ACKNOWLEDGEMENTS

Financial support for this project was provided by the Oklahoma Water Resources Research Institute Project A-065. Acknowledgement is extended to Loren Mason, Jim Skaggs, Mike Schrick and Dean Cummings of the Corps of Engineers for their encouragement and assistance. John Cloud of Arkansas Fish and Game Department is thanked for his aid and scientific curiosity. The effect of the management abilities of Rick Sellers of the Corps of Engineers and Steve Holmes, Northrup Corporation supervisor at Gillham Lake, was readily discernible in the smooth progress of the experiment.

Oklahoma State University personnel who played a role in the research were Norvil Cole, Karen Cole, Cathy Marshall, Richard Punnett, Gary Ramsdell and Darryl Toews.

To Ann. For her support and patience with me during my absence and presence. Without you there is no joy, no true success.

Yours Forever,
Richard 4 Mar 1978

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

WATER QUALITY ENHANCEMENT BY POINT DESTRATIFICATION

--GILLHAM LAKE, ARKANSAS

Introduction

Extreme energy expenditure precludes the probability of total destratification of many water supply reservoirs as a technique of quality improvement. Accordingly, destratification of the volume immediately surrounding the lake release valve has become an increasingly attractive procedure for reduction of municipal and industrial water treatment costs. The Garton Pump has been shown to be a low-energy destratifying device, worthy of extensive testing. This apparatus, composed of a motor or engine and fan propeller mounted on flotation, is anchored in position over the intake valve. (A view of a Garton Pump functioning at Lake Carl Blackwell is shown in Figure 1.) When activated, the propeller pushes water from the upper strata downward. (The propeller of a 72" Garton Pump is shown in Figure 2.) The result is extensive replacement of hypolimnetic by epilimnetic water in the release volume, and a corresponding improvement in the quality of the water being released. This trial is a beginning step of a project to determine the effects of pump diameter, RPM, and shrouding on water quality improvement by a Garton Pump.

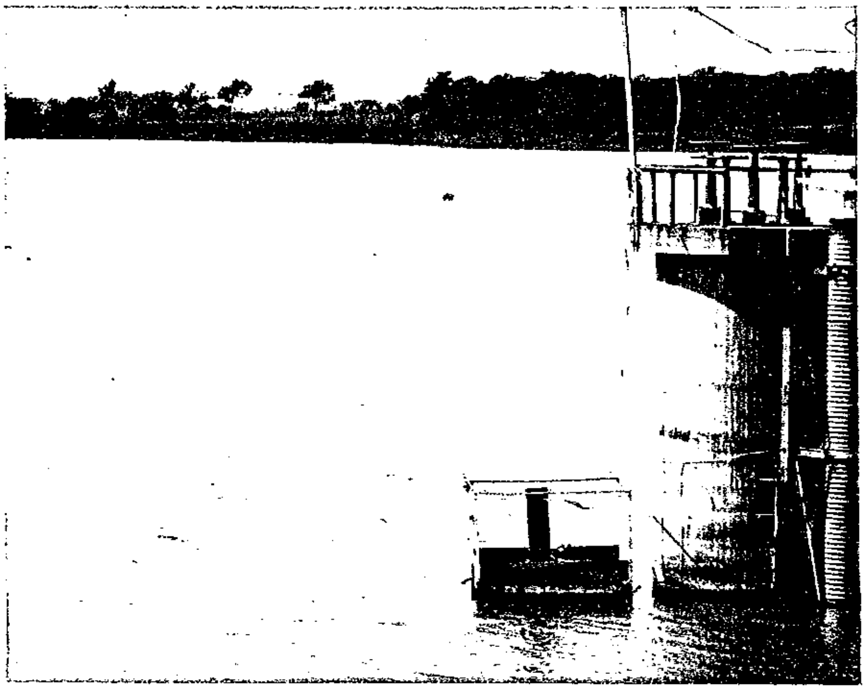

Figure 1. Garton Pump in Operation at Lake Carl Blackwell

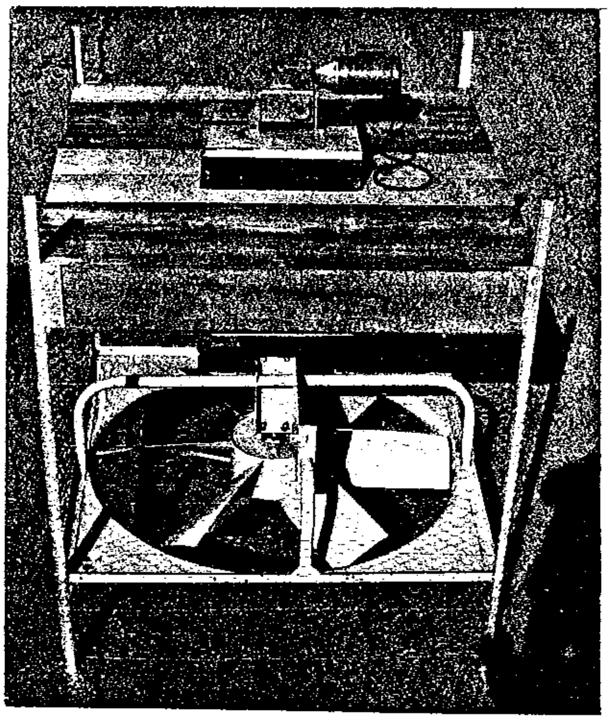

Figure 2. A 72" Garton Pump Showing the Propeller and Raft Assembly

THE SYSTEM

Gillham Lake, Arkansas, was selected as a test site because the reservoir becomes strongly stratified and its management has the capability of selective water withdrawal. Individuals of the Corps of Engineers, Northrup Corporation, and the Arkansas Fish and Game Department were professionally helpful in the regulatory and technical aspects of the experiment. Special arrangements with these persons allowed water withdrawal to be effected from below the thermocline during the testing phase. A diagram representation of the intake tower is shown in Figure 3. The Gillham Lake release system was ideal in that it allowed sampling immediately beyond the point of withdrawal. This prevented aeration due to hydraulic jump or other phenomenon commonly associated with flow through dam outlets from affecting the readings.

Fan Laws and conservation of momentum were utilized to estimate the depth of penetration of the buoyant plume which might be expected for 42" (1.067 m) and 72" (1.829 m) pumps running at different RPM. The upper release was closed and water was released from the 29.23 foot (8.91 m) depth opening at Gillham Lake during all of Phase I testing and most of Phase II.

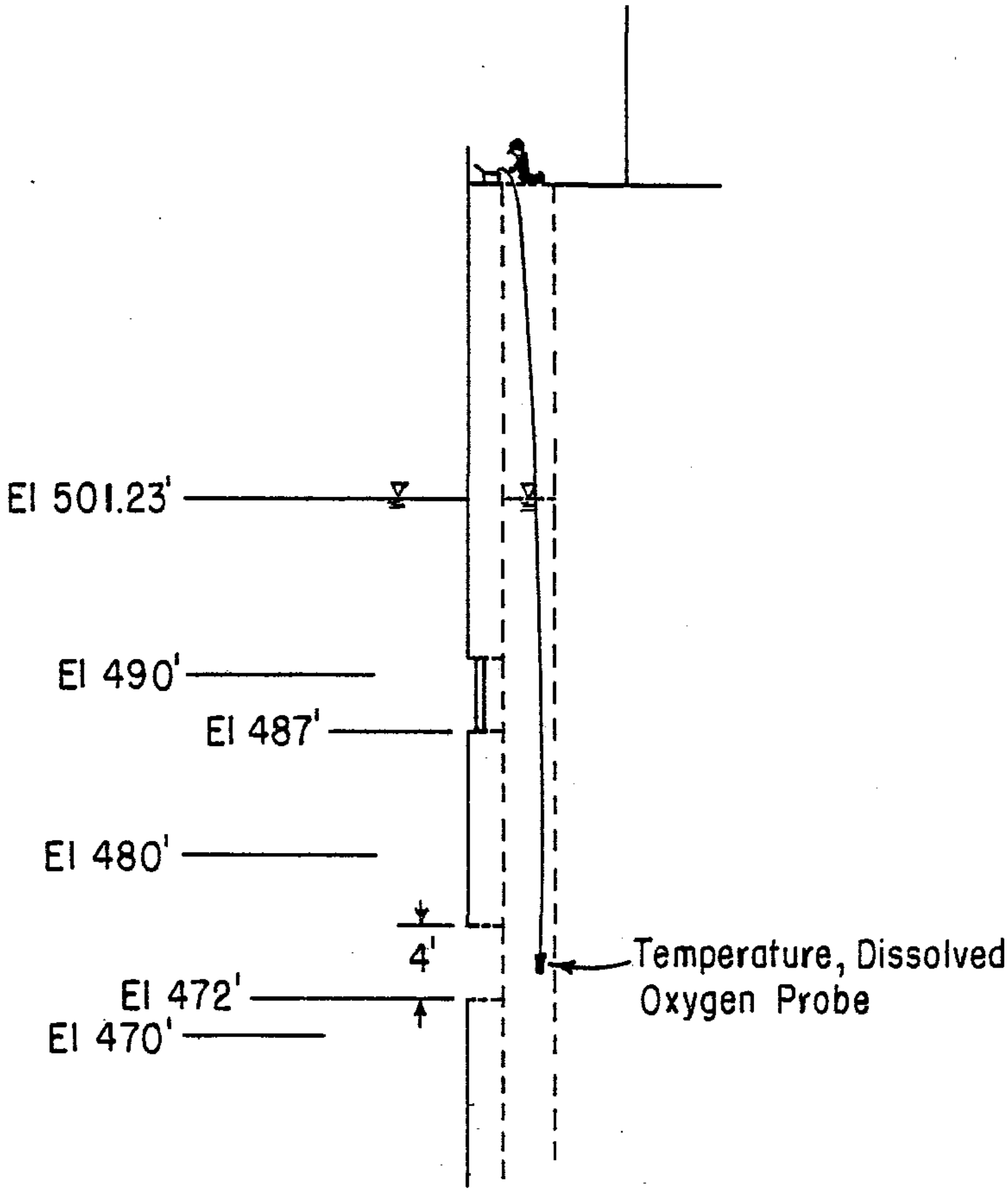

Figure 3. Gillham Lake, Arkansas, Intake Tower (only lower intake is open).

Procedure

Phase I.

A 42" (1.067 m) and a 72" (1.829 m) pump were each tied to the intake tower and were sequentially fixed in position over the intake valve. A lake profile (shown in Figure 4) was taken near the intake tower at 11 a.m. on 26 August 1977. At that time the bottom of the release gate was 29.33 feet (8.91 m) below the lake surface. The 55 cfs (1.56 cms) release was passing through a rectangular gate 4' high by 3.5' (1.22 m by 0.76 m) wide. Temperature and oxygen were sampled by probe (as shown in Figure 3) both before pump initiation and at intervals after the pumps had operated for a period of time at a known RPM. Before destratification the quality of the water being released corresponded closely to that found at the 28.9 foot (8.8 m) depth. The 72" (1.829 m) pump was utilized in the first series of trials shown in Figure 4. Ten minutes of running at 15 RPM increased the temperature 8.1°F (4.5°C) and the dissolved oxygen 2.5 mg/l. This resultant quality resembled that found in the 13.1 to 19.7 foot (4 to 6 m) depth. Turning the pump off for 25 minutes yielded an expected decrease in quality to the original conditions. Ten RPM provided insufficient energy to improve the quality of release. Similarly, the 42" (1.067 m) pump at 32 RPM afforded little improvement, but at 40 RPM or greater, the oxygen content increased to about 6 mg/l and the temperature changed from approximately 57°F to almost 73°F (14-23°C).

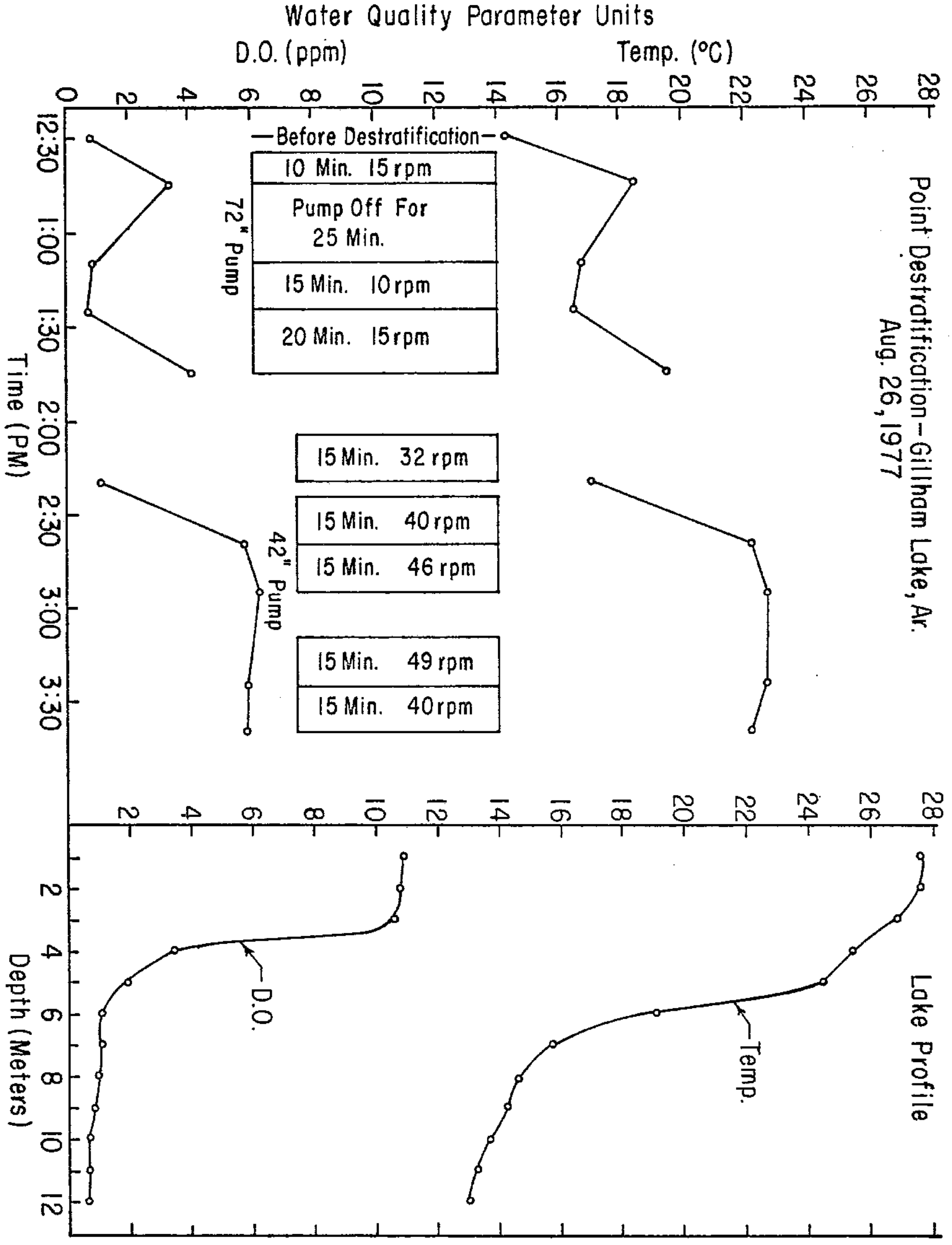

Figure 4: Point Destratification-Results of Phase I Testing

An average lake profile was prepared from profiles obtained at 11 a.m. and 4:30 p.m. on the day of testing (Table 1). Utilizing this profile and that shown for dissolved oxygen in Figure 4, a table of Depth of Equivalent Quality (relative to temperature and dissolved oxygen) verses pump diameter and RPM was prepared (Table 2).

TABLE 1: GILLHAM LAKE PROFILE DATA

Depth (m)	Temperature (°C)
1	27.4
2	27.2
3	26.5
4	25.3
5	24.2
6	19.45
7	16.35
8	14.9
9	14.5
10	13.85
11	13.35
12	12.75
13	12.65
14	12.4
15	12.15

TABLE 2: DEPTH OF EQUIVALENT QUALITY

FOR TEMPERATURE AND OXYGEN FOR PUMPS AT DIFFERENT RPM

PUMP	RPM	DEQ_T (m)	DEQ_0 (m)
42"	32	6.7	5.6
	40	5.4	3.3
	46	5.2	3.2
	49	5.2	3.3
72"	10	6.9	10
	15	6.2	3.8

DEQ_T before destratification = 8.8 m.

DEQ_0 before destratification = 13 m.

Depth of Equivalent Quality relative to parameter X (DEQ_X) is a descriptor which relates the released water quality with a depth from the lake profile. A DEQ_T of 6.7 means that the temperature of the water being released corresponds to the temperature of the water at the 6.7 meter depth in the lake. Units of DEQ_X are meters.

The Depth of Equivalent Quality for oxygen is different from that for temperature. The Depth in the lake at which the oxygen corresponds to that in the discharge averages about 2 meters shallower than the corresponding depth for temperature. As there appeared to be no opportunity for oxygen exchange in the outlet structure, the reason for this difference in unknown. The dissolved oxygen in the lake was more strongly stratified than temperature so the inaccuracies in interpolation should be somewhat greater, but this does not explain the differences in DEQ values.

Phase II.

Tables 3 and 4 contain calculated values of flow rate, velocity, and thrust at the fan blades. These values and the lake profile shown in Figure 5 were utilized in a program written by Richard Punnett (Graduate Research Assistant, Agricultural Engineering Department, Oklahoma State University) to predict the depth of penetration of the plume. The program philosophy is as follows: The temperature profile allows the formation of a density profile. Since warm (light) water is being forced into cold (heavy) water, Archimedes' principle may be applied. The depth of penetration is assumed to be the depth at which the thrust force is exactly balanced by the buoyant force exerted on the cone of pumped water (Figure 6).

TABLE 3: Garton Pump Analysis

(72" Acme Windmaster, Model DCH)

RPM	HP hp (w)	Q cfs (cms)	Vo fps (mps)	F_T lb (N)
9	0.1209 (90.16)	29.934 (0.847)	1.089 (.332)	63.17 (280.99)
10	0.1658 (123.64)	33.260 (0.942)	1.210 (.369)	77.99 (346.90)
15	0.5595 (417.22)	49.889 (1.412)	1.815 (.553)	175.47 (780.50)
17.5	0.889 (662.93)	58.205 (1.648)	2.117 (.645)	238.79 (1062.12)
20.0	1.326 (998.80)	66.52 (1.883)	2.420 (.738)	311.96 (1387.59)

RPM = revolutions per minute

HP = horsepower

Q = flow

Vo = mean orifice velocity

F_T = thrust force

TABLE 4: Garton Pump Analysis

(42" Aerovent, Cat. # 7-4288P, 7 blades)

RPM	HP	Q	Vo	F_T
	hp (w)	cfs (cms)	fps (mps)	lb (N)
32	0.12 (87.25)	13.57 (0.38)	1.54 (.47)	40.44 (179.86)
40	0.23 (171.51)	17.00 (0.48)	1.92 (.59)	63.32 (281.65)
46	0.35 (261.00)	19.50 (0.55)	2.216 (.67)	83.60 (371.85)
49	0.43 (320.65)	20.78 (.59)	2.35 (.72)	94.74 (421.39)

RPM= revolutions per minute

HP = horsepower

Q = flow

V_o = Mean Orifice Velocity

F_T = thrust

The thrust force, F_T, is calculated from:

(1) $F_T = Q\rho V$

where Q is the flow at the propeller in cfs (cms), ρ is the density of the water at the propeller in slugs/f^3 (kg/m^3), and V is the average velocity at the propeller calculated from:

(2) $V = A/Q$

where $A = \pi D^2/4$. D is the propeller diameter in feet or meters.

This portion of the trial was performed to indicate the effective depth of the 72" (1.829 m) pump at different RPM. It was conducted between 4:30 and 5 p.m. on 26 August 1977. The lake profile shown in Figure 5 was obtained at 4:30 p.m. The lake surface was 14.23 feet (4.34 m) above the bottom of the release gate, and the rate of release was a constant 55

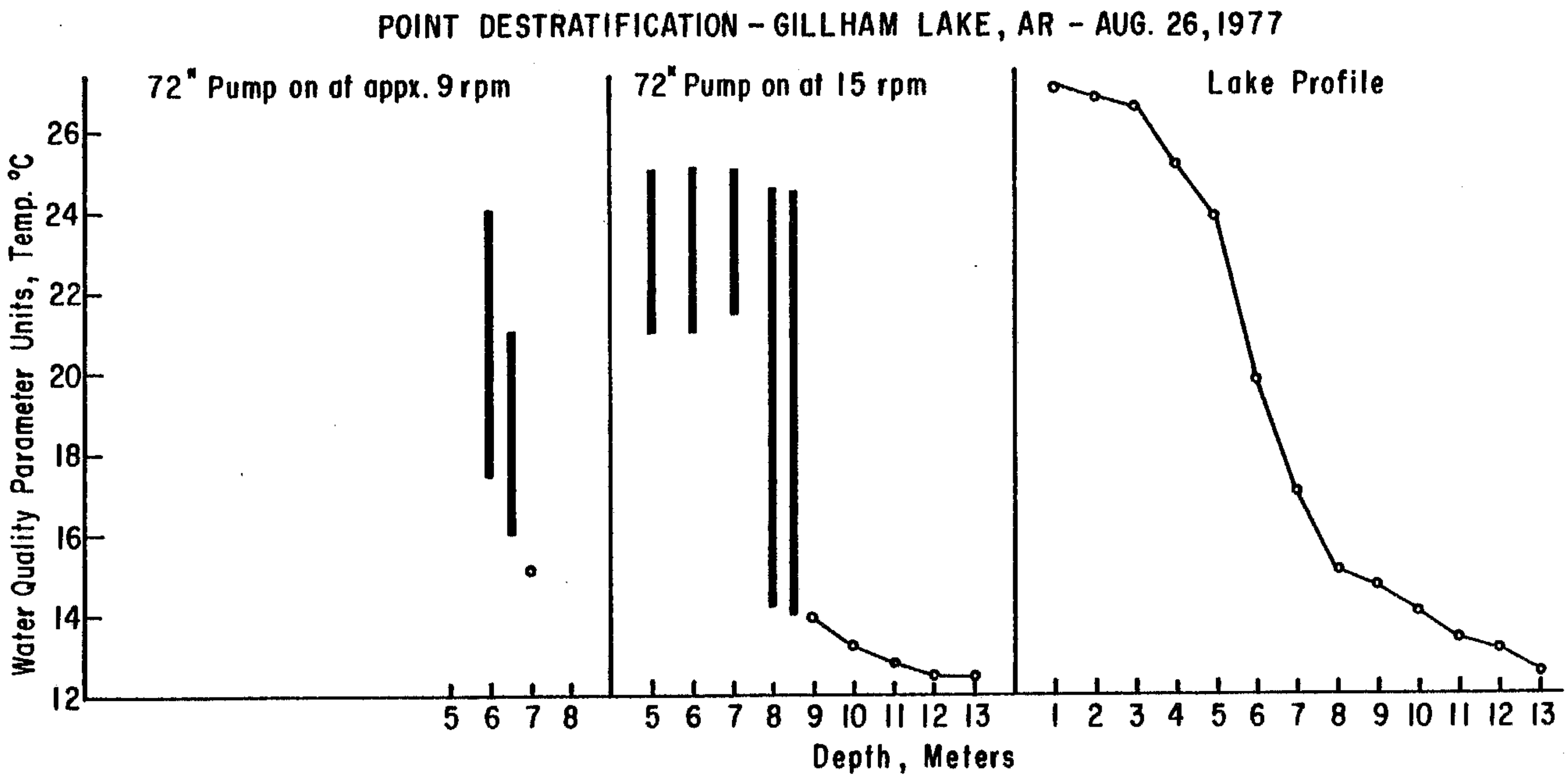

Figure 5. Point Destratification. Results of Phase II Testing.

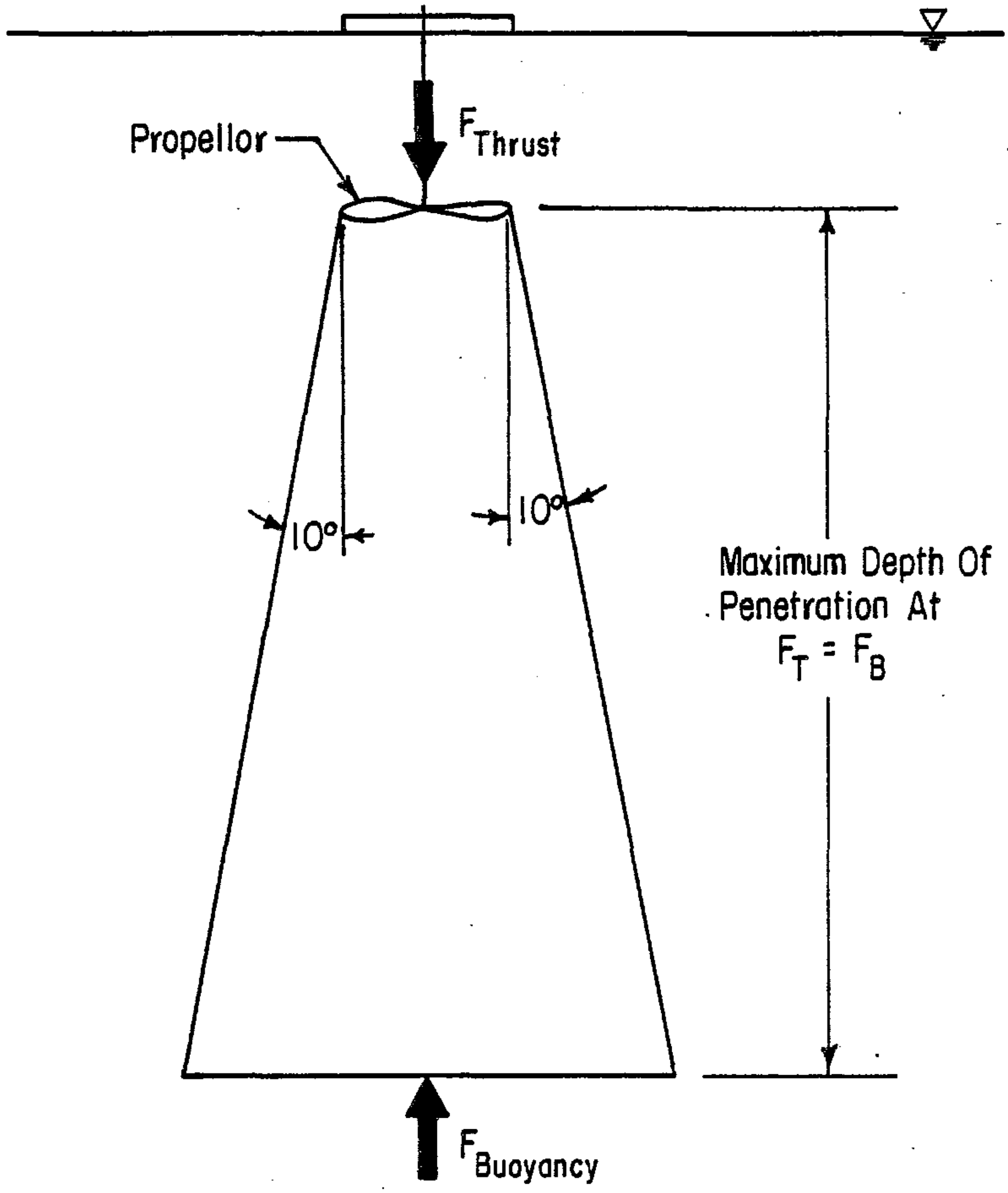

Figure 6. Force Balance on the Cone of Influence.

cfs (1.56 cms). The temperature probe was lowered alongside the pump to indicate the depth to which water was being turbulently mixed (Figure 5). When no single value could be determined for a certain depth, the range of values found by meter observation over approximately a one-minute interval were shown by a vertical bar. One would expect no quality enhancement to occur at depths below those at which mixing occurs. At 9 to 10 RPM and 15 RPM maximum penetration was recorded at 21.3 and 27.9 foot (6.5 and 8.5 m) depths. This corresponds with the computer predictions (Tables A-1 and A-2) of 21.9 feet (6.7 meters) and 27.7 feet (8.45 meters). The 42" pump at 40 RPM caused penetration to about 24.6 feet (7.5 meters) while withdrawal was being effected at the lower release gate. This matched the computer prediction shown by Table A-3.

The variation of velocity with distance from the hub is unknown. This would tend to increase the predicted depth of penetration. Since the observed and predicted values only differ by less than 0.5 meter, no attempt has been made to improve the prediction.

SUMMARY AND CONCLUSIONS

Prior to destratification, water being released at a depth of about 30 feet (9.14 meters) had a temperature of 57.7°F (14.3°C) and contained 0.6 mg/l dissolved oxygen. Utilization of the Garton Pump substantially improved the quality of the release. The 42" (1.067 m) pump operating at 46 RPM yielded an increase of 5.7 mg/l dissolved oxygen and 15.1°F (8.4°C). The results of Phase I testing are shown in Table 5. The 42 inch (1.067 m) pump (unshrouded) provided greater quality enhancement than did the 72" (1.829 m) pump (shrouded) over the range of RPM tested and did so with a lower HP requirement and less energy expenditure. Figure 7 compares predicted depth of penetration versus energy expenditure for the 2 pumps at different RPM. It is apparent that further testing is required to determine the optimal diameter-RPM combination and whether a pump should be shrouded or not, yet the results of Phase II testing indicate that such research is very likely to be fruitful.

Prediction of the depth of penetration may be accomplished by balancing the thrust and buoyant forces on a control volume consisting of the cone of water influenced by the pump. The field observations are shown on Figure 8 which also contains pump curves prepared from computer predictions. The maximum deviation between observed and predicted values is 0.2 meters. The quality of water being released is improved only when the velocity of the jet is sufficient to penetrate near the level of the outlet. When this requirement is met, the effects on the quality of the water being discharged may be dramatic.

The concept of Depth of Equivalent Quality (DEQ) has been introduced. This permits description of the released water quality by designating the depth in the lake at which a similar quality is found. The abbreviation may be subscripted to denote a parameter X (DEQ_X).

TABLE 5: PHASE I SUMMARY--POINT DESTRATIFICATION

PUMP	RPM	HP (w)	ΔDO (ppm or mg/1)	ΔTemp °F (°C)
42"	32	0.117 (87.25)	.6	5.0 (2.8)
42"	40	0.23 (171.51)	5.2	14.4 (8.0)
42"	46	0.35 (261.00)	5.7	15.1 (8.4)
42"	49	0.43 (320.65)	5.3	15.1 (8.4)
72"	10	0.166 (123.64)	.1	4.0 (2.2)
72"	15	0.560 (417.22)	3.1	8.5 (4.7)

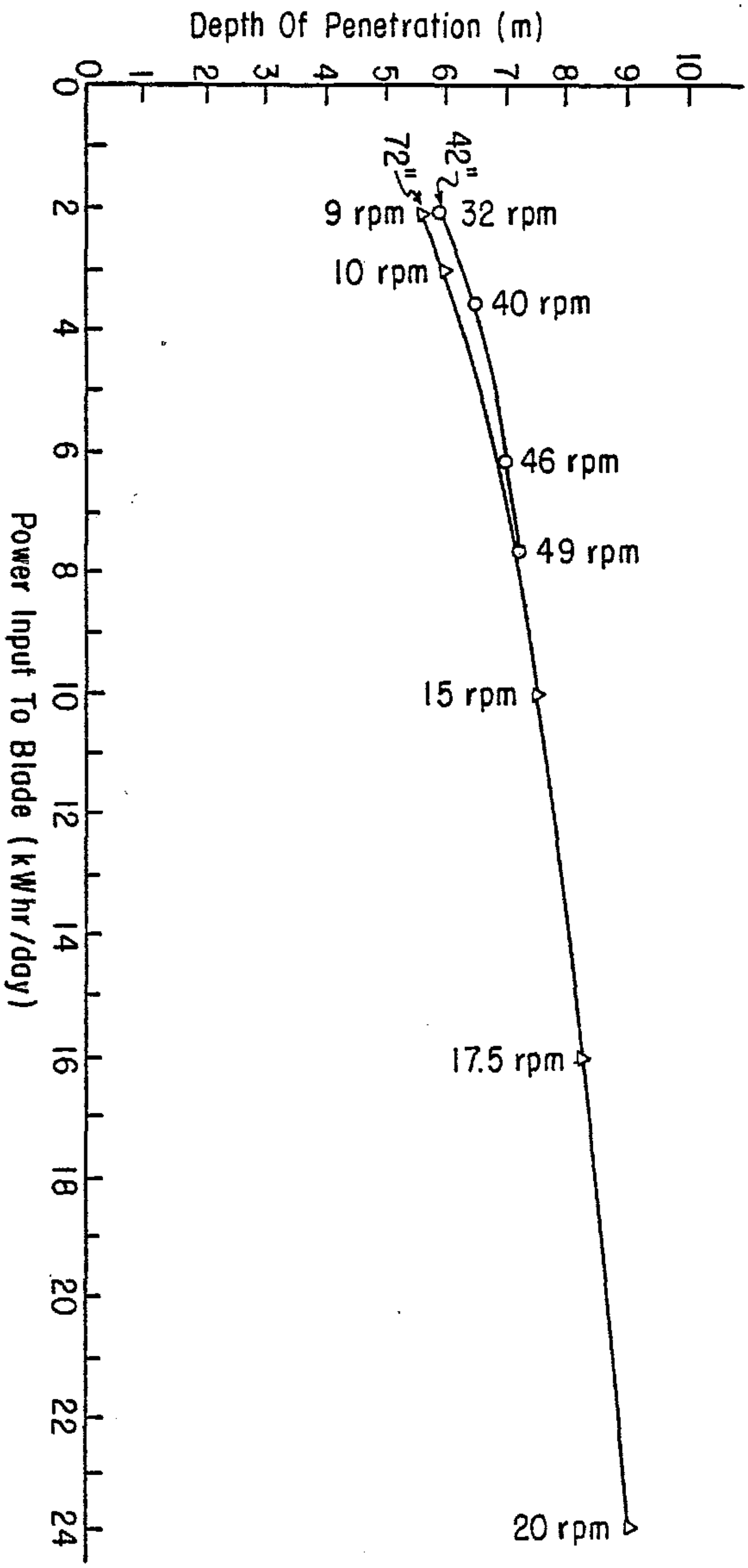

Figure 7. Predicted Depth of Penetration vs. Energy Expenditure for 42" and 72" Garton Pumps.

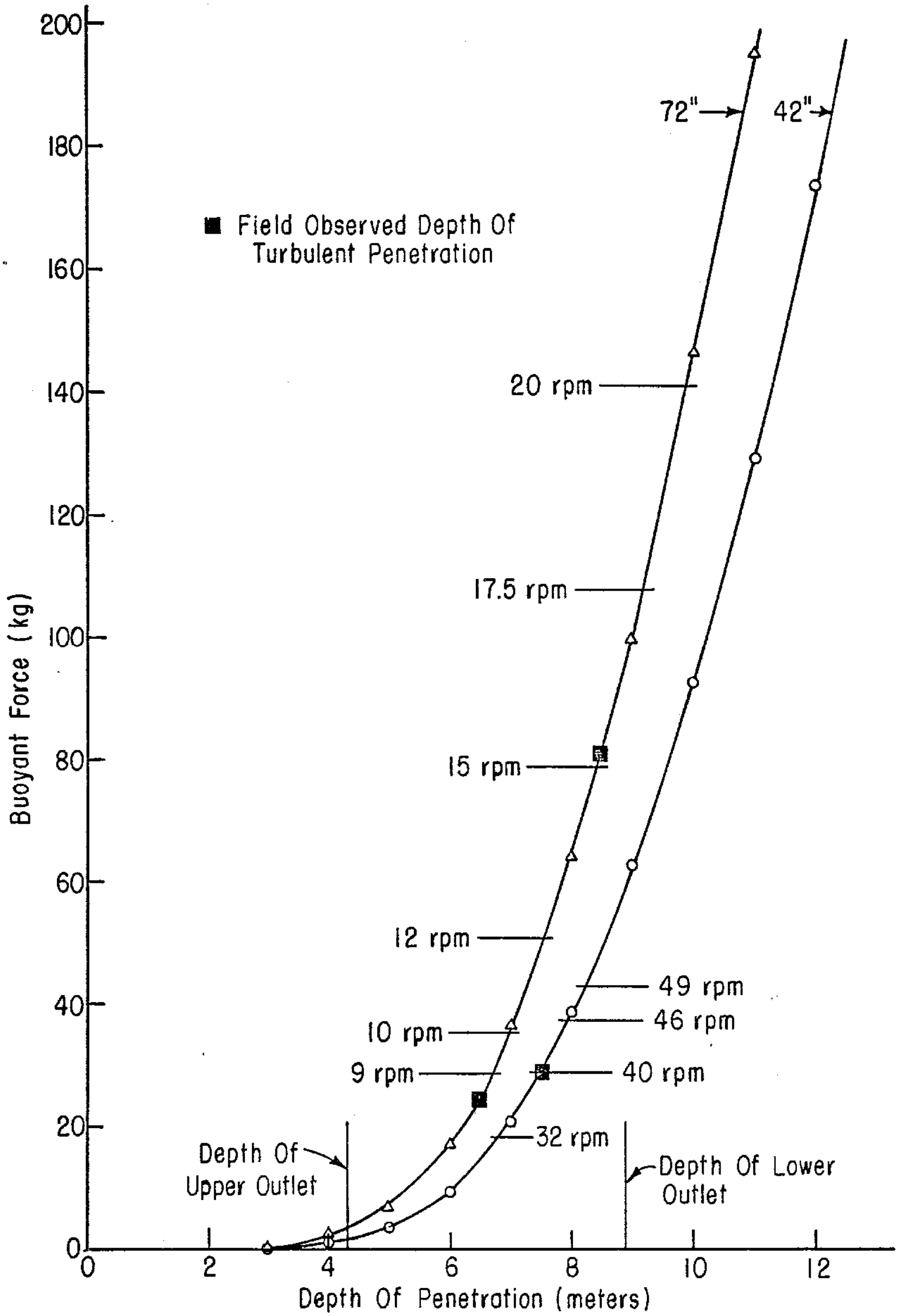

Figure 8. Comparison of Predicted and Observed Depth of Penetration.

A P P E N D I X

TABLE A-I

PREDICTION OF MAXIMUM DEPTH OF PENETRATION UTILIZING 72" PUMP
AT APPROXIMATELY 9 RPM AND ASSUMING A 20° CONE

AUG 26 77 4:30 PM

THE OBSERVED MIXING DEPTH WAS 6.5M

THE TOTAL PUMPING FORCE IS ANALOGUS TO 28.533 KG OF WEIGHT

THE VALUES PRESENTED IN THIS TABLE WERE BASED ON THE FOLLOWING PARAMETERS:

NUMBER OF PUMPING UNITS 1

A BASE PUMPING DIAMETER OF 1.829M — A BASE PUMPING AREA OF 2.627 SQ M

A PUMPING VELOCITY OF 0.332 M/S — A PUMPING FLOW RATE OF 0.847 CU M/S

A CONICAL SHAPE OF INFLUENCE — A CONE ANGLE OF 20.0 DEGREES

A BLADE DEPTH OF 2.0M — BLADE REVOLUTIONS: 9.0 RPM

SLICE DEPTH (METERS) TOP	SLICE DEPTH (METERS) BOTTOM	SLICE TEMPERATURE (DEG C) TOP	SLICE TEMPERATURE (DEG C) BOTTOM	WEIGHT OF 1M. SLICE OF WATER WITHIN THE PUMPING CONE (KG) VARIED TEMP	WEIGHT OF 1M. SLICE OF WATER WITHIN THE PUMPING CONE (KG) CONST TEMP	WEIGHT DIFFERENCE (KG)	SUMMATION OF WEIGHT DIFFERENCES
2.0	3.0	26.8	26.6	3149.397	3148.862	0.535	0.535
3.0	4.0	26.6	25.1	4352.383	4350.582	1.801	2.336
4.0	5.0	25.1	23.9	5750.906	5746.562	4.344	6.680
5.0	6.0	23.9	19.8	7347.000	7336.766	10.234	16.914
* * * * * * * THE PREDICTED DEPTH OF MIXING IS BETWEEN 6.0 AND 7.0M AT A WEIGHT OF: 28.533KG * * * * * * *							
6.0	7.0	19.8	17.0	9140.418	9121.227	19.191	36.105
7.0	8.0	17.0	15.1	11127.895	11099.930	27.965	64.070
8.0	9.0	15.1	14.7	13308.699	13272.844	35.855	99.926
9.0	10.0	14.7	14.0	15683.535	15640.031	43.504	143.430
10.0	11.0	14.0	13.4	18253.727	18201.453	52.273	195.703
11.0	12.0	13.4	13.1	21018.492	20957.168	61.324	257.027
12.0	13.0	13.1	12.5	23978.430	23907.039	71.391	328.418
13.0	14.0	12.5	12.3	27133.391	27051.215	82.176	410.594
14.0	15.0	12.3	12.3	30482.316	30389.598	92.719	503.312
15.0	16.0	12.3	12.3	34025.660	33922.352	103.309	606.621

TABLE A-2

PREDICTION OF MAXIMUM DEPTH OF PENETRATION UTILIZING 72" PUMP
AT 12 RPM AND ASSUMING A 20° CONE

AUG 26 77 4:30 PM

THE OBSERVED MIXING DEPTH WAS 8.5M

THE TOTAL PUMPING FORCE IS ANALOGUS TO 79,228 KG OF WEIGHT

THE VALUES PRESENTED IN THIS TABLE WERE BASED ON THE FOLLOWING PARAMETERS:

NUMBER OF PUMPING UNITS 1

A BASE PUMPING DIAMETER OF 1.829M

A BASE PUMPING AREA OF 2.627 SQ M

A PUMPING VELOCITY OF 0.555 M/S

A PUMPING FLOW RATE OF 1.412 CU M/S

A CONICAL SHAPE OF INFLUENCE

A CONE ANGLE OF 20.0 DEGREES

A BLADE DEPTH OF 2.0M

BLADE REVOLUTIONS: 15.0 RPM

SLICE DEPTH (METERS)		SLICE TEMPERATURE (DEG C)		WEIGHT OF 1M. SLICE OF WATER WITHIN THE PUMPING CONE (KG)		WEIGHT DIFFERENCE (KG)	SUMMATION OF WEIGHT DIFFERENCES
TOP	BOTTOM	TOP	BOTTOM	VARIED TEMP	CONST TEMP		
2.0	3.0	26.8	26.6	3149.397	3148.862	0.535	0.535
3.0	4.0	26.6	25.1	4352.383	4350.582	1.801	2.336
4.0	5.0	25.1	23.9	5750.906	5746.562	4.344	6.680
5.0	6.0	23.9	19.8	7347.000	7336.766	10.234	16.914
6.0	7.0	19.8	17.0	9140.418	9121.227	19.191	36.105
7.0	8.0	17.0	15.1	11127.895	11099.930	27.965	64.070
* * * * * * * THE PREDICTED DEPTH OF MIXING IS BETWEEN 8.0 AND 9.0M AT A WEIGHT OF: 79.228KG * * * * * *							
8.0	9.0	15.1	14.7	13308.699	13272.844	35.855	99.926
9.0	10.0	14.7	14.0	15683.535	15640.031	43.504	143.430
10.0	11.0	14.0	13.4	18253.727	18201.453	52.273	195.703
11.0	12.0	13.4	13.1	21018.492	20957.168	61.324	257.027
12.0	13.0	13.1	12.5	23978.430	23907.039	71.391	328.418
13.0	14.0	12.5	12.3	27133.391	27051.215	82.176	410.594
14.0	15.0	12.3	12.3	30482.316	30389.598	92.719	503.312
15.0	16.0	12.3	12.3	34025.660	33922.352	103.309	606.621

TABLE A-3

PREDICTION OF MAXIMUM DEPTH OF PENETRATION UTILIZING 42" PUMP
AT 40 RPM AND ASSUMING A 20° CONE

AUG 26 77 4:30 PM

THE OBSERVED MIXING DEPTH WAS 7.5M

THE TOTAL PUMPING FORCE IS ANALOGUS TO 28.795 KG OF WEIGHT

THE VALUES PRESENTED IN THIS TABLE WERE BASED ON THE FOLLOWING PARAMETERS:

NUMBER OF PUMPING UNITS 1

A BASE PUMPING DIAMETER OF 1.067M — A BASE PUMPING AREA OF 0.894 SQ M

A PUMPING VELOCITY OF 0.590 M/S — A PUMPING FLOW RATE OF 0.481 CU M/S

A CONICAL SHAPE OF INFLUENCE — A CONE ANGLE OF 20.0 DEGREES

A BLADE DEPTH OF 2.0M — BLADE REVOLUTIONS: 40.0 RPM

SLICE DEPTH (METERS) TOP	SLICE DEPTH (METERS) BOTTOM	SLICE TEMPERATURE (DEG C) TOP	SLICE TEMPERATURE (DEG C) BOTTOM	WEIGHT OF 1M. SLICE OF WATER WITHIN THE PUMPING CONE (KG) VARIED TEMP	WEIGHT OF 1M. SLICE OF WATER WITHIN THE PUMPING CONE (KG) CONST TEMP	WEIGHT DIFFERENCE (KG)	SUMMATION OF WEIGHT DIFFERENCES
2.0	3.0	26.8	26.6	1215.738	1215.530	0.208	0.208
3.0	4.0	26.6	25.1	1998.386	1997.540	0.846	1.054
4.0	5.0	25.1	23.9	2976.060	2973.798	2.262	3.316
5.0	6.0	23.9	19.8	4150.125	4144.297	5.828	9.144
6.0	7.0	19.8	17.0	5520.676	5509.027	11.648	20.793
* * * * * * * THE PREDICTED DEPTH OF MIXING IS BETWEEN 7.0 AND 8.0M AT A WEIGHT OF: 28.795KG * * * * * * *							
7.0	8.0	17.0	15.1	7085.852	7068.027	17.824	38.617
8.0	9.0	15.1	14.7	8845.070	8821.262	23.809	62.426
9.0	10.0	14.7	14.0	10798.652	10768.695	29.957	92.383
10.0	11.0	14.0	13.4	12947.504	12910.422	37.082	129.465
11.0	12.0	13.4	13.1	15291.031	15246.410	44.621	174.086
12.0	13.0	13.1	12.5	17829.742	17776.559	53.184	227.269
13.0	14.0	12.5	12.3	20563.277	20501.008	62.270	289.539
14.0	15.0	12.3	12.3	23491.102	23419.660	71.441	360.980
15.0	16.0	12.3	12.3	26613.437	26532.637	80.801	441.781