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ENHANCEMENT OF RELEASES FROM A STRATIFIED IMPOUNDMENT BY LOCALI--ETC(U)
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ENHANCEMENT OF RELEASES FROM A STRATIFIED IMPOUNDMENT BY LOCALIZED MIXING, OKATIBBEE LAKE, MISSISSIPPI.

by

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⑫ 18p.

⑪ Jan[redacted]78

⑨ Final Report.

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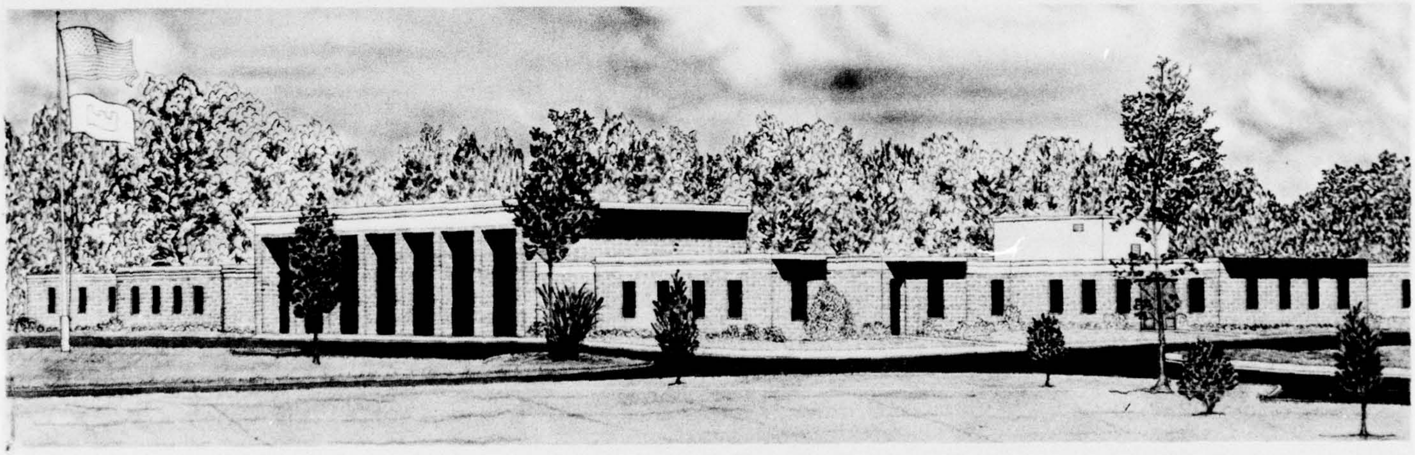
AD A051794



Prepared for Office, Chief of Engineers, U. S. Army
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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper H-78-1 | 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) ENHANCEMENT OF RELEASES FROM A STRATIFIED IMPOUNDMENT BY LOCALIZED MIXING, OKATIBBEE LAKE, MISSISSIPPI	5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) Mark S. Dortch Steven C. Wilhelms	8. CONTRACT OR GRANT NUMBER(*s*)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Mississippi 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314	12. REPORT DATE January 1978 13. NUMBER OF PAGES 15
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)	15. SECURITY CLASS. (*of this report*) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

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17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Impoundments
Lake Okatibbee
Mixing
Stratification (water)
Stratified flow
Water
Water quality

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Tests were conducted at Okatibbee Lake, Mississippi, to evaluate the effectiveness of localized mixing for enhancing the quality of low-level, low-flow releases from a stratified impoundment. A low-energy mechanical pump (Garton pump) that consisted of a submerged ventilating fan driven by a 1.12-kw electric motor was positioned immediately upstream of and above the low-level intake. Epilimnion water was forced toward the lake bottom where it was mixed

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20. ABSTRACT (Continued).

with hypolimnion water and then released through the fixed low-level flood control outlet. The quality of this water mixture was an improvement over the quality of the water released without the pump operating. It was estimated that the epilimnion water comprised about 50 percent of the total release. Use of a Garton pump to induce localized mixing upstream of a fixed low-level flood control outlet was demonstrated to be an effective and economical means of improving the quality of low-flow releases from a stratified reservoir.

Preface

During 15-16 June 1977, tests were conducted at Okatibbee Lake, Mississippi, by the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) to evaluate the effectiveness of a low-energy mixing device in producing sufficient localized mixing to enhance the quality of low-flow releases from a stratified lake and fixed low-level outlet works.

The participation by WES during this study was funded by a work unit, "Methods of Enhancing Water Quality," of the Reservoir Water Quality Research Program sponsored by the Office, Chief of Engineers.

The study reported herein was conducted under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division and Reservoir Water Quality Branch (Physical). Personnel participating in the tests were Messrs. M. S. Dortch, S. C. Wilhelms, and M. E. Neumann. This report was prepared by Messrs. Dortch and Wilhelms and reviewed by Mr. Grace.

Commander and Director of WES during this study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

Contents

ENHANCEMENT OF RELEASES FROM A STRATIFIED IMPOUNDMENT BY LOCALIZED MIXING, OKATIBBEE LAKE, MISSISSIPPI

Background

1. Releases from the hypolimnion of an impoundment during the stratification season often result in poor downstream water quality. During stratification, the hypolimnion may be anaerobic or contain a large biochemical oxygen demand, turbidity, or dissolved metals and solids compared with the epilimnion. Many of the older existing reservoir outlet works were not constructed with the flexibility of providing selective withdrawal from various levels of the lake and regulation of downstream water quality. For example, some structures permit release only from the bottom of the pool when it would be preferable from a water-quality standpoint to release from the upper levels of the pool.

2. There are several methods of enhancing the quality of water released from fixed low-level outlet works. If cold-water releases are desired, some of the methods may include hypolimnion oxygenation and/or reaeration through the structure.

3. If warmwater releases are desired during the stratification season or downstream temperature objectives are not stringent, then other methods might be considered. Such methods could involve artificial destratification, structural modifications like "add-on" withdrawal systems, or localized mixing. Destratification eliminates stratification, thus redistributing water-quality constituents throughout the water column. However, destratifying a large body of water requires a great amount of energy and eliminates temperature stratification which may be desirable relative to user interests. Structural add-ons provide direct withdrawal of epilimnion water, but such modifications can be costly. Localized mixing enhances low-level releases by forcing epilimnion water down to the bottom to be mixed and then released with hypolimnion water. Localized mixing preserves stratification while

providing an economically attractive means of improving downstream release quality. This method provides only a partial enhancement of release quality, whereas structural add-ons provide the maximum enhancement by releasing primarily epilimnion water. Additionally, localized mixing may not enhance the water quality within the lake.

Project Description

4. Okatibbee Lake is located about 11 km north of Meridian, Mississippi (Figure 1). Built and operated by the U. S. Army Engineer

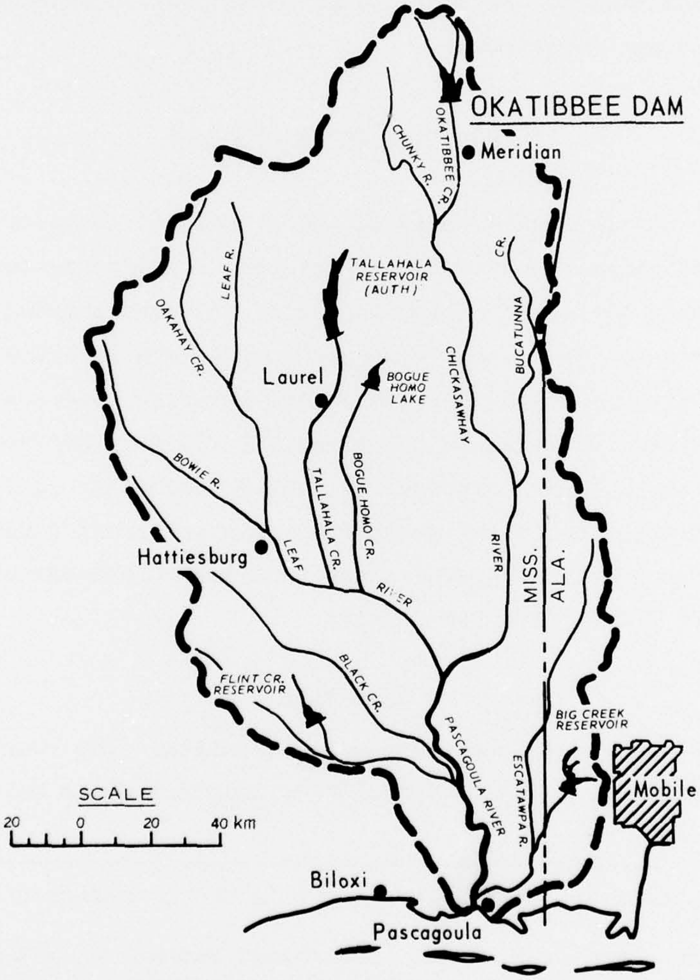

Figure 1. Location map

District, Mobile (SAM), Lake Okatibbee is shallow with a maximum depth of about 10 m. The surface area is approximately 1538 ha at el 104.55* (normal summer pool) and the corresponding storage capacity is about 5.2×10^7 m^3. The reservoir outlet works (Plate 1) consist of a fixed low-level intake structure (invert el 94.5), a horseshoe-shaped conduit, and a stilling basin.

5. Temperature and chemical stratification develops during the summer accompanied by oxygen depletion in the hypolimnion. If the hypolimnion of a lake becomes anaerobic, numerous compounds such as hydrogen sulfide, ammonia, iron, and manganese may exist in solution within the hypolimnion. Releasing this water could create adverse water-quality conditions downstream.

Purpose and Scope of Study

6. The SAM desired a reliable and economical means of improving the quality of water released into Okatibbee Creek during periods of stratification. Localized mixing is one of the alternatives initially considered by SAM. This study was conducted to evaluate the effectiveness of this alternative on the quality of low-flow releases discharged through the fixed low-level outlet works. U. S. Army Engineer Waterways Experiment Station (WES) personnel evaluated the effect on release quality immediately below the structure. SAM personnel conducted a separate study on evaluating the subsequent downstream effect. Results of the WES effort are reported herein.

Apparatus

7. The concept of the low-energy mechanical pump (Garton pump) was developed by Dr. James E. Garton** of Oklahoma State University

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* All elevations (el) cited herein are in metres referred to mean sea level.

** J. E. Garton and C. E. Rice, "Low Energy Mechanical Methods of Reservoir Destratification," OWRRI Final Technical Completion Report, A-028-OKLA, 1974, Oklahoma State University, Stillwater, Okla.

(OSU) for the purpose of destratifying lakes. The Garton pump, furnished and installed by OSU, consisted of a 1.83-m-diam ventilating fan suspended about 1 m below the surface by a 2-m-square raft. The fan was driven by a 1.12-kw electric motor at a design speed of 17 rpm. The pumping rate at this speed was approximately 1.7 m^3/sec.

8. The pump was attached to the upstream face of the intake structure immediately over the intake (Figure 2). The fan pumps water from the surface toward the bottom, resulting in turbulent mixing of the surface and bottom waters. The excess quantity of mixed water that is not withdrawn rises to neutral buoyancy and spreads as a density current. This phenomenon was observed in laboratory flume tests conducted at WES and is illustrated in Figure 3. It is the mixture of surface and bottom waters within the turbulent mixing zone that is withdrawn through the low-level outlet and contributes to the improved quality of the releases.

9. The Garton pump was operated in a prior test at Okatibbee Lake during August 1976 to demonstrate its effect on the enhancement of releases. SAM and OSU personnel participated in these tests; the results were published by OSU.* Unfortunately, during those tests a strong cold front passed through the area causing natural destratification. It was difficult to completely evaluate the success of the pump. The Garton pump was left by OSU for further testing.

10. Depth, temperature, dissolved oxygen (D.O.), and conductivity measurements were made in the lake with Hydrolab Surveyor Model 6D Water Quality Analyzer. D.O. measurements were also made with a Yellow Springs Instrument (YSI) D.O.-Temperature meter. The sensors were calibrated with the azide modification of the Winkler titration technique. Additionally, D.O. readings were periodically checked against titrations of samples.

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* J. E. Garton and H. R. Jarrell, "Demonstration of Water Quality Enhancement Through the Use of the Garton Pump," Supplement to Technical Completion Report, C-5228, 1976, Oklahoma State University, Stillwater, Okla.

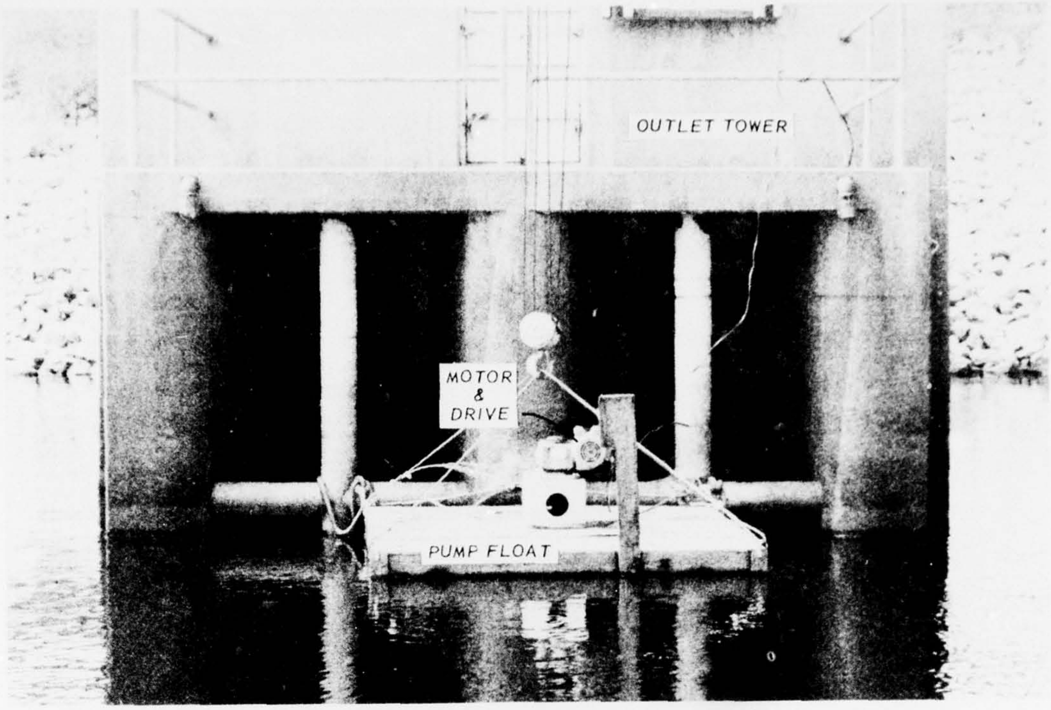


Figure 2. Location of Garton pump

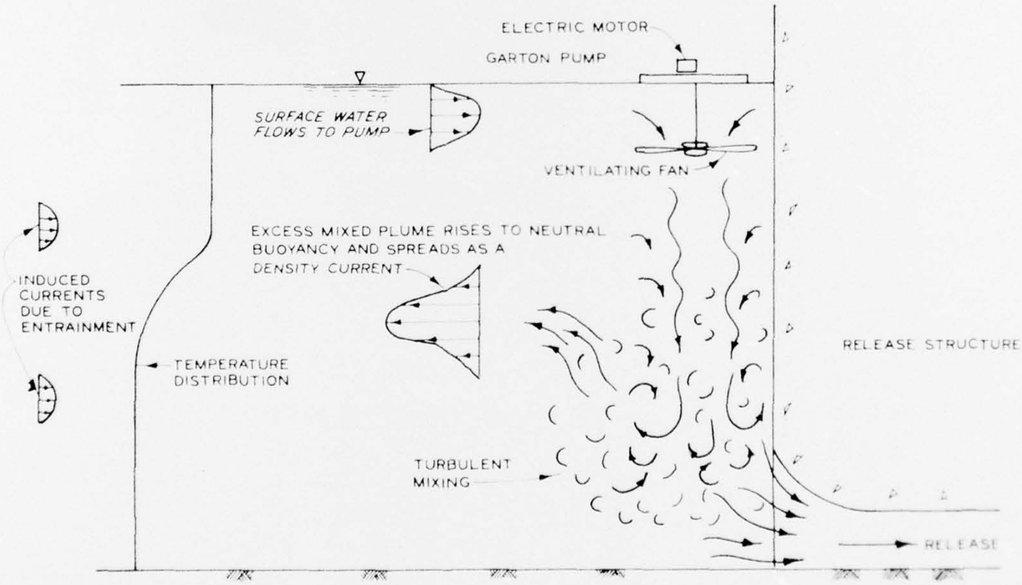


Figure 3. Localized mixing

Tests and Results

11. Water-quality data were taken in the reservoir and stilling basin before and after initiation of pumping. Profiles of temperature, D.O., and conductivity were taken from a boat anchored directly above the approach channel to the intake structure about 20-30 m upstream of the structure. Profiles observed before and after initiation of pumping are presented in Plate 2. The "before" profiles were collected on the morning of 15 June 1977. The pump was started at about 1500 hr on 15 June. The "after" profiles were collected on the morning of 16 June.

12. During the night of 15 June, there was a rainstorm which may have had some influence on the "after" profiles. Considering the possibility of measurement error and the occurrence of the storm, the profiles are quite similar. The spreading density current, resulting from the pump-induced mixing, would cause some change within the profiles at the intermediate depths as suggested by the profiles in Plate 2. The pump was not intended to completely mix the lake, so the changes within the lake should be small with respect to the changes in the release quality. However, within the immediate mixing zone of the pump, there should be sharp changes in the quality characteristics. It is not clear why there was an increase in the conductivity (with the pump on) near the bottom. Perhaps the downward flow stirred up sediment on the lake bottom (Plate 2).

13. Release water-quality measurements at the conduit outlet portal prior to pumping and with the pump operating are presented in Table 1. Without localized mixing, water that was void of D.O. was drawn into the intake and was reaerated within the conduit providing a measured release D.O. concentration of about 5.9 mg/ℓ (Table 1). The temperature and conductivity of the release water were representative of that found in the hypolimnion. Data taken only 15 min after the pump was started indicated a definite effect of the localized mixing on release quality. With the pump on, the temperature and D.O. of the release water were increased by 3.6°C and 1.0 mg/ℓ, and the conductivity

was decreased by 20 µmho/cm (Table 1). The discharge rate was held constant throughout the tests at about 1.4 m^3/sec as determined by a downstream gage.

14. The quality of the release water was improved by causing epilimnion water to be withdrawn from the pool, thus diluting the poorer quality water withdrawn from the hypolimnion. To estimate how much epilimnion water contributed to the total outflow, the following calculations were performed. From preservation of continuity, the concentration of a tracer can be determined from the equation

$$C_oV_o = C_1V_1 + C_2V_2 \tag{1}$$

If conductivity is used as a tracer, then

C_o = conductivity of water released with the pump on, µmho/cm
V_o = volume of water released in a time period, m^3
C_1 = conductivity of water released prior to pumping, µmho/cm
V_1 = volume of hypolimnion water released in a time period, m^3
C_2 = conductivity of epilimnion water, µmho/cm
V_2 = volume of epilimnion water released in a time period, m^3

From conservation of volume

$$V_o = V_1 + V_2 \tag{2}$$

By substitution of Equation 2 into Equation 1, Equation 1 can be written as:

$$\frac{V_2}{V_o} = \frac{C_o - C_1}{C_2 - C_1} \tag{3}$$

By substituting appropriate conductivity values, the proportion of epilimnion water contained in the total release can be estimated. The conductivities of the epilimnion water, C_2 , the release water prior to pumping, C_1 , and the release water with pump on, C_o , were 35, 65, and 50 µmho/cm, respectively. This indicates that about 50 percent of the total flow released was epilimnion water. Because conductivity prevails throughout the depth of the pool, this calculation is not an exact determination of the dilution but provides an estimate of the minimum amount of dilution.

Conclusions

15. Localized mixing in the immediate vicinity of the fixed low-level intake of the Okatibbee outlet works was demonstrated to provide a significant change in the quality of low-flow releases. Epilimnion water of good quality was forced down toward the bottom of the lake by a low-energy mechanical pump. The surface water was mixed and released with the poorer quality water of the hypolimnion. The epilimnion water comprised approximately 50 percent of the total release when the pump was operating. The low-energy mechanical pump is an economical means for inducing localized mixing of stratified waters.

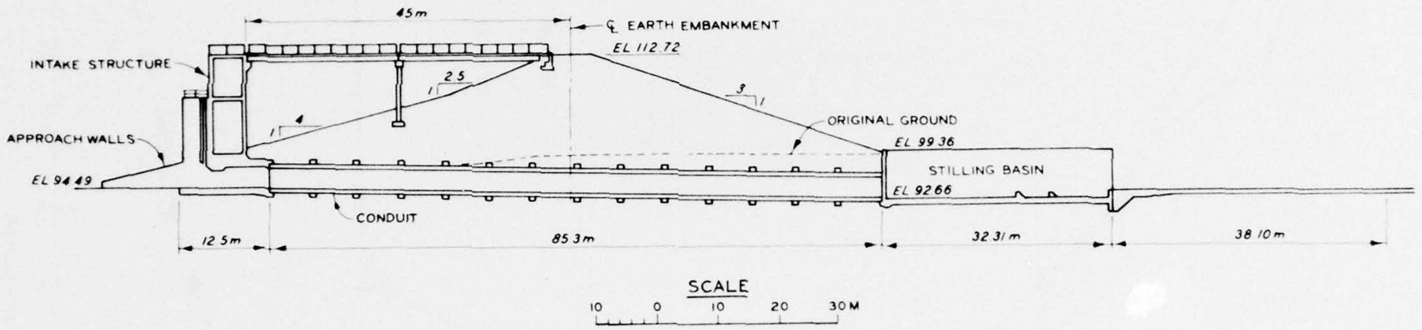
16. Several design parameters need further investigation for the purpose of developing design and application guidance. The discharge rate of the pump with respect to the release rate, the thrust of the pump, and the depth of penetration of the pump discharge with respect to the outlet depth should be important factors to consider during the design of such a system. It is considered that the percent of epilimnion water dilution could be much higher than 50 percent for a well-designed system. It is also emphasized that the pump system tested at Okatibbee Lake may be inadequate for application at other projects; for example, the pump discharge rate necessary to provide effective enhancement of a release would be dependent on the release rate. Additionally, the lake depth would influence the pump design.

Table 1

Outflow Quality

Condition	Temperature °C	D.O., mg/ℓ	Conductivity μmho/cm
Prior to pumping	23.4	5.9*	65.0
Pump on after 15 min	27.0	6.9	45.0
Pump on after 20 hr	26.7	6.8	50.0

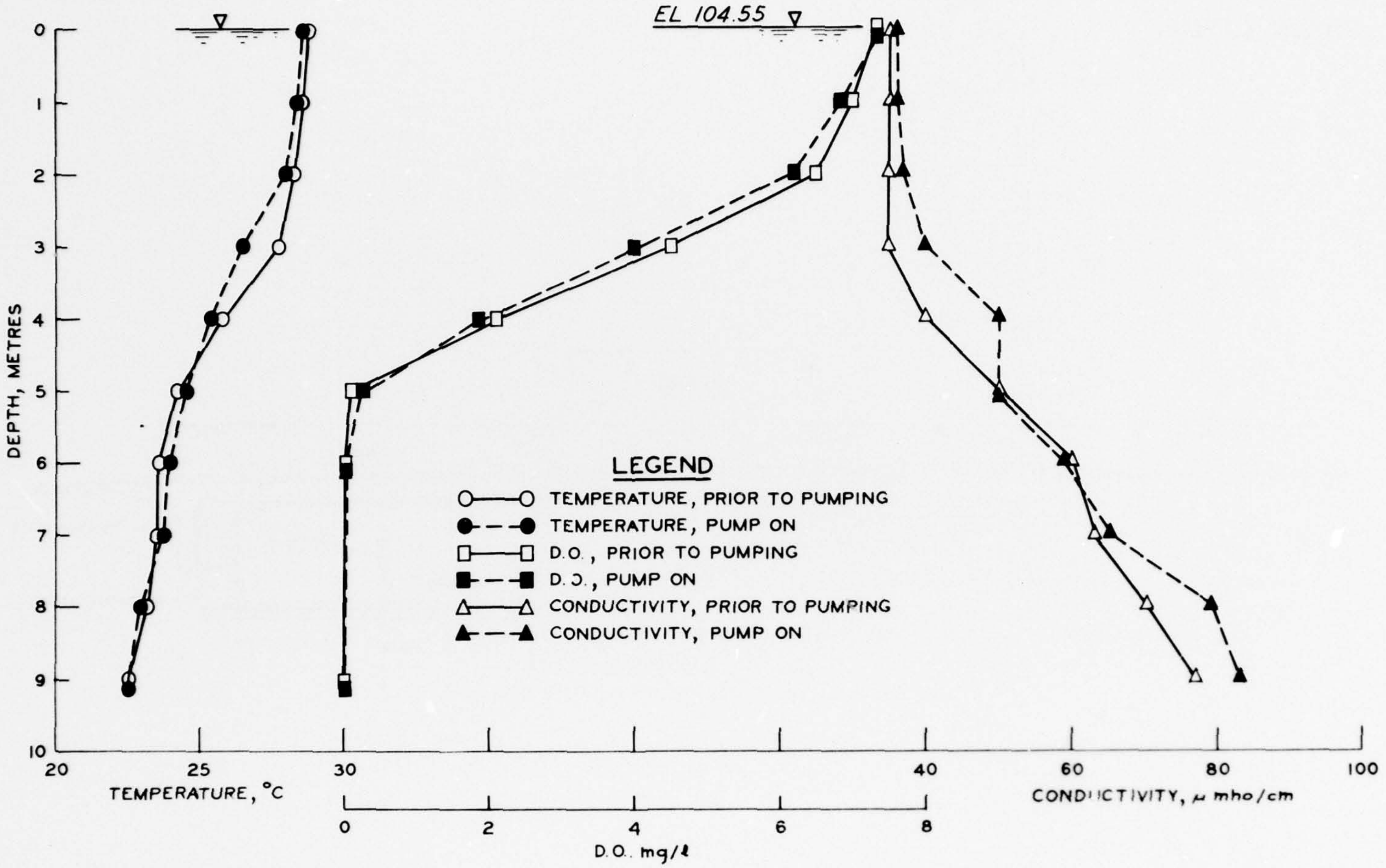
Note: Measurements made at the conduit outlet portal.
* Water that was void of D.O. was withdrawn and reaerated within the conduit.



OUTLET WORKS

PLATE 1

PLATE 2



NOTE: PROFILES WERE TAKEN 20-30 m UPSTREAM OF INTAKE STRUCTURE

WATER-QUALITY PROFILES

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Dortch, Mark S
Enhancement of releases from a stratified impoundment by localized mixing, Okatibbee Lake, Mississippi / by Mark S. Dortch, Steven C. Wilhelms. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
11, [3] p., 2 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; H-78-1)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

1. Impoundments. 2. Lake Okatibbee. 3. Mixing. 4. Stratification (Water). 5. Stratified flow. 6. Water. 7. Water quality. I. Wilhelms, Steven C., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; H-78-1.
TA7.W34m no.H-78-1