RESERVOIR RELEASE WATER QUALITY IMPROVEMENT
BY LOCALIZED DESTRATIFICATION

By

KERRY MARK ROBINSON

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1975

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1981

RESERVOIR RELEASE WATER QUALITY IMPROVEMENT
BY LOCALIZED DESTRATIFICATION

Thesis Approved:

James E Garton
Thesis Adviser

Jerry Wilhm

Charles E Rice

Norman N Durham
Dean of Graduate College

ACKNOWLEDGMENTS

The work upon which this report is based was supported in part by funds provided by the U. S. Department of the Interior, Office of Water Research and Technology, as authorized by the Water Resources Research Act of 1964. Funding was also provided in part by the Oklahoma Agricultural Experiment Station and the U. S. Army Engineer Waterways Experiment Station.

The Department of Agricultural Engineering, headed by Dr. C. T. Haan, provided the research assistantship and facilities which made this study possible. Department faculty and staff took a genuine interest in my work and provided encouragement and support during every phase of this project.

I sincerely appreciate the guidance and assistance of my major adviser, Dr. James E. Garton. His patience, enthusiasm, and constant support are deeply appreciated. The constructive criticism and professional advice offered by Dr. Jerry Wilhm, Dr. Charles Rice, and Dr. Peter Moretti are gratefully acknowledged.

My gratitude is extended to Jack Fryrear for his helpful advice and preparation of the illustrations. The efforts and advice of Norvil Cole and Bruce Lambert were invaluable during the preparation of test equipment. The assistance of Edward D. Bevers, Ricky Heflin, and Richard Punnett while preparing, transporting, and testing the research equipment is truly appreciated.

I am indebted to my wife, Rene'e, for undertaking the thankless task of typing this thesis. The constant support and endless sacrifices of my wife and son, Hunter, made this work possible.

My parents, Mr. & Mrs. Robert Calvin Robinson, have been a constant source of inspiration. They planted the seeds of individual thought and self-reliance and taught me the meaning of hard work. To my parents, I gratefully dedicate this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Statement of Problem

Impounding free flowing streams in order to provide municipal and industrial water supplies, irrigation, flood control, power generation, and recreation has been widely practiced. Unfortunately, dam construction appears to have outpaced the overall understanding of the physical, chemical, and biological factors affecting impounded waters.

As water changes from a flowing environment to an essentially standing environment, the effects on water quality can be dramatic. Smalley and Novak (1980) 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, 1914). 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 aquatic biota. The zone with rapid changes in temperature and dissolved oxygen between the epilimnion and hypolimnion is the metalimnion. The density gradient within the metalimnion supresses wind induced circulation of hypolimnetic waters.

Various methods have been used to prevent thermal stratification of reservoirs. Compressed air has been released within the hypolimnion to aerate and circulate overlying waters, and hypolimnetic waters have been pumped to the surface and released. Systems have also been developed to pump hypolimnion water to the surface where it is oxygenated and returned to the hypolimnion.

An axial flow pump was developed by Quintero and Garton (1973) to pump oxygen rich surface waters down to the hypolimnion. Extensive lake destratification tests of the Garton pump were conducted at several Oklahoma reservoirs using a wide range of pump diameters and flow rates. These studies suggested the possibility of using the Garton pump to improve the quality of reservoir release water without destratifying the entire water body. The Garton pump provides an alternative to retrofitting existing structures with multi-level intakes. This research continues study of the Garton pump as a means of reservoir release water quality improvement.

Objectives

The following objectives were identified to assist the development of uniform design and application guidelines for localized destratification using the Garton pump:

1. To identify optimum pump performance by varying reservoir release rate with respect to pump discharge rate.

2. To evaluate pump performance by varying pump propellor diameter.

Limitations of the Study

Since research equipment had to be operated on existing reservoirs experiencing thermal stratification, the testing period was limited to the time period between mid-summer and early fall.

Coordination and support of reservoir operating authorities was necessary. The logistics involved in transporting necessary research equipment for testing at a time acceptable to controlling authorities limited the duration of testing. That is, other studies in progress and requirements on release rates necessitated short-term tests.

CHAPTER II

LITERATURE REVIEW

Impoundment Effects

Thermal Stratification

Many of the quality problems associated with stored water result from the development of normal thermal stratification, first measured by De Saussure in 1779 (Hutchinson, 1957).

Direct absorption of solar radiation by a water body provides the vast majority of heat distributed throughout the impoundment. The retention of heat is coupled with factors that influence its distribution within the lake system: physical work of wind energy, currents and other water movements, morphometry of the basin, and water losses (Wetzel, 1975). The major driving force in the process of heating in the water column is that of wave action. Winds blowing across the reservoir create turbulence which mixes the water to varying depths depending on wind speed, fetch (the distance the wind travels across the reservoir surface), and exposure of the reservoir (Smalley and Novak, 1980).

Temperate, dimictic lakes circulate freely in spring and fall between summer stratification and inverse stratification in winter. Kittrell (1965) provided a particularly clear summary for stratification in reservoirs.

Once thermal stratification is established, the water body is composed of three distinct zones or strata (Figure 1). The epilimnion is fairly warm, turbulent, and circulating (Hutchinson, 1957). Below the epilimnion is the metalimnion which has a steep thermal gradient. The term thermocline has been defined variously, but correctly refers to the plane or surface of maximum rate of decrease of temperature with respect to depth (Wetzel, 1975). The depth of the metalimnion is mainly determined by the wind stress applied to the water surface (Hutchinson, 1957). Below the metalimnion is a strata of colder, relatively undisturbed water called the hypolimnion. The depth required to stratify thermally varies so greatly with surface area, basin orientation in relation to prevailing winds, depth-volume relations, protection by surrounding topography and vegetation, and other factors that generalizations in this regard are misleading (Wetzel, 1975).

Summer stratification persists until the fall when the surface water and the influent water becomes cooler. The cooler water is mixed throughout the epilimnion and the upper portions of the metalimnion by convection and wind action. Cooling continues until the temperatures and densities of the epilimnion and the metalimnion approach those of the hypolimnion. When this is accomplished resistance to mixing is diminished, and the fall overturn occurs (Kittrell, 1965).

As winter progresses, the water body may cool to below 4° C if temperatures are low. Since water is less dense at 0° C than at 4° C an inverse stratification may result which is much less stable than summer stratification and can be overcome by wind. As spring approaches, the water is warmed until it becomes isothermal and mixes as a spring overturn. The stratification cycle begins again as surface waters become warmer.

Water is unique in that its density is at maximum near 4° C. Physical work is required to mix fluids of differing densities. The amount of work required to mix layered water masses between 29 and 30° C is 40 times, and between 24 and 25° C is 30 times that required for the same masses between 4 and 5° C (Wetzel, 1975).

Impoundment Water Quality

Thermal stratification in lakes and reservoirs has a dramatic effect on water quality. Beneficial effects of impoundment on water quality are reductions of turbidity and coliform bacteria, and entrapment of sediment (Love, 1961). Water quality problems resulting from thermal stratification are often brought about by deoxygenation of the hypolimnion. Accumulations of iron and manganese in the hypolimnion induce microbial deposition of iron and manganese slimes in distribution lines which cause increased friction losses and staining during water use. Increased evaporation, algal growths in the photic zone, and unpleasant tastes and odors are a few of the detrimental effects of impoundment (Powling and Burns, 1979).

Stratification of dissolved oxygen often produces oxidizing conditions in the epilimnion and reducing conditions in the hypolimnion. The cycles of iron, manganese, sulfur, nitrogen, and phosphorous are greatly affected. A detailed treatment of the physical, chemical, and biological cycles within lakes is available in Hutchinson (1957).

Release Water Quality

Reservoirs with low level intakes are nutrient exporters and heat traps, as opposed to natural lakes which act as nutrient traps and heat exporters (Odum, 1971). The deterioration of water quality within a stratified impoundment becomes particularly pronounced when hypolimnetic waters are released. When bottom water of a stratified reservoir is used as a source of drinking water or during the natural fall turnover period when this water is mixed throughout the reservoir, an additional burden is placed on the water treatment plant. Production of acceptable finished water may be difficult (Symons, Carswell, and Robeck, 1970). Detrimental effects of bottom discharges from stratified impoundments are loss of essential nutrients from the reservoir, cold release water, and fish kills resulting from discharge of hydrogen sulfide-laden water (Wright, 1967).

With dissolved oxygen greatly reduced over that of the surface waters of the reservoir or of the natural stream, the waste assimilating capacity of the water is reduced, resulting in problems in use of the downstream reaches for water discharge (Smalley and Novak, 1980). The Roanoke River in North Carolina experienced this situation when the river was forced to absorb a heavy organic waste loading before it had recovered from the degrading effects of impoundment (Fish, 1959).

According to Kittrell (1959), before the development of large valves which could be operated under high pressure heads, penstock intakes were located in the upper levels of reservoirs and drew water from the epilimnion. The elevation of the intake is a primary factor with regard to the quality of water in the reservoir and in its discharge (Wunderlich and Elder, 1969). Wunderlich and Elder also state that the increasing awareness of the necessity to maintain or restore high water quality has generated a growing interest in methods which can be used in the planning, design, and operation of engineering structures to achieve satisfactory water quality control.

The use of multi-level intakes, which enable water to be withdrawn from selected depths, provides a partial answer to release water quality problems. However, this will be satisfactory only in those cases where a limitation of the useable water volume is acceptable and avoidance of a particular zone is a solution to the problems. It will do nothing to prevent a deteriorating situation in either the hypolimnion (iron, manganese, and hydrogen sulfide) or the epilimnion (algae). Moreover, multi-level intakes are expensive since to be effective they must have an outlet spacing of less than the minimum thermocline depth and each outlet must be large enough to deliver the maximum required summer discharge (Bowles, Powling, and Burns, 1979).

Destratification

Methods

Many methods have been devised to break up thermal stratification within a reservoir and to provide improvements in water quality. While individual systems vary significantly, they can be classified broadly as pumped water systems, diffused air pumping systems, or combinations of each.

Compressed air released near the bottom of a reservoir induces mixing action and has been shown to break down thermal stratification. The rising air bubbles released from numerous diffuser heads on a manifold produce circulation of overlying waters. Diffused air systems often have high power requirements, high friction losses in distribution systems, and high maintenance costs. Excellent case studies of destratification by diffused air pumping and mechanical pumping were compiled by Powling and Burns (1979).

Pumped water systems or mechanical systems have been developed to break up stratification. A system was used in Lac de Bret, Switzerland, to pump water from the hypolimnion through an aeration chamber and return it to the same depth from which it was withdrawn (Kittrell, 1959). Irwin, Symons, and Robeck (1966) developed a system to pump cold, dense water from near the lake bottom to the surface where it could mix warm water, lose density, and absorb oxygen. Quintero and Garton (1973) developed an axial flow pump to transfer high quality epilimnion water down to the hypolimnion.

Effects

Artificial destratification will affect only those water quality parameters that initially show a concentration gradient with depth or are influenced by the vertical transport of some other water quality constituent. For example, vertical transport of carbon dioxide will lower the surface pH even if the pH initially did not show a vertical gradient (Symons, Irwin, and Robeck, 1968).

A disadvantage of compressed air systems is the possible formation of substantial nitrogen gas supersaturations relative to surface pressures, which have a negative impact on the biota (Powling and Burns, 1979). Mechanical pumping has little effect on nitrogen gas supersaturation.

Artificial destratification techniques increase the overall temperature of an impoundment and its release waters. This characteristic may be good or bad depending on downstream water use.

Symons, Carswell, and Robeck (1970) indicated that artificial destratification added dissolved oxygen to the water and oxidized any reduced substances such as iron, manganese, and sulfide. These same authors also observed that plankton populations decreased temporarily during reservoir mixing and were shifted in predominance from blue-green toward green algae.

Axial Flow Pump

Lake Destratification

Quintero and Garton (1973) developed an axial flow propellor pump to move relatively large volumes of water at low velocity, low head, at a low power requirement. A seven-blade propellor of 1.06 m diameter was used to pump epilimnion water down to the hypolimnion.

Steichen (1974) used a pump with a nine-blade propellor, also of 1.06 m diameter to destratify Ham's Lake. This pump discharged 0.77 m^3/sec at an energy input of 0.37 kW. A 1.83 m diameter propellor pump was tested by Strecker (1976) which discharged 1.58 m^3/sec at an energy input of 1.1 kW. This pump also successfully destratified Ham's Lake. Extensive water quality tests performed by Steichen and Strecker indicated overall improvements in lake water quality. Strecker (1976) concluded that the fan laws provided an effective means of predicting the performance in water from the available data in air. Therefore, with diameter constant, the following relations are valid:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad (1)$$

$$\frac{H_1}{H_2} = \frac{N_1^2 \ \gamma_1}{N_2^2 \ \gamma_2} \tag{2}$$

$$\frac{P_1}{P_2} = \frac{N_1^3 \ \gamma_1}{N_2^3 \ \gamma_2} \tag{3}$$

where Q = rate of flow

N = rotative speed

H = increased energy content in the fluid pumped, or head

γ = density of the fluid

P = input power

Destratification of Arbuckle Lake was attempted with a 5.03 m diameter propellor pumping 13.1 m^3/sec at an input power of 7.3 kW. Pumping reduced lake stability but did not destratify the lake. Chemical stratification was maintained even though the lake was weakly stratified thermally. While the pump did not destratify the lake, it did advance the date of fall turnover (Garton and Rice, 1976). A cluster of 16 pumps, each with a propellor diameter of 1.77 m, was installed on Arbuckle Lake (Punnett, 1978). The total pumping rate for these pumps was 26 m^3/sec, but the device was unable to penetrate to the lake bottom. While total destratification was not achieved, lake stability decreased, and a larger volume of the lake maintained dissolved oxygen levels over 2.0 mg/l.

Detailed observations of physiochemical data and biological conditions were made at Ham's and Arbuckle Lakes during destratification testing and were reported by Garton, et al. (1976).

Localized Mixing

Observation of dissolved oxygen concentrations near an operating pump were higher than at like depths further from the pump, suggesting the possibility of improving reservoir release water quality without destratifying the entire lake. Garton and Jarrell (1976) demonstrated the applicability of localized destratification at Lake Okatibbee, Mississippi. A 1.83 m diameter pump discharging approximately 1.7 m^3/sec was able to increase discharge dissolved oxygen and temperature levels within minutes after start-up. The hydrogen sulfide odor was also dimished.

Dortch and Wilhelms (1978) conducted further tests with the same pump. Pump operation resulted in turbulent mixing of the surface and bottom waters. The excess quantity of mixed water that is not withdrawn rises to neutral bouyancy and spreads as a density current (Figure 2). To calculate the contribution of surface water in the release water, Dortch and Wilhelms (1978) used the following calculation. From preservation of continuity, the concentration of a tracer can be determined from the equation:

$$C_oV_o = C_1V_1 + C_2V_2 \tag{4}$$

If conductivity is used as a tracer, then

C_o = conductivity of water released with pump on

V_o = volume of water released in a time period

C_1 = conductivity of water released prior to pumping

V_1 = volume of hypolimnion water released in a time period

C_2 = conductivity of epilimnion water

V_2 = volume of epilimnion water released in a time period

From conservation of volume

$$V_o = V_1 + V_2 \tag{5}$$

By substitution of equation (5) into equation (4), equation (4) was rewritten as:

$$\frac{V_2}{V_o} = \frac{C_o - C_1}{C_2 - C_1} \tag{6}$$

Dortch and Wilhelms (1978) concluded that 50% of the 1.4 m^3/sec release was epilimnion water at Lake Okatibbee.

Peralta and Garton (1978) examined the effects of 1.06 m and 1.83 m pumps on release water quality at Gilham Lake, Arkansas. Use of the Garton pumps substantially improved release water quality at a release rate of 1.56 m^3/sec.

Moon, McLaughlin, and Moretti (1980) conducted hydraulic model tests of localized mixing using scale models of Lake Okatibbee and Cave Run Lake outlet structures. Several conclusions from their tests are listed as follows:

1. Accurate hydraulic modeling of the near flowfield of a propellor pump jet impinging on a density interface may be performed with the densimetric Froude number as the principal modeling parameter.

2. The effect of not matching the Reynolds number in the prototype and model is negligible, provided that the flowfield is entirely turbulent.

3. The dilution factor and the non-dimensional penetration depth are functions of the densimetric Froude number, non-dimensional propellor diameter, non-dimensional propellor depth, flowrate ratio, and the

non-dimensional metalimnion location.

4. The dilution factor is a strong function of the flowrate ratio when the flowrate ratio (pumped water volume divided by released water volume) is less than about 0.35. The dilution factor is a weak function of the flowrate ratio when this ratio is greater than about 0.40.

5. The data relating the dilution factor and its functional relationships were insensitive to the differences in geometry of the two release structures tested.

Garton and Punnett (1980) reported additional field tests of the Garton pump at Pine Creek Reservoir and the Lake of the Ozarks. The major conclusions drawn are listed as follows:

1. Localized mixing might be a low-cost method of improving the downstream releases from moderately shallow impoundments.

2. As lake depth increases, the power required to penetrate to the outlet will be expected to increase.

3. The increase in dissolved oxygen downstream with localized mixing is accompanied by an increase in temperature. These higher temperatures may preclude the development of a cold water fishery downstream.

CHAPTER III

EXPERIMENTAL EQUIPMENT

Garton Pumps

Three Garton pumps with variable speed capability were operated during this study. Each pump consisted of a propellor and orifice shroud, a supporting platform, and a gasoline motor operating through a right angle reduction gearbox.

Propellors

Three geometrically similar aluminum ventilation fans of 1.22, 1.83, and 2.44 m diameter along with matching orifice shrouds were purchased from Aerovent. The six blades on the 1.22 m 48R622 fan were permanently attached to the hub at a pitch of 22° measured at two-thirds of the propellor radius. The six blades on the 1.83 m 72R622 and 2.44 m 96R622 fans were adjustable and were also set as above.

The propellor hubs were fastened to cold rolled steel shafts using tapered friction hubs (Figure 3). The propellor shafts were held in place by two sleeve and thrust bearings. The propellors were suspended 1.7 m below the water surface.

The manufacturer's stated performance in air for the 1.22, 1.82, and 2.44 m propellors was 12.5 m^3/sec at 1160 RPM at a power input of 1.7 kW, 21.2 m^3/sec at 580 RPM at a power input of 1.6 kW, and 50.4

m^3/sec at 580 RPM at a power input of 6.7 kW, respectively. The performance of the propellors in water was calculated using equations (1) and (3) and the manufacturer's stated performance in air.

Supporting Platform

A redwood raft filled with gasoline resistant expanded foam supported the pump in the water. The support platforms for the 1.22 and 1.83 m pumps were 2 m long and 2 m wide. The 2.44 m pump was supported by a 2.0 m by 2.4 m platform, 0.3 m thick. Angle irons attached at each corner of the rafts supported the propellor and orifice shroud. Each raft had sufficient floatation capacity to support additional test equipment and personnel. Pumps were mounted on wheels to simplify loading and unloading.

Power Sources

Briggs and Stratton gasoline engines were used to power each raft. For the relatively short duration tests, the gasoline engines provided rapid pump installation and variable speed capability. The 1.22 m pump was powered by a 3.7 kW motor operating through a 15.5:1 Falk gearbox. A 3.7 kW motor powered the 1.83 m pump and operated the propellor through a 20.5:1 Falk gearbox. The 2.44 pump was powered by an 11.9 kW motor operating through a 29.5:1 Falk gearbox.

Adjustable diameter v-belt sheaves were attached to the motor output shaft and allowed flexibility in matching pump speed to engine RPM. The 1.22 and 1.83 m pumps used a single v-belt, while the 2.44 m pump used two v-belts to transfer power from the engine to the gearbox. The power units and support platforms are shown in Figure 4.

Measuring Devices

A Kemmerer water sampler was used to collect water samples from different depths. Temperature and dissolved oxygen were measured with a Yellow Springs (YS) meter at Pine Creek Lake. A YS conductivity meter was also used at Pine Creek Lake. A Hydrolab #4041 meter was used to measure temperature, dissolved oxygen, pH, and conductivity at Lake Texoma. 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 Hach spectrophotometer. A hand-held tachometer was used to measure gearbox input RPM. Propellor RPM was calculated using the gearbox ratio. Water samples were analyzed on site as soon as possible after collection. An air conditioned mobile laboratory equipped with ample counter space and 115 volt circuits to power laboratory equipment was used for sample testing.

Test Location and Description

Release water quality improvement tests were conducted at Pine Creek Lake and Lake Texoma during the summer of 1980. At Pine Creek Lake the 1.22, 1.83, and 2.44 m pumps were tested, while only the 2.44 m pump was used at Lake Texoma.

Pine Creek Lake

Pine Creek Lake is located in McCurtain, Choctaw, and Pushmataha Counties in the Ouachita Mountain Region of southeastern Oklahoma (Figure 5). The damsite on the Little River is approximately 8 km northwest of Wright City and 13 km north of Valliant, Oklahoma.

The dam is a rolled earth structure, 2290 m in length, which rises 37.5 m above the original riverbed. The outlet works include an intake gate tower on the west bank of the river, a 4.0 m diameter conduit, a 1.22 m low-flow line with an invert elevation of 122.05 m, and a 0.91 m water supply line for domestic and industrial use (Tulsa District Corps of Engineers, 1976a).

Construction began in 1963, and the project was completed in 1969. Project purposes include flood control, water supply, and water conservation. At conservation pool elevation, 133.5 m above sea level, there are 6.63 X 10^7 m^3 of water storage, 119 km of shoreline, and a surface area of 1539 ha. At flood control elevation, 146.3 m above sea level, there are 5.74 X 10^8 m^3 of floodwater storage and a surface area of 6966 ha. The drainage area consists of 1644 square kilometers (Tulsa District Corps of Engineers, 1976a).

Texoma Lake

Lake Texoma is in southern Oklahoma and northern Texas. The dam is located on the Red River in Bryan County, Oklahoma, and Grayson County, Texas. The damsite is approximately 8 km northwest of Denison, Texas, and 24 km southwest of Durant, Oklahoma (Figure 6). Denison 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 5244 m, and maximum height above the streambed is 50.3 m (Tulsa District Corps of Engineers, 1976b).

The project was approved for construction in 1938 for flood control and power generation and was completed by 1944. At flood control elevation, 195.1 m above sea level, the impoundment surface area is

58,036 ha with a total storage capacity of 6.63×10^9 m^3 of water. At the power pool elevation of 188.1 m above sea level the surface area is 36,045 ha, and the storage capacity is 2.06×10^9 m^3. The drainage area controlled by Texoma Lake is 102,828 square kilometers (Tulsa District Corps of Engineers, 1976b).

CHAPTER IV

METHODS AND PROCEDURES

Profiles

Upon arrival at the test location, temperature and dissolved oxygen profiles were obtained by taking readings at meter increments from the surface to the bottom. Temperature and dissolved oxygen profiles were also taken just prior to release water improvement tests. Water samples were collected at different depths in the lake. Profile sample turbidity and conductivity, total iron, manganese, sulfide, ammonia nitrogen, pH, and phosphorous concentrations were measured. The chemical test procedures conformed to methods outlined in the Hach Chemical Company Water Analysis Handbook (1977). Specific chemical test methods are described in Appendix C. All test equipment was calibrated and/or standardized according to the manufacturer's specification.

The preliminary profiles were taken at the buoy line just upstream from the intake structure. Profiles were not obtained at the intake due to the possibility of probe damage resulting from ongoing releases.

Penetration Depth

Depth of penetration tests were conducted prior to the release improvement tests to insure that the plume of pumped water penetrated to outlet depth. By locating the Garton pumps at the buoy line near the intake structure, each pump was tested separately at various pump speeds. The depth of penetration was determined by allowing the pump to operate at constant speed for several minutes and then slowly lowering a temperature probe below the pump until a significant change in temperature was observed. By comparing the temperatures with and without pumping, the depth of penetration was identified. Penetration tests were conducted from low to high pump speed and small to large diameters to minimize the effect of a previous test on depth of penetration.

Localized Destratification Tests

Release water quality improvement tests were conducted at Pine Creek Lake on 25-26 June and 5 August 1980. Release improvement tests were conducted at Lake Texoma on 17-18 August 1980 using only the 2.44 m diameter pump.

Pine Creek

The Garton pumps were positioned inside the open rectangular intake structure directly over a 1.22 by 1.22 m outlet. Figure 7, although taken in 1978, depicts pump location over the intake. Pumps were tied to the intake structure to prevent raft rotation. The Corps of Engineers granted permission to change the release rates through the dam and provided an operations technician to make the scheduled gate changed when requested. Before the pumps were started, the temperature and dissolved oxygen were measured at the downstream outlet. A water sample was also collected at the outlet.

The release rates and pumping rates for each Garton pump are shown in Table I for the 26 June test. Samples of release water without pumping were taken only at 1.82 m^3/sec. Each pump was operated at a specific release rate for 15 min and water quality samples were collected at the end of each trial. The invert of the 1.22 m by 1.22 m top outlet was 6.6 m below the water surface during the 26 June test. The lower intake gate (11.8 m below water surface) was closed and received no flow.

TABLE I

TEST SEQUENCE ON 26 JUNE 1980
AT PINE CREEK LAKE

Test Numbers	Pump Diameter (m)	Pumping Rate (m^3/sec)	Release Rate (m^3/sec)
1	--	0	1.82
2-4	1.22	0.85	1.82, 0.84, 2.52
5-7	1.83	1.74	2.52, 1.82, 0.56
8-10	2.44	3.42	0.84, 2.52, 1.82
11	--	0	1.82

During the 5 August test, the top outlet invert was 5.8 m, and the bottom outlet invert was 11.0 m below the water surface. As part of another Corps of Engineers test, 14.00 m^3/sec was being released from the lower outlet. To take advantage of this relatively high release rate, the 2.44 m pump was positioned over the outlet and operated at

4.00 m^3/sec. Samples were collected at the outlet before and during pumping.

Texoma Lake

The water surface elevation was 27.7 m above the invert of the 6.1 m diameter flood control conduits. The 2.44 m Garton pump was positioned directly over the center flood control gate. The pontoon boat was positioned between the intake structure and the pump to allow the plume of pumped water to bypass the top of the intake structure located 9.5 m below the water surface.

Temperature and dissolved oxygen readings were obtained at the downstream outlet at the point where the 6.1 m diameter conduit emptied into the stilling basin. Samples of release water were collected at release rates of 1.4, 4.2, 8.4, 12.6, and 16.8 m^3/sec with the pump operating. The Garton pump was discharging 4.06 m^3/sec at each release rate. Samples of release water without pumping were collected before the test (1.4 m^3/sec), during the test (8.4 m^3/sec), and after the test (16.8 m^3/sec). The pump was operated for approximately 30 min at each release rate. Tests were conducted from low to high release rates.

Difficulties Encountered

Extremely high velocities made use of the Kemmerer sampler difficult since the trapping mechanism operated satisfactorily only in a vertical plane.

The temperature probe was carried downstream before it stayed underwater. A high possibility of probe damage exists while it is being tossed around in strong currents. Temperature profiles near the intake gate were not obtained while releases were being made due to the possibility of probe damage from being drawn into the intake.

The release gate setting at Pine Creek and especially Texoma were not marked for accurate flow measurement at relatively small release rates. At Texoma, gate settings were necessary to the nearest tenth of a foot, while gates were marked only in one-half foot increments. Understandably, errors in release water discharges are likely.

The Yellow Springs dissolved oxygen meter never registered lower than approximately 0.3 to 0.4 mg/l even when a modified Winkler dissolved oxygen test confirmed that no dissolved oxygen was present. A more accurate means of measuring dissolved oxygen should be used in future studies.

CHAPTER V

PRESENTATION AND ANALYSIS OF DATA

Pine Creek, 25 and 26 June 1980

Profiles

The 1.22 m by 1.22 m top outlet was located in the lower metalimnion, 6.8 m below the water surface and received all outflows for this test series. Dissolved oxygen was depleted approximately 7.0 m below the water surface (Figure 8).

Profile water samples were collected at the surface, 5, 10, and 12 m depths (Figure 9). Vertical variation in pH, sulfide, ammonia nitrogen, and phosphorous were relatively small (Appendix B).

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 II) 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 pump produced the best results, and the 2.44 m pump produced the poorest results (Figures 10 through 13). The 2.44 m pump caused an increase in release water iron and turbidity concentrations. Since the outlet was only 6.8 m 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.

TABLE II

PUMPING RATES FOR PINE CREEK
26 JUNE 1980

Pump Diameter (m)	Propellor Rotation (RPM)	Calculated Discharge (m^3/sec)	Calculated Velocity (m/sec)
1.22	80	0.85	0.74
1.83	48	1.74	0.67
2.44	40	3.42	0.74

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 pump.

The 1.22 and 1.83 m pumps were projected to penetrate 10.5 and 11.0 m, respectively, while the 2.44 m pump was projected to penetrate approximately 12.5 m to the reservoir bottom. Substantial disturbance and resuspension of bottom sediments were likely while operating the 2.44 m pump. The pump operator noted updwelling, a pronounced decrease in surface temperature, and floating debris while the 2.44 m pump was operating at a release rate of 0.84 m^3/sec.

By comparing pump performances at a release rate of 1.82 m^3/sec, the percentage improvements for several parameters were calculated and summarized in Table III.

TABLE III

WATER QUALITY IMPROVEMENT AT A RELEASE RATE OF 1.82 m^3/sec
PINE CREEK, 26 JUNE 1980

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

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. Equations (4), (5), and (6) were modified as follows to calculate the dilution factor. From preservation of continuity, the enthalpy tracer can be determined from the equation:

$$h_0 Q_0 = h_1 Q_1 + h_2 Q_2 \tag{7}$$

where h_0 = enthalpy of release water while pumping
Q_0 = release rate through outlet
h_1 = enthalpy of release water prior to pumping
Q_1 = release rate of low level waters
h_2 = enthalpy of surface waters
Q_2 = release rate of surface waters

However, for conservation of flow:

$$Q_0 = Q_1 + Q_2$$

therefore,

$$Q_1 = Q_0 - Q_2 \tag{8}$$

Substituting equation (8) into equation (7) and simplifying provides the following equation:

$$\text{Dilution Factor} = \frac{Q_2}{Q_0} = \frac{h_0 - h_1}{h_2 - h_1} \tag{9}$$

Dilution factors versus release rates for each pump are shown in Figure 14. As was expected from the water quality data, the 1.83 m pump attained the highest dilution factor, while the 2.44 m pump was lowest.

Since the outlet release rate was known for each test, the amount of surface water discharged through the outlet was easily calculated (Figure 15). 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 16 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 17. Operations personnel were releasing 14.0 m^3/sec from the 1.22 by 1.22 m bottom outlet as part of another test. The lower outlet invert was 11.0 m below the water surface.

Total iron, turbidity, manganese, and ammonia nitrogen exhibited the most dramatic concentration increases with depth (Figure 18). Depth of penetration tests were conducted near the intake structure at the buoy line. The 2.44 m diameter pump reached 9.5 and 11.0 m 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 was the only pumping rate tested.

The observed effects of pumping on release water quality are displayed in Table IV.

TABLE IV

RELEASE IMPROVEMENT AT PINE CREEK LAKE
5 AUGUST 1980

Parameter	Concentration Without Pump	Concentration With Pump	Percent Improvement
Temperature (°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

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 of the total 14.0 m^3/sec 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.

Texoma Lake

Profiles

Release water improvement tests were conducted at Lake Texoma on 18 August 1980 using the 2.44 m diameter pump. The epilimnion extended from the surface to a depth of approximately 16.0 m, and the metalimnion extended from 16.0 m to 20.0 m (Figure 19). The reservoir was anoxic below a depth of 18.0 m, and the 6.1 m diameter outlet was located entirely in the hypolimnion.

The pH and total iron profiles were fairly uniform with depth and obviously could not be greatly affected by localized mixing (Figures 20 and 21). 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 2.44 m diameter pump was operated at a pumping rate of 4.06 m^3/sec which required 47.5 propellor revolutions per minute. The calculated discharge velocity was 0.88 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 2.44 m diameter pump was operated for approximately 30 min at release rates of 1.4, 4.2, 8.4, 12.6, and 16.8 m^3/sec. Samples were also collected at release rates of 1.4, 8.4, and 16.8 m^3/sec while the pump was not operating. The effect of pumping on release water temperature, turbidity, total iron, manganese, sulfide, phosphorous, and ammonia nitrogen is shown in Figures 22 through 28, respectively.

All release water quality parameters measured were improved by pump operation. Table V lists the maximum percentage improvement for selected parameters and their corresponding release rates. Ammonia nitrogen and manganese concentrations without pumping at a release rate of 4.2 m^3/sec were determined by assuming a linear relationship between concentrations at release rates of 1.4 and 8.4 m^3/sec.

TABLE V

MAXIMUM IMPROVEMENT AT TEXOMA LAKE
2.44 m PUMP

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

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 4.2 and 12.6 m^3/sec were determined by assuming a linear relationship between surrounding data points. Surface water enthalpy was obtained by averaging the surface, 1 m, and 2 m values.

The Garton pump discharging 4.06 m^3/sec at the surface attained a maximum dilution factor of 32.5 % at a release rate of 8.4 m^3/sec (Figure 29). That is, 2.7 m^3/sec of surface water were pumped through the outlet when the release gate discharged 8.4 m^3/sec. The ratio of pump discharge to release water discharge at the maximum dilution factor was 0.48 (Figure 30).

CHAPTER VI

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 were tested at Pine Creek Lake on 26 June 1980. The 2.44 m diameter pump was also tested at Pine Creek on 5 August 1980 and Lake Texoma on 18 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 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 pump and 0.96 for the 1.83 m pump. At Texoma Lake the optimum pumping to release rate ratio was 0.48 for the 2.44 m pump.

Recommendations for Further Study

1. Vary the horizontal distance between the pump and intake structure to determine an optimum pump location.

2. Vary the submerged depth of the propellor below the water surface to determine an optimum propellor depth.

3. Design and test a control circuit which will automatically change the pumping rate depending on reservoir profile temperatures and release rates.

4. Verify a reliable method of predicting the depth of penetration for use in design of axial flow pump installations.

A SELECTED BIBLIOGRAPHY

Birge, E. A., and C. Juday. *A Limnological Study of the Finger Lakes of New York*. Bulletin U.S. Bureau of Fisheries, Vol. 32 (1914) pp. 525-609.

Bowles, B. A., I. J. Powling, and F. L. Burns. *Effects on Water Quality of Artificial Aeration and Destratification of Tarago Reservoir*. Australian Water Resources Council, Technical Paper No. 46 (1979).

Dortch, M. S., and S. C. Wilhelms. *Enhancement of Releases From a Stratified Impoundment by Localized Mixing, Okatibbee Lake, Mississippi*. Misc. Paper H-78-1, Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (1978).

Fish, F. F. "Effect of Impoundment on Downstream Water Quality, Roanoke River, N. C." *Journal American Water Works Association*, Vol. 51 (1959) pp. 47-50.

Garton, J. E., and C. E. Rice. *Improving the Quality of Water Releases from Reservoirs by Means of a Large Diameter Pump*. Final Technical Report, Oklahoma Water Resources Research Institute, Okla C-5228, Agreement No. 14-31-0001-4215 (1976).

Garton, J. E., and H. R. Jarrell. *Demonstration of Water Quality Enhancement Through Use of the Garton Pump*. Supplement to the Technical Completion Report, Project C-5228, Oklahoma Water Resources Research Institute (1976).

Garton, J. E., and R. C. Peralta. *Water Quality Enhancement by Point Destratification, Gillham Lake, Arkansas*. A Special Report of the Oklahoma Water Resources Research Institute, Project A-065 (1978).

Garton, J. E., and R. E. Punnett. "Quality Improvement of Releases from Reservoirs." (Unpub. paper presented at the Symposium on Surface Water Impoundments, Minneapolis, Minnesota, June 1980.)

Garton, J. E., R. Summerfelt, D. Toetz, J. Wilhm, and H. Jarrell. *Physiochemical and Biological Conditions in Two Oklahoma Reservoirs Undergoing Artificial Destratification*. Oklahoma Water Resources Research Institute (1976).

Hach Chemical Company. *Hach Water Analysis Handbook*. Ames, Iowa (1977).

Hutchinson, G. E. A Treatise on Limnology. Vol. 1. New York: John Wiley and Sons (1957).

Irwin, W. H., J. M. Symons, and G. G. Robeck. "Impoundment Destratification by Mechanical Pumping." Journal Sanitary Engineering Division, ASCE, Vol. 92, No. SA-6 (1966) pp. 21-40.

Kittrell, F. W. "Effects of Impoundments on Dissolved Oxygen Resources." Sewage and Industrial Wastes, Vol. 31, No. 9 (1959) pp. 1065-1078.

Kittrell, F. W. "Thermal Stratification in Reservoirs." In: Symposium on Streamflow Regulation for Quality Control. U.S. Department of Health, Education, and Welfare, Public Health Service (1965).

Love, S. K. "Relationship of Impoundment to Water Quality." Journal American Water Works Association, Vol. 53, No. 5 (1961) pp. 559-568.

Moon, J. J., D. K. McLaughlin, and P. M. Moretti. Enhancement of Reservoir Release Water Quality by Localized Mixing - Hydraulic Model Investigation. First Phase Final Report, U.S. Army Engineer Waterways Experiment Station, Contract DACW-39-78-C-0045 (1979).

Odum, E. P. Fundamentals of Ecology. W. B. Saunders Co., Philadelphia, Pennsylvania (1971).

Powling, J. and F. Burns. "Reservoir Destratification to Improve Water Quality." In: Proceedings of Joint U.S. and Australia Seminar and Workshop on Destratification of Reservoirs (1979).

Punnett, R. E. "Destratification of Lake Arbuckle with a Cluster of Low Energy Pumps." (Unpub. M. S. Thesis, Oklahoma State University, Stillwater, Oklahoma, July 1978.)

Quintero, J. E., and J. E. Garton. "A Low Energy Lake Destratifier." Transactions of the American Society of Agricultural Engineers, Vol. 16, No. 5 (1973) pp. 973-978.

Smalley, D. H. and J. K. Novak. "Natural Thermal Phenomena Associated with Reservoirs." In: Environmental Effects of Large Dams. American Society of Civil Engineers, New York (1980) pp. 29-49.

Steichen, J. M. "The Effect of Lake Destratification on Water Quality Parameters." (Unpub. Ph. D. Thesis, Oklahoma State University, Stillwater, Oklahoma, July 1974.)

Strecker, R. G. "Design, Construction, and Evaluation of a Prototype Low-Energy Lake Destratifier." (Unpub. M. S. Thesis, Oklahoma State University, Stillwater, Oklahoma, December, 1976.)

Symons, J. M., J. K. Carswell, and G. G. Robeck. "Mixing of Water Supply Reservoirs for Quality Control." Journal American Water Works Association, Vol. 62, No. 5 (1970) pp. 322-334.

Symons, J. M., W. H. Irwin, and G. G. Robeck. "Control of Reservoir Water Quality by Engineering Methods." In: Proceedings of the Specialty Conference on Current Research Into the Effects of Reservoirs on Water Quality. Elder, Krenkel, and Thackston, Eds. Technical Report No. 17, Department Environmental and Water Resources Engineering, Vanderbilt University, Nashville, Tennessee (1968) pp. 335-390.

Tulsa District Corps of Engineers. Broken Bow Lake, Mountain Fork River, Oklahoma; Pine Creek Lake, Little River, Oklahoma; and Millwood Lake, Little River, Arkansas Operation and Maintenance Program. Final Environmental Statement, Tulsa, Oklahoma (1976a).

Tulsa District Corps of Engineers. Operation and Maintenance Program Denison Dam, Lake Texoma, Red River, Oklahoma and Texas. Final Environmental Statement, Tulsa, Oklahoma (1976b).

Wetzel, R. G. Limnology. Pennsylvania: W. B. Saunders Co. (1975).

Wright, J. C. "Effects of Impoundments on Productivity, Water Chemistry and Heat Budgets of Rivers." In: Reservoir Fishery Resources Symposium. Charles E. Lane, Jr. (Chairman). Reservoir Committee, Southern Division American Fisheries Society, University of Georgia, Athens, Georgia (1967).

Wunderlich, W. O. and R. A. Elder. "Effect of Intake Elevation and Operation on Water Temperature." Journal of the Hydraulics Div, ASCE, No. HY 6, Paper 6917 (1969) pp. 2081-2091.

APPENDIXES

APPENDIX A

FIGURES

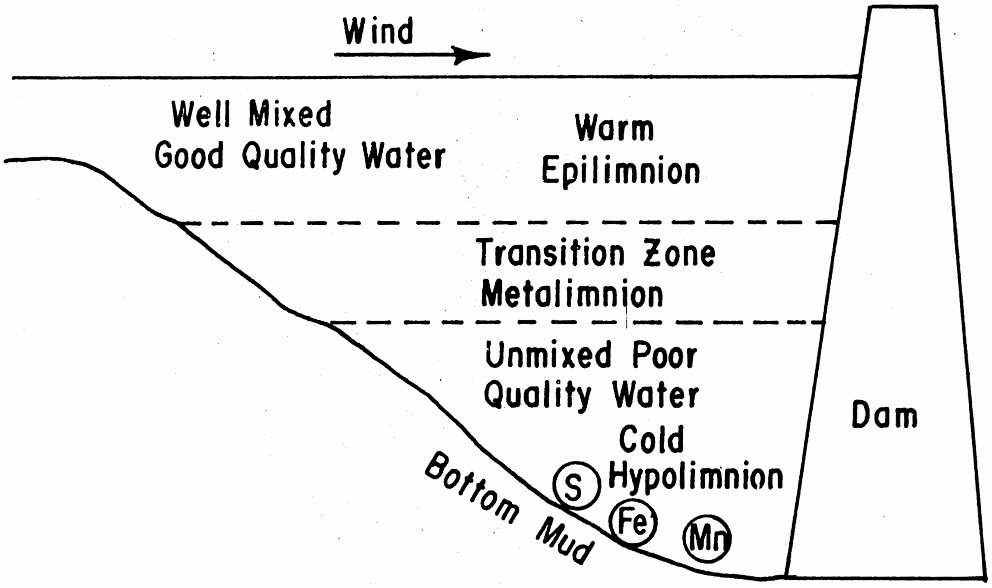

Figure 1. Typical Summer Thermal Stratification Pattern (Modified from Symons, J. M., 1970)

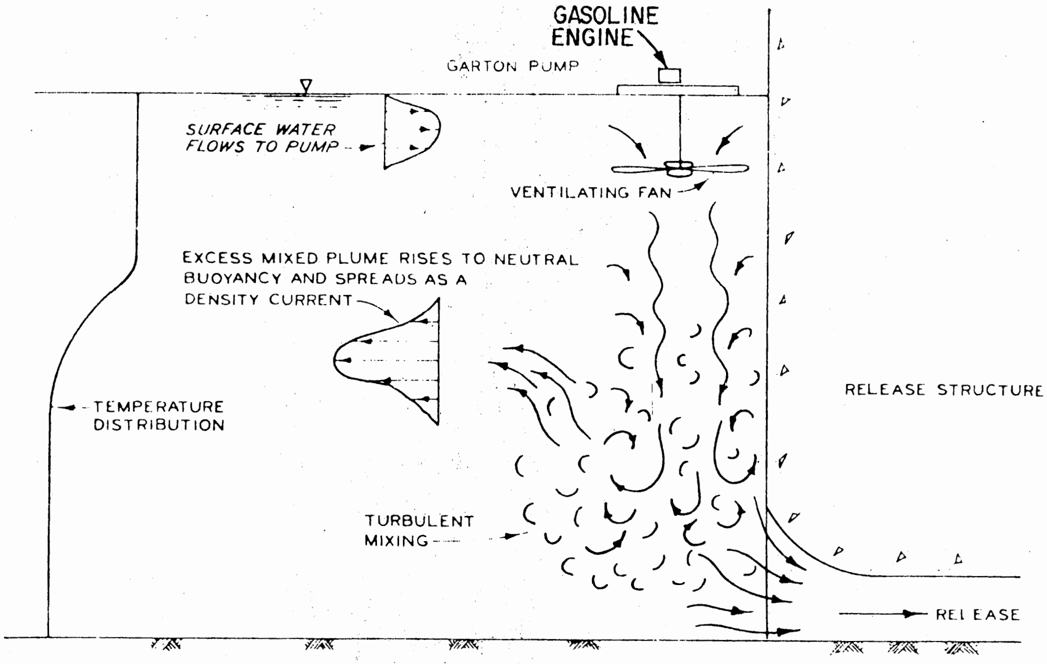

Figure 2. Localized Mixing (After Dortch, M. S. and Wilhelms, S. C., 1978)

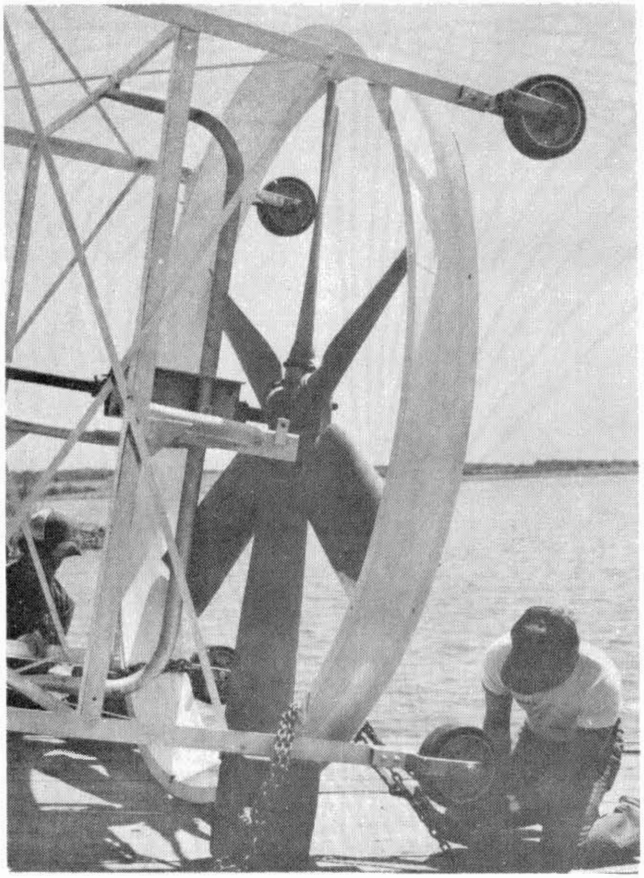

Figure 3. View of 2.44 m Propellor, Shroud, and Support Framework

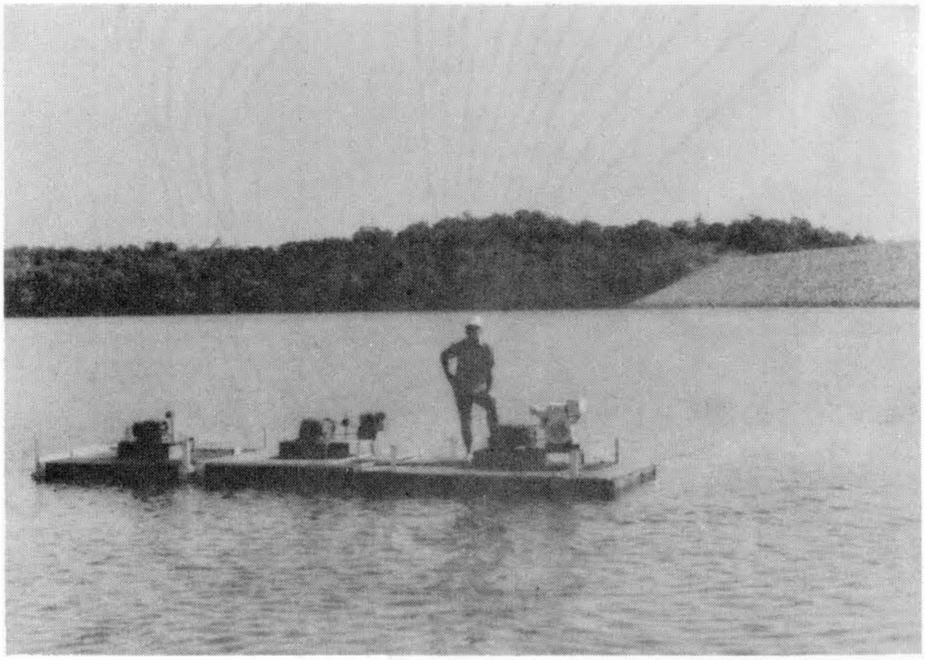

Figure 4. View of Power Units and Support Platforms

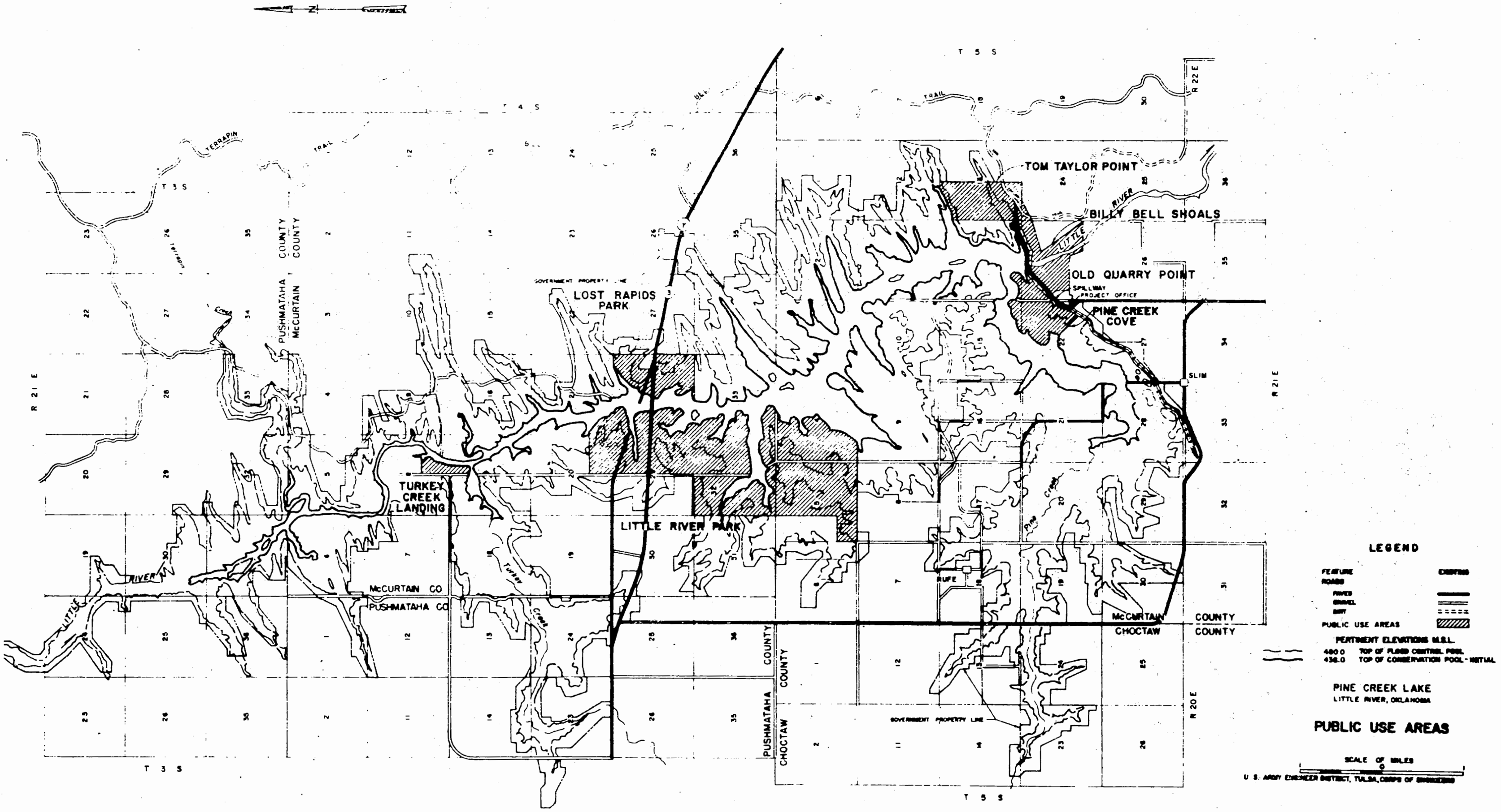

Figure 5. Map of Pine Creek Lake

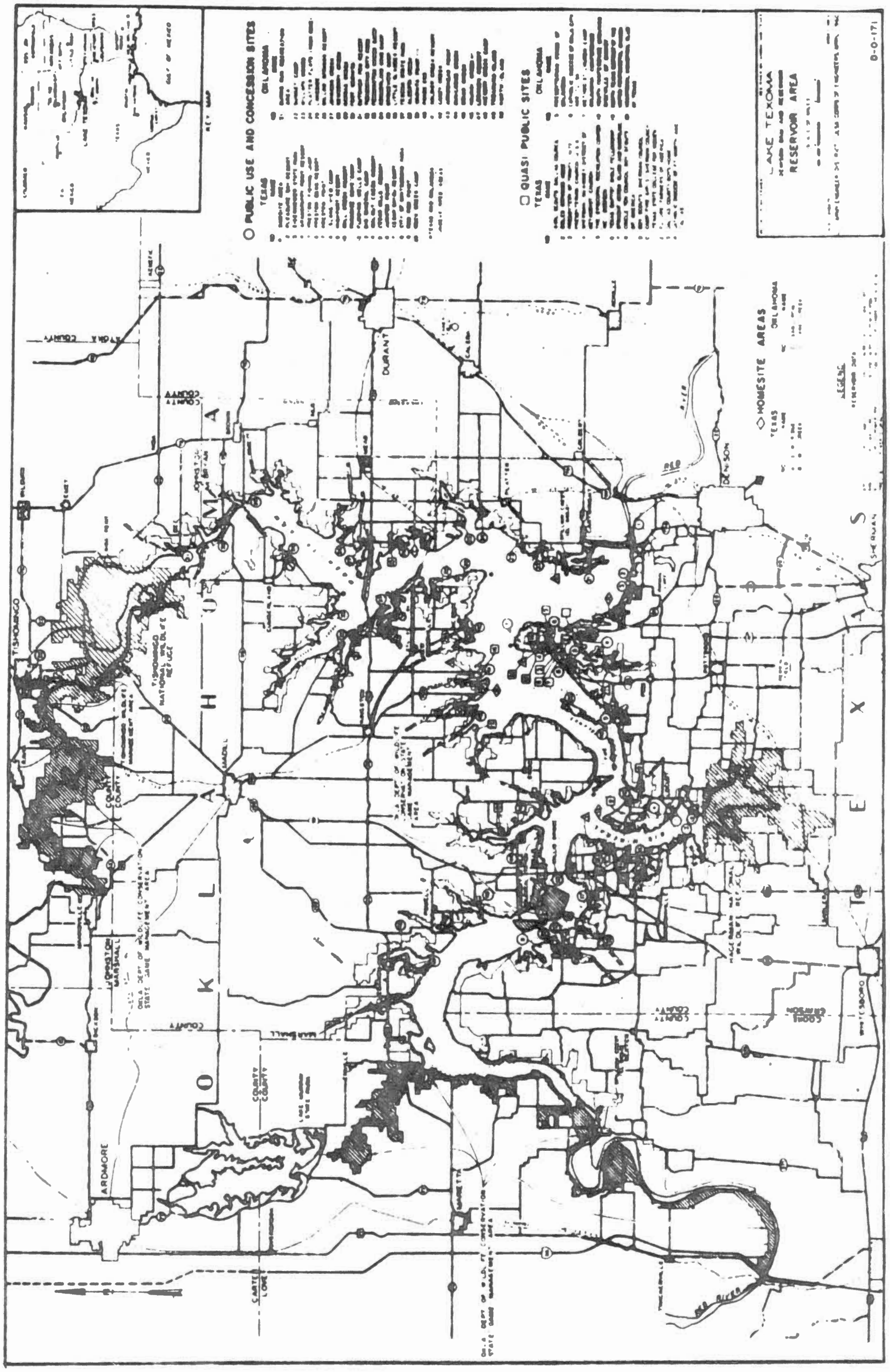

Figure 6. Map of Lake Texoma

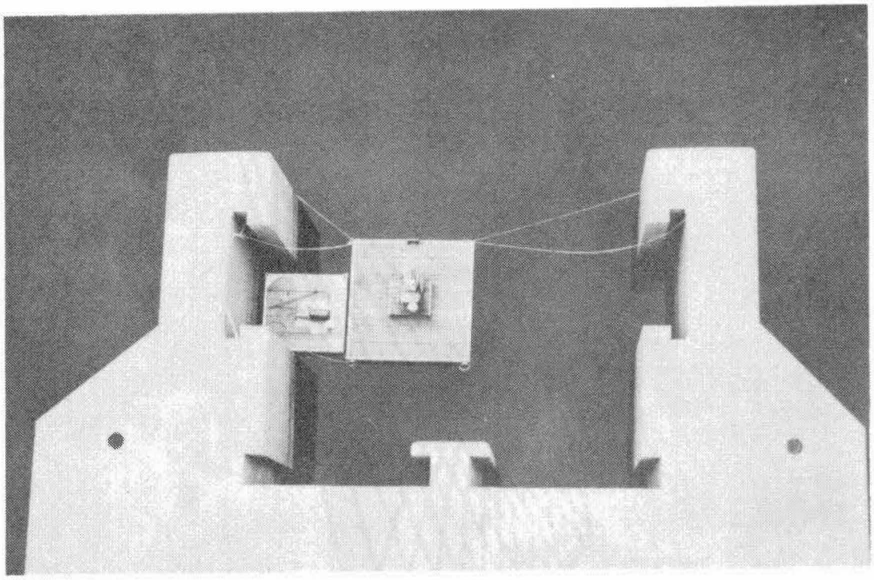

Figure 7. Top View of Pump Location at Pine Creek Lake

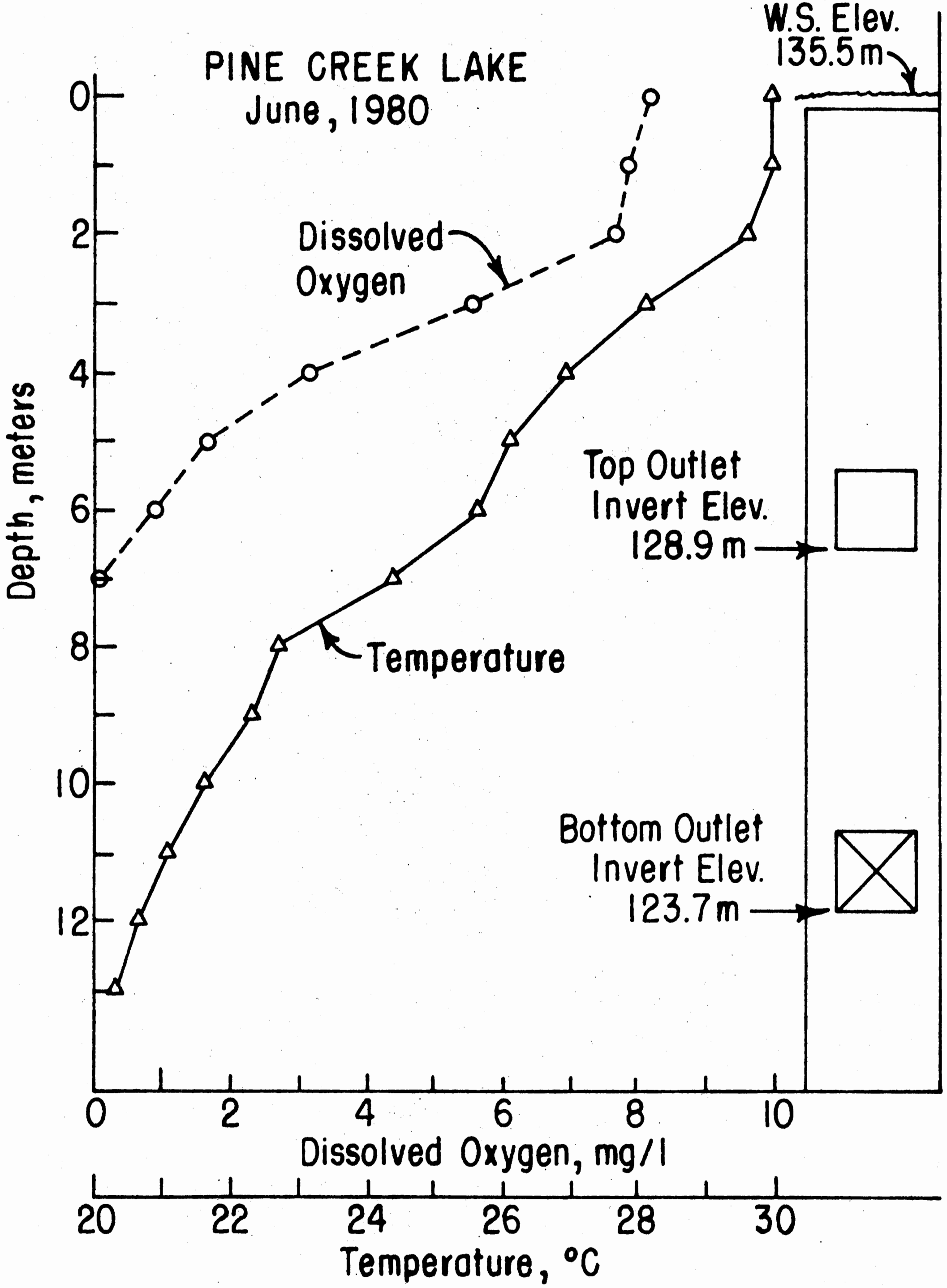

Figure 8. Temperature and Dissolved Oxygen Profiles at Pine Creek Lake on 26 June 1980

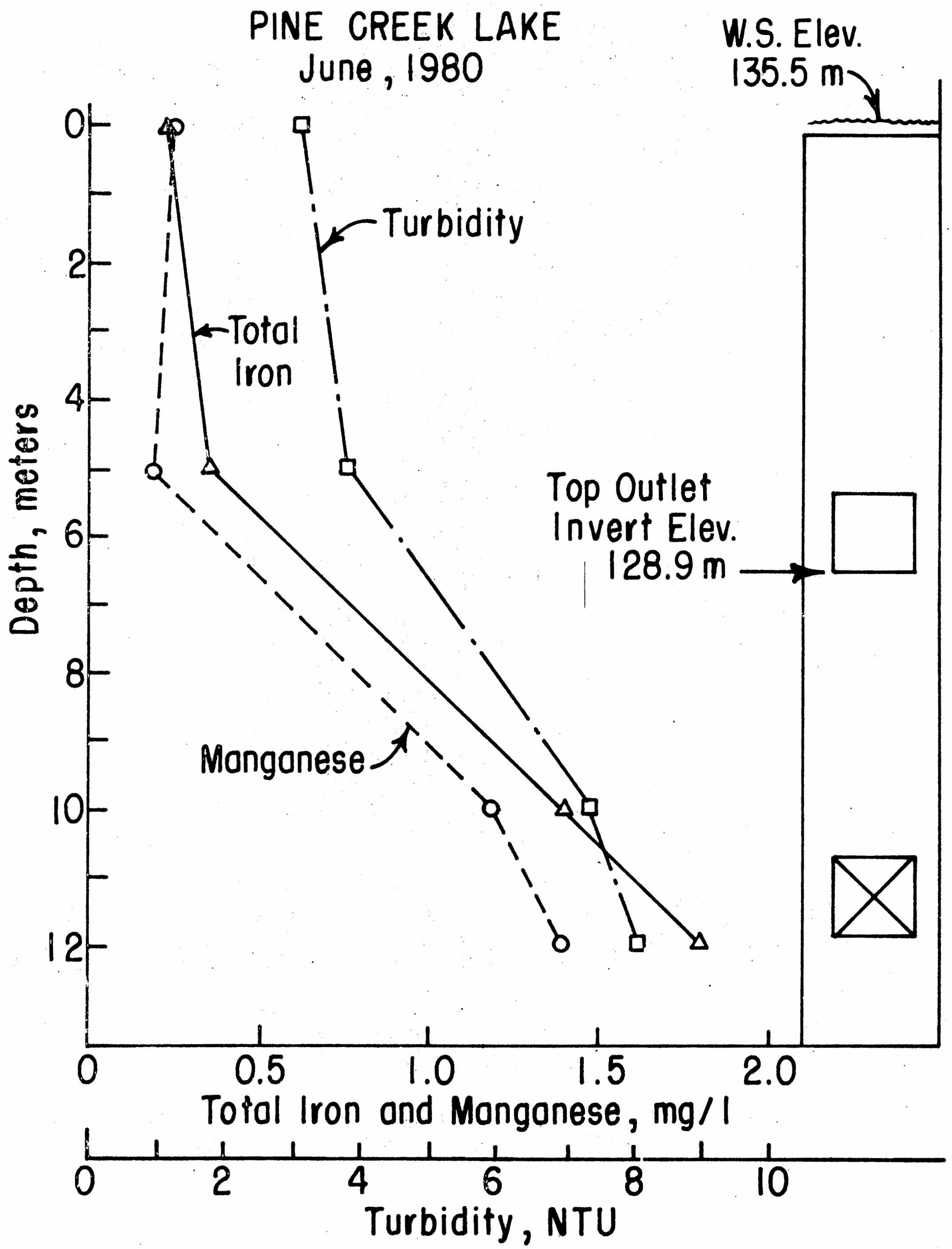

Figure 9. Selected Chemical Profiles at Pine Creek Lake on 26 June 1980

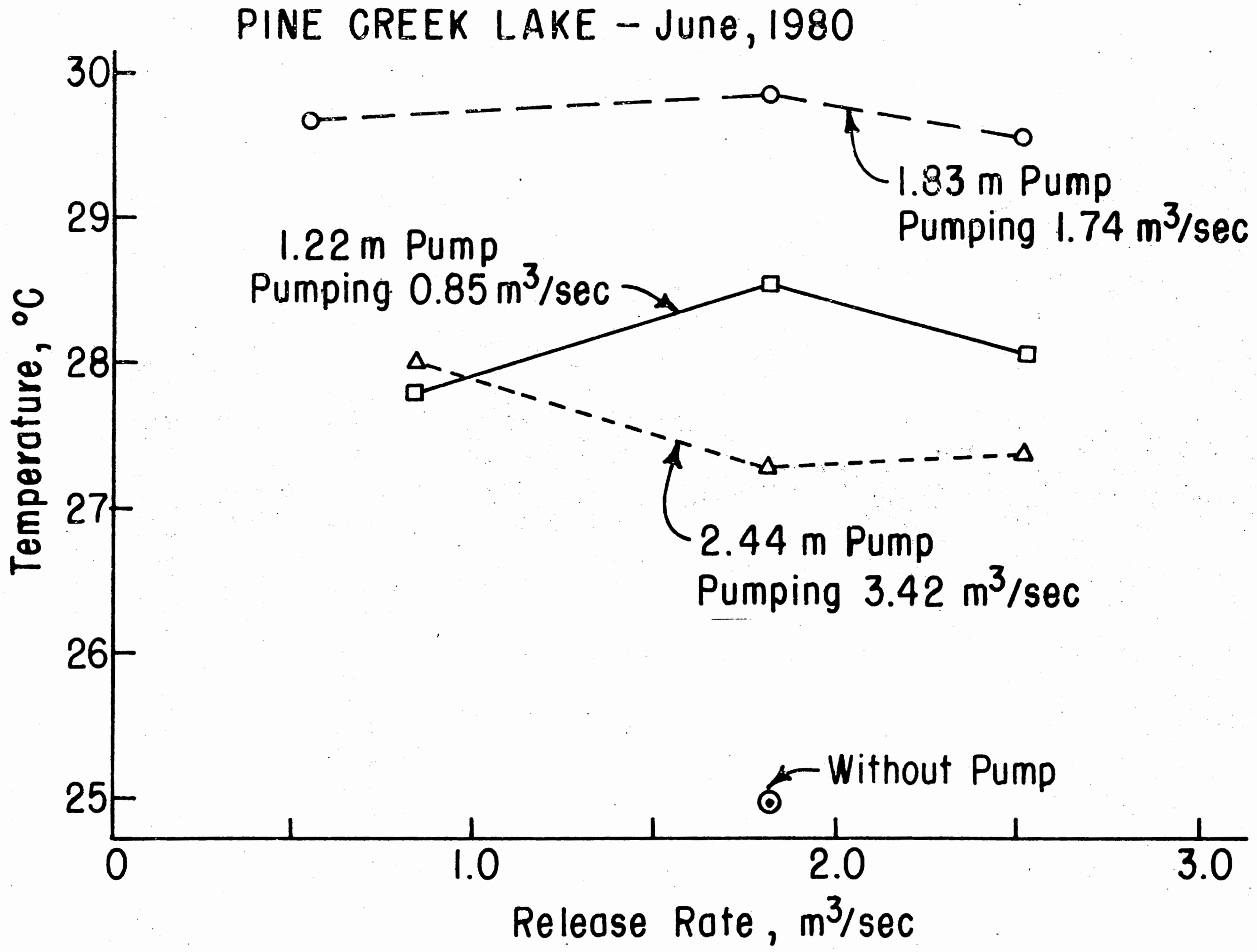

Figure 10. Temperature as a Function of Release Rate at Pine Creek Lake on 26 June 1980

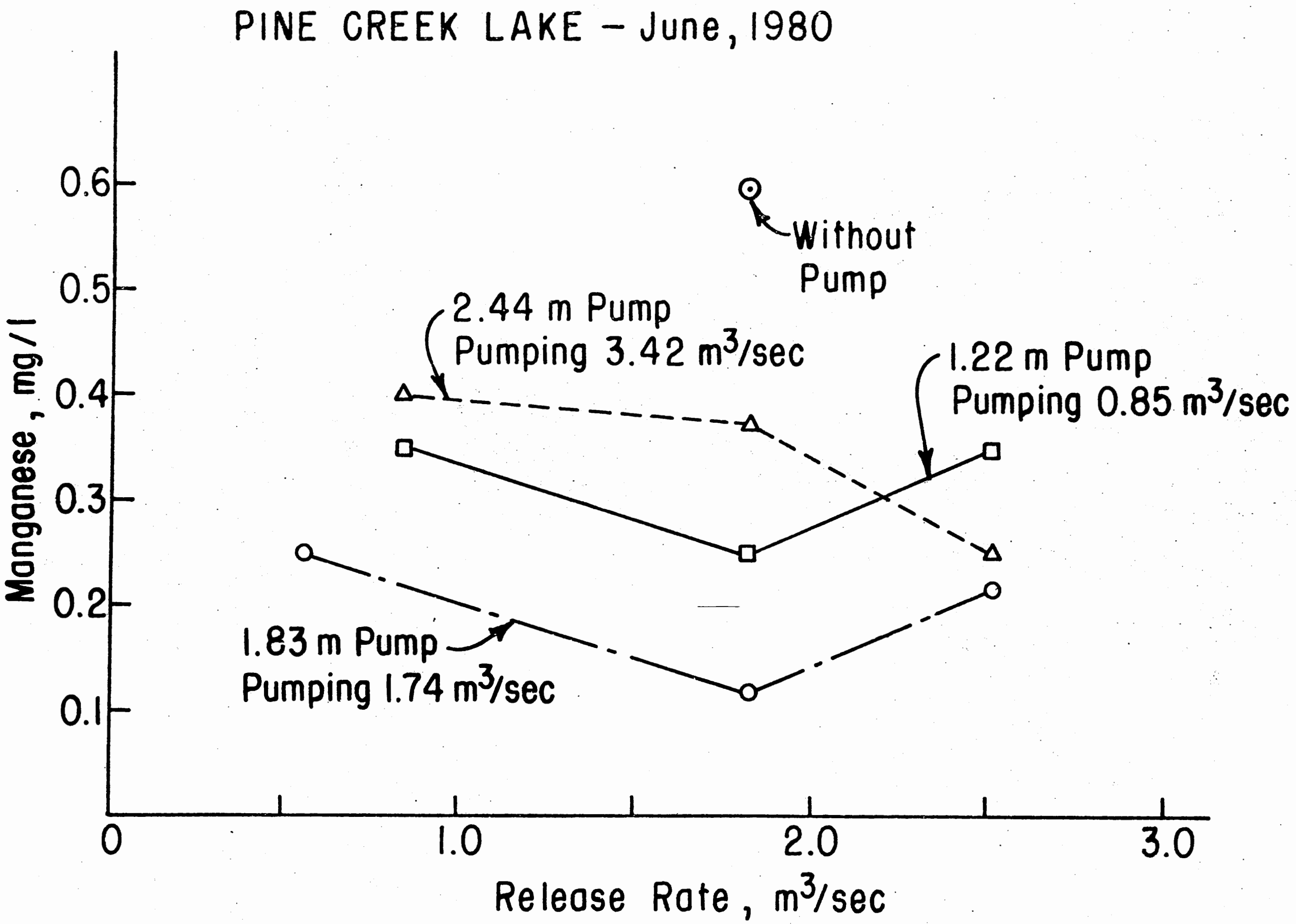

Figure 11. Manganese Concentration as a Function of Release Rate at Pine Creek Lake on 26 June 1980

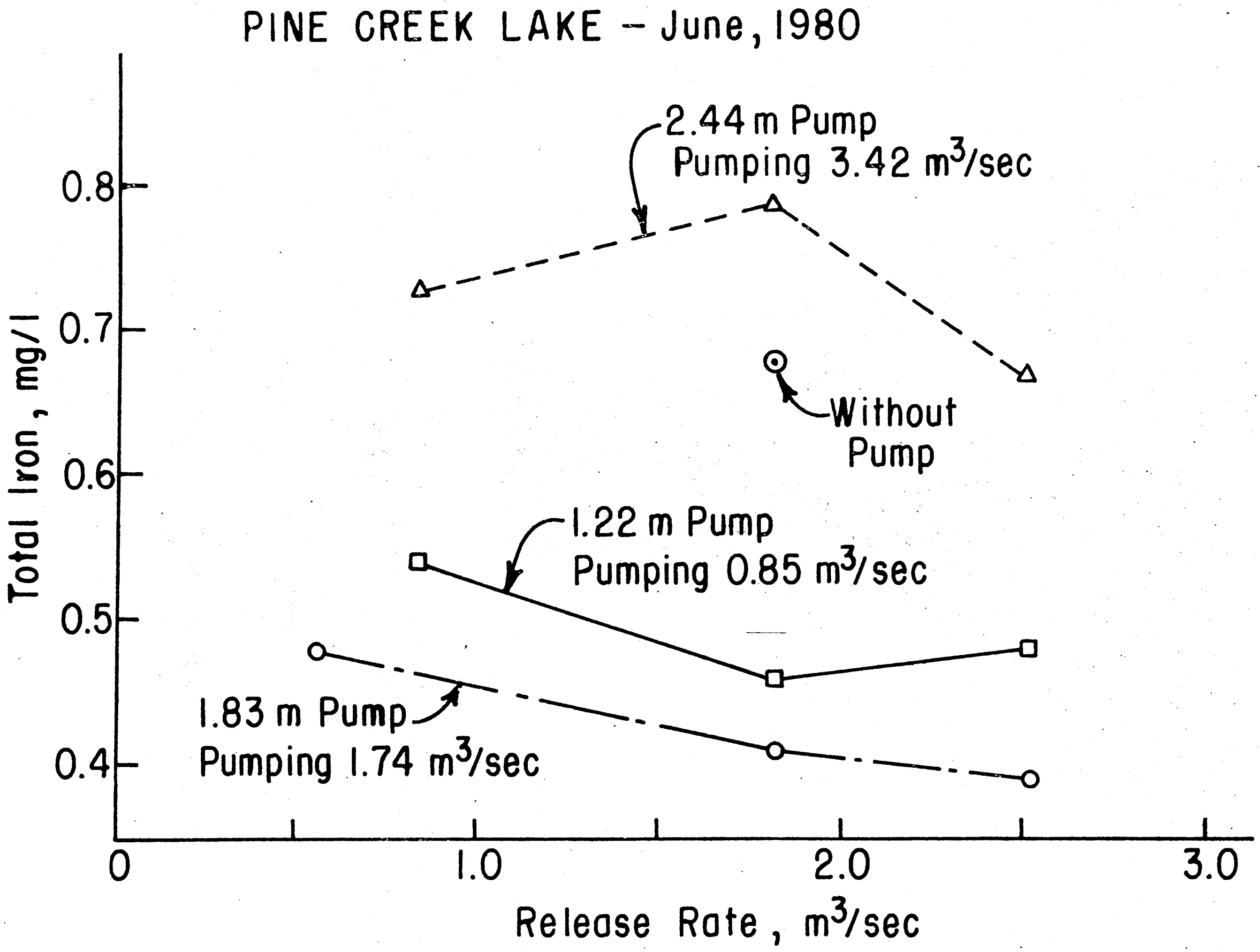

Figure 12. Total Iron Concentration as a Function of Release Rate at Pine Creek Lake on 26 June 1980

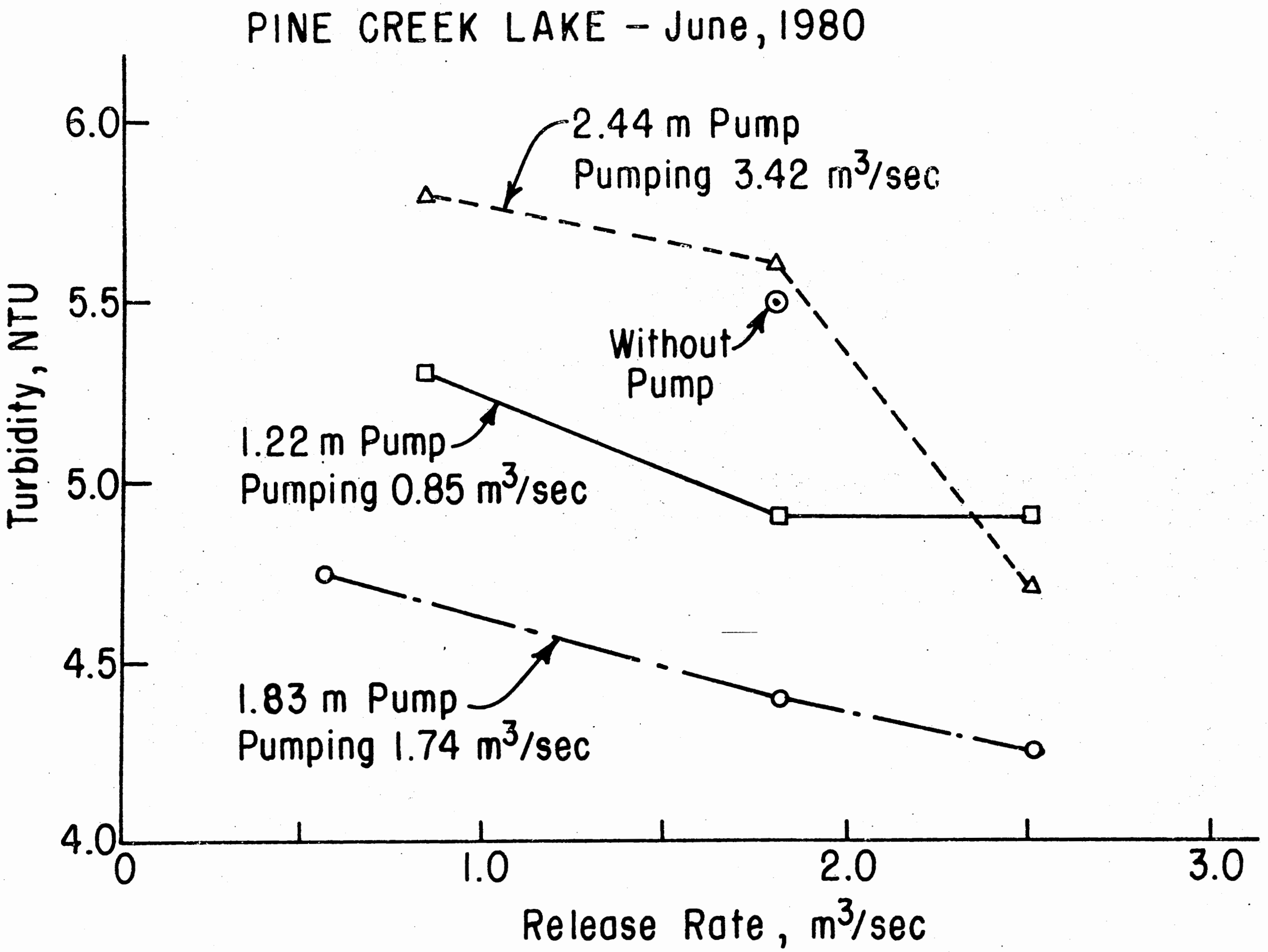

Figure 13. Turbidity as a Function of Release Rate at Pine Creek Lake on 26 June 1980

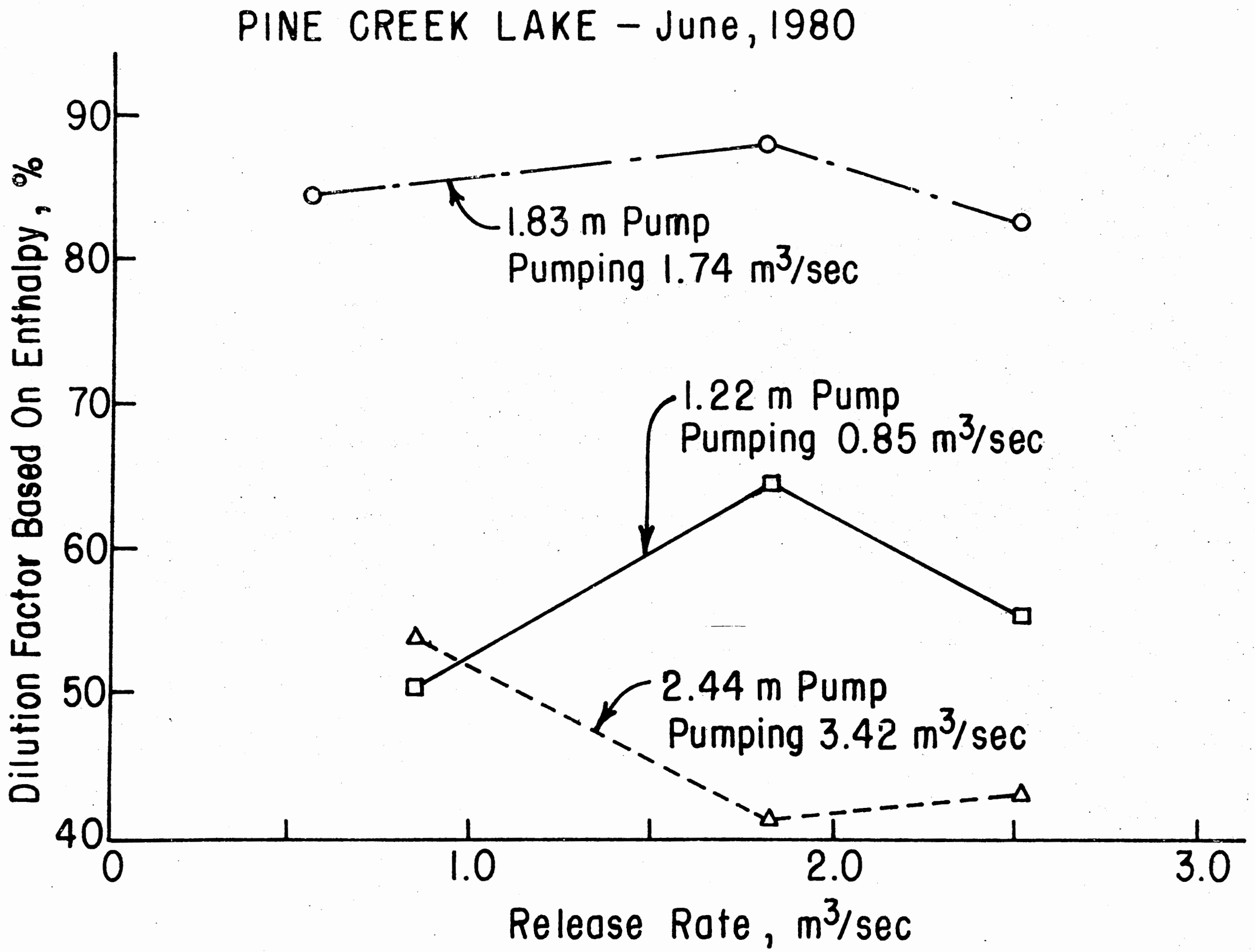

Figure 14. Dilution Factor Based on Enthalpy as a Function of Release Rate at Pine Creek on 26 June 1980

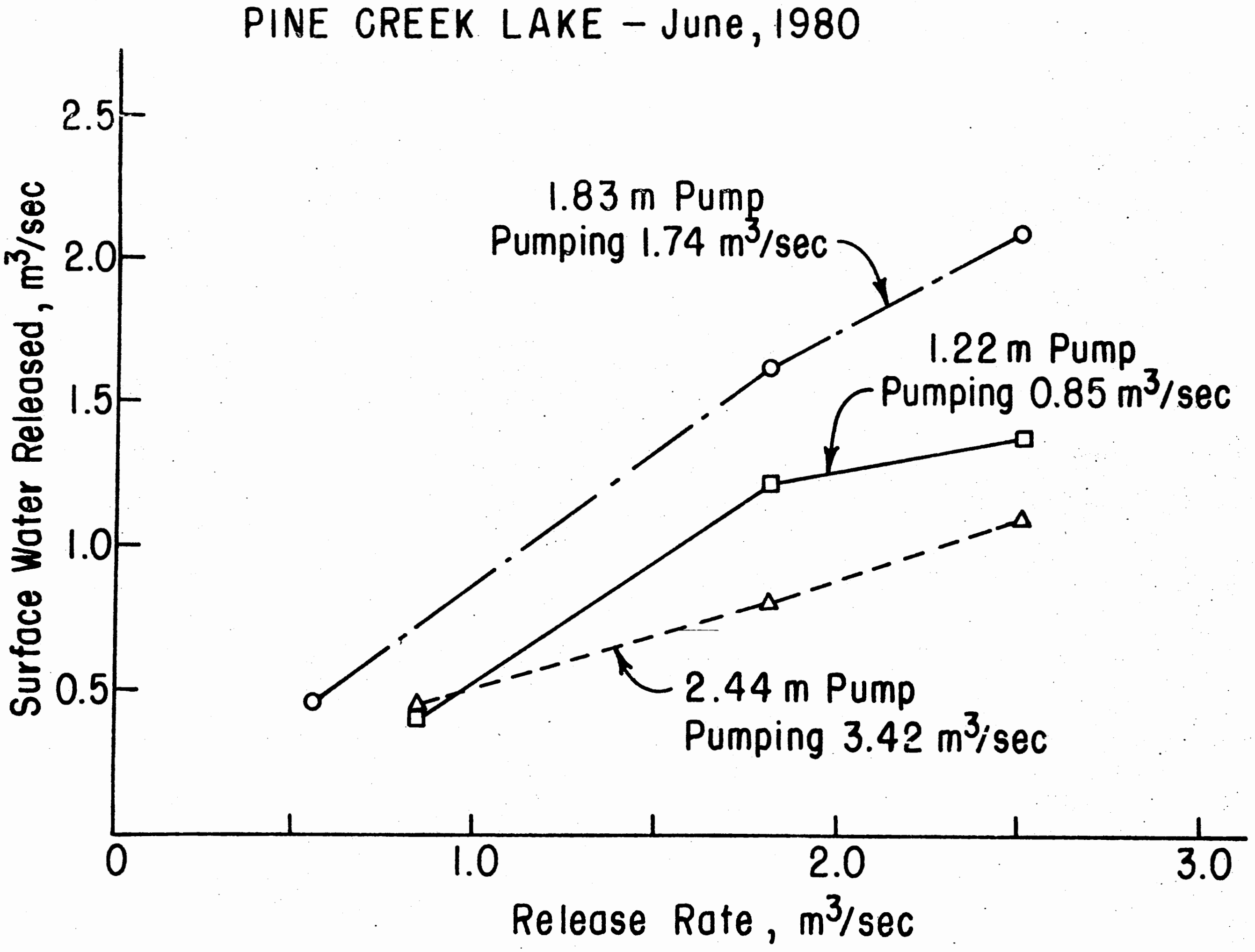

Figure 15. Surface Water Release Rate as a Function of Reservoir Release Rate at Pine Creek on 26 June 1980

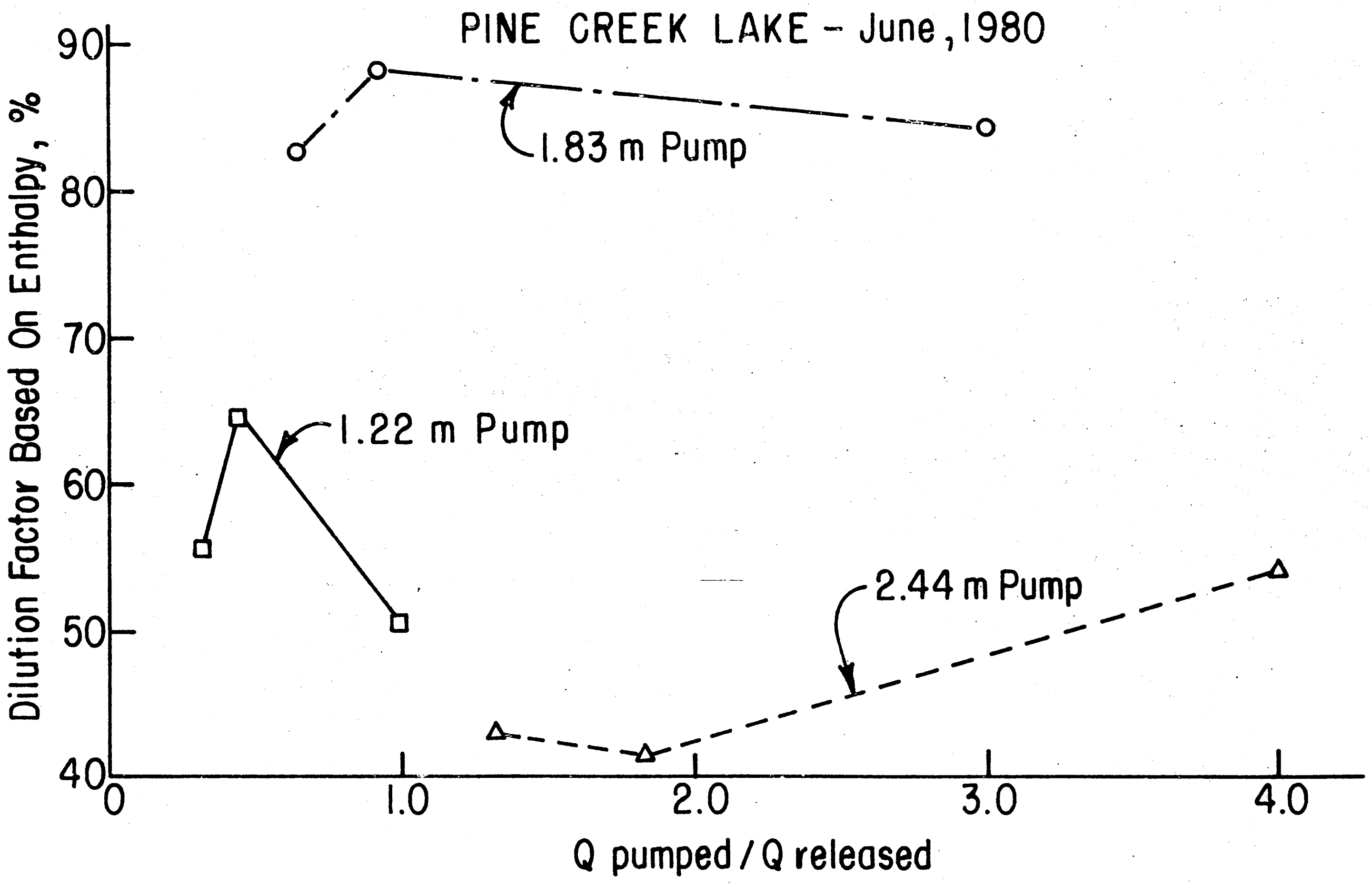

Figure 16. Dilution Factor Based on Enthalpy as a Function of the Ratio of Pumping to Release Rate at Pine Creek on 26 June 1980

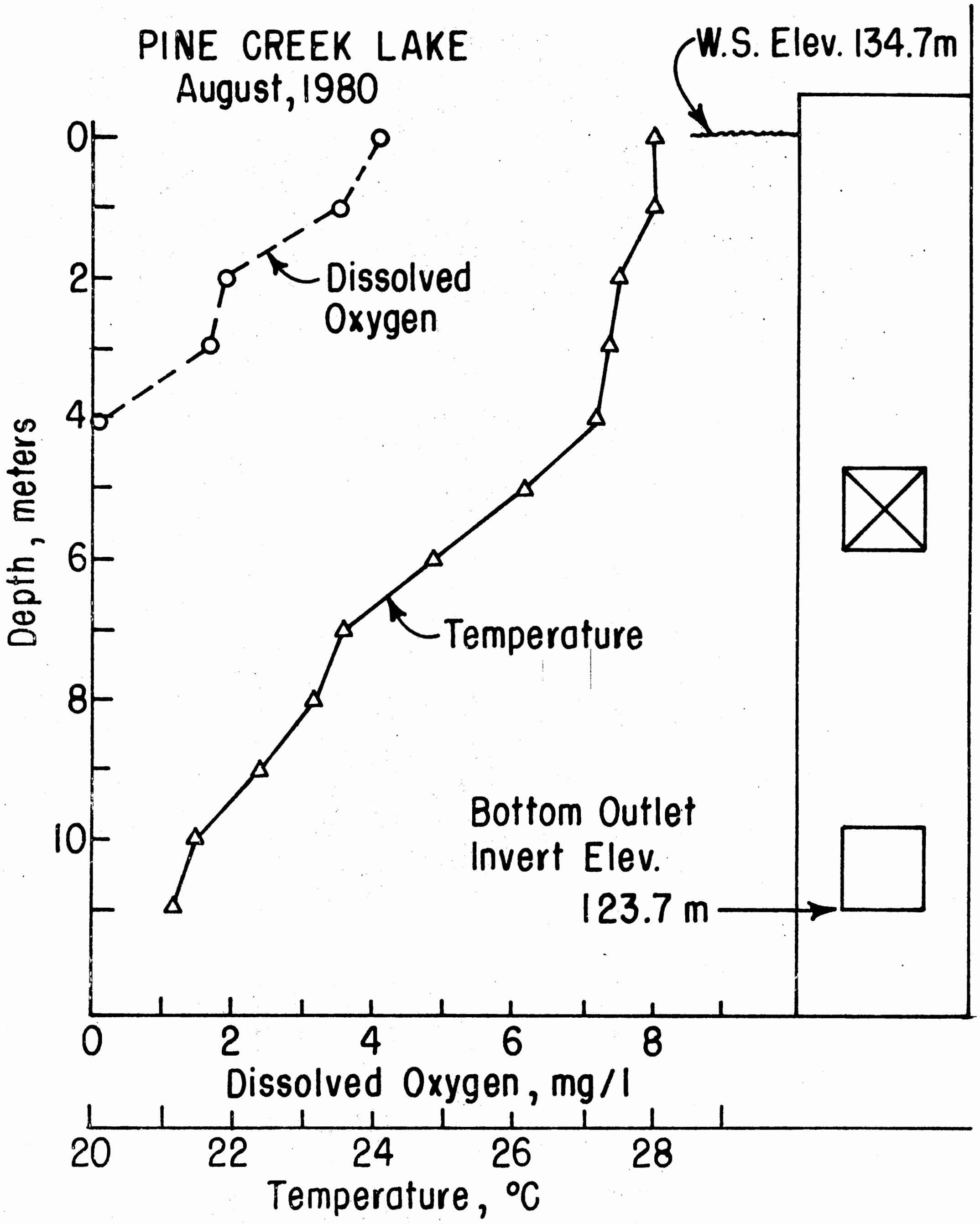

Figure 17. Temperature and Dissolved Oxygen Profiles at Pine Creek Lake on 5 August 1980

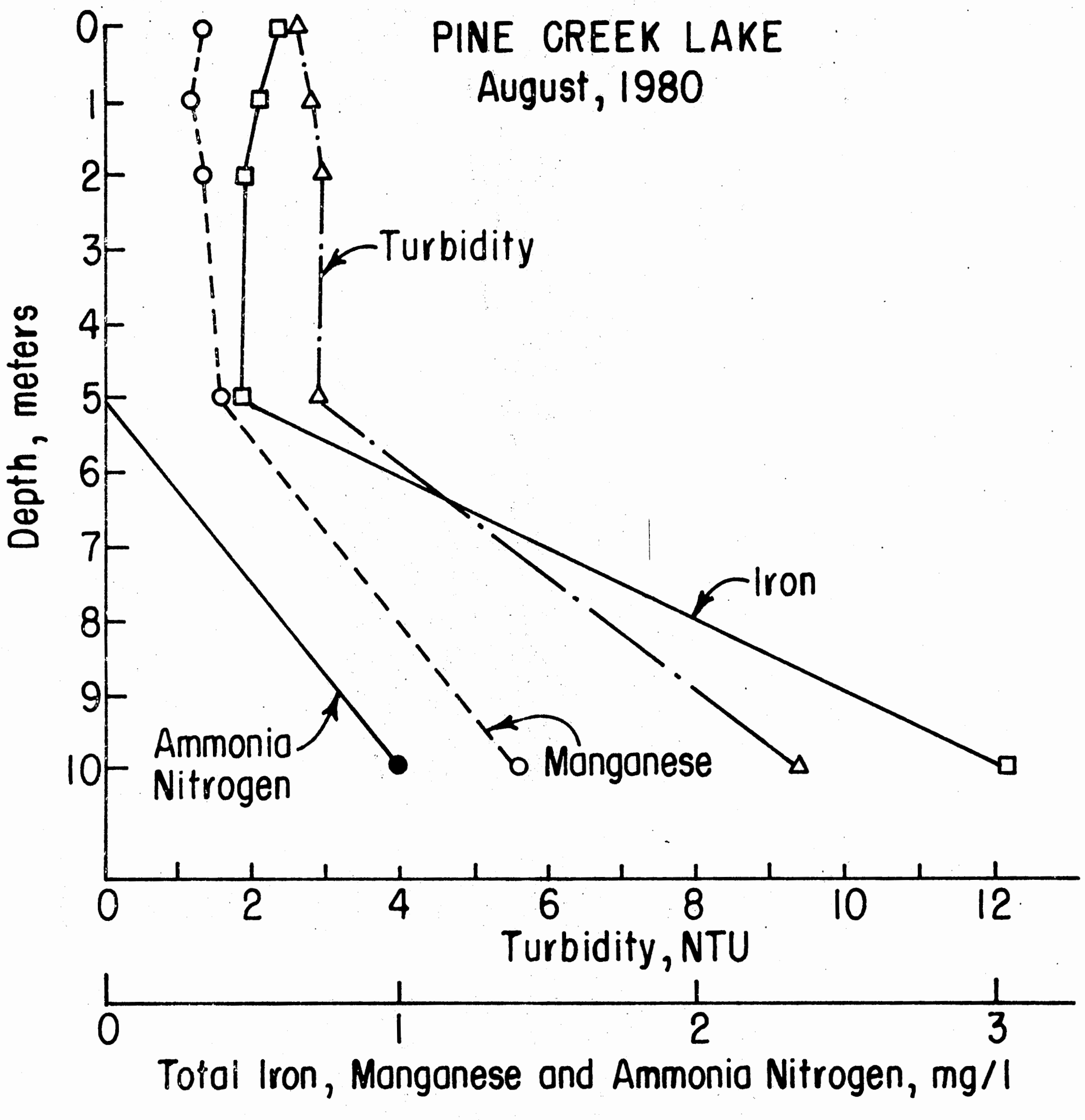

Figure 18. Selected Chemical Profiles at Pine Creek Lake on 5 August 1980

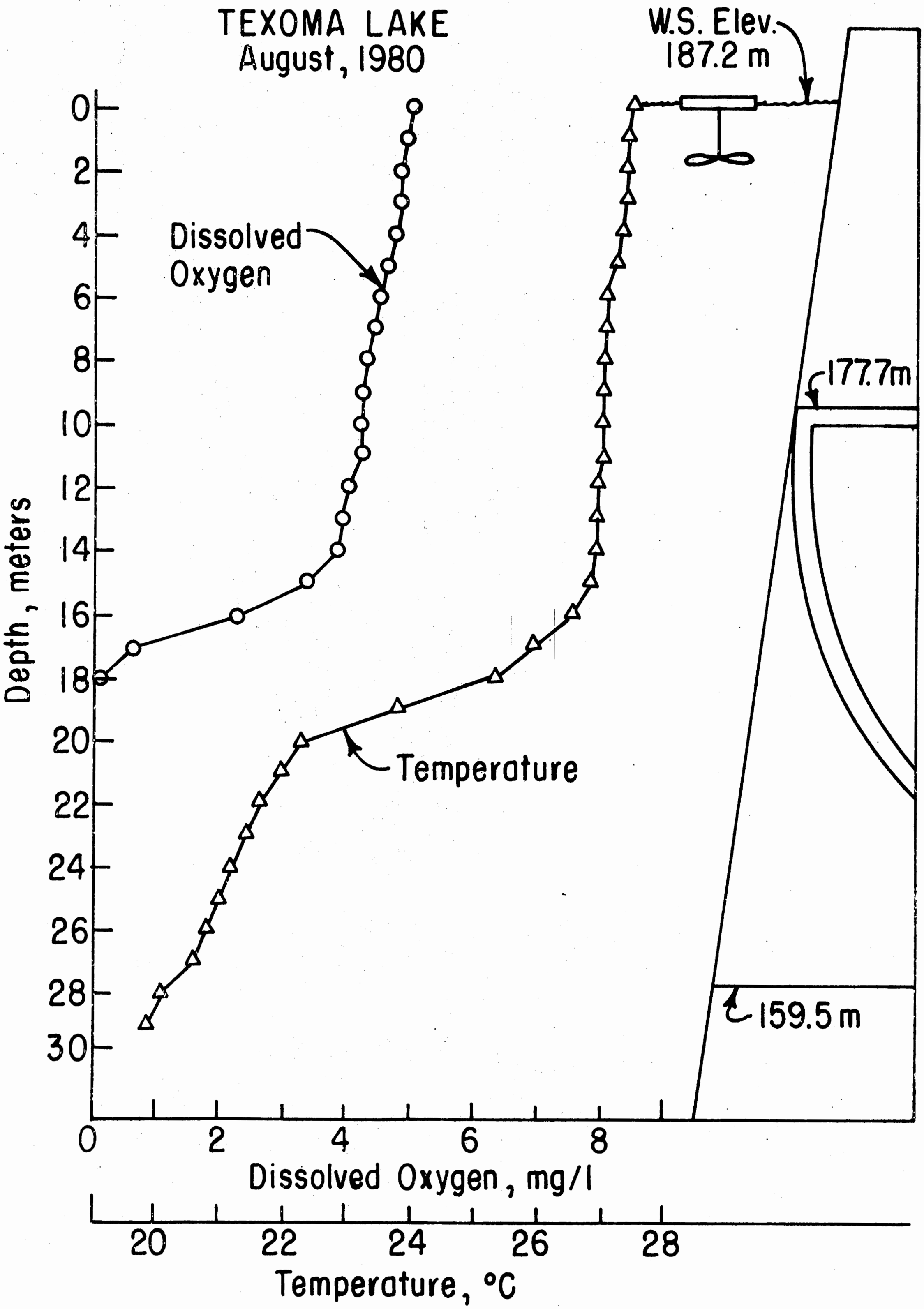

Figure 19. Temperature and Dissolved Oxygen Profiles at Lake Texoma on 18 August 1980

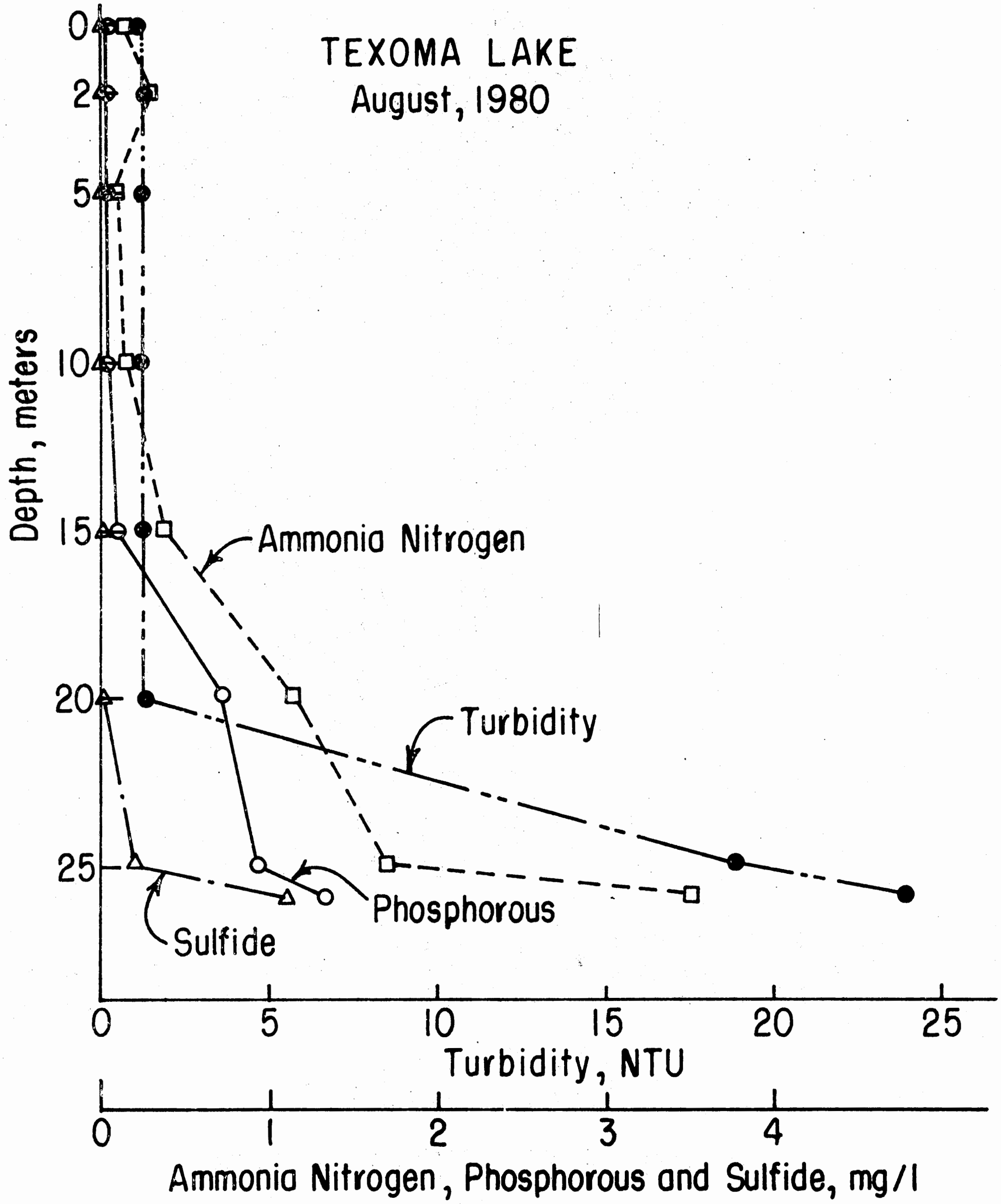

Figure 20. Selected Water Quality Profiles at Lake Texoma on 18 August 1980

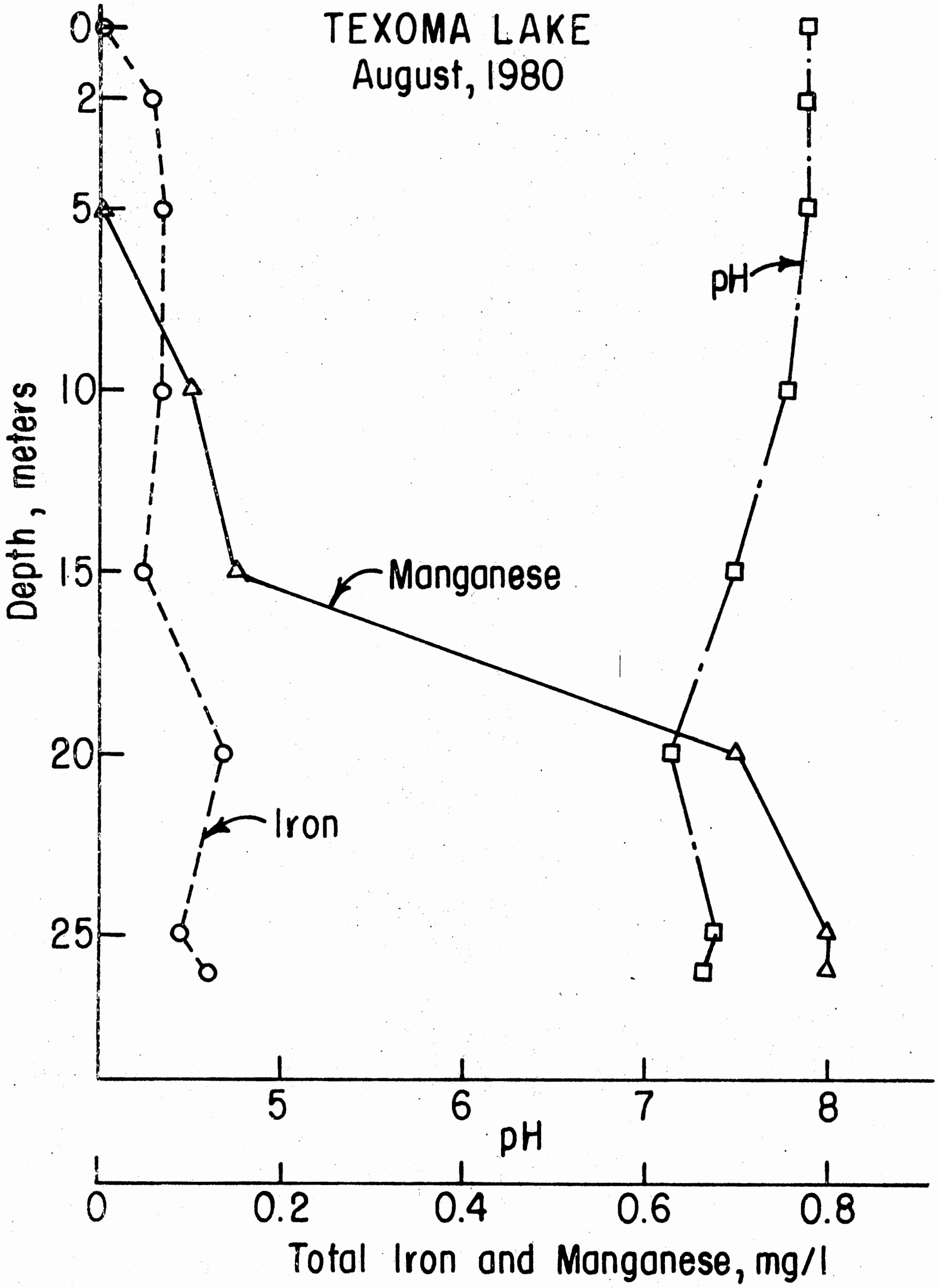

Figure 21. Selected Water Quality Profiles at Lake Texoma on 18 August 1980

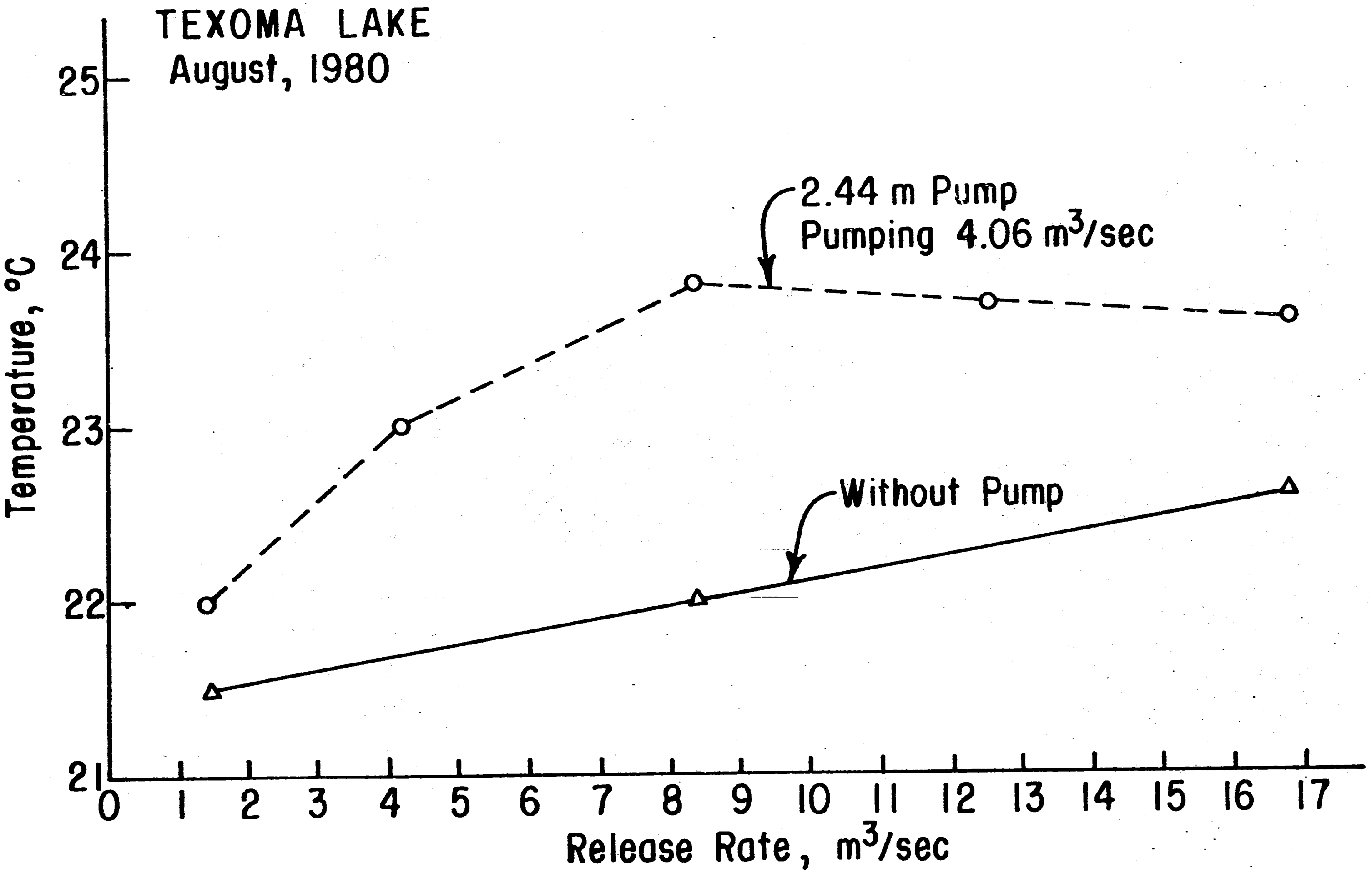

Figure 22. Temperature as a Function of Release Rate at Lake Texoma

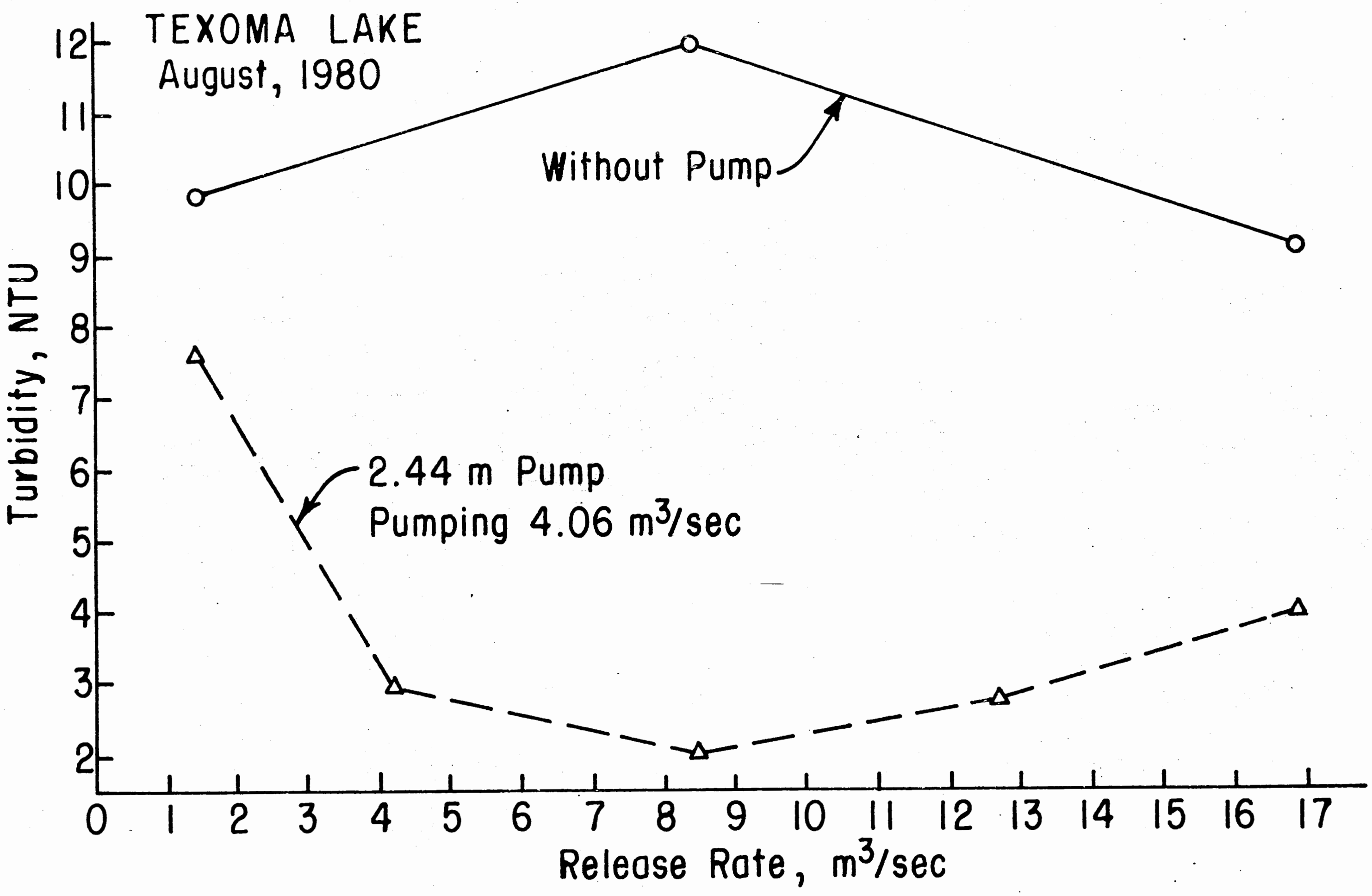

Figure 23. Turbidity as a Function of Release Rate at Lake Texoma

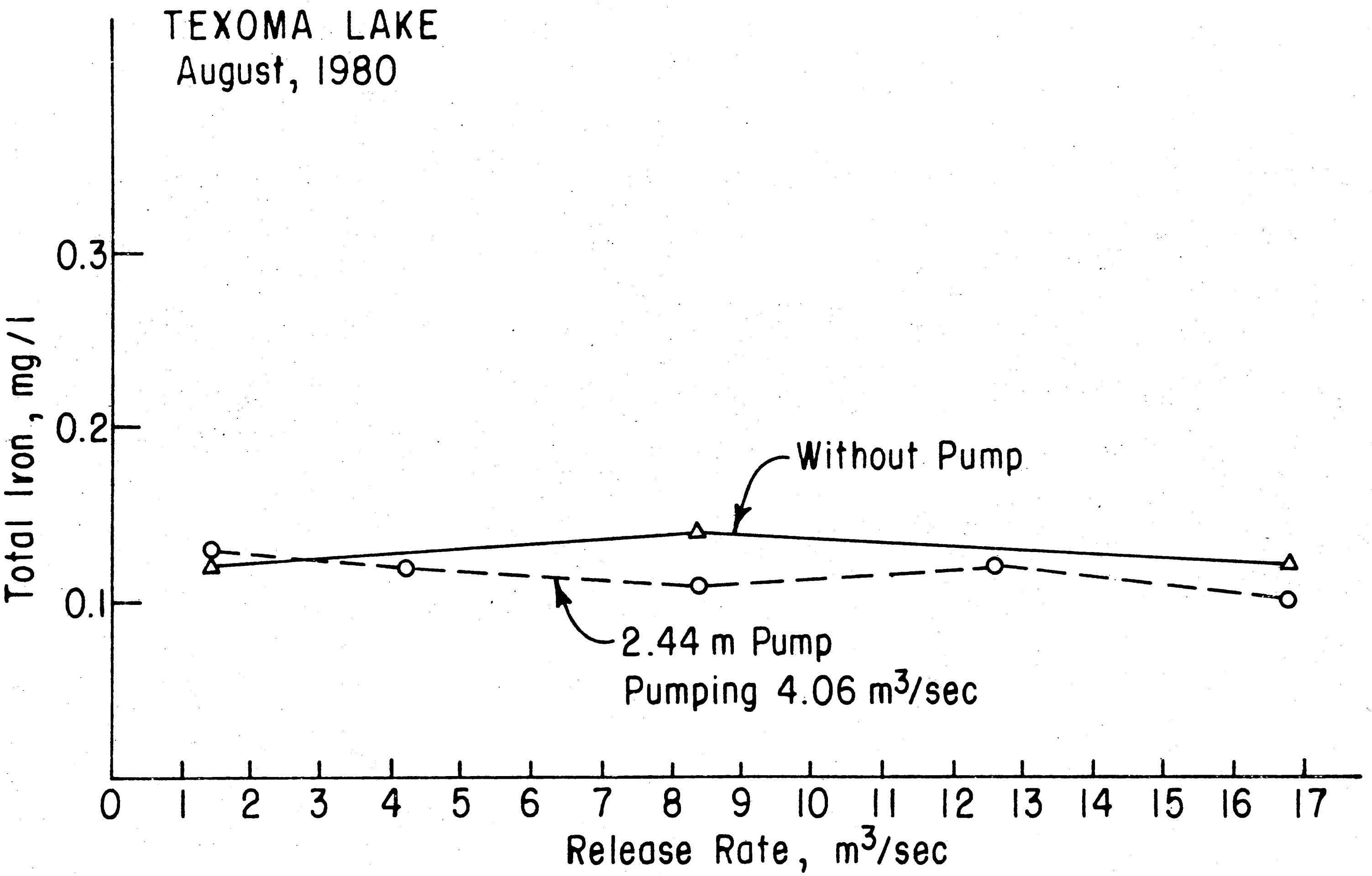

Figure 24. Total Iron Concentration as a Function of Release Rate at Lake Texoma

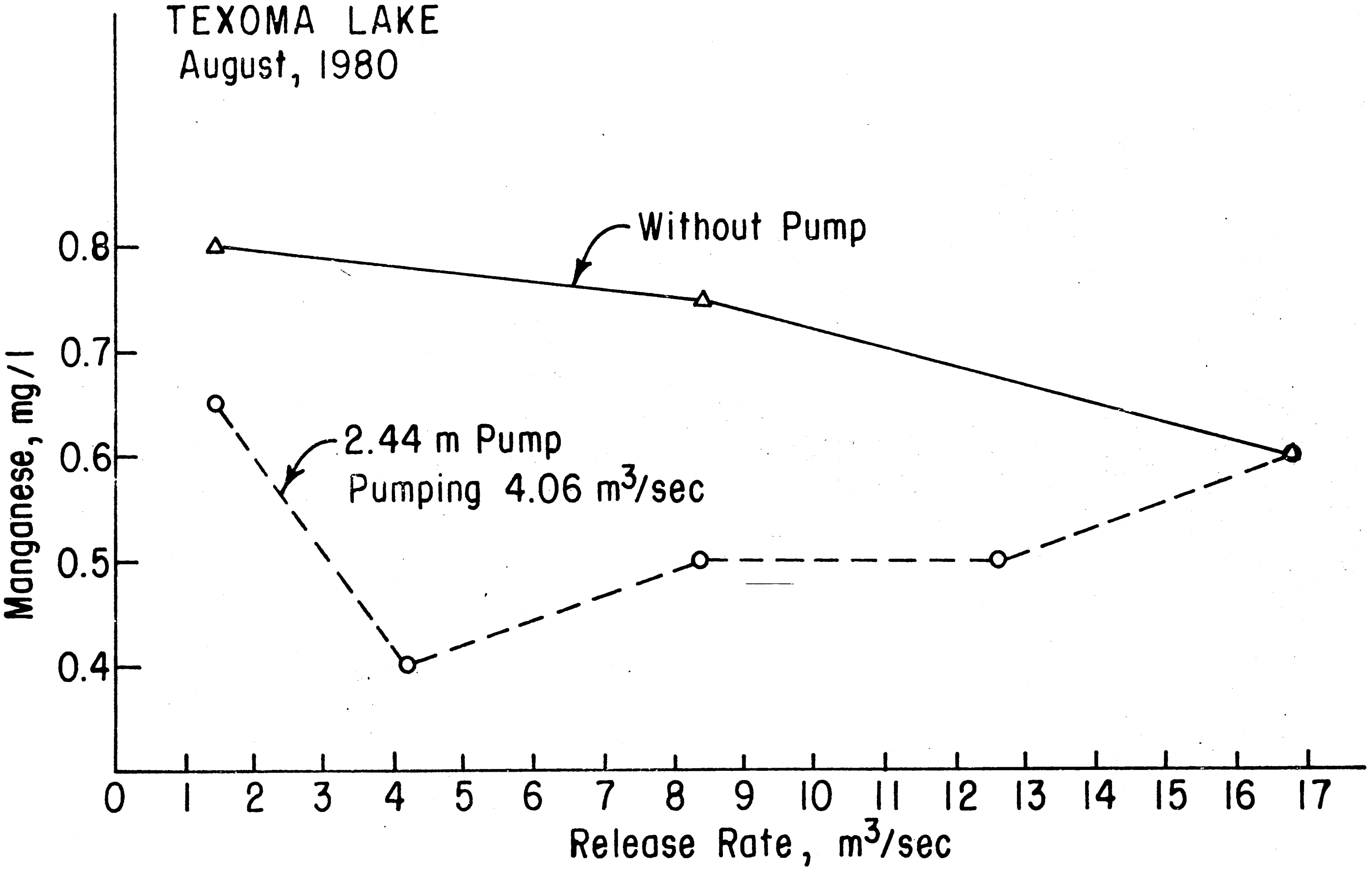

Figure 25. Manganese Concentration as a Function of Release Rate at Lake Texoma

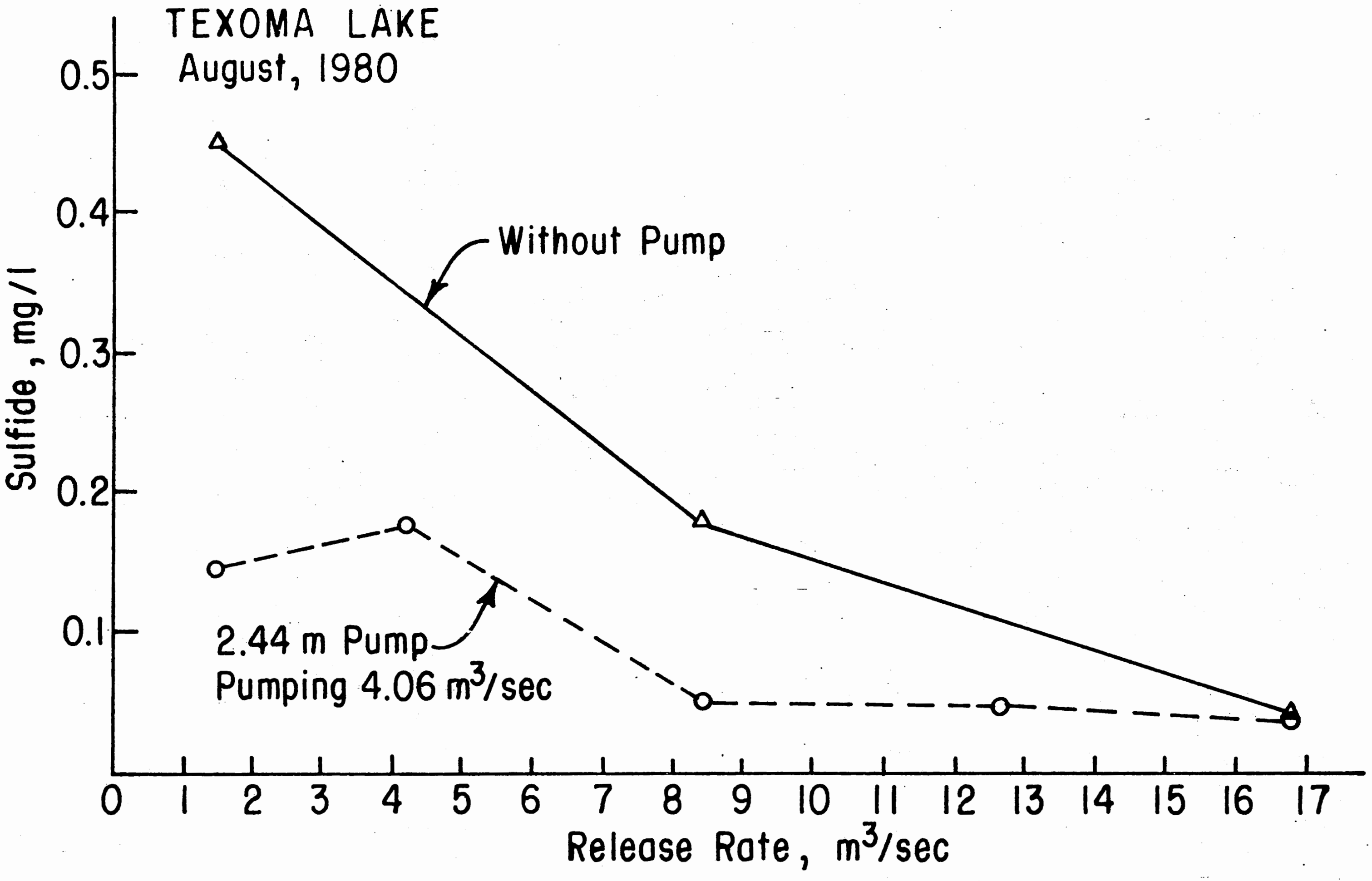

Figure 26. Sulfide Concentration as a Function of Release Rate at Lake Texoma

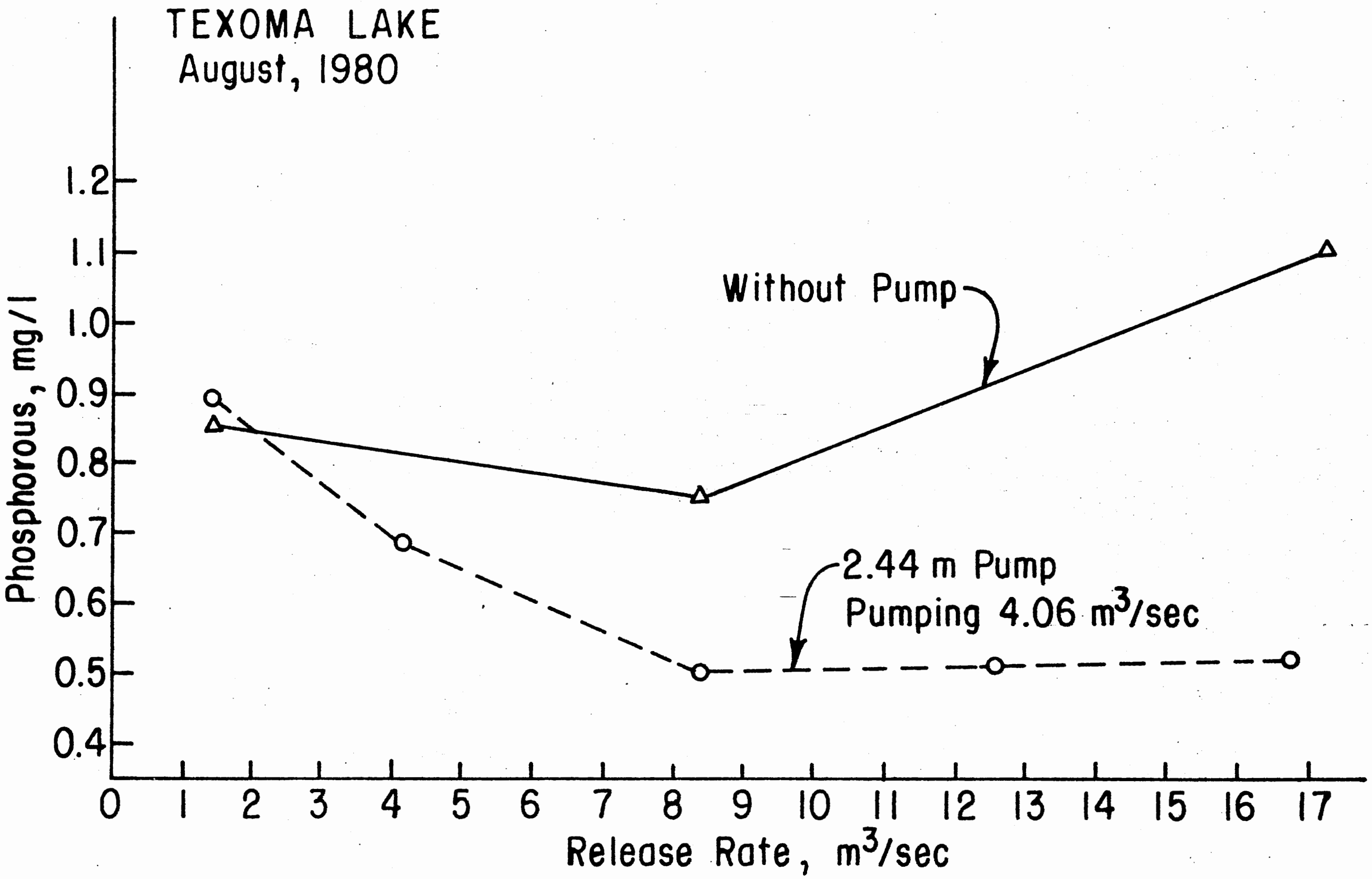

Figure 27. Phosphorous Concentration as a Function of Release Rate at Lake Texoma

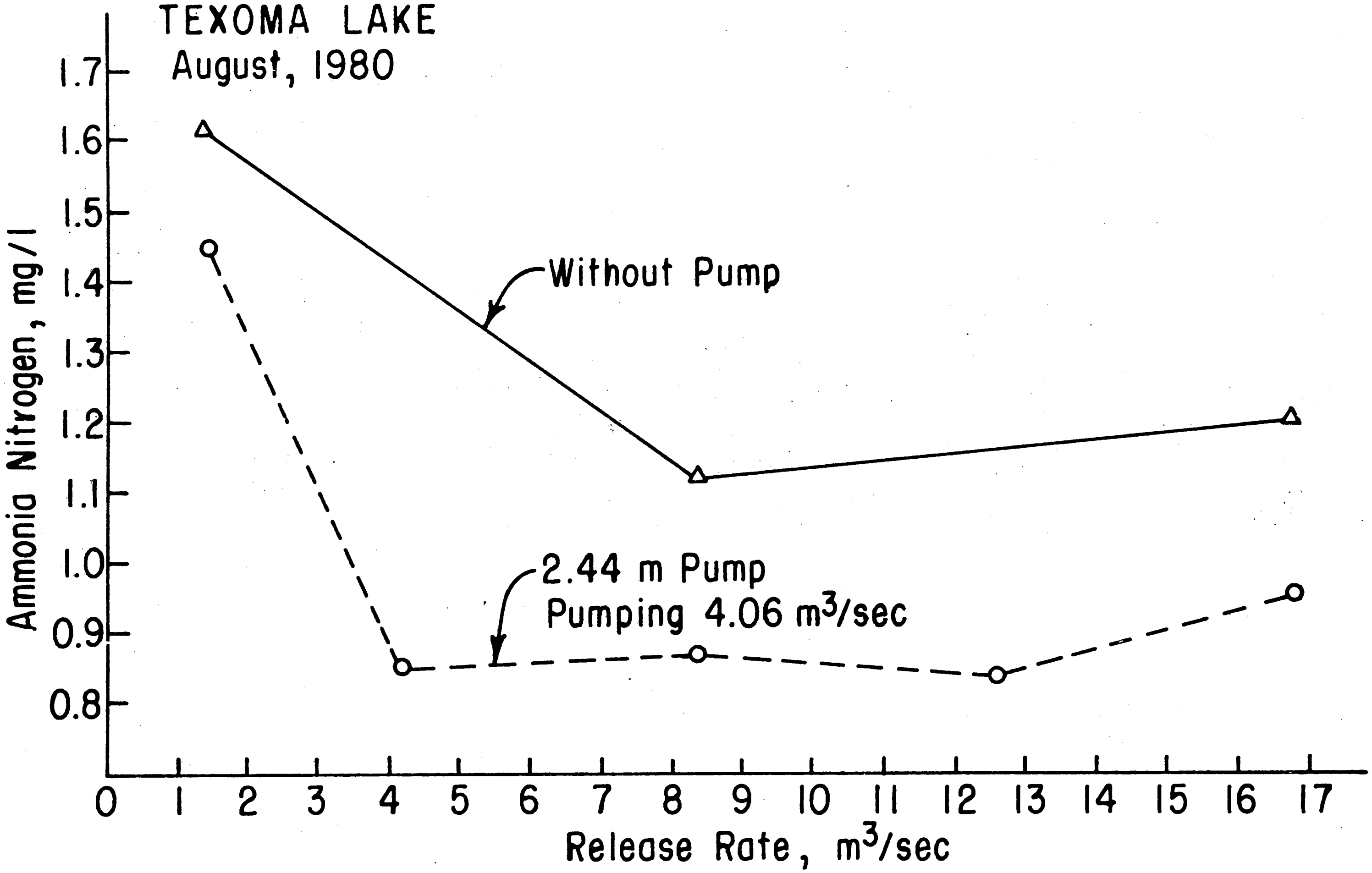

Figure 28. Ammonia Nitrogen Concentration as a Function of Release Rate at Lake Texoma

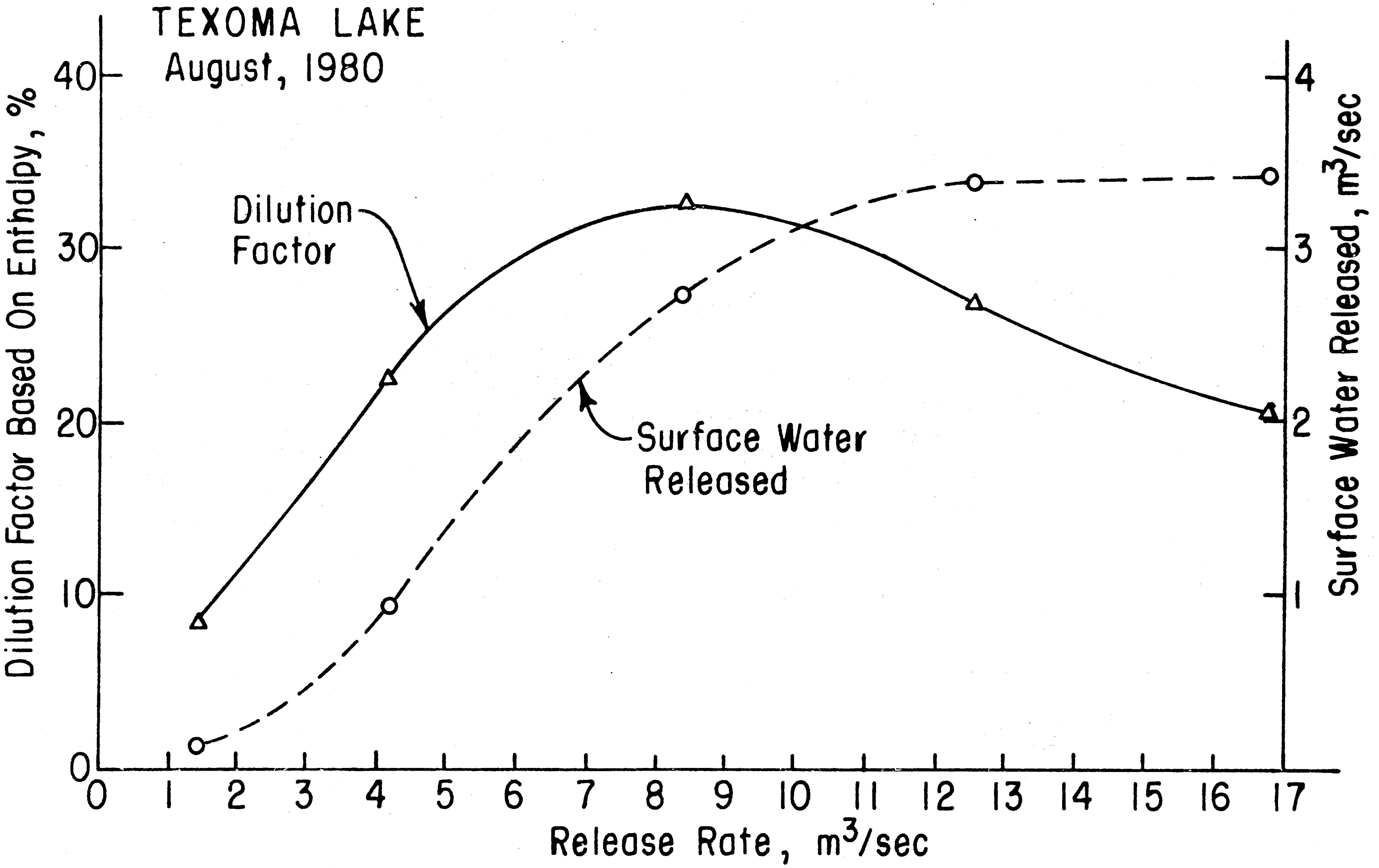

Figure 29. Dilution Factor and Surface Water Release Rate as a Function of Reservoir Release Rate at Lake Texoma

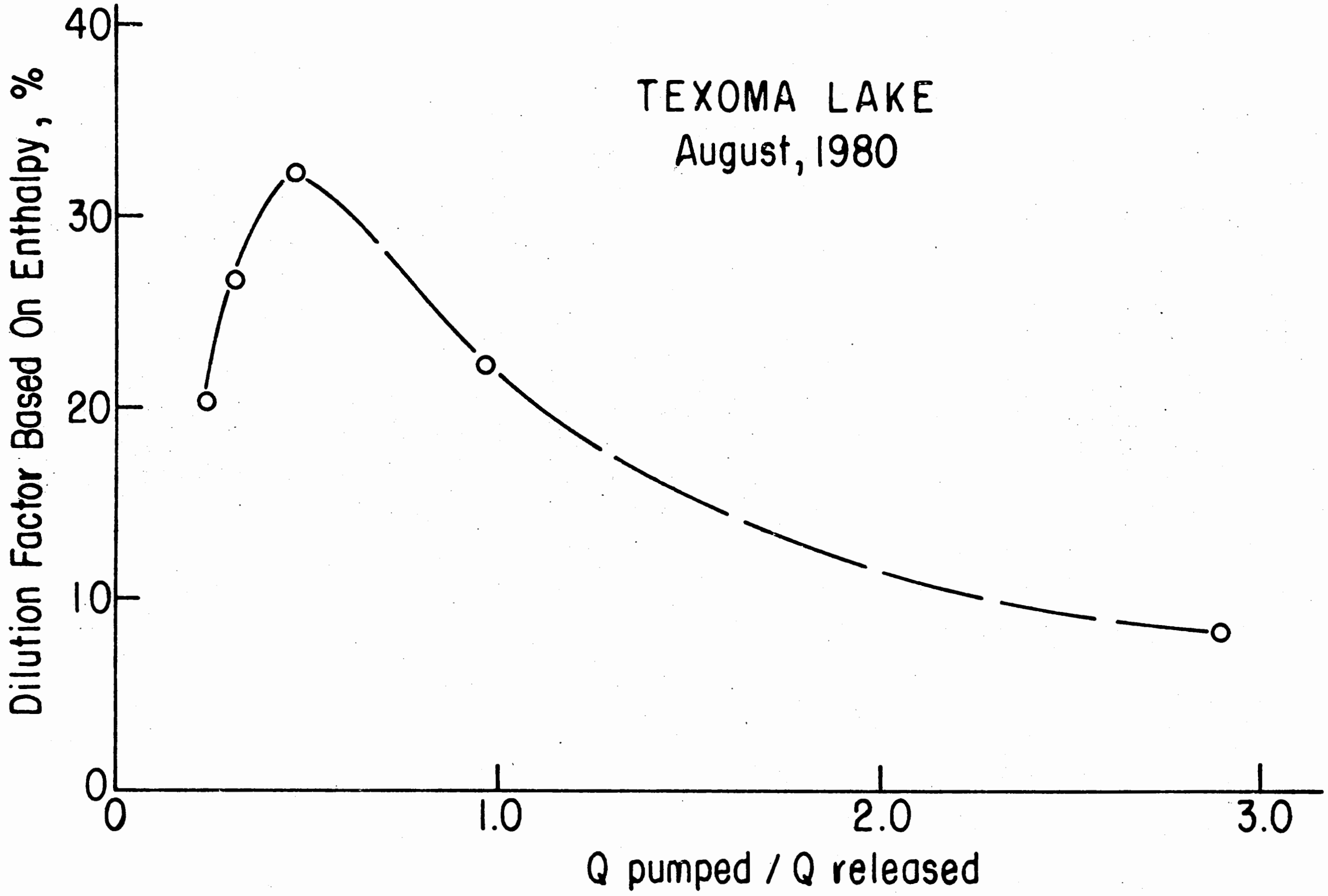

Figure 30. Dilution Factor as a Function of the Ratio of Pumping to Release Rate at Lake Texoma

APPENDIX B

DATA SUMMARY

TABLE VI

DEPTH OF PENETRATION TESTS FOR PINE CREEK
26 JUNE 1980

Pump Diameter (m)	Propellor Rotation (RPM)	Calculated Discharge (m^3/sec)	Calculated Velocity (m/sec)	Depth of Penetration (m)
1.22	50.0	0.54	0.46	7.5
	66.1	0.71	0.61	9.5
	81.3	0.87	0.75	10.5
	85.8	0.92	0.79	11.0
1.83	23.9	0.86	0.33	7.0
	32.9	1.19	0.46	8.5
	43.2	1.56	0.60	10.5
	48.3	1.75	0.67	11.0
2.44	19.5	1.67	0.36	8.0
	25.4	2.18	0.47	9.0
	29.8	2.56	0.56	10.5
	37.5	3.22	0.70	12.0
	41.4	3.55	0.77	13.0

TABLE VII

PROFILE OF PINE CREEK LAKE
26 JUNE 1980

Depth (m)	Temp (^{o}C)	D.O. (mg/l)	Fe (mg/l)	Mn (mg/l)	N (mg/l)	P (mg/l)	S (mg/l)	pH	Turb (NTU)
0	31.8	8.2	0.23	0.25	0.015	0.02	0.01	6.90	3.2
5	26.8	1.7	0.37	0.20	0.015	0.05	T	6.34	3.8
10	22.2	0.35	1.40	1.20	0.10	0.04	0.03	6.25	7.4
12	20.5	0.35	1.80	1.40	0.06	0.05	0.04	6.35	8.1

TABLE VIII

RELEASE IMPROVEMENT TEST FOR PINE CREEK LAKE
26 JUNE 1980

Pump Dia. (m)	Q_p (m^3/sec)	Q_{rel} (m^3/sec)	Temp (°C)	D.O. (mg/l)	Fe (mg/l)	Mn (mg/l)	N (mg/l)	P (mg/l)	S (mg/l)	pH	Turb (NTU)
--	0	1.82	25.0	7.9	--	--	--	--	--	--	--
1.22	0.85	1.82	28.6	8.4	0.46	0.25	ND	0.04	T	7.5	4.9
1.22	0.85	0.84	27.8	8.5	0.54	0.35	0.05	0.02	T	6.86	5.3
1.22	0.85	2.52	28.1	8.1	0.48	0.35	0.06	0.05	0.012	6.0	4.9
1.83	1.74	2.52	29.6	7.9	0.39	0.22	ND	0.05	ND	6.86	4.25
1.83	1.74	1.82	29.9	8.0	0.41	0.12	ND	0.047	T	6.0	4.4
1.83	1.74	0.56	29.7	7.4	0.48	0.25	ND	0.035	T	6.85	4.75
2.44	3.42	0.84	28.0	7.7	0.73	0.40	ND	0.04	T	6.37	5.8
2.44	3.42	2.52	27.4	7.8	0.67	0.25	T	0.06	T	6.39	4.7
2.44	3.42	1.82	27.3	7.8	0.79	0.37	ND	0.06	0.01	6.53	5.6
--	0	1.82	25.1	7.6	0.68	0.60	0.1	0.03	T	6.42	5.5

TABLE IX

PROFILE OF PINE CREEK LAKE
5 AUGUST 1980

Depth (m)	Temp (°C)	D.O. (mg/l)	Fe (mg/l)	Mn (mg/l)	N (mg/l)	P (mg/l)	S (mg/l)	pH	Turb. (NTU)	Cond. (µmhos/cm)
0	28.0	4.1	0.60	0.35	ND	0.06	ND	6.5	2.70	50
1	28.0	3.5	0.52	0.30	ND	0.03	ND	6.53	2.85	50
2	27.5	1.9	0.49	0.35	ND	0.03	T	6.54	3.00	50
5	26.2	0.4	0.47	0.40	ND	0.025	ND	6.59	2.90	50
10	21.5	0.4	3.05	1.40	1.0	0.075	0.05	6.38	9.40	67

TABLE X

PROFILE OF TEXOMA LAKE
18 AUGUST 1980

Depth (m)	Temp (°C)	D.O. (mg/l)	Fe (mg/l)	Mn (mg/l)	N (mg/l)	P (mg/l)	S (mg/l)	pH	Turb. (NTU)	Cond. (µmhos/cm)
0	27.6	5.1	T	T	0.16	0.06	ND	7.90	1.10	2100
2	27.5	4.9	0.06	T	0.24	0.06	ND	7.90	1.30	2150
5	27.3	4.7	0.07	T	0.08	0.04	ND	7.90	1.30	2170
10	27.1	4.3	0.07	0.10	0.18	0.04	ND	7.80	1.25	2180
15	26.9	3.4	0.05	0.15	0.38	0.10	T	7.50	1.30	2190
20	22.3	0.1	0.14	0.65	1.17	0.74	T	7.15	1.30	2300
25	21.0	0.1	0.09	0.80	1.70	0.94	0.2	7.40	19.0	2330
26	20.8	0.0	0.12	0.80	3.50	1.35	1.10	7.33	24.0	2340

TABLE XI

RELEASE IMPROVEMENT TEST FOR TEXOMA LAKE
18 AUGUST 1980

Q_p (m^3/sec)	Q_{rel} (m^3/sec)	Temp (°C)	D.O. (mg/l)	Fe (mg/l)	Mn (mg/l)	N (mg/l)	P (mg/l)	S (mg/l)	pH	Turb. (NTU)	Cond. (μmhos/cm)
0	1.40	21.5	6.6	0.12	0.80	1.62	0.85	0.45	7.7	9.8	2200
4.06	1.40	22.0	6.5	0.13	0.65	1.45	0.89	0.145	7.7	7.6	2200
4.06	4.20	23.0	6.1	0.12	0.40	0.85	0.68	0.175	7.6	2.9	2300
0	8.40	22.0	5.6	0.14	0.75	1.12	0.75	0.18	7.5	12.0	2300
4.06	8.40	23.8	5.6	0.11	0.50	0.87	0.50	0.05	7.6	2.0	2300
4.06	12.60	23.7	6.0	0.12	0.50	0.83	0.51	0.045	7.7	2.75	2250
4.06	16.80	23.6	5.6	0.10	0.60	0.95	0.52	0.036	7.6	4.0	2200
0	16.80	22.6	5.6	0.12	0.60	1.20	1.10	0.04	7.5	9.2	2200

APPENDIX C

CHEMICAL TEST PROCEDURES

TOTAL IRON

1, 10-Phenanthroline Method

Range: 0-2 mg/l

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Take a water sample by filling a clean sample cell to the 25 mark.
2. Add the contents of one FerroVer Iron Reagent Powder Pillow and swirl to mix. An orange color will develop if iron is present. Allow at least 3 minutes for the color to fully develop, but do not wait more than 30 minutes before completing Steps 3 and 4.
3. Fill another sample cell to the 25 mark with original water sample and place it into the cell holder. Insert the Iron (FerroVer Method) Meter Scale into the meter and adjust the wavelength dial to 510 nm. Adjust the light control for a meter reading of zero mg/l.
4. Place the prepared sample in the cell holder and read the mg/l total iron (Fe).

MANGANESE

Periodate Oxidation Method

Range: 0-10 mg/l

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Take a water sample by filling a clean sample cell to the 25 mark.
2. Add the contents of one Buffer Powder Pillow, citrate type, for manganese (cold periodate method) and swirl to mix.

3. Add the contents of one Sodium Periodate Powder Pillow, for manganese (cold periodate method) and swirl to mix. A violet color will develop if manganese is present. Allow at least 2 minutes for the color to fully develop, but do not wait more than 10 minutes before completing Steps 4 and 5.
4. Fill another sample cell to the 25 mark with original water sample and place it into the cell holder. Insert the Manganese (Periodate Oxidation Method) Meter Scale into the meter and adjust the wavelength dial to 525 nm. Adjust the light control for a meter reading of zero mg/l.
5. Place the prepared sample in the cell holder and read the mg/l manganese (Mn).

NOTE: Water samples were collected in polyethylene containers. Manganese has a strong tendency to be absorbed on glass storage bottles, and low test values will result.

AMMONIA NITROGEN

Nessler Method

Range: 0-2 mg/l

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Measure 25 ml demineralized water by filling a clean 25-ml graduated cylinder to the 25-ml mark. Pour the demineralized water into the clean sample cell.
2. Take a water sample by filling the 25-ml graduated cylinder to the 25-ml mark. Pour the sample into another clean sample cell.
3. Add 1.0 ml of Nessler Reagent to each sample cell using the 1.0 ml

calibrated dropper and swirl to mix. A yellow color will develop if ammonia nitrogen is present. Allow at least 10 minutes for the color to fully develop, but do not wait more than 25 minutes before completing Steps 4 and 5.

4. Place the sample cell containing the prepared demineralized water solution into the cell holder. Insert the Nitrogen, Ammonia (Nessler Method) Meter Scale into the meter and adjust the wavelength dial to 425 nm. Adjust the light control for a meter reading of zero mg/l.
5. Place the prepared sample in the cell holder and read the mg/l ammonia nitrogen (N).

NOTE: To eliminate the interference of magnesium hydroxide, one drop of Rochelle Salt Reagent was added to the demineralized water and to the water sample before adding the Nessler Reagent.

pH

Colorimetric Method

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Take a water sample by accurately filling a clean 25-ml graduated cylinder to the 25.0-ml mark. Pour the sample into a clean, dry sample cell.
2. Add 1.0 ml of Wide Range pH Indicator Solution using a calibrated transfer pipet and swirl to mix.
3. Fill another sample cell with about 25 ml of original water sample and place it into the cell holder. Insert the pH, Wide Range Meter Scale into the meter and adjust the wavelength dial to 520 nm.

Adjust the light control so the meter needle rests at the far right end of the arc.

4. Place the prepared sample in the cell holder and read the pH value from the center of lower scale, according to the developed color. If the color does not correspond to those indicated on the center or lower scales, and/or the meter reading does not fall within the range indicated, proceed with Step 5.
5. Adjust the wavelength dial to 615 nm and standardize the instrument as described in Step 3. Place the prepared sample in the cell holder and read the pH value on the upper scale.

REACTIVE PHOSPHOROUS

Ascorbic Acid Method

Range: 0-2 mg/l

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Take a water sample by filling a clean sample cell to the 25 mark.
2. Add the contents of one PhosVer III Phosphate Reagent Powder Pillow and swirl to mix. A blue color will develop if phosphate is present. Wait at least 2 minutes for full color development, but not more than 10 minutes before completing Steps 3 and 4.
3. Fill another sample cell to the 25 mark with original water sample, and place it into the cell holder. Insert the Phosphate (PhosVer III Method) Meter Scale into the meter and adjust the wavelength dial to 700 nm. Adjust the light control for a meter reading of zero mg/l.

4. Place the prepared sample in the cell holder and read the mg/l phosphate (PO_4).

SULFIDE

Methylene Blue Method

Range: 0-0.5 mg/l

Equipment: Hach DR/2 Spectrophotometer

Procedure:

1. Measure 25 ml of demineralized water by filling a clean 25-ml graduated cylinder to the 25-ml mark. Pour the demineralized water into a clean sample cell.
2. Take a water sample by filling the 25-ml graduated cylinder to the 25-ml mark. Pour the sample into another clean sample cell.
3. Using the 1-ml calibrated dropper, add 1 ml of Sulfide 1 Reagent to each sample cell and swirl to mix.
4. Using the 1-ml calibrated dropper, add 1 ml of sulfide 2 Reagent to each sample cell and immediately swirl to mix. A pink color will develop and turn blue if sulfide is present. Allow 5 minutes for the color to fully develop and proceed with Step 5.
5. Place the sample cell containing the demineralized water into the cell holder. Insert the Sulfide (Methylene Blue Method) Meter Scale into the meter and adjust the wavelength dial to 665 nm. Adjust the light control for a meter reading of zero mg/l.
6. Place the prepared sample in the cell holder and read the mg/l sulfide (S).

TURBIDITY

Nephelometric Method

Range: 0-1000 NTU

Equipment: Hach 2100A Turbidimeter

Procedure:

1. Prepare the Model 2100 A Laboratory Turbidimeter as directed in the Start-Up Section of the instrument manual.
2. Calibrate the ranges to be used with the secondary Hach Latex Turbidity Standards.
3. Fill a clean sample cell with 25 ± ml of the sample to be tested.
4. Place the sample in the instrument and cover with the light shield.
5. Read the turbidity directly in nephelometric turbidity units (NTU).

VITA

Kerry Mark Robinson

Candidate for the Degree of

Master of Science

Thesis: RESERVOIR RELEASE WATER QUALITY IMPROVEMENT BY LOCALIZED DESTRATIFICATION

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Altus, Oklahoma, October 19, 1953, the son of Calvin and Jean Robinson.

Education: Graduated from Gould High School, Gould, Oklahoma, in May 1971; attended Cameron University, Lawton, Oklahoma, from September 1971 to May 1972; attended Oklahoma State University, Stillwater, Oklahoma, from September 1972 to December 1975 and received a Bachelor of Science degree in Agricultural Engineering in December 1975; attended Oklahoma State University from January 1980 to May 1981 and completed requirements for a Master of Science degree in May 1981.

Professional Experience: Served as a civilian staff engineer in the facilities engineering department at Fort Sill, Oklahoma, from February 1976 to November 1979, and a Graduate Research Assistant from January 1980 to January 1981 for the Agricultural Engineering Department of Oklahoma State University.

Professional and Honorary Organizations: Associate member of the American Society of Agricultural Engineers; National Society of Professional Engineers; Oklahoma Society of Professional Engineers; Tau Beta Pi, Phi Kappa Phi, Registered Engineer-in-Training in Oklahoma.