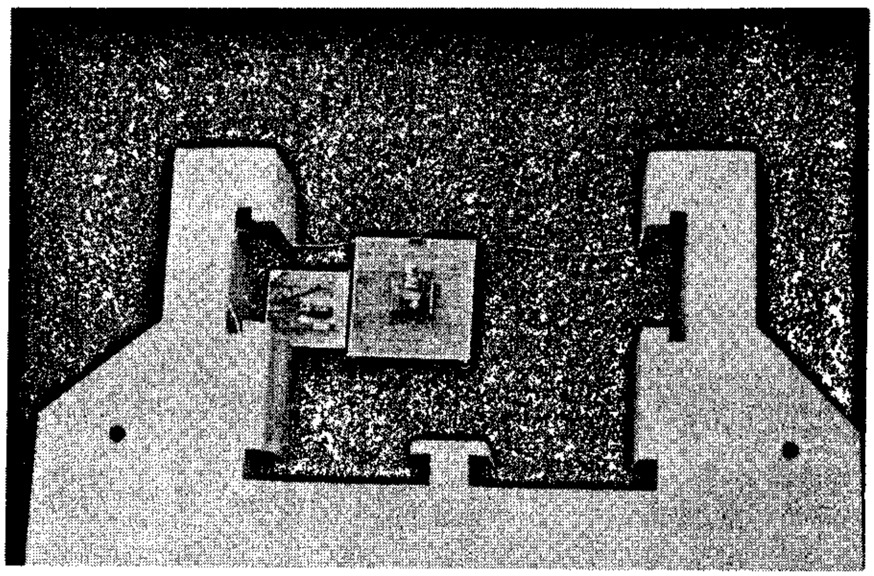

Figure 2-1. Top View of Pump Location at Pine Creek Lake

A strong hydraulic jump within the structure was probably responsible for the high level of dissolved oxygen before pumping and the relatively small increase with pumping.

The total power input to both pumps was less than two horsepower. The 74 percent reduction in total iron, the 57 percent reduction in manganese and the 50 percent reduction in sulfide would cost less than $2.00 per day for power at 4 cents per kWh.

These encouraging results led to a more comprehensive study in 1979. New pumps were constructed. Geometrically similar 4-foot and 6-foot pumps were used in the tests.

Samples were obtained at 5 meter intervals in the lake before operation and during each test. The level in the lake during the 1979 tests was approximately 7 feet deeper than the previous summer. The lake level was raised to increase the release rate. The increased depth placed the outlets farther below the thermocline and did not improve the discharge quality.

During the 1979 tests, the normal discharge of 65 cfs was lowered to 30 cfs, then increased to 90 cfs. For each of the three outlet flows, samples were obtained at pump flows of 40 and 80 cfs. The results of the 1979 test are shown in Table 2-II.

Using no pumping at the normal flow of 65 cfs as a basis, the maximum reduction in total iron was 68 percent; the maximum reduction in manganese was 79 percent, and during some tests the levels of ammonia and sulfide were reduced to below detection levels.

Figure 2-2 shows that, based on temperature, the dilution factor may reach a maximum near the point where the pump discharge is approximately equal to the discharge from the lake. The chemical data in Table 2-II also tend to have the same trends.

Table 2-2

THE EFFECTS OF LOCAL DESTRATIFICATION ON THE QUALITY OF RELEASED WATER, 1979

PINE CREEK RESERVOIR, OKLA
(1.22 meter outlets with inverts 6.2 and 11.4 m from surface)

LAKE PROFILE

Depth (m)	Temp C	D. O. mg/l	Total Iron mg/l	Manganese mg/l	Ammonia Nitrogen mg/l	Phosphorus mg/l	Sulfide
0	31.8	7.0	0.20	0	0	0.05	0
5	27.2	0.0	0.22	0.50	0	0.04	0.01
10	24.0	0.0	2.30	1.90	0.6	0.04	0.04
15	19.0	0.0	2.40	1.30	1.7	0.16	0.06

DOWNSTREAM FROM PINE CREEK

Outflow CFS	Pumping Rate CFS (Pump Diam)	Temp ^{o}C	D.O. mg/l	Total Iron mg/l	Manganese mg/l	Ammonia Nitrogen mg/l	Phosphorus mg/l	Sulfide
				8/8/79				
65	40(4ft)	27.8	5.4	1.20	0.30	0.0		0.00
65	80(4ft + 6ft)	26.9	5.5	1.40	0.40	0.25		
				8/9/79				
30	38(6ft)	27.9	5.4	1.00	0.50	0.00	0.02	0.00
30	78(6ft + 4ft)	27.2	5.4	1.50	0.60	0.30	0.10	0.02
90	38(6ft)	26.0	5.4	2.20	0.70	0.50	0.10	0.04
90	78(6ft + 4ft)	27.6	5.3	1.20	0.40	0.10	0.05	0.02
65	0	24.8	5.6	2.40	1.40	0.70	0.10	0.05
65	38(6ft)	27.7	5.4	1.30	0.40	0.20	0.05	0.04

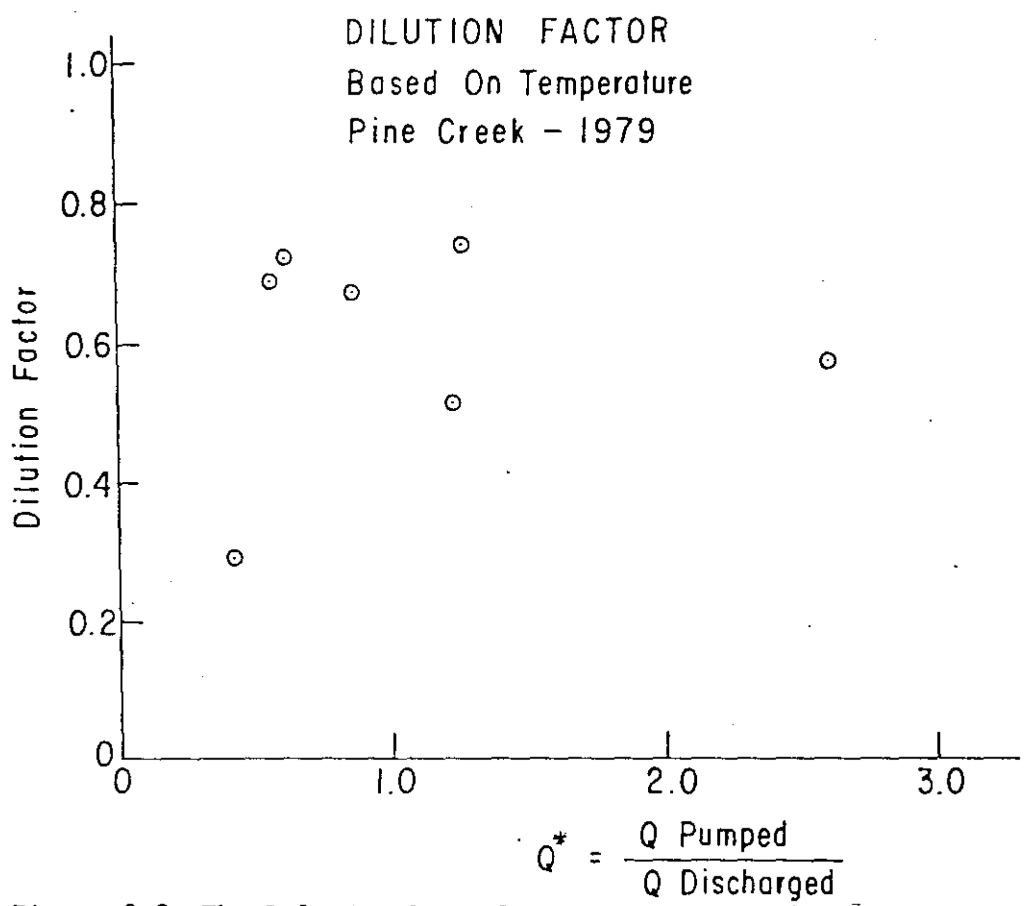

Figure 2-2. The Relationship of Dilution Factor (percent of surface water being released) to the Ratio of Pump Discharge to Discharge Rate.

PINE CREEK, 25, 26 June 1980

Profiles

The 1.22 by 1.22 m (4 ft x 4 ft) top outlet was located in the lower metalimnion, 6.8 m (22.3 ft) below the water surface and received all outflows for this test series. Dissolved oxygen was depleted approximately 7.0 m (23 ft) below the water surface (Figure 2-3).

Profile water samples were collected at the surface, 5, 10, and 12 m (16.4, 32.8, and 39.4 ft) depths (Figure 2-4). Vertical variation in pH, sulfide, ammonia, nitrogen, and phosphorous were relatively small.

Total iron, manganese, and turbidity as well as temperature displayed concentration gradients with depth and were most affected by localized destratification tests. Dissolved oxygen had a pronounced gradient with depth, but a strong hydraulic jump within the release structure increased dissolved oxygen levels at the outlet. Therefore, dissolved oxygen was not a reliable indicator of the effects of pumping.

Release Water Quality

The pumping rates selected for each pump (Table 2-III) were held constant while release rates were changed. Based on the effect of localized mixing on temperature, manganese, total iron, and turbidity at varied release rates for each pump, the 1.83 m (6 ft) pump produced the best results and the 2.44 m (8 ft) pump produced the poorest results (Figures 2-5 through 2-8). The 2.44 m (8 ft) pump caused an increase in release water iron, and turbidity concentrations. Since the outlet was only 6.8 m (22.3 ft) below the water surface and water quality deteriorated rapidly below the outlet, entrainment and discharge of water below the outlet was suspected. The large volume of pumped water in relation to release water allowed mixing and discharge of deeper, poorer quality water.

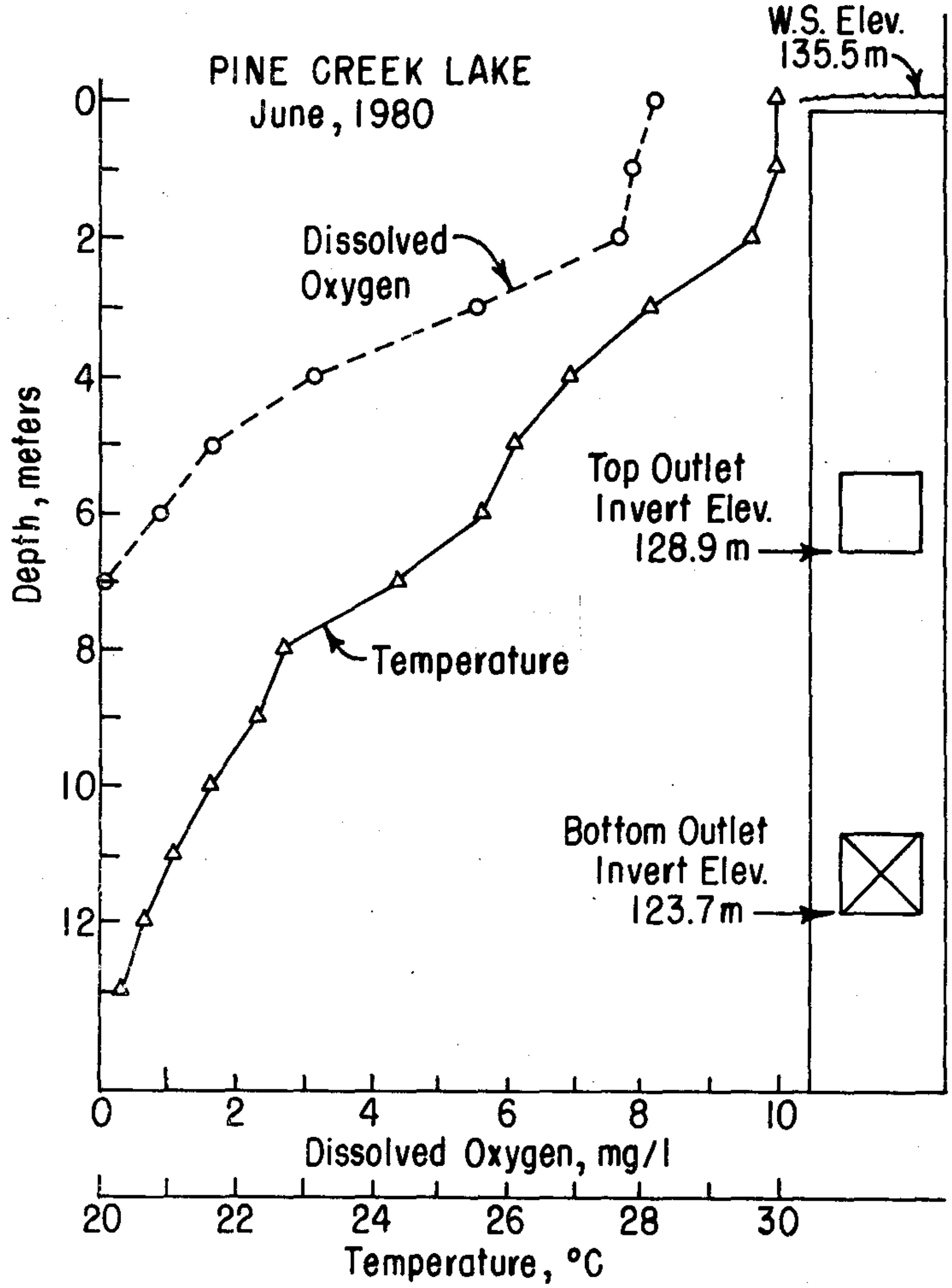

Figure 2-3. Temperature and Dissolved Oxygen Profiles at Pine Creek Lake on 26 June 1980

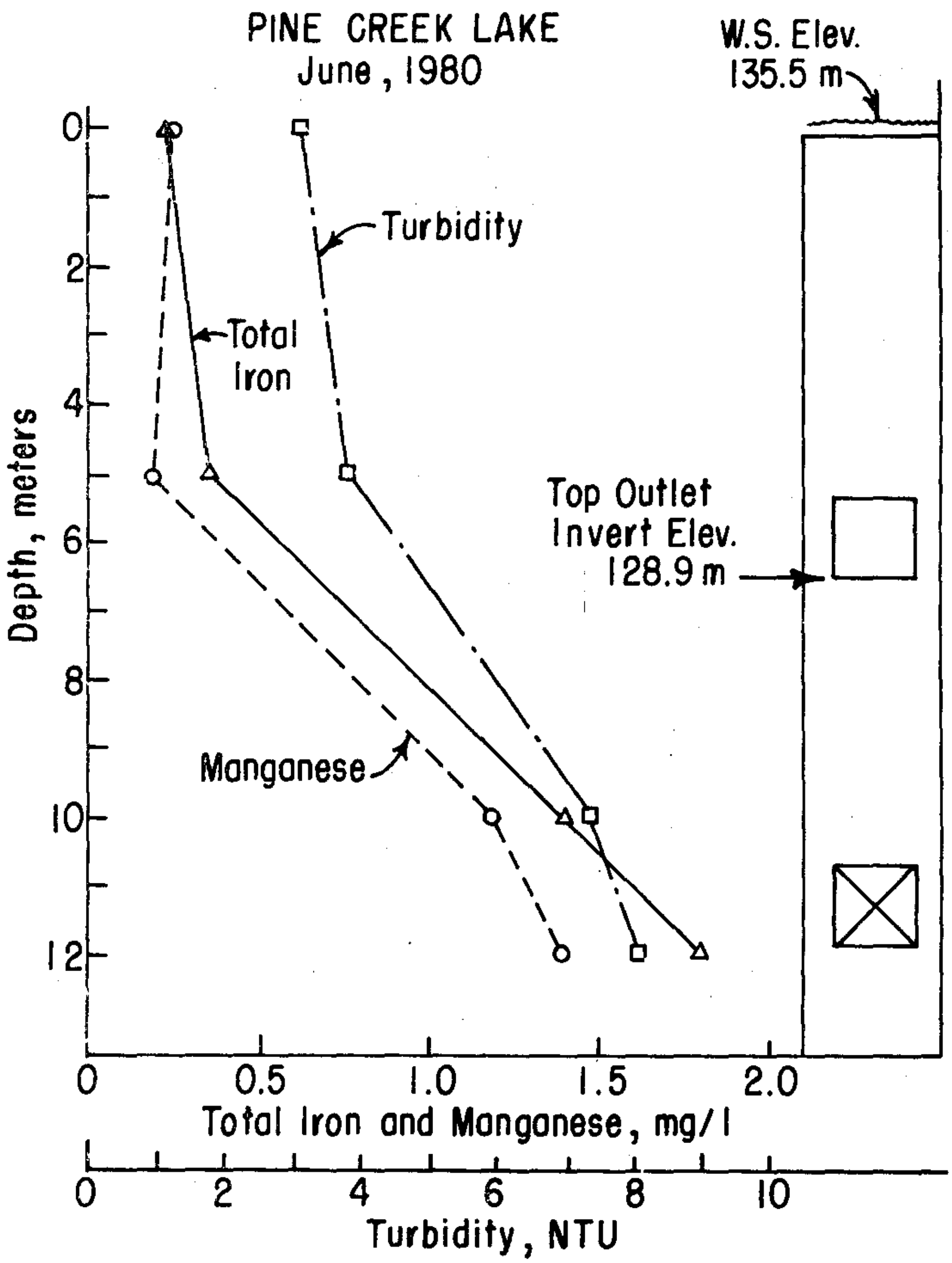

Figure 2-4. Selected Chemical Profiles at Pine Creek Lake on 26 June 1980

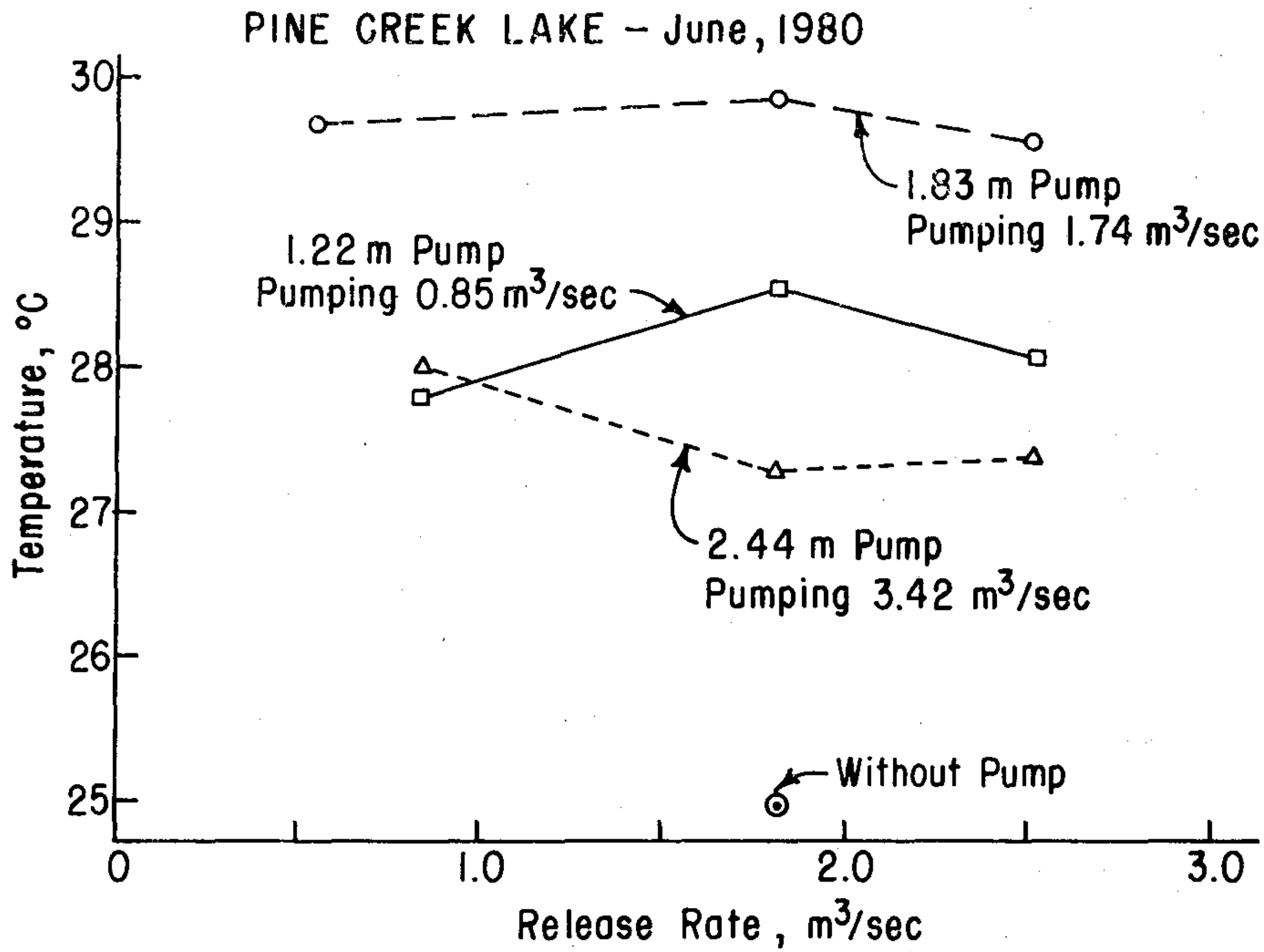

Figure 2-5. Temperature as a Function of Release Rate at Pine Creek Lake on 26 June 1980

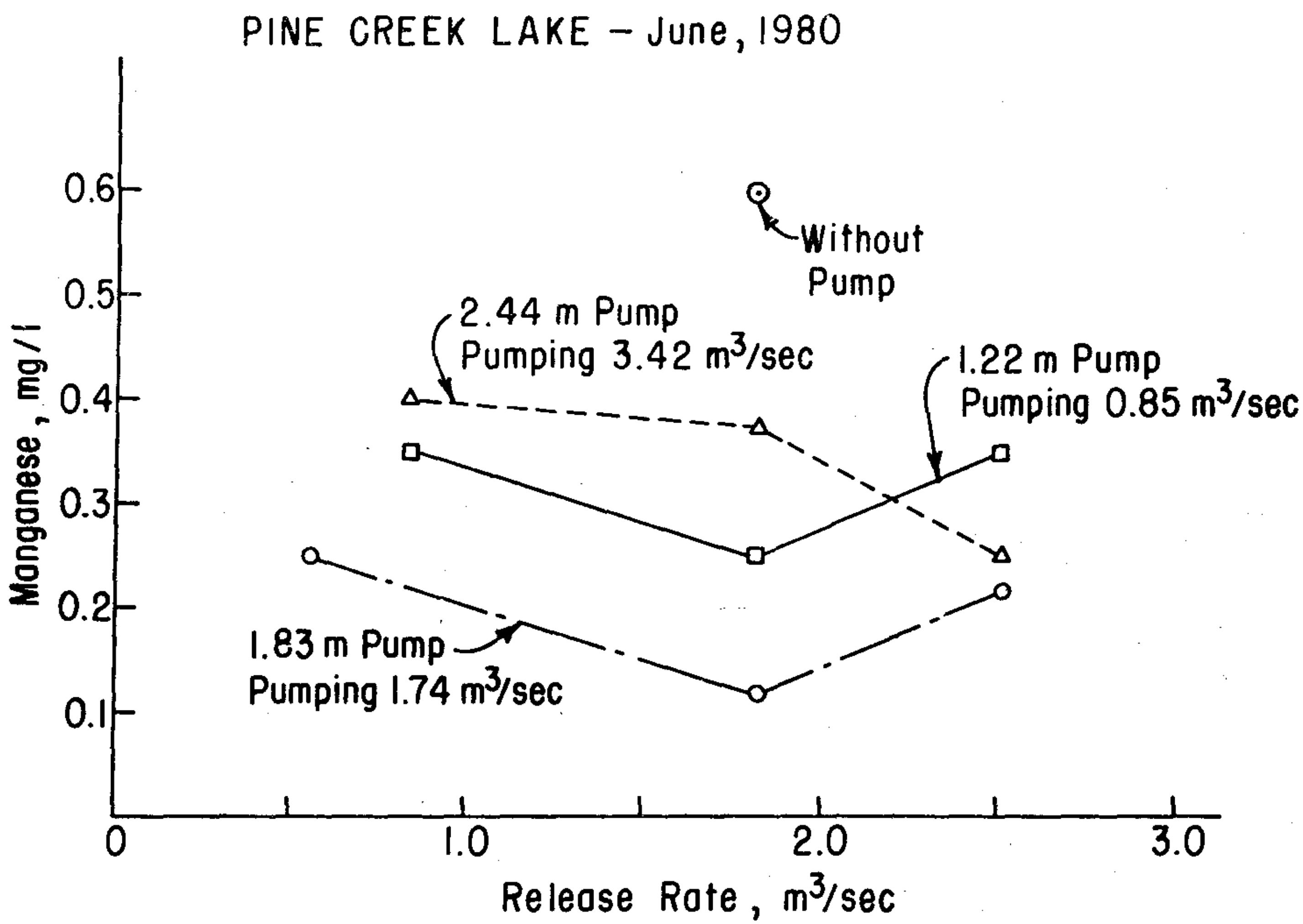

Figure 2-6. Manganese Concentration as a Function of Release Rate at Pine Creek Lake on 26 June 1980

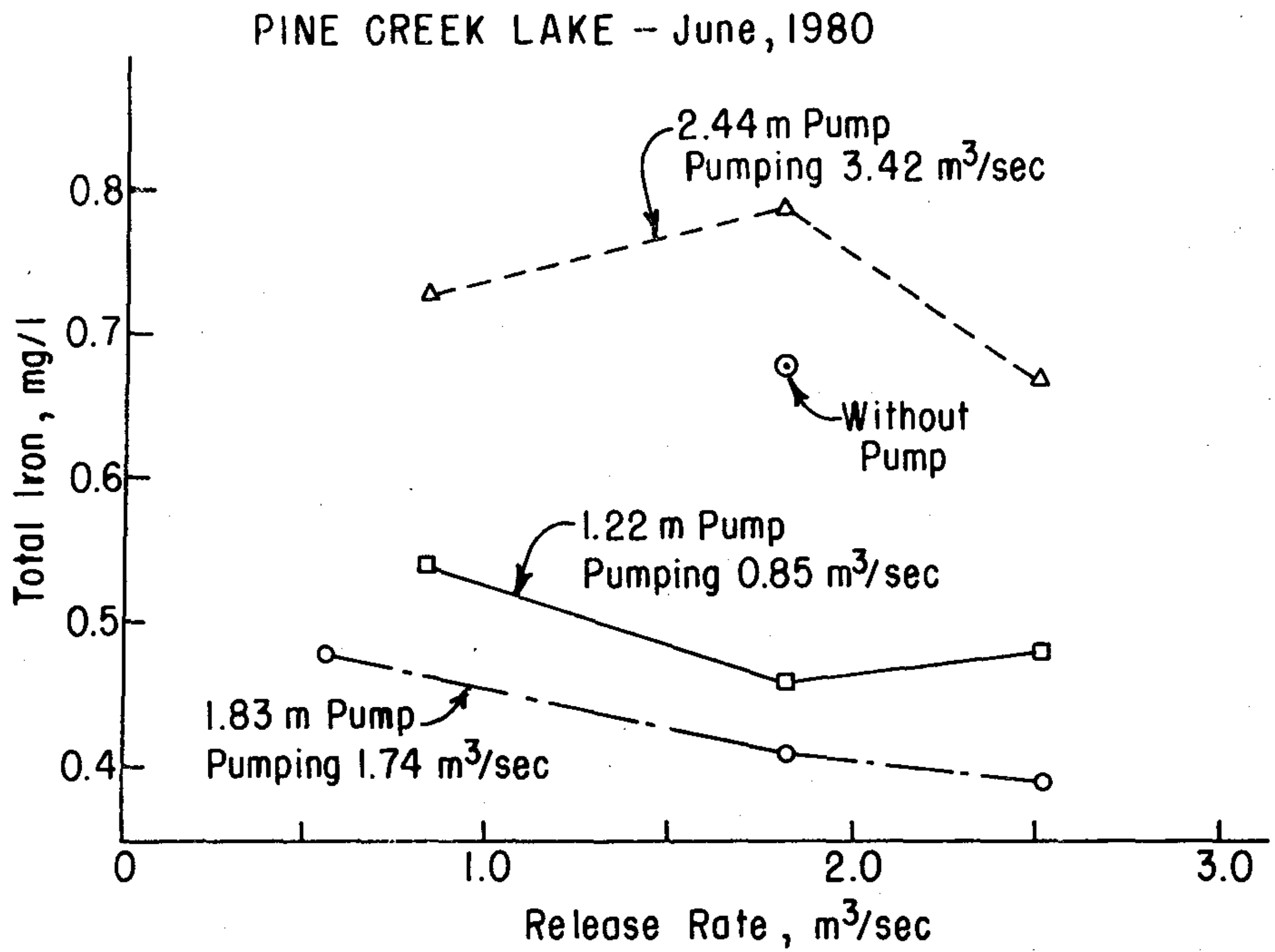

Figure 2-7. Total Iron Concentration as a Function of Release Rate at Pine Creek Lake on 26 June 1980

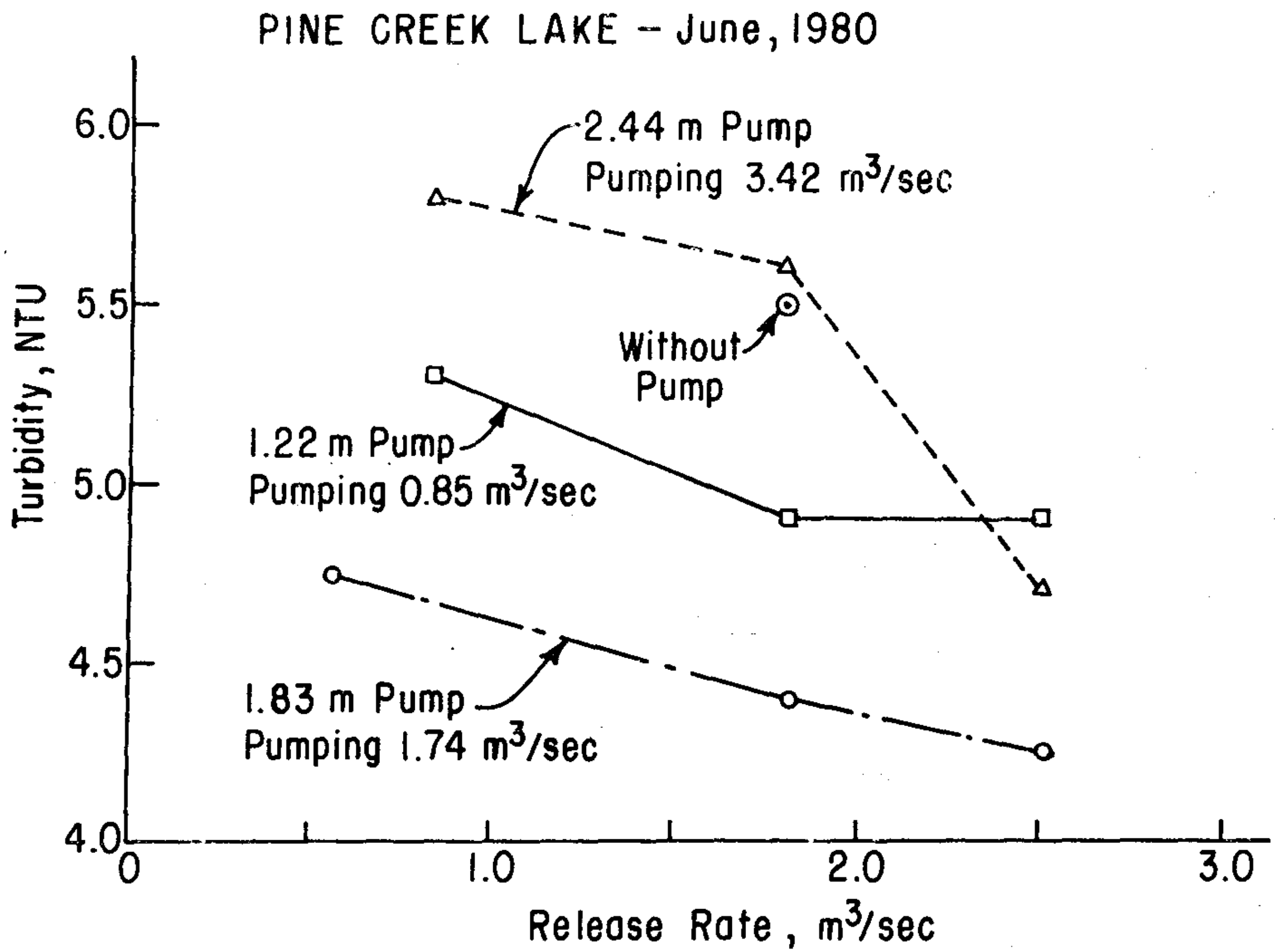

Figure 2-8. Turbidity as a Function of Release Rate at Pine Creek Lake on 26 June 1980

Table 2-3

PUMPING RATES FOR PINE CREEK
26 June 1980

Pump Diameter (ft)	Propellor Rotation (RPM)	Calculated Discharge (cfs)	Calculated Velocity ft/sec
1.22 (4)	80	0.85 (30)	0.74 (2.4)
1.83 (6)	48	1.74 (61)	0.67 (2.2)
2.44 (8)	40	3.42 (121)	0.74 (2.4)

While depth of penetration tests were conducted at the buoy line and not inside the intake structure where dilution tests were performed, comparison of the anticipated penetration depth for each pump provides some insight into the poor performance of the 2.44 m (8 ft) pump.

The 1.22 (4 ft) and 1.83 m (6 ft) pumps were projected to penetrate 10.5 (34.4 ft) and 11.0 m (36.1 ft) respectively, while the 2.44 m (8 ft) pump was projected to penetrate approximately 12.5 m (41 ft) to the reservoir bottom. Substantial disturbance and resuspension of bottom sediments were likely while operating the 2,44 m (8 ft) pump. The pump operator noted updwelling, a pronounced decrease in surface temperature, and floating debris while the 2.44 m (8 ft) pump was operating at a release rate of 0.84 m^3/sec (30 cfs).

By comparing pump performances at a release rate of 1.82 m^3/sec (64 cfs), the percentage improvements for several parameters were calculated and summarized in Table 2-IV.

Dilution Factor

Changes in energy content or enthalpy of release waters were used to determine the amount of surface water pumped down and released from the outlet at each test discharge.

Table 2-4

WATER QUALITY IMPROVEMENT AT A RELEASE RATE OF 1.82 m^3/sec (64 cfs)
PINE CREEK, 26 June 1980

Parameter	Pump Diameter (ft)	Concentration Without Pump	Concentration With Pump	Percent Improvement
Manganese (mg/l)	1.22 (4)	0.60	0.25	58.3
	1.83 (6)	0.60	0.12	80.0
	2.44 (8)	0.60	0.37	38.3
Total Iron (mg/l)	1.22 (4)	0.68	0.46	32.4
	1.83 (6)	0.68	0.41	39.7
	2.44 (8)	0.68	0.79	-16.2
Turbidity (NTU)	1.22 (4)	5.5	4.9	10.9
	1.83 (6)	5.5	4.4	20.0
	2.44 (8)	5.5	5.6	- 1.8

Dilution factors versus release rates for each pump are shown in Figure 2-9. As was expected from the water quality data, the 1.83 m (6 ft) pump attained the highest dilution factor, while the 2.44 m (8 ft) pump was lowest.

Since the outlet release rate was know for each test, the amount of surface water discharged through the outlet was easily calculated (Figure 2-10). The amount of surface water released was highest for the 1.83 m pump followed by the 1.22 and 2.44 m pumps, respectively. The dilution factor based on enthalpy is shown in Figure 2-11 versus the ratio of pumping and release rates.

PINE CREEK, 5 August 1980

Profiles

Temperature and dissolved oxygen profiles for Pine Creek Lake on 5 August 1980 are shown in Figure 2-12. Operations personnel were releasing

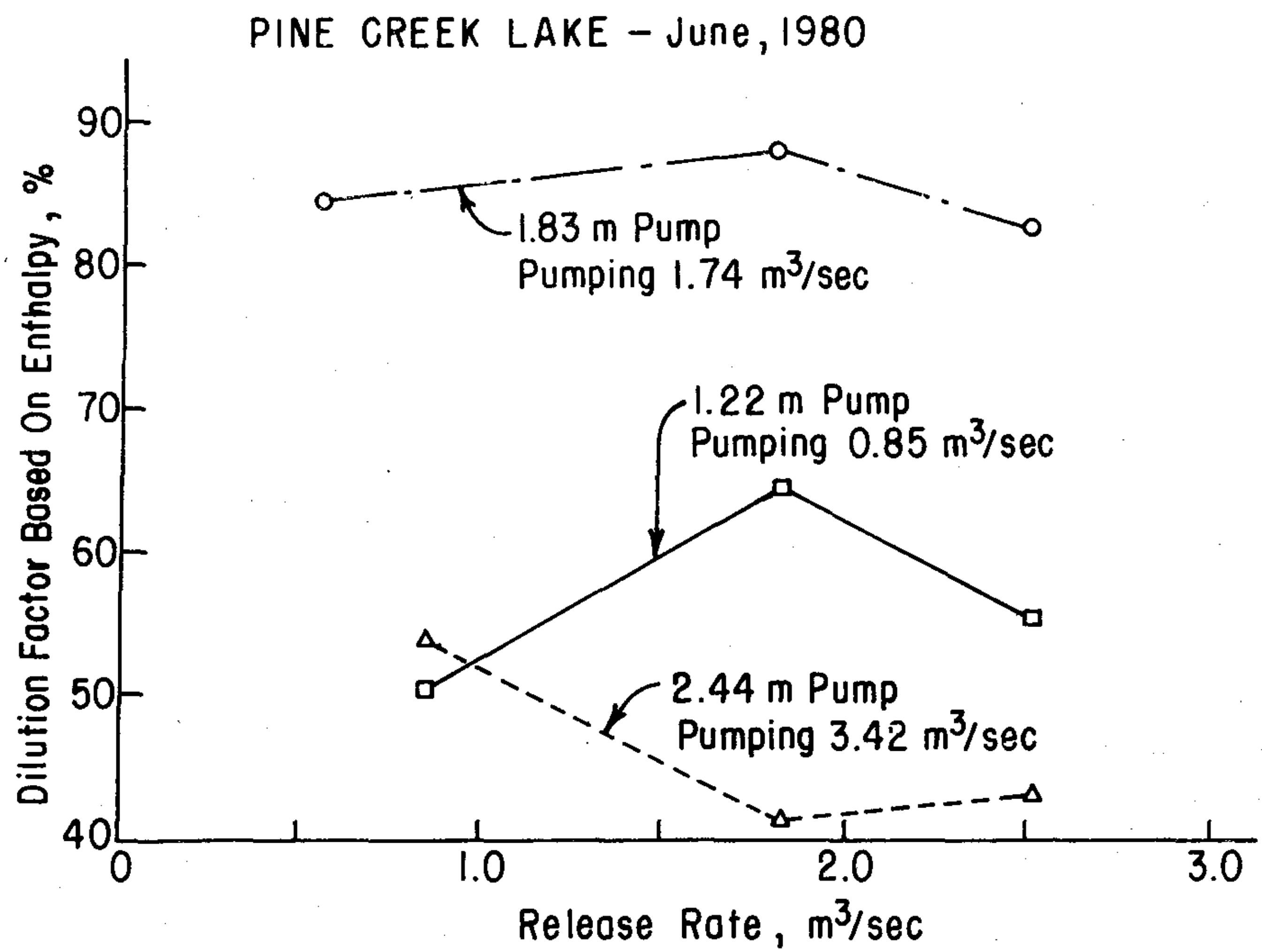

Figure 2-9. Dilution Factor Based on Enthalpy as a Function of Release Rate at Pine Creek on 26 June 1980

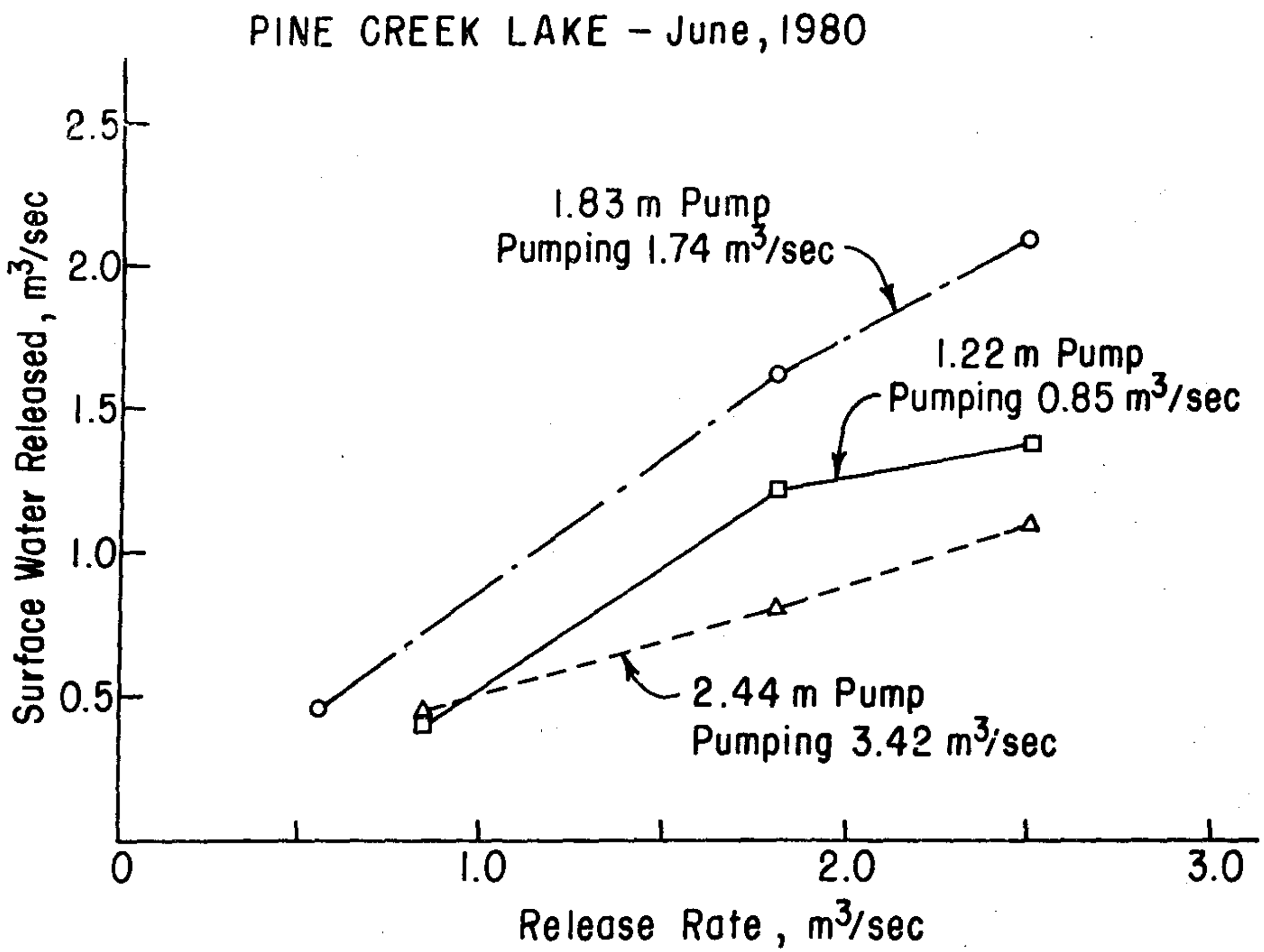

Figure 2-10. Surface Water Release Rate as a Function of Reservoir Release Rate at Pine Creek on 26 June 1980

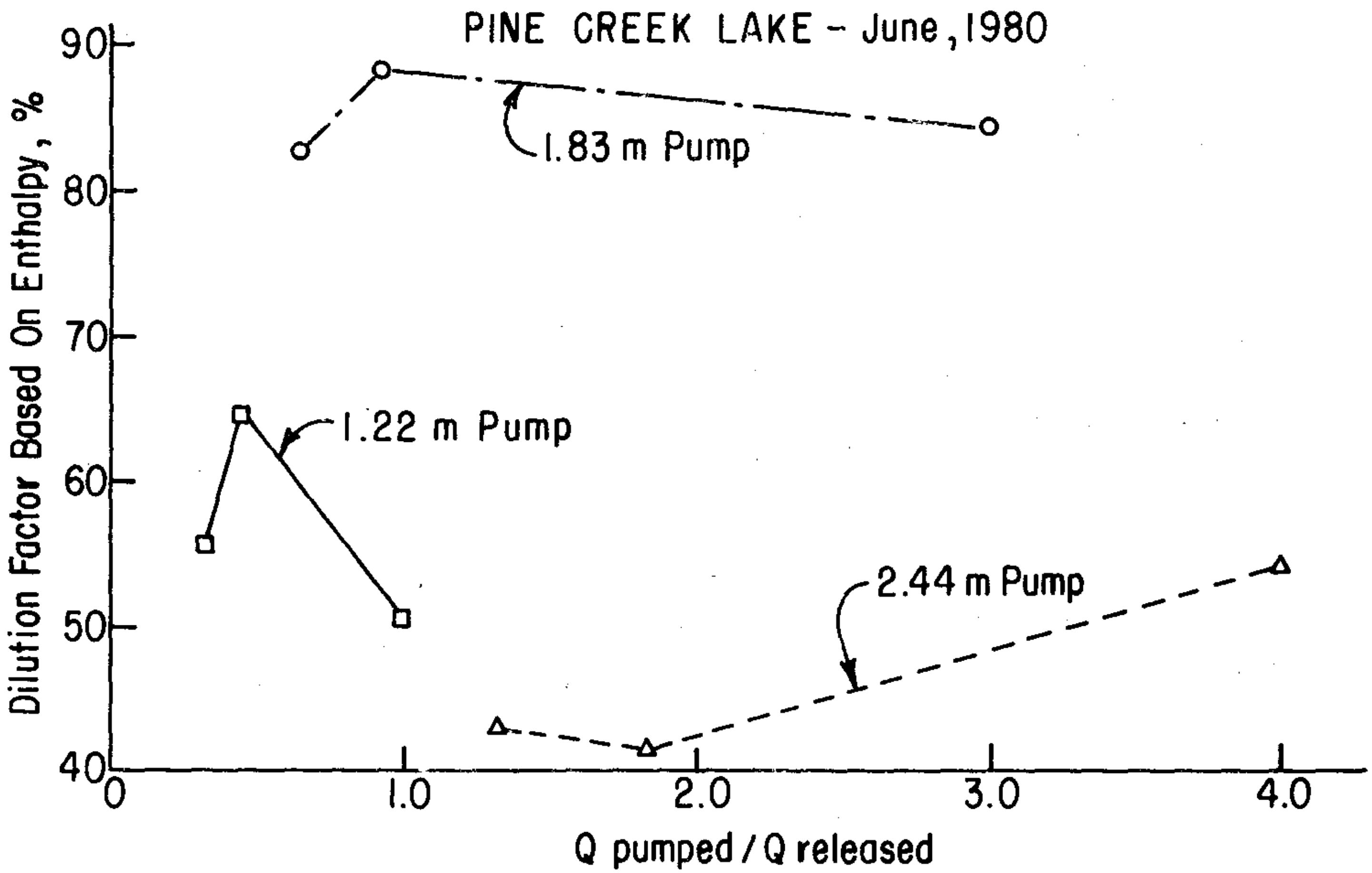

Figure 2-11. Dilution Factor Based on Enthalpy as a Function of the Ratio of Pumping to Release Rate at Pine Creek on 26 June 1980

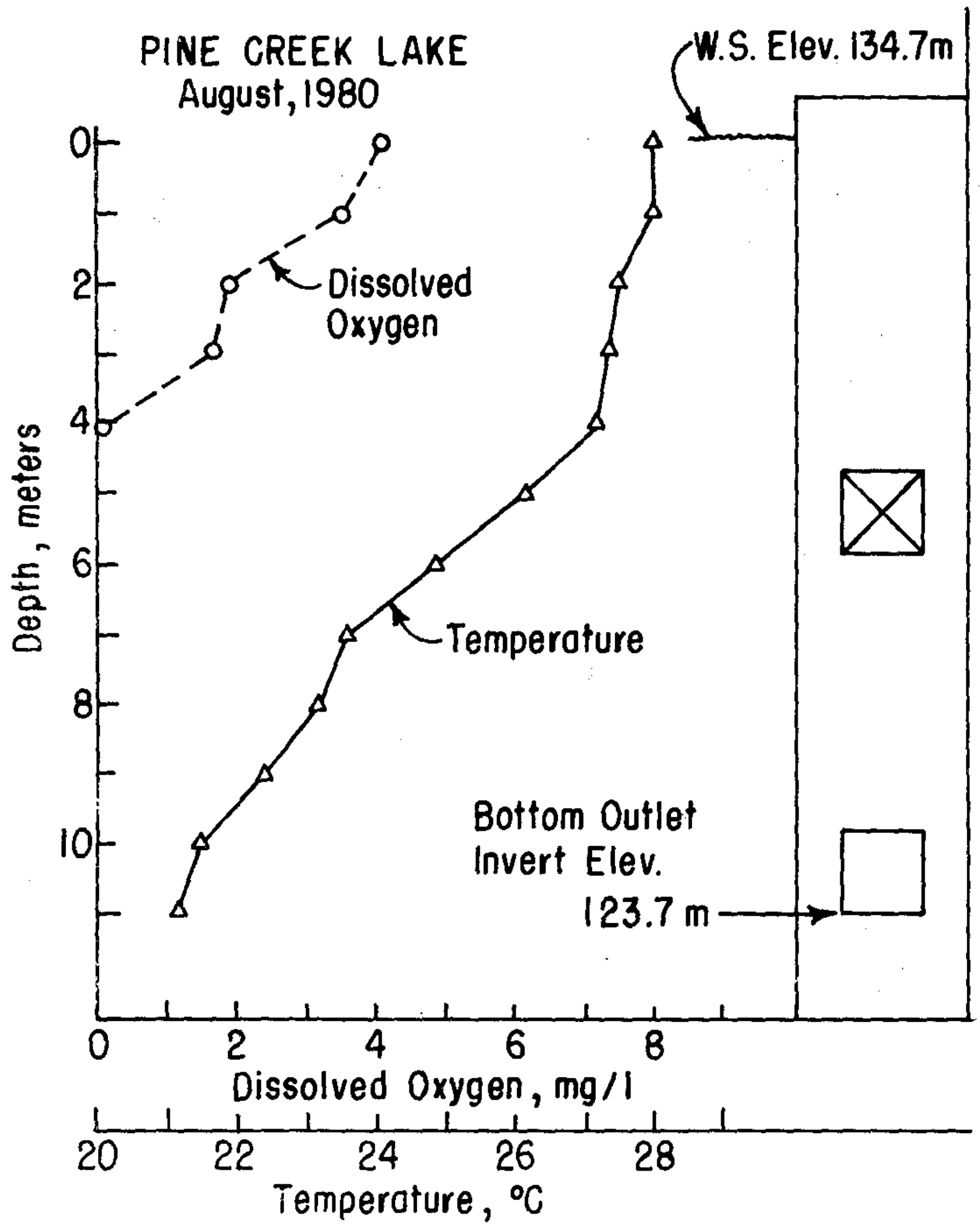

Figure 2-12. Temperature and Dissolved Oxygen Profiles at Pine Creek Lake on 5 August 1980

14.0 m^3/sec (494 cfs) from the 1.22 by 1.22 m (4 x 4 ft) bottom outlet as part of another test. The lower outlet invert was 11.0 m (36 ft) below the water surface.

Total iron, turbidity, manganese, and ammonia nitrogen exhibited the most dramatic concentration increases with depth (Figure 2-13). Depth of penetration tests were conducted near the intake structure at the buoy line. The 2.44 m (8 ft) diameter pump reached 9.5 and 11.0 m (31.1 and 36.1 ft) at propellor speeds of 19.7 and 25.1 RPM, respectively.

Release Improvement Tests

Due to the relatively large release rate on 5 August, the release improvement test was conducted using only the 2.44 m diameter pump. The maximum pumping rate of 4.0 m^3/sec (141 cfs) was the only pumping rate tested. The observed effects of pumping on release water quality are displayed in Table 2-V.

Table 2-5

RELEASE IMPROVEMENT AT PINE CREEK LAKE
5 August 1980

Parameter	Concentration Without Pump	Concentration With Pump	Percent Improvement
Temperature (^{o}C)	22.0	23.0	--
Dissolved Oxygen (mg/l)	4.0	7.0	75.0
Total Iron (mg/l)	3.4	2.96	12.9
Manganese (mg/l)	1.3	1.2	7.7
Sulfide (mg/l)	0.11	0.015	86.4
Ammonia Nitrogen (mg/l)	0.95	0.66	30.5
Phosphorous (mg/l)	0.12	0.09	25.0
pH	6.5	6.4	--
Conductivity (µmhos/cm)	64	62	3.1
Turbidity (NTU)	6.6	6.6	0.0

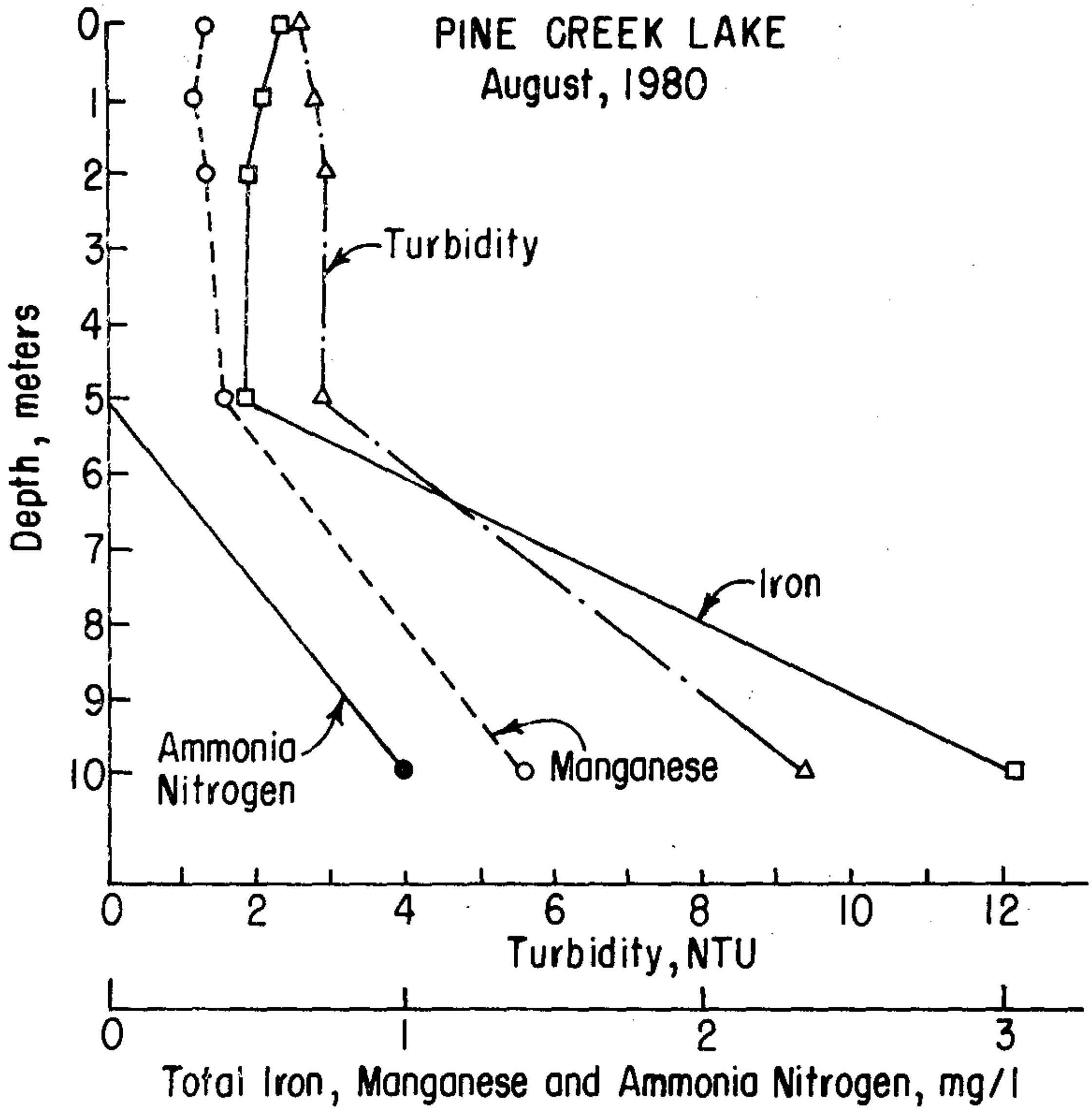

Figure 2-13. Selected Chemical Profiles at Pine Creek Lake on 5 August 1980

The dilution factor (release rate of surface waters divided by release rate) corresponding to the observed increase in water temperature, and thus enthalpy, was 17.2%; 2.4 m^3/sec (85 cfs) of the total 14.0 m^3/sec (494 cfs) of release water was surface water. Surface water enthalpy values were determined by averaging enthalpy values from the surface, 1m, and 2m levels in the reservoir. The ratio of pumping rate to release rate was 0.29.

SUMMARY AND CONCLUSIONS

Summary

Research was conducted to assist in developing uniform design and application guidelines for localized destratification using the Garton Pump. The objectives of this study were to identify optimum pump performance by varying reservoir release rate with respect to pump discharge rate and to evaluate pump performance by varying pump propellor diameter.

Three geometrically similar Garton axial flow pumps with propellor diameters of 1.22, 1.83, and 2.44 m (4, 6 and 8 ft) were tested at Pine Creek on 5 August 1980.

By positioning the Garton pumps directly over the reservoir intake gate and operating them over a range of reservoir release rates, the effects of localized mixing on release water quality was observed. Water quality parameters observed were: temperature, dissolved oxygen, turbidity, conductivity, pH, total iron, manganese, sulfide, ammonia nitrogen, and phosphorous.

Water quality profiles were recorded for the reservoir water column near the intake structure, and samples were collected at the downstream outlet for each pump at various pumping to release rate combinations.

Pump propellor RPM was measured and flow rates were calculated using the fan laws and the propellor manufacturer's stated performance in air. The amount of pumped surface water in the total reservoir release (dilution factor) was calculated using changes in release water enthalpy with and without pumping as a base.

Conclusions

1. Operating an axial flow Garton pump over a low level intake gate in the hypolimnion of a stratified impoundment will increase release water temperature and improve release water quality provided the plume of pumped water reaches outlet depth.
2. Operating a Garton Pump over an intermediate level intake gate located in the metalimnion or upper hypolimnion of a stratified impoundment can decrease release water quality and temperature if the plume of pumped water penetrates well below the outlet depth. Reductions in discharge water quality are most likely when pumping rate exceeds release rate.
3. Localized destratification will affect only those water quality parameters which display a concentration increase with depth above the release outlet.
4. The dilution factor resulting from pump operation can best be determined by using temperature or enthalpy changes in release waters as a base.
5. Increasing pump diameter while maintaining a discharge velocity sufficient to penetrate to outlet depth increases the discharge rate and increases the dilution factor. Additional tests should be conducted using the low outlet at Pine Creek to verify this conclusion for the 2.44 m (8 ft) pump.
6. Optimum release water quality improvements are obtained at a specific pumping rate to release rate ratio. At Pine Creek the optimum dilution factor was obtained at a pumping to release rate ratio of 0.47 for the 1.22 m (4 ft) pump and 0.96 for the 1.83 (6 ft) pump.

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PART III

WINTER ICE REMOVAL

PART III

WINTER ICE REMOVAL

INTRODUCTION

In this study two methods of ice melting were involved. The methods are identified as the Garton Pump and the Savonius Rotor. The objectives of the study were to assess the performance of the two methods to melt ice in lakes and reservoirs. In both cases, water was pumped from deeper depths to the lake surface.

During winter, many temperate zone lakes are covered by ice layers. The ice layer with a snow cover shades the water from the sun and separates the water from the atmosphere. This, combined with organism respiration, renders the lakes anaerobic due to the inhibition of photosynthesis and the lack of atmospheric transfer of oxygen. It is known that less than 2 ppm of dissolved oxygen content in snow-covered lakes is detrimental to fish survival. The purpose of the study was to find a means to eliminate the ice layers from the surface of lakes and reservoirs. Eliminating the ice layers also provides a free access to water for farm use and also for swimming purposes for ducks and swans, etc.

The study was conducted on Ham's Lake located 9.6 km west of Stillwater, Oklahoma. The maximum depth of the lake is 10 m. The study included measuring the area of melted ice, ice-thickness, and occasionally the water temperature profile. The relationship between the area of melted ice by each method, daily average temperature, and wind travel was examined.

EXPERIMENTAL APPARATUS

Two different apparatuses were used. The Garton Pump was connected to electric power supply, whereas the Savonius Rotor was driven by wind. The common concept was to pump water of higher temperature from deeper depths to melt ice on the surfaces of the lakes and reservoirs. Since temperature below the ice layer is relatively uniform, it was not necessary to pump water from greater depths.

Garton Pump

The Garton Pump was composed of an electric motor, a right angle gear-reduction, a floating raft, a propeller, and an orifice shroud. The Garton Pump is shown in Figure 3-1. The maximum power requirement of the pump is 746 W (1 horsepower), and at this power its capacity is 1.7 m^3/s (60 cfs) at 17.5 rpm.

The propeller of 1.83 m (6 ft) diameter was made of six blades. The raft that carried the propeller was 2 m^2 (6.6 ft) and was anchored from each four corners. An underwater cable was used to connect the pump to the power supply.

Savonius Rotor

The second method employed to melt ice was a wind driven apparatus and is referred to as a Savonius Rotor. It consisted of a rotor, a shaft, a floating raft, and a propeller. Figure 3-2 shows this apparatus on the site of the experiment. This figure does not show the propeller which is beneath the water surface.

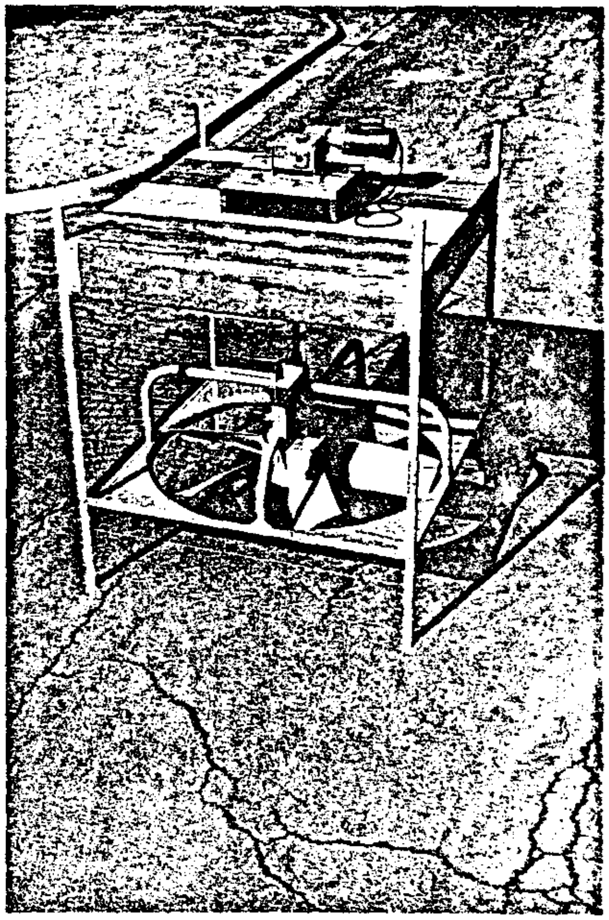


Figure 3-1. A view of the Garton Pump

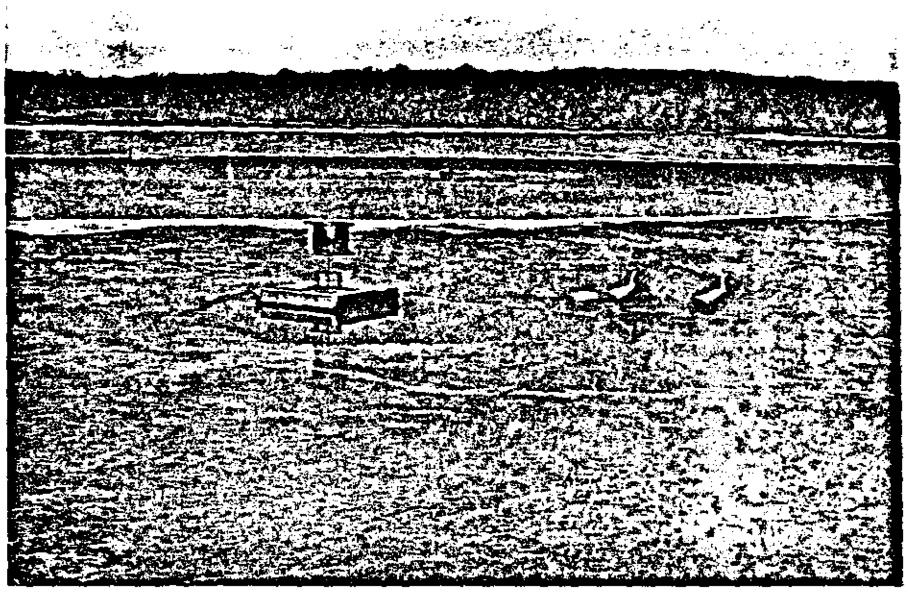


Figure 3-2. The Savonius Rotor

PROCEDURE

Observation was commenced on January 12, 1979 and ended on February 21, 1979. In the case of the Savonius Rotor, not many observations were made.

Area of melted ice, ice-thickness, and temperature profiles were measured. Observations were not made on a regular basis because of bad weather and bad road conditions. Ice-thickness and water temperature profiles were seldom measured because of the danger of thin ice.

Areas of melted ice were planimetered from photographs taken approximately from the same respective spots. For the Savonius Rotor, the raft of known area was planimetered for each observation; and area of melted ice for each observation date was computed proportionally. In the case of the ice melted by the Garton Pump, the area of the raft as compared to the area of the melted ice was insignificantly small. Thus, it was not possible to use the raft to compute the area of melted ice. Instead, the area of melted ice on January 12, 1979 was determined using a transit. Different points on the edge of the melted ice were located in respect to a reference line. These points were plotted on paper and were connected by a smooth line. Then the area was determined. The area of the melted ice for this date was used to determine the area of melted ice for the rest of the observation dates.

Maximum and minimum daily temperatures and daily wind travel were obtained from the Agronomy Weather Station in Stillwater, Oklahoma. The daily average temperature (Table 3-I) was computed as the average of the maximum and minimum.

RESULTS, DISCUSSION AND CONCLUSIONS

Table 3-II shows the areas of ice melted by each method, the daily average temperature, and daily wind travel for the indicated date of observation. The ice thickness for most of the study period varied between ten

Table 3-1. Daily Average Temperature and Wind Travel for Stillwater for the Months of January and February, 1979

Date	January Ave. Temperature (°C)	January Wind Travel (Km/day)	February Ave. Temperature (°C)	February Wind Travel (Km/day)
1	-11.4	-	-14.4	40
2	-14.4	270	-6.7	241
3	-9.2	77	-8.9	135
4	-5.6	43	-8.3	151
5	-6.1	217	-8.9	163
6	-10.3	183	-8.6	71
7	-8.6	200	-6.4	230
8	-11.9	77	-5.6	177
9	-9.4	121	-11.1	277
10	-1.9	64	-6.1	105
11	-5.3	177	2.2	76
12	-3.9	182	3.9	150
13	-3.6	264	-3.9	98
14	-14.7	468	-1.1	61
15	-9.7	132	5.0	100
16	-1.4	171	-4.2	235
17	2.5	138	-8.3	174
18	2.5	123	-6.7	251
19	6.1	143	-0.3	261
20	2.8	88	4.4	272
21	3.9	344	1.7	127
22	3.3	262	5.8	138
23	3.1	82	10.8	227
24	-7.8	547	3.6	288
25	-1.1	121	1.1	241
26	1.9	198	3.1	246
27	-4.4	351	5.3	182
28	-10.3	169	10.6	312
29	-11.9	92		
30	-8.9	158		
31	-13.6	172		

Table 3-2. Area of Melted Ice by the Garton Pump and the Savonius Rotor, and the Daily Average Temperature and Wind Travel for the Indicated Observation Dates.

Date	Daily Average Temperature (°C)	Wind Travel (km/day)	Area of Melted Ice (m^2)	
			Garton Pump	Savonius Rotor
1/12/79	-3.9	182	4600	-
1/15/79	-9.7	132	6500	20
1/17/79	2.5	138	8400	60
1/19/79	6.1	143	15800	60
1/24/79	-7.8	547	6000	-
1/26/79	1.9	198	9300	-
1/31/79	-13.6	172	4600	-
2/2/79	-6.7	241	5100	-
2/5/79	-8.9	163	7900	-
2/9/79	-11.1	277	4200	-
2/12/79	3.9	150	9300	20
2/15/79	5.0	100	15300	-
2/16/79	-4.2	235	14400	-

and twenty centimeters. Temperature profiles of the water ranged from $0^{o}C$ to $2.0^{o}C$. However, only a few measurements of ice thickness and temperature profile were made during the study period. Nevertheless, it was enough to indicate the prevailing conditions of the lake.

Garton Pump

More observations were made on the Garton Pump than the other device. Ham's Lake was frozen starting January 1 and the pump was turned on by an unknown person sometime before the first observation date on January 12, 1979. The area of melted ice ranged from 4600 to 15,300 m^2 (1.1 to 3.8 ac) as shown in Table 3-II and Figure 3-3. The period from January 31 to February 9 was a good interval of time to evaluate the capacity of the Garton Pump to melt the ice. The biggest area of melted ice during this period was 7900 m^2 (2.0 ac). The overall average area of melted ice by the Garton Pump method was 8600 m^2 (2.1 ac).

Figure 3-4 shows the melted ice of February 9. The rest of the lake was covered with ice and snow. Ducks and swans are also shown swimming on the open water.

If wind speed had any strong influence on the area of melted ice, it could have been reflected on January 24. The area of melted ice was 6000 m^2 (1.5 ac). The daily average temperature was $-7.8^{o}C$, and the daily wind travel was 547 km (340 mi) per day. For January 15 the area was 6500 m^2 (1.6 ac), the daily average temperature was $-9.7^{o}C$, and the wind travel was 132 km (82 mi) per day. As shown in Figure 3-3 average temperature for the days prior to January 15 was below freezing, but for those prior to January 24 was above freezing. Thus, it was not observed that wind travel had any effect on the size of melted ice.

Figure 3-3. Wind Travel, Average Daily Temperature and Area of Melted Ice by the Garton Pump Versus Time.

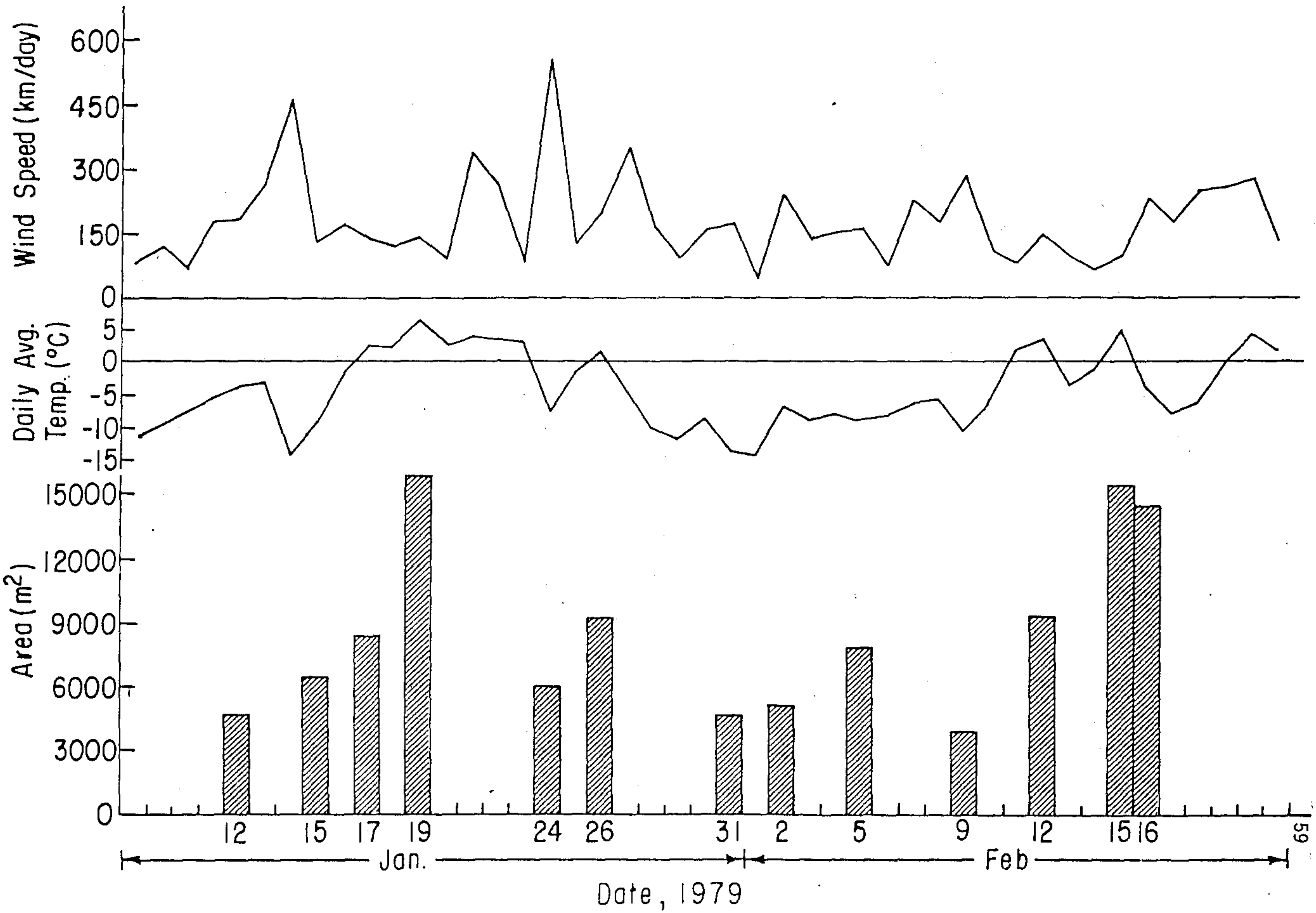


Figure 3-4. The Melted Ice by the Garton Pump for February 9, 1979, the date of minimum area.

The study revealed that the Garton Pump can be used to melt ice of appreciable size. It can solve the problem of accessibility to water by cattle and wildlife, and since it melted an appreciable area of ice it could also eliminate the ill effects on oxygen content due to the ice layer covering the surface of the water body.

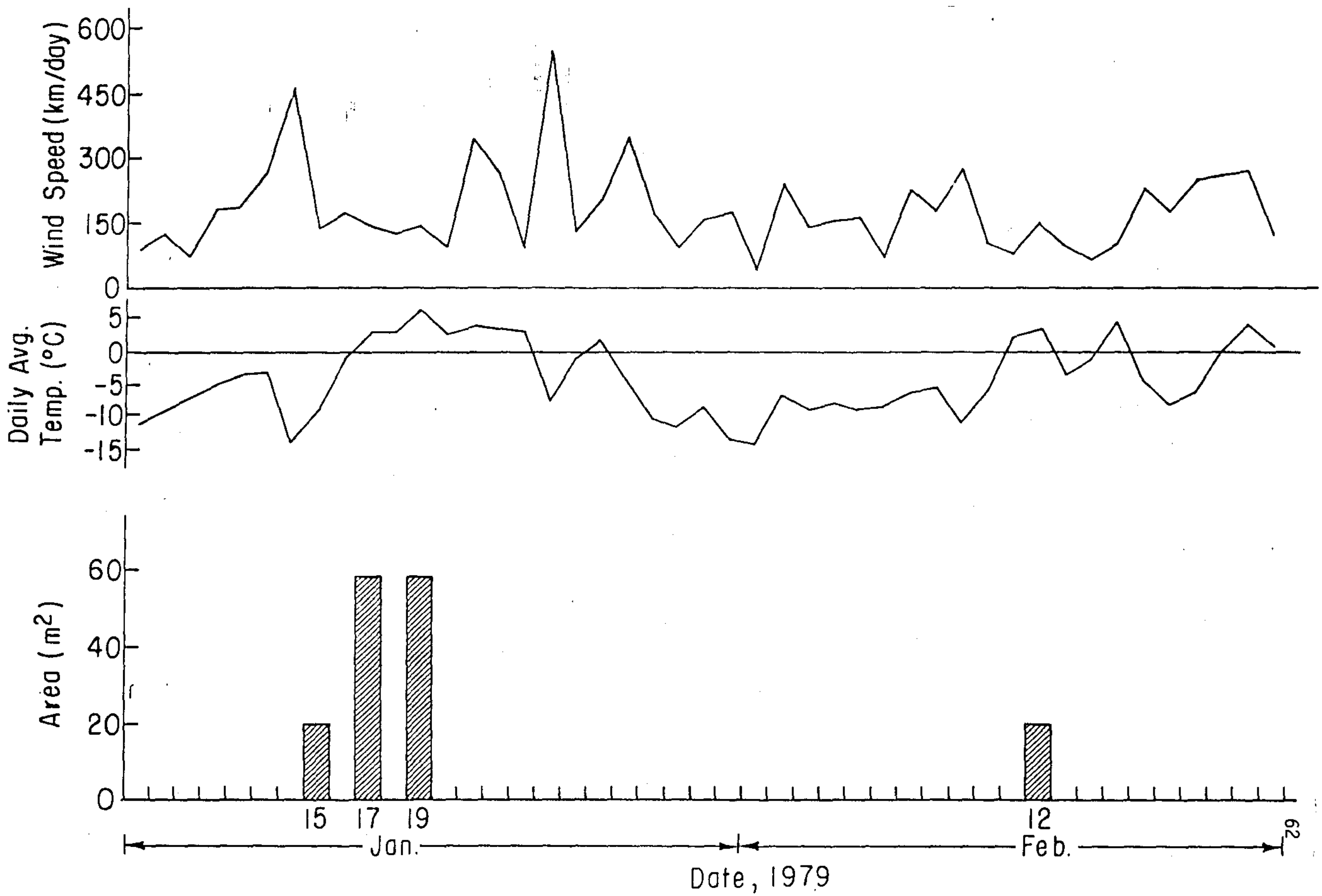
Savonius Rotor

In the case of the Savonius Rotor, due to the inadequate wind travel at a particular time, refreezing occurred and the ice layer formed prevented the rotation of the shaft. Thus, the observations (Table 3-II and Figure 3-5) made were inadequate. Except for one observation date, the daily average temperature was above freezing point. The area of melted ice was 20 m^2 (0.005 ac) when the daily average temperature was below freezing point. The overall average was 40 m^2 (0.01 ac).

In the design of the apparatus the rotor and the propeller were connected by a shaft. When ice was formed it prevented the rotation of the shaft, and it was necessary to break the ice mechanically. However, this cannot be done unless the ice is thick enough for a person to walk on, or unless a special means is designed for this particular purpose. Since wind is the energy supplier, it is likely an ice layer will be formed every now and then during calm days.

Concerning this method, this particular study could not evaluate the performance of the Savonius Rotor conclusively. However, the few observations made suggests that the Savonius Rotor cannot be depended on to keep ice melted during periods of low wind speeds.

Figure 3-5. Wind Travel, Average Daily Temperature and Area of Melted Ice by the Savonius Rotor Versus Time.



SUMMARY

The objective of the study was to evaluate the performance of the Garton Pump (746 W, (1 horsepower)) and the Savonius Rotor to melt ice in lakes and reservoirs. The study was conducted in Ham's Lake situated 9.6 km (6 mi) west of Stillwater, Oklahoma.

In this study, area of melted ice, ice-thickness, water temperature profile, daily average temperature, and wind travel were measured. Photographs were used to determine area of melted ice for each observation date. The ice thickness for most of the study period varied between ten and twenty centimeters. The temperature profile ranged from $0^{o}C$ to $2^{o}C$.

The Garton Pump was able to melt ice of an average area of 8600 m^2 (2.1 ac). The Savonius Rotor was also able to melt ice of 40 m^2 (0.01 ac) on the average. Concerning the Garton Pump, the area of melted ice varied with temperature variation; but no variation in the area of melted ice was observed with wind travel variation.