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REAERATION TESTS, OUTLET WORKS, BELTZVILLE DAM, POHOPOCO CREEK,--ETC(U)
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TECHNICAL REPORT H-77-14

REAERATION TESTS, OUTLET WORKS BELTZVILLE DAM, POHOPOCO CREEK PENNSYLVANIA

by

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July 1977
Final Report

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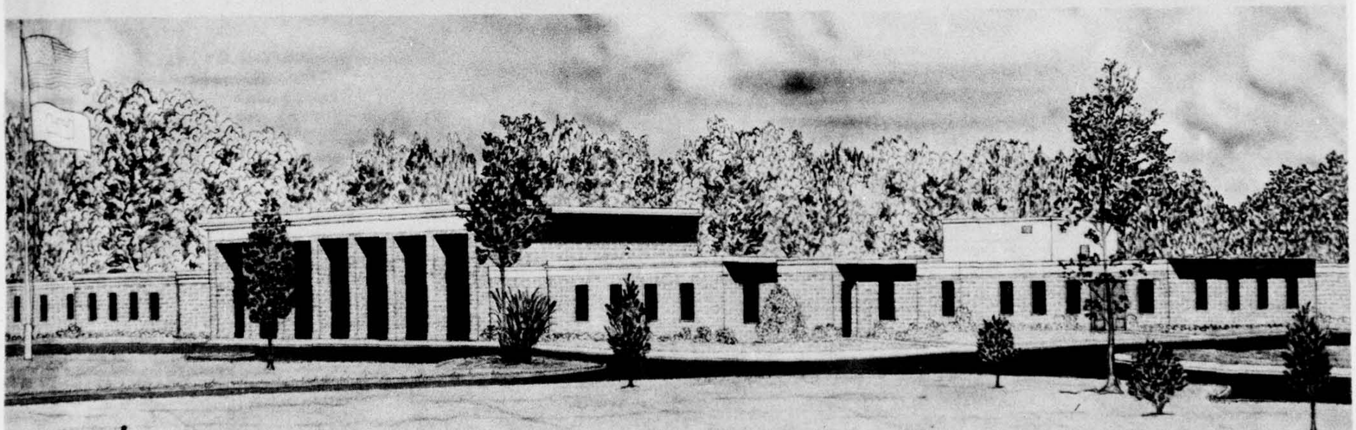

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Prototype water-quality tests were conducted at Beltzville Dam during August 1976. The purposes of these tests were to: (a) determine the location and degree of reaeration of flow that occurred as it passed through the outlet works, (b) provide prototype data with which to evaluate the accuracy of the U. S. Army Engineer Waterways Experiment Station selective withdrawal numerical model, SELECT, and (c) supplement results of hydraulic prototype tests conducted at Beltzville Dam in May 1973. (Continued) next page

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20. ABSTRACT (Continued).

Twelve tests were conducted. Temperature and dissolved oxygen data (vertical profiles) were collected upstream of the dam, at seven stations within the outlet structure, and at one station in the downstream channel. The tests involved various flow rates and various outflow port elevations.

The results of these prototype tests showed: (a) the dissolved oxygen content of the release flows was approximately 90 to 95 percent of the saturation level regardless of the dissolved oxygen content of the flow entering the structure or the discharge, and major reaeration occurred within the outlet structure downstream of the water-quality gate; (b) the predictions of the SELECT model were in close agreement with the observed data; and (c) the hydraulic measurements were close to those of the 1973 tests.

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PREFACE

These tests were conducted at the Beltzville Dam by personnel of the U. S. Army Engineer Waterways Experiment Station (WES), Hydraulic Laboratory (HL), in August 1976. The study was sponsored by the Office, Chief of Engineers, and the U. S. Army Engineer District, Philadelphia.

Messrs. H. B. Simmons, Chief, HL, E. B. Pickett, Chief, Hydraulic Analysis Division, and J. L. Grace, Jr., Chief, Structures Division, directed the tests. Messrs. E. D. Hart, Chief, Prototype Branch, C. H. Tate, Jr., and S. C. Wilhelms, Reservoir Water Quality Branch (Physical), conducted the tests. Mr. Hart and Mr. Wilhelms prepared this text. Mr. D. G. Fontane, Reservoir Water Quality Branch (Physical), assisted in developing the testing program.

The following personnel assisted in performing tests at Beltzville Dam: Messrs. Dave Erickson, Frank Schaefer, Vince Hill, John Borchick, and Carl Warner, Philadelphia District, and Ken Brooker, Norfolk District.

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

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acre-feet	1233.482	cubic metres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

REAERATION TESTS, OUTLET WORKS, BELTZVILLE DAM, POHOPOCO CREEK, PENNSYLVANIA

PART I: INTRODUCTION

Pertinent Features of the Project

1. Beltzville Dam (Figure 1) is the initial unit of a comprehensive plan for flood control and development of water resources of the Delaware River Basin. The project is located in the Lehigh River Basin on Pohopoco Creek in northeastern Pennsylvania (Figure 2). The earth and rock-fill dam extends 4500 ft* across the Pohopoco Valley and rises

Figure 1. Beltzville Dam and Reservoir

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

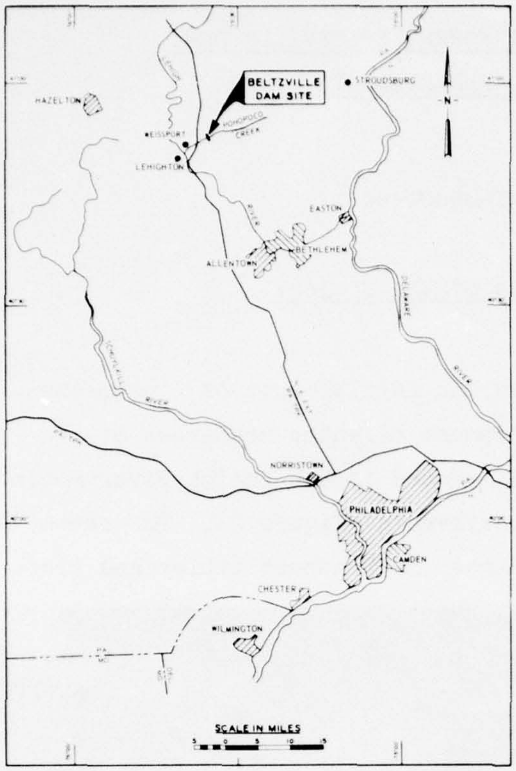

Figure 2. Vicinity map

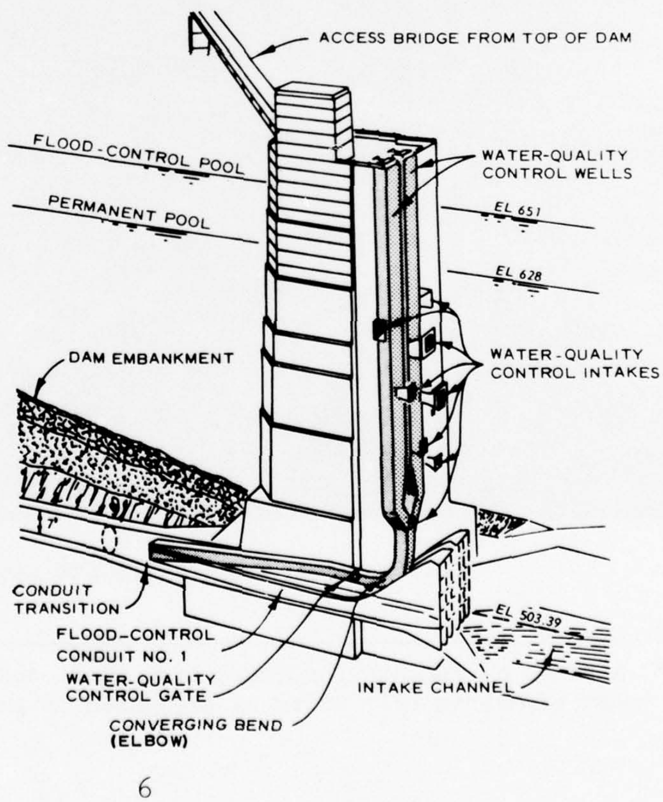

Figure 3. Details of the gated intake tower

170 ft above the creek bed. Diversion flows and low-level reservoir releases pass through a conduit in the south end of the dam. Total storage capacity of the reservoir is 68,260 acre-ft when filled to spillway crest el 641.0.*

Outlet Works

2. Flow through the dam is regulated by a gated intake tower (Figure 3) that contains two flood-control intakes (2.83 by 7.33 ft) located at the base of the structure (el 503.39) and a water-quality control system, the intakes of which are located at various levels of the tower. Discharge through the flood-control inlets is regulated by vertical-lift service gates. The water-quality control system permits selective withdrawal through any one or a combination of the eight 2- by 4-ft multilevel intakes with invert elevations ranging from 545.5 to 615.0 (Plate 1). Flow passes through the multilevel intakes into a divided wet well that converges downward into a single vertical riser. From the vertical riser flow passes through a converging bend (or elbow), past a 2- by 3-ft control gate, and into the water-quality control conduit. The flow then exits the water-quality control conduit (which runs between the two flood-control conduits) through a portal in the structure's transition section. In the 70.17-ft-long transition section the two flood-control conduits and the water-quality control conduit converge to form a single 1231-ft-long, 7-ft-diam conduit. Finally, the flow passes through a conventional, hydraulic-jump-type stilling basin and into the creek. Details of the water-quality control system are shown in Plate 1.

Purpose and Scope of Tests

Purpose

3. The primary purpose of these tests was to determine the

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* All elevations (el) cited herein are in feet above mean sea level (msl).

locations and degree of reaeration that occurs as flow passes through the Beltzville Dam outlet works. The dissolved oxygen (DO) content of releases has become one of the prominent considerations in design of Corps impoundments. It is generally accepted that reaeration occurs as flow passes through the outlet works. However, the locations and degree of reaeration have not been determined. This information is needed to evaluate whether proposed projects can meet release DO requirements and to determine appropriate design modifications to increase reaeration characteristics of both proposed and existing projects.

4. A secondary purpose of these tests was to use prototype measurements of the reservoir temperature and DO profiles and the resulting outflow characteristics to evaluate the accuracy of the U. S. Army Engineer Waterways Experiment Station (WES) selective withdrawal numerical model, SELECT. The WES Hydraulics Laboratory has conducted investigations to determine the withdrawal zone characteristics created by releases from a density-stratified impoundment. Through these studies, generalized mathematical relationships for describing the distribution of flow and the vertical limits of the withdrawal zone for outlets have been developed.[1] This information can be applied, given the profile of any water-quality parameter in a reservoir, to predict the resulting quality of flow entering an outlet works. Based on these generalized mathematical relationships, SELECT was developed.

5. Tests were also conducted to check results of hydraulic prototype tests conducted at Beltzville Dam[2] in May 1973.

Scope

6. The subject tests were conducted at Beltzville Dam during the period 18-26 August 1976. DO and temperature profiles were measured in the reservoir at the beginning of each day. These profiles were considered representative for the entire day's testing. Check measurements during the day indicated that this assumption was reasonable. In addition, DO and temperature levels were measured at seven stations within the outlet works and at one station in the downstream channel for varying test conditions. The measurement stations are listed below. (See also Plate 2.)

Measurement Station	Location and Description
1	Reservoir: every 5 ft (in some cases every foot through the metalimnion) from the surface to the bottom
2	Wet well: below the invert elevation of the intake when flow conditions permitted
3	Water-quality gate: 5 ft upstream
4	Conduit: sta 5+09.0
5	Conduit: sta 9+29.0
6	Conduit: sta 11+91.0
7	Portal
8	Baffles
9	Channel: about 600 ft downstream of the stilling basin

PART II: TEST FACILITIES AND EQUIPMENT

DO and Temperature Measurements

7. The DO and temperature tests were conducted using a Yellow Springs Instrument (YSI) Company Model 57 Oxygen Meter that includes a temperature sensor (Figure 4). The instrument has a DO measurement range of 0 to 20 ppm and a quoted accuracy of ±1 percent of full scale at calibration temperature (+0.1 ppm on the 0 to 10 scale of 0.1 ppm, whichever is larger). It has a temperature measurement range of -5° to +45°C with a quoted accuracy of ±0.5°C.

8. The YSI meter was calibrated at the beginning of each day using the Azide Modified Winkler titration method (Figure 5). This is a process for determining the amount of DO in terms of the smallest amount of reagent of known concentration required to bring about a given chemical reaction in a known volume of water. The process is described in detail in Appendix A. The method was also used to check DO readings at regular intervals throughout the test period. Depths at which titration checks were made in the reservoir are given in Table 1. The location of titration checks in the outlet works and downstream channel are given in Table 2. A thermometer was used to check temperature readings indicated by the meter. The depths in the reservoir where DO and temperature were recorded were measured by attaching a weighted measurement tape to the sensor.

Other Instrumentation

9. At measurement stations 4-6 in the conduit, samples were taken in 3-in.-diam by 18-in.-deep canisters. The canisters were attached to 7-ft house jacks that were wedged vertically in the conduit as shown in Figure 6 and were set just below the predetermined water surface anticipated for each test condition.

10. Discharge measurements were made at a gaging station approximately 1/2 mile downstream from the dam. The stage recording

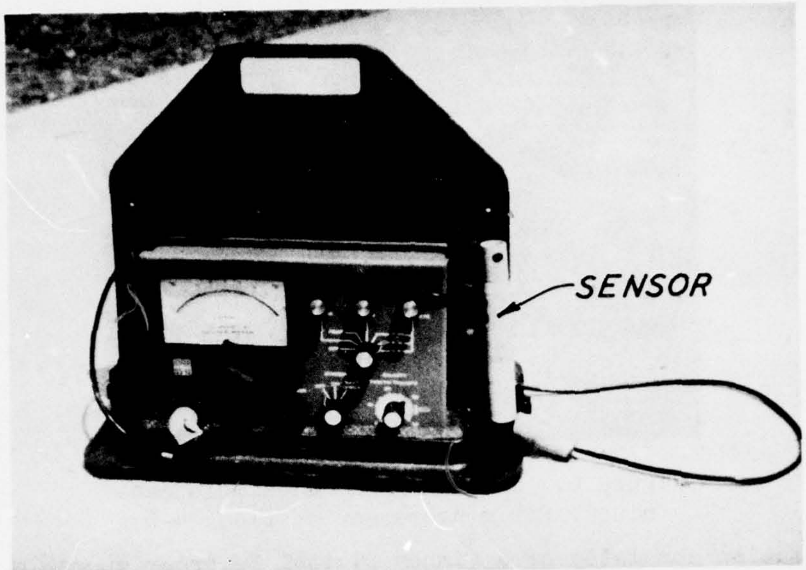

Figure 4. DO and temperature sensor, cable, and meter

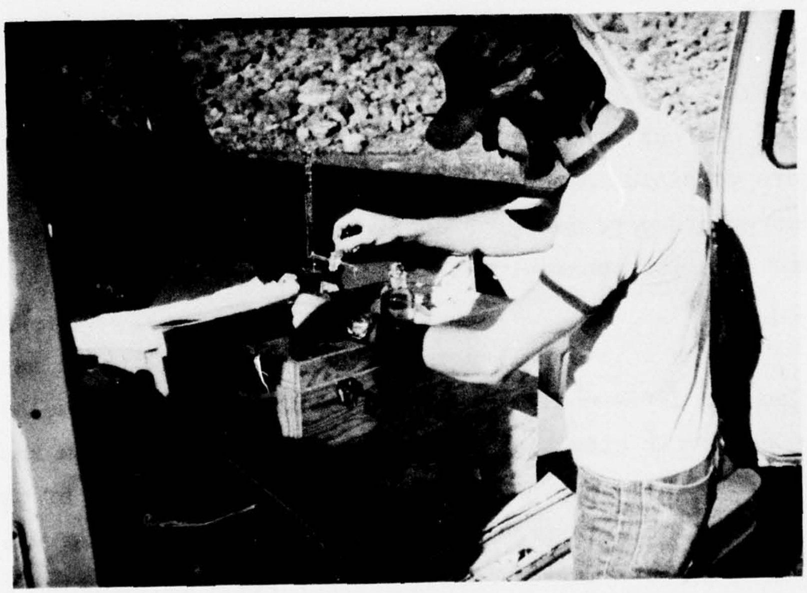

Figure 5. Azide modified Winkler titration being performed for DO content

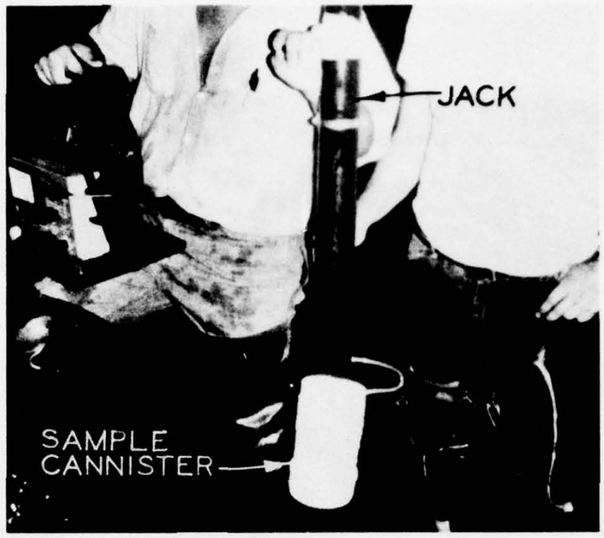

Figure 6. Conduit jack and sample cannister for measurement stations 4-6

instrumentation consisted of a Fisher Digital Recorder operating on a Cheisea Timer with a 15-min cam, referenced to an electric tape gage. Air temperature readings were obtained at the weather station situated near the project office.

Hydraulic Measurement Equipment

11. Hydraulic prototype tests were conducted at Beltzville Dam[2] in May 1973. It was considered desirable to check results of the earlier tests, where possible, during conduct of the 1976 test program. Therefore, measurements were made for confirmation of discharge rating curves at the water-quality intakes, wet well elbow, and water-quality control gate.

12. For the water-quality intake rating curve, it was necessary to determine the differential head between the reservoir and the wet well. The reservoir elevation was read from a staff gage on the intake tower. Wet well water surfaces were measured from the top of the tower with an M-scope. This instrument consisted of a sensor that was lowered into the wet well on a marked cable. At the point of touching the water surface, the sensor circuit closed and was monitored on a meter at the top of the tower.

13. The elbow measurements were made, as in the 1973 tests, by recording the pressure differential between piezometers P1 and P2. These piezometers were oriented opposite each other on the outside and inside radius, respectively, of the elbow. This elbow, as described in paragraph 2 and shown in Figure 3 and Plate 1, is located just upstream of the water-quality control gate. Openings of the water-quality control gate were set and recorded in the gate control room located at el 658.0 in the tower.

PART III: TEST CONDITIONS AND PROCEDURES

Operating Conditions

14. Twelve tests were conducted at Beltzville Dam. The conditions for each test are listed below. Eleven of these were made while releasing flow through the water-quality system and one test was conducted with flow through the flood-control release system only. The reservoir pool elevation was practically constant at el 629.0 (±0.2 ft) throughout the testing program. Variables in the water-quality system tests were the number and location of intakes opened and the percentage opening of the water-quality control gate. For the flood-control test, both gates were open 3.25 ft.

Test No.	Intake No. (100 Percent Open)	Control Gate Opening percent	Control Gate Opening ft	Discharge cfs	Pool el	Air Temperature °F	Aug 1976 Date
1	FC*	44	3.25	1234.0	629.0	74	19
2	5	10	0.3	25.4	628.8	50	20
3	5	50	1.5	159.0	629.1	68	23
4	5	100	3.0	331.0	629.0	82	23
5	3	10	0.3	23.0	629.0	71	24
6	3	50	1.5	156.0	629.0	80	24
7	3	100	3.0	255.0	629.0	57	24
8	7	10	0.3	26.6	629.0	62	25
9	7	50	1.5	155.6	629.0	82	25
10	7	100	3.0	328.5	629.0	75	25
11	4, 7	50	1.5	159.0	629.0	64	26
12	1	50	1.5	155.0	629.0	80	24

* Flood-control test.

Test Procedures

15. The DO meter was calibrated each morning to a titrated DO reading as described in paragraph 8 and Appendix A. Throughout the day titrations were made to check the meter's accuracy and provide a supplementary data set. When necessary, the meter was recalibrated. Plate 2

shows the stations where measurements were made. The test procedures were as follows:

a. Calibrate DO meter to titrated reading.

b. Make intake and control gate settings.

c. Measure reservoir DO and temperature profiles.*

d. Record reservoir pool and wet well water surface elevations.

e. Record DO and temperature levels at stations 2, 3, 7, 8, and 9.*

f. Record piezometers P1-P2 pressure differential in the water-quality elbow.

g. Record discharge.

h. Record air temperature.

i. Close control gate.

j. Record DO and temperature levels at stations 4-6.*

k. Adjust intakes and gate for the next test.

Test Data

16. The data consisted of:

a. For all tests:

(1) DO (meter and titration) and water temperature at all stations (stations listed in paragraph 6).

(2) Reservoir staff gage elevations.

(3) Discharge.

(4) Air temperature.

(5) Control gate opening.

b. For the water-quality system tests (tests 2-12):

(1) Elbow manometer differentials.

(2) Wet well water surface elevations.

(3) Intakes open.

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* Titrations were included at some stations.

PART IV: TEST RESULTS

Reaeration Characteristics

17. The primary purpose of the test program as stated in paragraph 3 was to determine the location and degree of reaeration that occurred as flow passed through the structure. In general, the following tests and analyses indicate that the Beltzville outlet works reaerate flows to a level such that the DO content of release is essentially 90 to 95 percent of the saturated value, regardless of the discharge or DO content entering the structure.

Flood-control system

18. Because of downstream channel restrictions only one flood-control test was conducted (test 1). During this period the dissolved oxygen meter was inoperative and only temperatures were recorded. The test conditions are listed in paragraph 14. Reservoir temperatures are listed in Table 1 and the profile is plotted in Plate 3. The water was drawn from near the bottom of the reservoir where the temperature was almost a constant 7°C. As would be expected, the downstream channel temperature was approximately the same, 7.7°C (see Plate 3).

19. Although no DO measurements were made in the reservoir during the flood-control test, a sample from the downstream channel was titrated and its DO was 11.8 ppm (Table 2). Table 1 shows that DO from near the bottom of the reservoir was always less than 3.0 ppm. These measurements indicate that the structure (probably due primarily to the partial gate openings and the stilling basin) effectively reaerated the water during the flood-control test.

Water-quality control system

20. The minimum allowable daily average DO level for tributaries of the Lehigh River[3] is 7.0 ppm. No discharge is allowed with a DO content below 6.0 ppm. During the period of the testing program the minimum probe recording in the downstream channel was 7.88 ppm (test 6). All other recordings were greater than 8.0 ppm indicating that the Beltzville Dam water-quality system effectively reaerates flow through the

structure regardless of the level of withdrawal.

21. The reservoir metalimnion was found to lie approximately between the depths of 20 and 25 ft. Table 1 indicates that the sharpest DO reduction occurs at depths from 23 to 25 ft. Because of this sharp decrease and the large size of the titration sampler, it was difficult to confirm some DO meter readings. (For example, see Table 1, tests 3 and 4 at depth 22.5 ft.)

22. In most tests a major portion of the reaeration occurred below the water-quality control gate (between stations 3 and 4). Table 2 indicates that substantial reaeration also took place in the wet well for tests 4, 6, 7, and 12 because of the heavy surface churning and turbulence due to less intake submergence and greater flow (higher control gate openings). Because of the high turbulence in tests 4, 6, 7, and 12, it was not always possible to lower the DO sensor below the intake invert. Some of the DO readings in the wet well were, therefore, questionable.

23. The low flows passed tranquilly through the stilling basin, and little foaming action was observed. Samples taken upstream of, within, and downstream of the stilling basin indicated that little reaeration took place in the stilling basin. However, true effectiveness of the stilling basin could not be determined because of the low demand for reaeration due to the aforementioned large change in DO occurring between the control gate and station 4. The effectiveness of the water-quality control gate operation as a means for inducing reaeration is demonstrated in the tabulation below. The DO and temperature profiles for all tests are presented in Plates 3-8.

	DO			
Test No.	Above Water-Quality Gate Sta 3 ppm	Below Water-Quality Gate Sta 4 ppm	Change ppm	Change percent
2	2.75	9.00	6.25	227
3	2.80	8.95	6.15	219
4	5.95*	8.52	2.57	43

(Continued)

* See comments in paragraph 22 and in Table 2.

Test No.	DO Above Water-Quality Gate Sta 3 ppm	DO Below Water-Quality Gate Sta 4 ppm	Change ppm	Change percent
5	6.00	8.40	2.40	40
6	8.30*	8.00	-0.30	-4
7	7.98*	8.09	-0.11	-1
8	3.50	10.00	6.50	186
9	3.05	9.40	6.35	208
10	2.98	9.80	6.82	229
11	3.13	9.35	6.22	199
12	11.00*	8.10	--	--

* See comments in paragraph 22 and in Table 2.

Comparison with other observed data

24. Analysis of DO data from the outlet works of four north Mississippi reservoirs is presented in Figure 7.[4] Several details of these outlet works are shown in Figure 8. As Figure 7 indicates, the DO content of the release flows (measured below the stilling basin) of all four reservoirs was approximately 80 to 90 percent of the saturation level* regardless of the discharge. This same analysis was applied to Beltzville Dam DO data, which yielded similar results (Figure 9). Analysis indicated that sufficient reaeration occurred in the outlet works to enhance the release DO content to approximately 90 to 95 percent of the saturation level regardless of discharge, DO content entering the structure, or the control system used to regulate flow.

Selective Withdrawal

25. One purpose of the testing program, as stated in paragraph 4, was to validate the WES Generalized Selective Withdrawal Techniques,[1] the result of which was the numerical model SELECT. SELECT predicts the limits and shape of the withdrawal zone due to outflow from a lake. As stated in paragraph 4, this information can be applied, given the

* Based on temperature and saturation tables for DO (Reference 5).

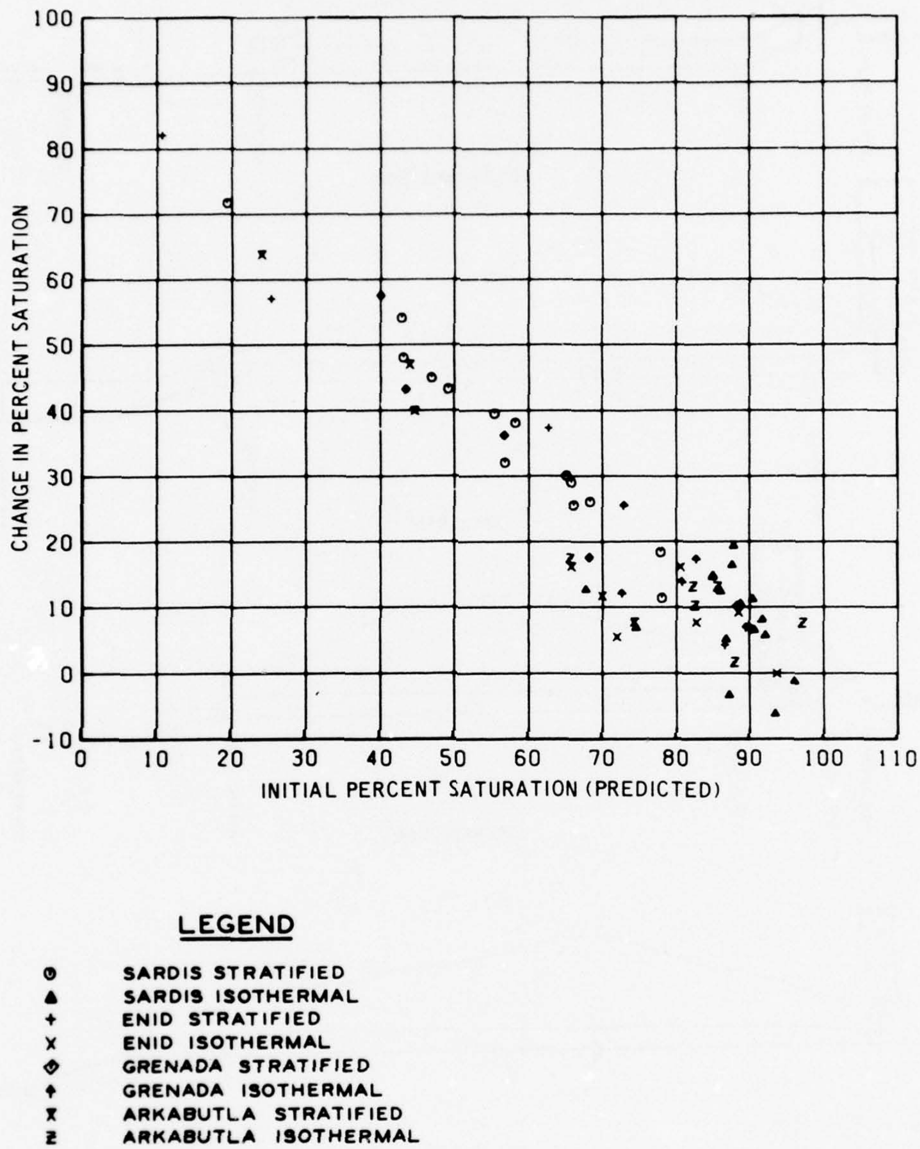


Figure 7. Reaeration through north Mississippi reservoir outlet works

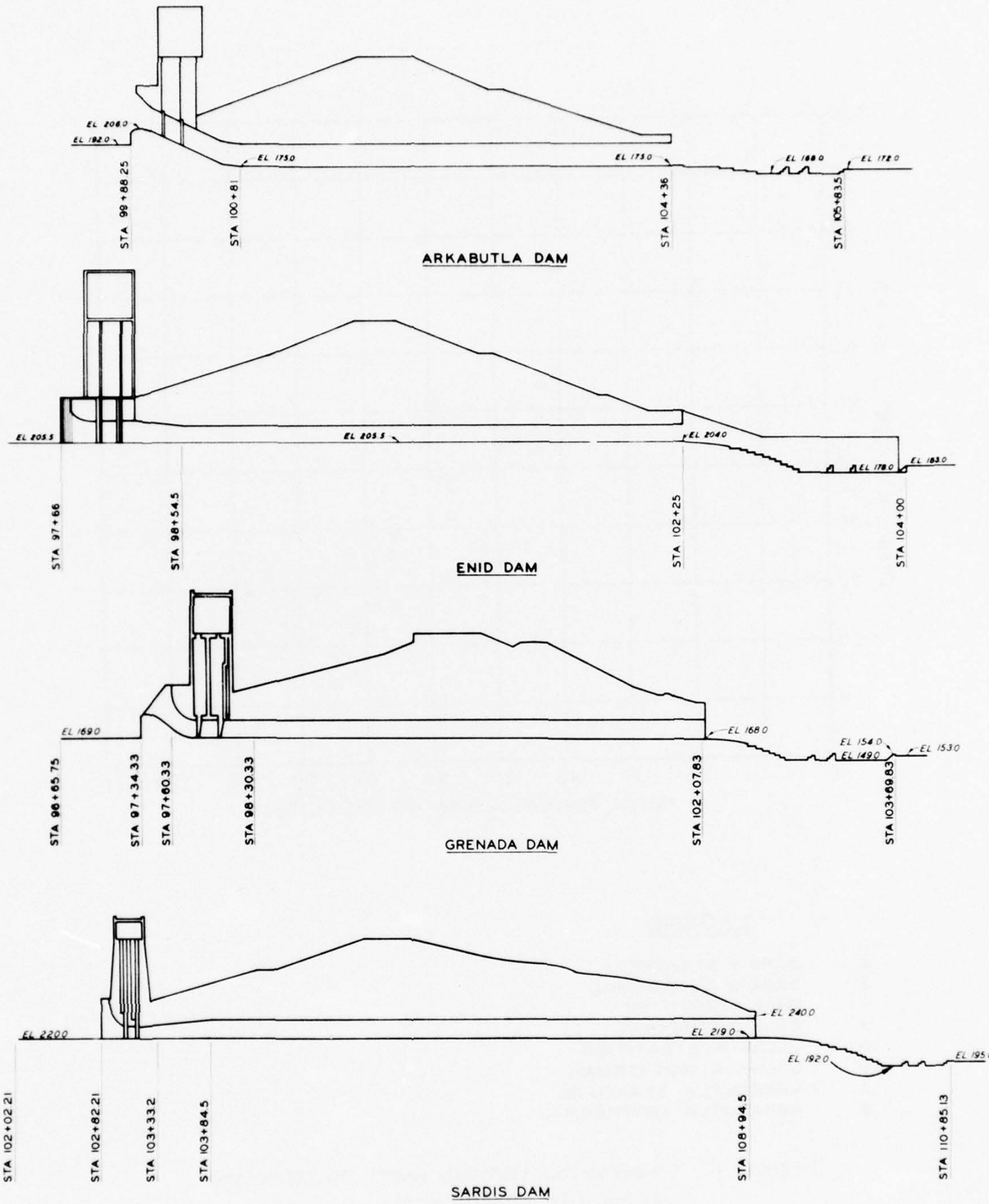


Figure 8. Structural details of north Mississippi reservoir outlet works

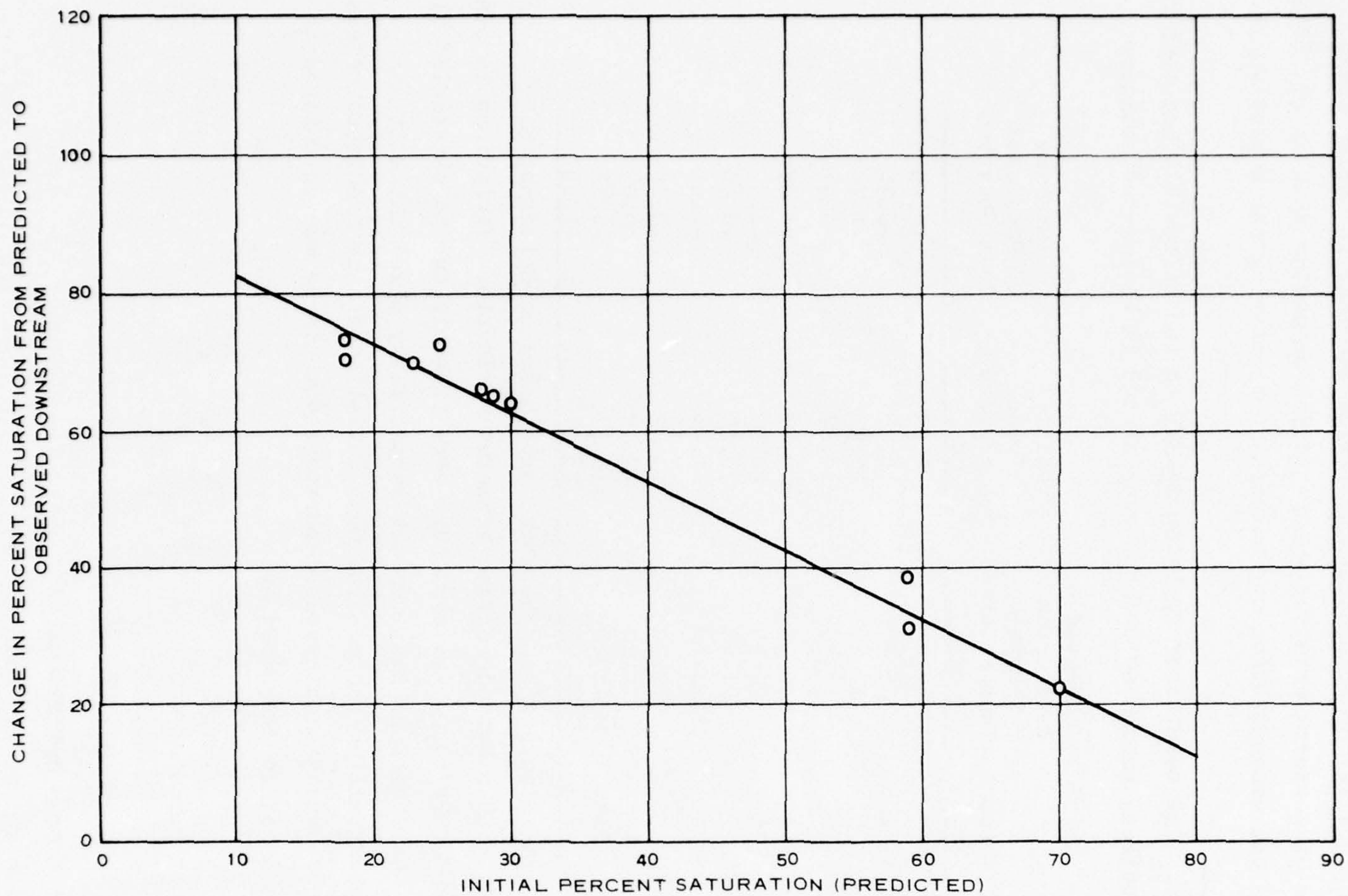


Figure 9. Reaeration through Beltzville Dam outlet works

profile of any water-quality parameter in a reservoir, to predict the resulting quality or concentration of flow entering an outlet works. In the case of a nonconservative water-quality parameter such as DO, SELECT predicts the concentration of the parameter entering the outlet works.

Temperature

26. The results of applying SELECT to the Beltzville Dam temperature profiles, tabulated below and presented in Plates 3-8, compare

Test No.	Observed Downstream Channel Temperature °C	Predicted Released Temperature °C	Deviation of Predicted from Observed °C
1	7.70	8.26	+0.56
2	16.40	16.05	-0.35
3	17.70	15.93	-1.77
4	16.40	16.33	-0.07
5	20.90	20.83	-0.07
6	21.90	20.61	-1.29
7	21.40	20.80	-0.60
8	13.50	11.88	-1.62
9	12.70	11.92	-0.78
10	12.20	12.13	-0.07
11*	15.80	15.07	-0.73
12	25.00	23.87	-1.13

* Flow division between ports based on Reference 6.

favorably with observed release temperature levels. Variations in temperatures observed in the structure were probably due to stratified flow through the structure that may not become fully mixed until it has passed the stilling basin. The mean deviation of the predicted release temperature and the observed temperature downstream was calculated to be -0.66°C and is described by

$$\overline{\Delta} = \sum_{i=1}^{N} \frac{\Delta_i}{N} \qquad (1)$$

where

$\overline{\Delta}$ = mean deviation, °C

N = number of tests

Δ_i = deviation in test i, °C

The maximum temperature deviation was -1.77°C (test 3).

Dissolved Oxygen

27. Applying SELECT to the DO profiles resulted in the prediction of DO entering the water-quality intakes. The results of this application, which also agreed closely with the observed data, are as follows:

Test No.	Observed DO at Water-Quality Gate ppm	Predicted DO Entering Water-Quality Port ppm	Deviation of Predicted from Observed ppm
1	N/A	N/A	N/A
2	2.75	2.28	-0.47
3	2.80	1.73	-1.07
4	5.95*	1.81	-4.14*
5	6.00	6.27	+0.27
6	8.30*	5.30	-3.00*
7	7.98*	5.28	-2.62*
8	3.50	3.28	-0.22
9	3.05	3.15	+0.10
10	2.98	3.05	+0.07
11**	3.13	2.48	-0.65
12	11.00*	8.13	-2.87*

* See comments in paragraph 22 and Table 2.

** Flow division between ports based on Reference 6.

The mean deviation of the predicted DO entering the water-quality control system and the observed DO at station 3, described in the same manner as the mean temperature deviation (Equation 1), was calculated to be -1.33 ppm. The maximum deviation was -4.14 ppm (test 4). However, disregarding those tests in which reaeration was probably occurring in the wet well due to surface turbulence (tests 4, 6, 7, and 12, as discussed in paragraph 22), the mean deviation was calculated to be 0.28 ppm, and the maximum deviation was 1.07 ppm (test 3). The results of both temperature and DO tests and analyses indicate the adequacy of the WES generalized selective withdrawal techniques.

Hydraulic Measurements

28. The differential pressures measured between piezometers P1

and P2 (see Plate 1) in the elbow of the water-quality control system are plotted in Plate 9 (Plate 3 of the earlier report).[2] All points fall slightly above the original regression line. The new data were not utilized to recalculate a best-fit line and equation.

29. A hydraulic model investigation of outlet works was conducted at WES in 1964.[7] Plate 10 (Plate 4 of Reference 2) is a comparison of the hydraulic model and the prototype discharge rating characteristics for the water-quality control system. The average discharge through the water-quality control gate in the 1976 prototype tests agreed reasonably well with the hydraulic model and the earlier field tests, being slightly higher at 50 percent openings and lower at 100 percent openings. The submerged flow discharge characteristics for the 1976 tests were much the same as those predicted by the model and measured during the 1973 tests. Discharge coefficients for the water-quality control gate are plotted for comparison. The head, H, used in the equation in Plate 10, is the distance from the wet well water surface to the center line of the control gate.

PART V: CONCLUSIONS

30. The following conclusions regarding the reaeration of flow through the Beltzville Dam outlet works were drawn:

- a. For all tests conducted, the DO content of the release flows was approximately 90 to 95 percent of the saturation level, regardless of the discharge or DO content of the flow entering the structure with releases through either the flood-control or water-quality control systems. The release DO level was above the State of Pennsylvania minimum requirements.
- b. Most of the reaeration in the water-quality facilities occurred between the water-quality control gate and station 4 due to the high air entrainment induced by the relatively shallow, turbulent, and supercritical flow in the water-quality conduit downstream of the control gate. For these low-flow tests, the stilling basin had a minimal effect on the DO content of the release because the demand was satisfied upstream of the stilling basin.
- c. The one flood-control test (test 1) indicated that the flood-control facilities of the outlet works effectively reaerate releases also.

It should be noted that these results address only the DO content of the flow as it leaves the structure. The DO content of the flow farther downstream can be effected by either a supply of or demand for oxygen, depending on downstream conditions relative to reaeration and to the chemical and biological characteristics.

31. The results show that SELECT can predict with minimal deviation the release concentrations of conservative water-quality parameters for the Beltzville Dam outlet works and the concentrations of nonconservative parameters entering the Beltzville gated intake tower. This indicates that the effect of an outlet works on a nonconservative water-quality parameter such as DO can be estimated by: (a) validating SELECT results on observed data of a conservative water-quality parameter, (b) predicting the concentration of the nonconservative parameter entering the outlet works, and (c) comparing these predicted values and observed values within and downstream of the structure.

32. The hydraulics measurements agreed very well with those of the 1973 tests.[2]

33. The Beltzville Dam water-quality tests illustrate a relatively simple but excellent means of obtaining data pertinent to reaeration, selective withdrawal, and hydraulic characteristics of all existing reservoir outlet works.

REFERENCES

1. Bohan, J. P. and Grace, J. L., Jr., "Selective Withdrawal from Man-Made Lakes," Technical Report H-73-4, Mar 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Hart, E. D. and Pugh, C. A., "Outlet Works for Beltzville Dam, Pohopoco Creek, Pennsylvania; Prototype Tests," Technical Report H-75-10, May 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Title 25, Rules and Regulations, Commonwealth of Pennsylvania, Part I: Department of Environmental Resources, Subpart C: Protection of Natural Resources, Article II: Water Resources, 1974.

4. Loftis, B., Saunders, P. E., and Grace, J. L., Jr., "B. Everett Jordan Lake Water-Quality Study," Technical Report H-76-3, Feb 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. American Public Health Association, Standard Method for the Examination of Water and Wastewater, Including Bottom Sediment and Sludges, 14th ed., 1975; Published jointly with American Water Works Association and Water Pollution Control Federation, New York.

6. Marcinski, E. J., An Evaluation of One Dimensional Temperature Prediction Models for Reservoirs, M.S. Thesis, Villanova University, Villanova, Pa., May 1975.

7. Melsheimer, E. S., "Outlet Works for Beltzville Dam, Pohopoco Creek, Pennsylvania; Hydraulic Model Investigation," Technical Report H-69-18, Dec 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

8. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, Including Bottom Sediment and Sludges, 13th ed., 1971; Published jointly with American Water Works Association and Water Pollution Control Federation, New York.

9. Hach Chemical Co., Water Handbook, Ames, Iowa.

Table 1

Reservoir Profiles, Beltzville Dam Water-Quality Measurements, Aug 1976

		Test No.															
		1*	2			3, 4			5, 6, 7, 12			8, 9, 10			11		
Depth ft	El	Temperature °C	DO Probe ppm	DO Titration ppm	Temperature °C	DO Probe ppm	DO Titration ppm	Temperature °C	DO Probe ppm	DO Titration ppm	Temperature °C	DO Probe ppm	DO Titration ppm	Temperature °C	DO Probe ppm	DO Titration ppm	Temperature °C
Surface	629.0	23.8	8.08**	8.05	23.9**	7.95**	7.75	24.6**	7.98	7.85	24.8	8.30	8.10	24.8	8.55	8.30	24.8
5	624.0	23.8	8.10**		23.9**	7.94**		24.5**	7.98		24.7	8.32		24.8	8.55		24.8
10	619.0	23.3	8.00		23.8	8.20		24.2	7.95		24.5	8.40		24.5	8.65		24.3
15	614.0	23.0	8.20		23.8	8.25		23.5	8.20		23.9	9.18		22.8	9.25		23.5
20	609.0	23.0	5.35**	7.65	21.3**	8.49**		21.7**	9.05		21.5	9.55	9.45	21.3	9.47**	9.15	22.6**
21	608.0											9.40		21.2	9.70		22.1
22	607.0					4.95†	8.50†		8.90		21.2	9.18		21.0	9.80		21.6
23	606.0								8.55		21.0	8.65		20.9	9.62		21.2
24	605.0								5.20		20.8	4.75		20.8	8.00		20.8
25	604.0	19.7	4.70		20.5	3.26**	3.95	20.5**	3.80	4.30	20.3	3.13		20.2	2.70		20.3
30	599.0	18.8	3.05		20.0	3.23		19.8	2.00		19.4	2.90		19.1	2.43		19.1
35	594.0	17.9	1.95		18.9	1.60		19.0	1.20		18.3	1.98		18.5	1.05		18.2
40	589.0	16.8	1.80**	1.72	18.0**	0.93**	1.35††	17.7**	0.80	0.70	17.5	0.76**	1.00	17.7†	0.65	0.70	17.3
45	584.0	15.3	1.87		16.8	0.93		16.8	1.24		15.9	1.23		16.0	1.05**		16.5**
50	579.0	13.9	2.68		15.0	2.15		14.9	2.21		14.4	1.85		14.4	1.68		14.4
55	574.0	12.3	3.55		13.8	3.05		13.6	3.01		13.2	2.65		13.4	3.08		13.1
60	569.0	12.1	3.55**	3.20	13.1**	3.47	2.85	12.9	3.35		12.7	3.33	3.20	12.8	3.80	3.40	12.6
65	564.0	11.9	3.80		12.8	3.66	3.50	12.4	3.60	3.55	12.0	3.54		12.3	3.74		12.2
70	559.0	11.5	3.74		12.4	3.33		12.0	3.42		11.9	3.25		11.9	3.30		11.9
75	554.0	11.2	3.58		12.0	3.02		11.8	3.29		11.4	3.20		11.5	3.35		11.5
80	549.0	10.8	3.12**	3.10	11.4**	2.65**	3.50	11.2**	2.68	2.70	11.0	2.67	2.80	11.0	2.68	2.55	11.1
85	544.0	10.0	2.83		11.2	2.08		10.7	2.08		10.0	2.40		10.8	2.40		10.8
90	539.0	9.2	2.60		10.3	1.83		10.1	2.02		9.4	2.03		9.8	2.08**		9.8**
95	534.0	8.0	2.95		9.3	2.22		9.3	2.33		8.9	2.44		8.8	2.52		8.8
100	529.0	7.8	2.99**	2.55	8.7**	2.11**	2.30	8.2**	2.38	2.20	8.2	2.07	2.00	8.0	2.17	2.00	8.1
105	524.0	7.5	2.45		8.2	1.40		8.0	1.70		7.9	1.10		7.9	1.00		7.9
110	519.0	7.4	2.00		8.0	0.95**		7.8**	0.70		7.4	0.75		7.8	0.60		7.9
115	514.0	7.2	1.38		8.0	0.50		7.5	0.44		7.6	0.35		7.8	0.35		8.0
120	509.0	7.2	1.10		8.0	0.45		7.6	0.37		7.5	0.27		7.9	0.33		8.0
125	504.0	7.2	1.03		8.0	0.42		7.5	0.25		7.8	0.25		8.0	0.33		8.1

Note: Test conditions are described in Part III.
* DO data for test 1 considered unreliable.
** Average of original and check recording.
† Depth = 22.5 ft.
†† Depth = 42.5 ft.

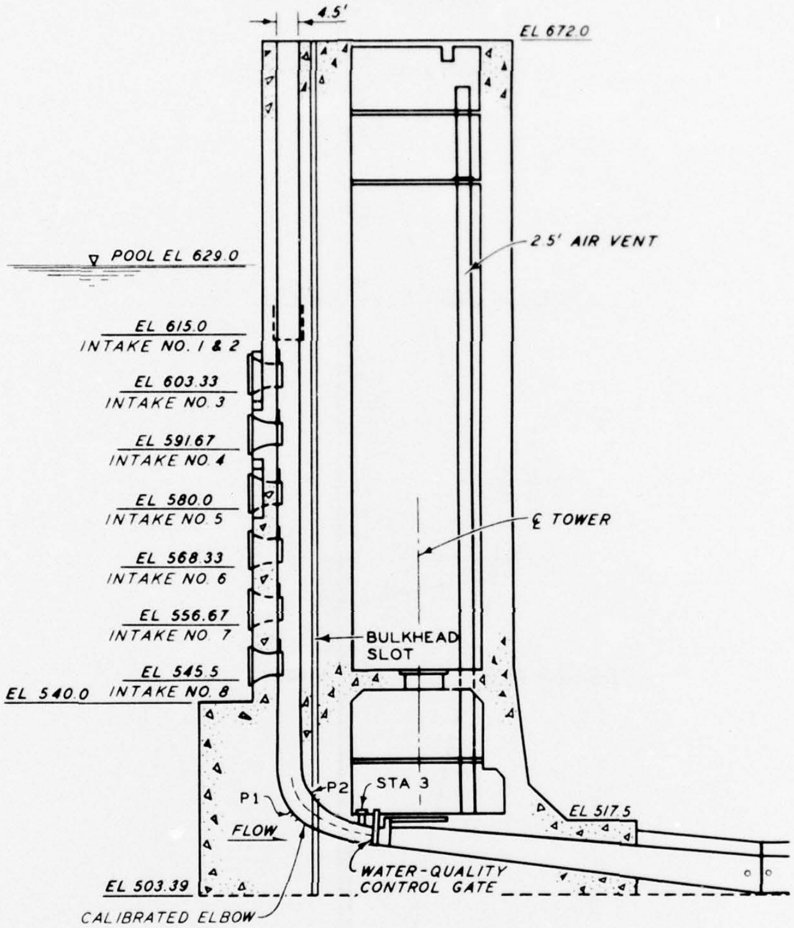
Table 2

Structure and Downstream Channel, Beltzville Dam Water-Quality Measurements, Aug 1976

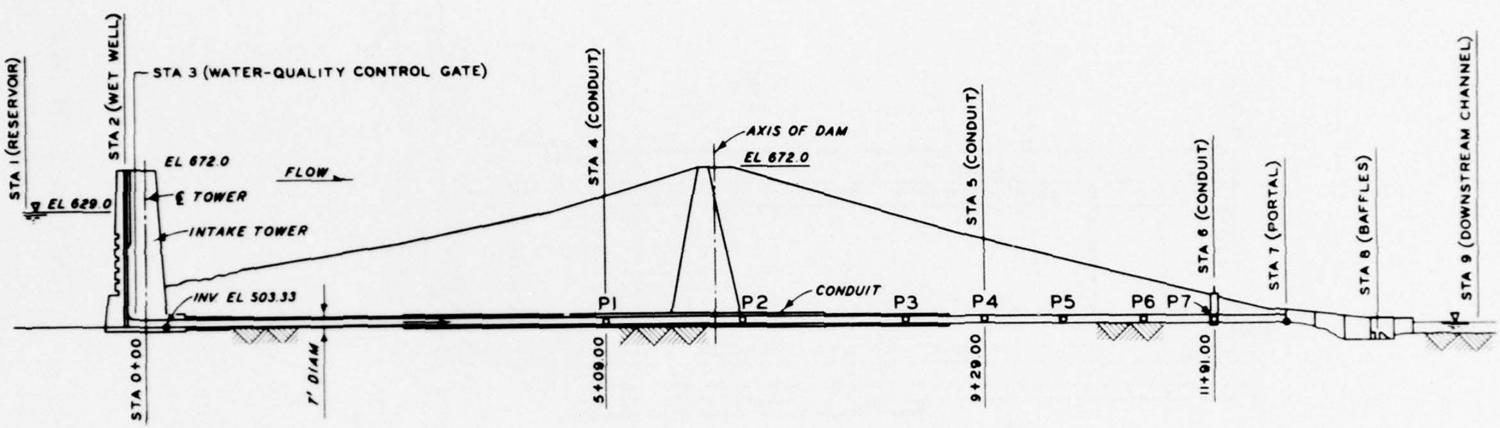
				Wet Well						Water-Quality Gate		Conduit							
												Sta 5+09		Sta 9+29		Sta 11+91		Portal	
Test No.	Pool El	Intakes Open	Gate Opening ft	Water Surface El* L	Water Surface El* R	Intake ℄	Probe El	DO Probe ppm	Temperature °C	DO Probe/Titration ppm	Temperature °C	DO Probe ppm	Temperature °C	DO Probe/Titration ppm	Temperature °C	DO Probe ppm	Temperature °C	DO Probe/Titration ppm	Temperature °C
1	629.0	Both-FC**	3.25	NA	NA	NA	NA	NA	NA	NA	NA	--	--	--	--	--	--	--	--
2	628.8	5	0.3	--	--	580.00	572.0	2.45	16.2	2.75/1.70	16.5	9.00	15.8	9.00/9.00	16.0	9.00	17.0	9.10/ --	16.0
3	629.1	5	1.5	620.6	621.4	580.00	572.0	1.30	17.5	2.80/1.70	16.0	--	--	--	--	8.95	15.0	9.00/8.55	16.3
4	629.0	5	3.0	597.0	598.0	580.00	572.0	5.40	18.0	5.95/5.65	17.0	--	--	8.52/8.62	16.3	8.38	17.0	8.40/ --	17.2
5	629.0	3	0.3	627.8	628.8	603.33	592.0	6.25	21.1	6.00/5.80	21.0	8.40	20.3	8.40/8.30	20.5	8.35	20.5	8.40/ --	20.3
6	629.0	3	1.5	619.6	621.6	603.33	605.0	8.75	23.8	8.30/8.00	22.0	8.00	20.9	7.95/7.40	21.5	7.90	22.3	8.40/ --	22.4
7	629.0	3	3.0	580.9	618.8	603.33	612.7	7.85	23.9	7.98/8.20	21.2	8.09	21.1	7.80/7.90	21.5	7.80	22.0	7.82/ --	21.7
8	629.0	7	0.3	628.7	628.7	556.67	539.0	3.20	12.2	3.50/3.20	13.6	10.00	12.0	10.00/10.10†	12.2	10.1	12.5	10.00/9.85	13.1
9	629.0	7	1.5	620.5	622.0	556.67	548.0	3.55	12.2	3.05/2.45	13.2	9.40††	12.2	9.60††/9.70	12.3	9.70††	12.9	9.80††/9.70	13.1
10	629.0	7	3.0	592.7	599.0	556.67	596.5	3.15	13.0	2.98/2.90	12.9	9.80	12.2	9.88/9.75	12.4	9.80	12.8	9.90/ --	13.2
11	629.0	4,7	1.5	627.2	627.0	591.67-L	614.0-L	2.55-L	19.4-L	3.13‡/2.00	17.2	9.35	15.2	9.15/9.15	15.7	9.15	16.6	9.80/ --	16.0
						556.67-R	571.0-R	3.50-R	13.0-R										
12	629.0	1	1.5	619.9	622.2	615.00	--	8.10‡‡	25.1‡‡	11.00§/10.60§	25.2§	8.10	21.5	8.15/ --	21.0	8.05	21.9	7.90/ --	24.7

				Stilling Basin		Downstream Channel		Discharge, cfs		
Test No.	Pool El	Intakes Open	Gate Opening ft	DO Probe/Titration ppm	Temperature °C	DO Probe/Titration ppm	Temperature °C	Gage	Elbow Meter	Intake Velocity fps
1	629.0	Both-FC**	3.25	--	--	-- /11.80	7.70	1234.0	NA	NA
2	628.8	5	0.3	8.90/ --	16.0	9.05/8.80	16.4	25.4	--	3.18
3	629.1	5	1.5	8.70/ --	17.4	8.35/8.55	17.7	159.0	141.4	19.88
4	629.0	5	3.0	8.95/ --	17.0	8.90/8.90	16.4	331.0	313.6	41.38
5	629.0	3	0.3	8.15/8.25	21.0	8.20/8.40	20.9	23.0	--	2.88
6	629.0	3	1.5	8.10/8.20	22.7	7.88/8.15	21.9	156.0	144.7	19.50
7	629.0	3	3.0	8.15/8.50	21.9	8.55/8.45	21.4	255.0	--	31.88
8	629.0	7	0.3	9.96/ --	12.6	9.75/10.00	13.5	26.6	22.9	3.33
9	629.0	7	1.5	10.05††/ --	13.1	10.00††/10.00	12.7	155.6	155.1	19.45
10	629.0	7	3.0	9.80/9.90	13.3	10.10††/10.10	12.2	328.5	326.7	41.06
11	629.0	4,7	1.5	9.50/9.40	16.5	9.65/9.40	15.8	159.0	148.2	19.88
12	629.0	1	1.5	7.80/7.70	25.2	8.00/7.80	25.0	155.0	§	19.38

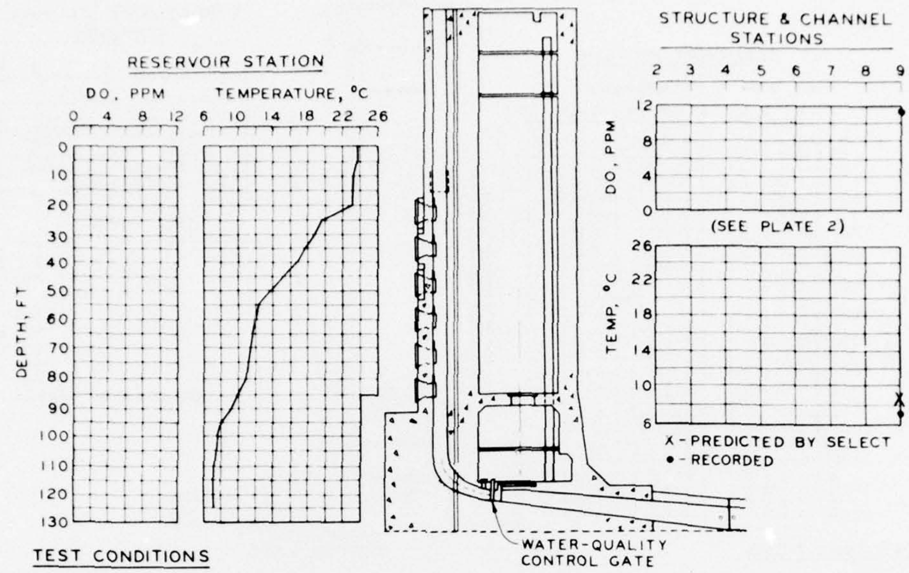
Note: Dashes indicate measurements not taken.
* Looking downstream.
** FC = flood-control system, all others are the water-quality system.
† Sample taken at sta 2+50, no temperature measurement.
†† Readings adjusted following calibration.
‡ Mean value; fluctuating 2.25-4.00.
‡‡ Heavy turbulence, measured near boiling surface.
§ Air in withdrawal line.



DETAILS OF WATER-QUALITY CONTROL SYSTEM

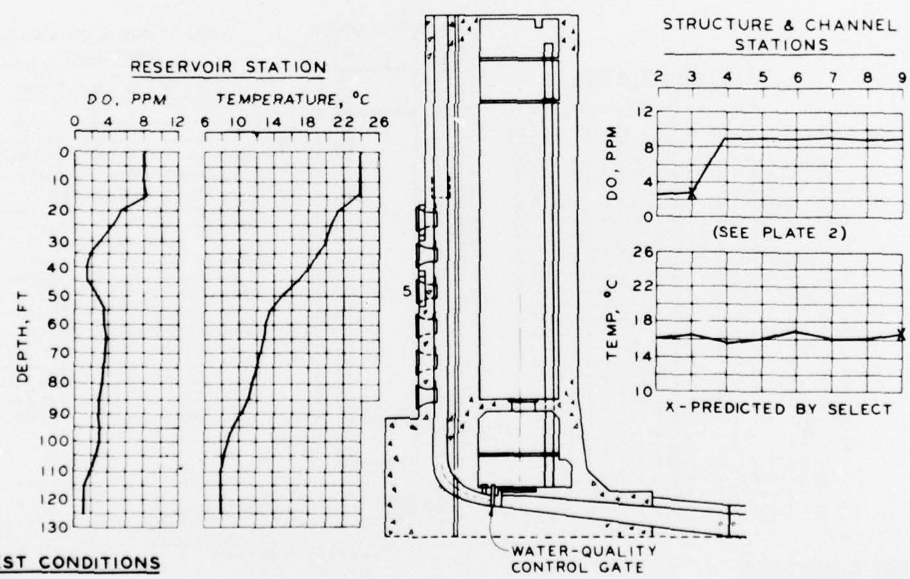


WATER-QUALITY MEASUREMENT STATIONS



TEST CONDITIONS

TEST: 1 (FLOOD CONTROL)
GATE OPENING: ALL AT 3.25 FT
DISCHARGE: 1234.0 CFS

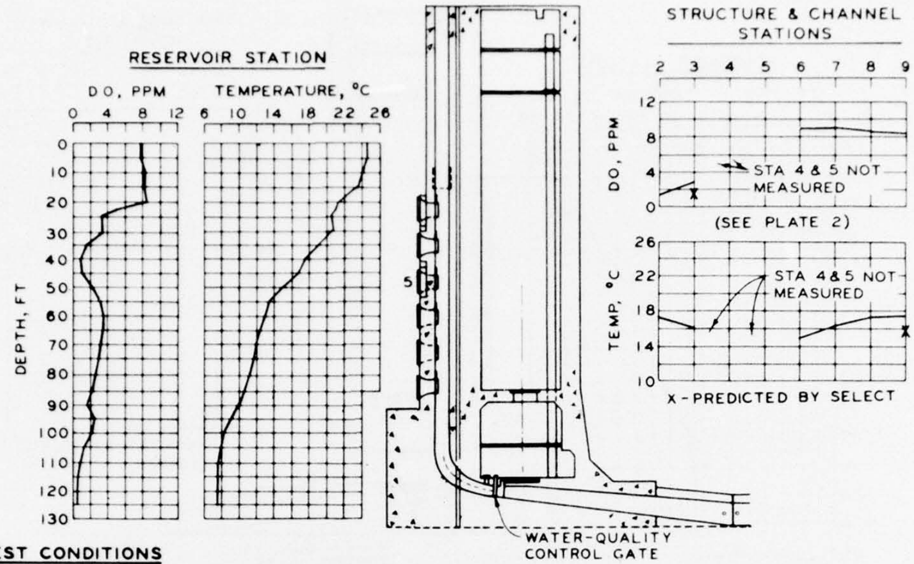


TEST CONDITIONS

TEST 2
INTAKE: 5
WQ GATE OPENING: 10 %
DISCHARGE: 25.4 CFS

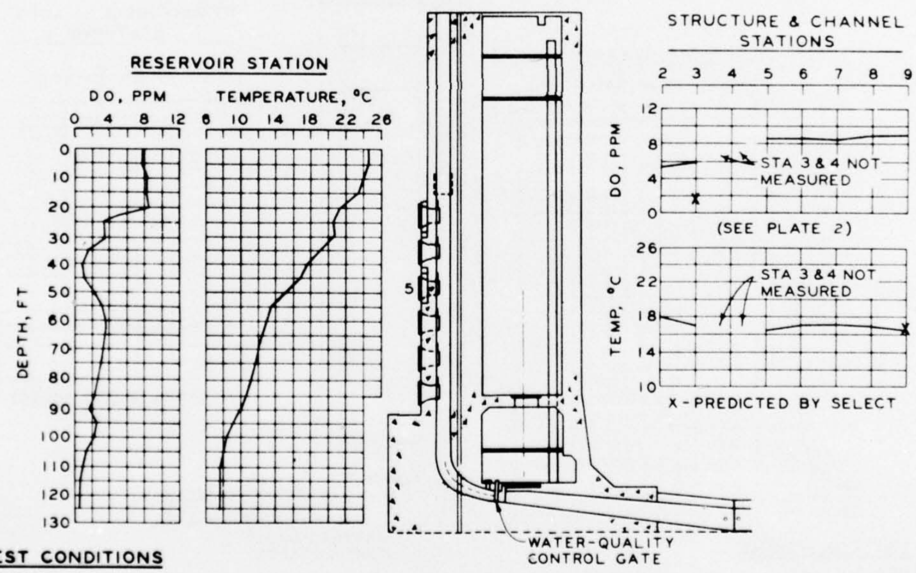
WATER-QUALITY MEASUREMENTS

TEST 1 AND 2



TEST CONDITIONS

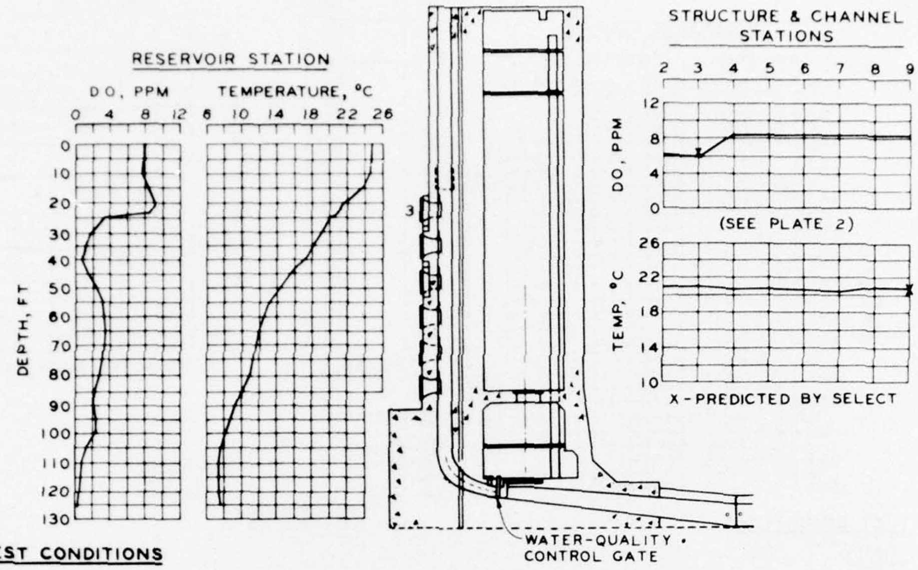
TEST 3
INTAKE: 5
WQ GATE OPENING: 50%
DISCHARGE: 159.0 CFS



TEST CONDITIONS

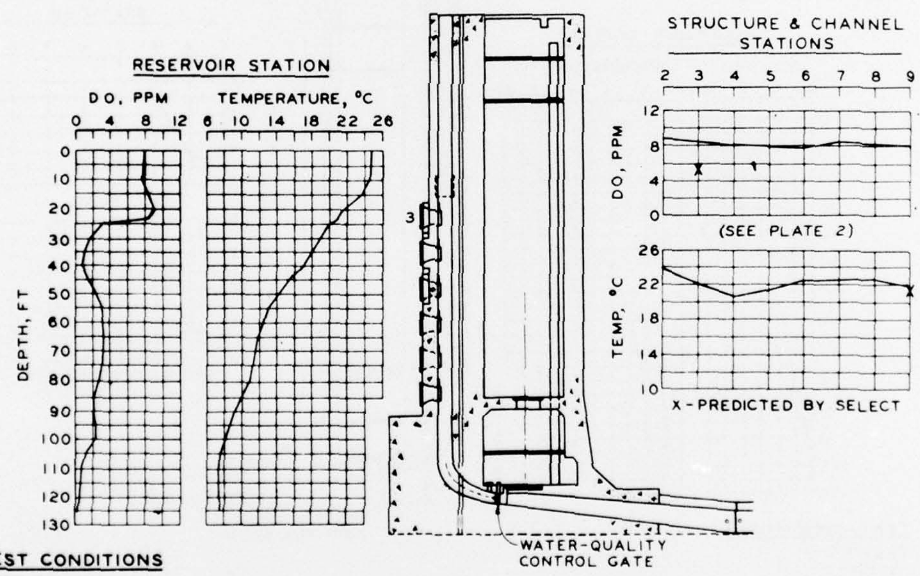
TEST 4
INTAKE: 5
WQ GATE OPENING: 100%
DISCHARGE: 331.0 CFS

WATER-QUALITY MEASUREMENTS
TEST 3 AND 4



TEST CONDITIONS

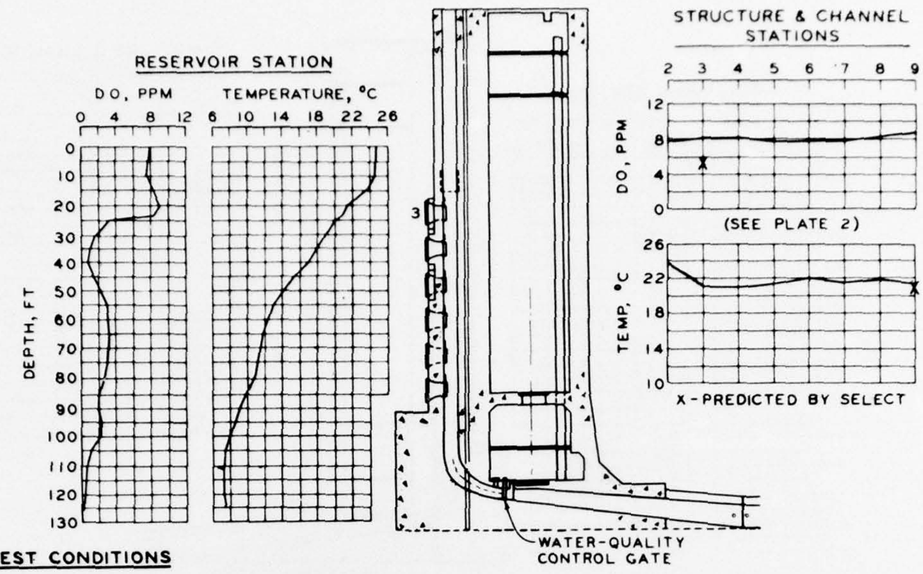
TEST 5
INTAKE: 3
WQ GATE OPENING: 10%
DISCHARGE: 23.0 CFS



TEST CONDITIONS

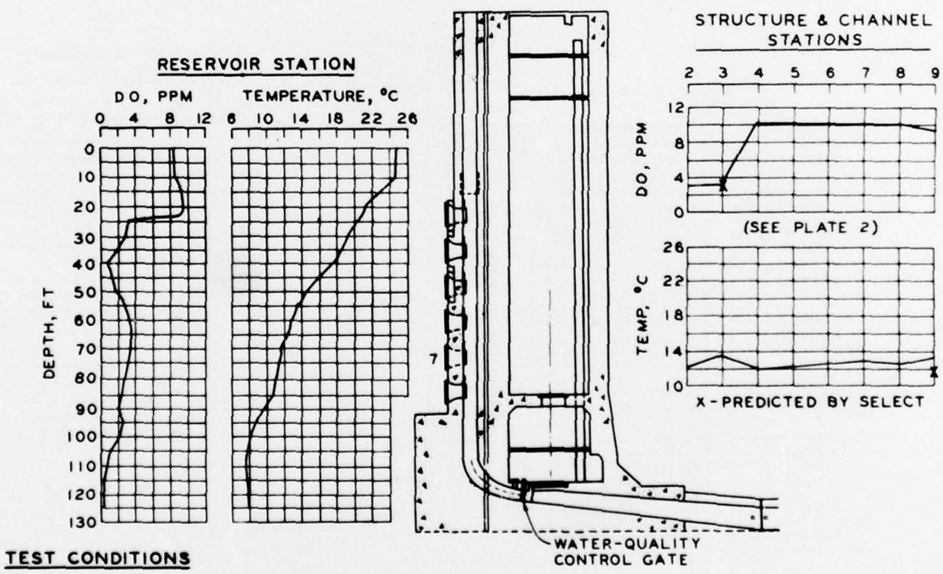
TEST 6
INTAKE: 3
WQ GATE OPENING: 50%
DISCHARGE: 156.0 CFS

WATER-QUALITY MEASUREMENTS
TEST 5 AND 6



TEST CONDITIONS

TEST: 7
INTAKE: 3
WQ GATE OPENING: 100 %
DISCHARGE: 255.0 CFS

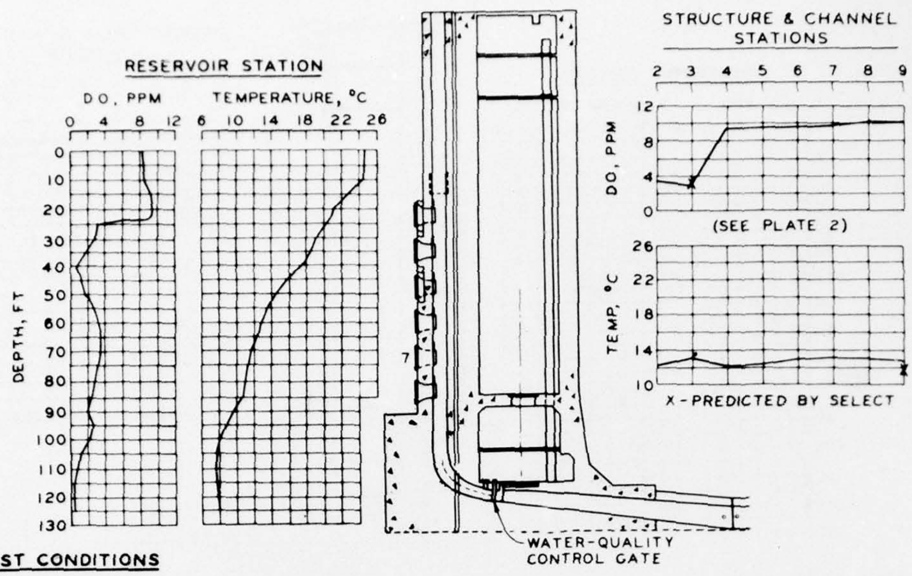


TEST CONDITIONS

TEST: 8
INTAKE: 7
WQ GATE OPENING: 10 %
DISCHARGE: 26.6 CFS

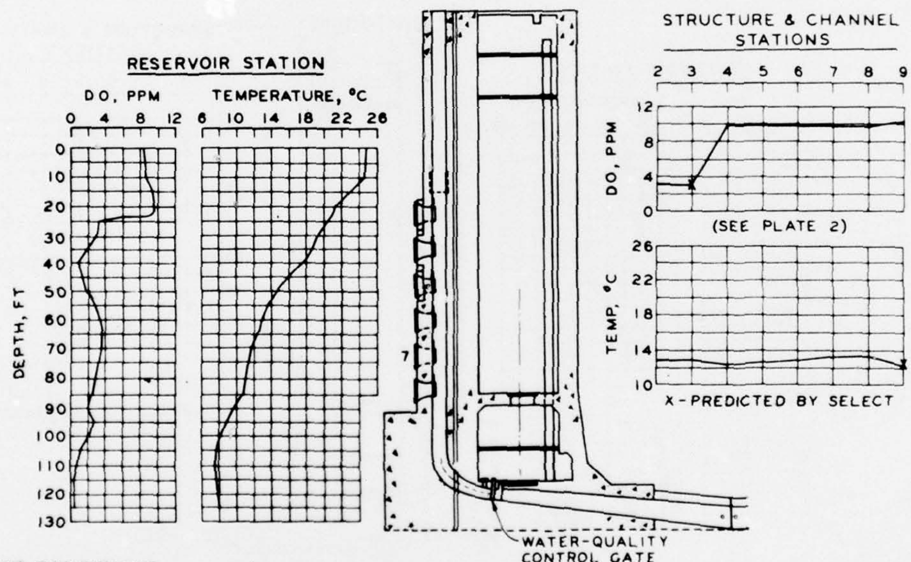
WATER-QUALITY MEASUREMENTS

TEST 7 AND 8



TEST CONDITIONS

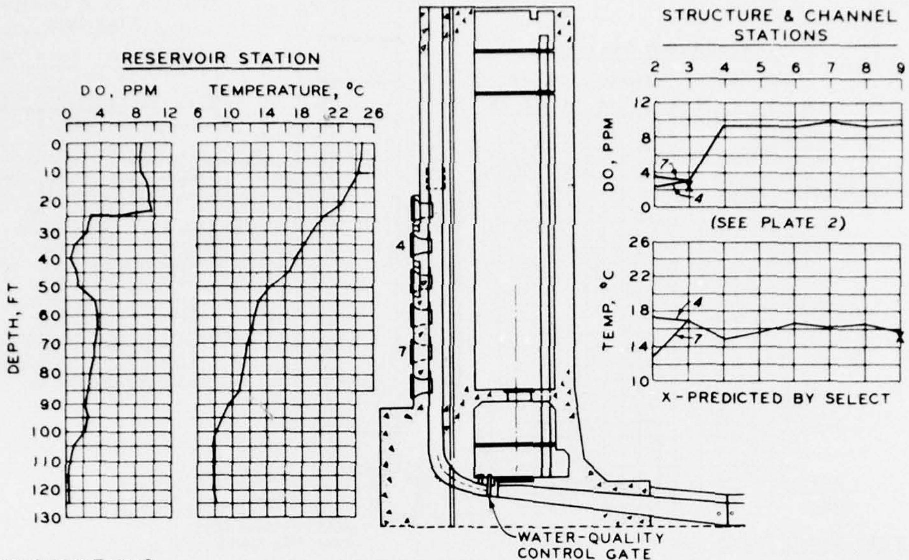
TEST: 9
INTAKE: 7
WQ GATE OPENING: 50%
DISCHARGE: 155.6 CFS



TEST CONDITIONS

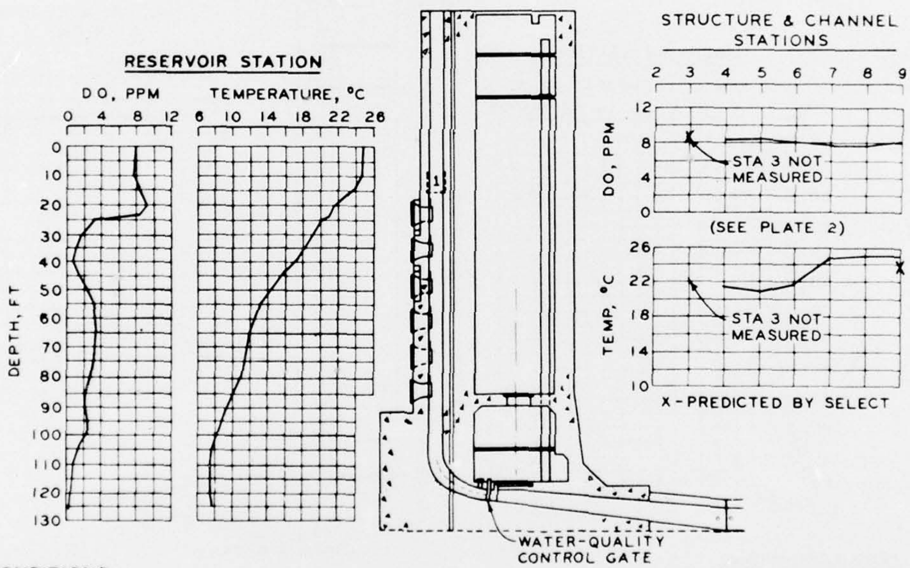
TEST: 10
INTAKE: 7
WQ GATE OPENING: 100%
DISCHARGE: 328.5 CFS

WATER-QUALITY MEASUREMENTS
TEST 9 AND 10



TEST CONDITIONS

TEST: 11
INTAKES: 4 & 7
WQ GATE OPENING: 50%
DISCHARGE: 159.0 CFS

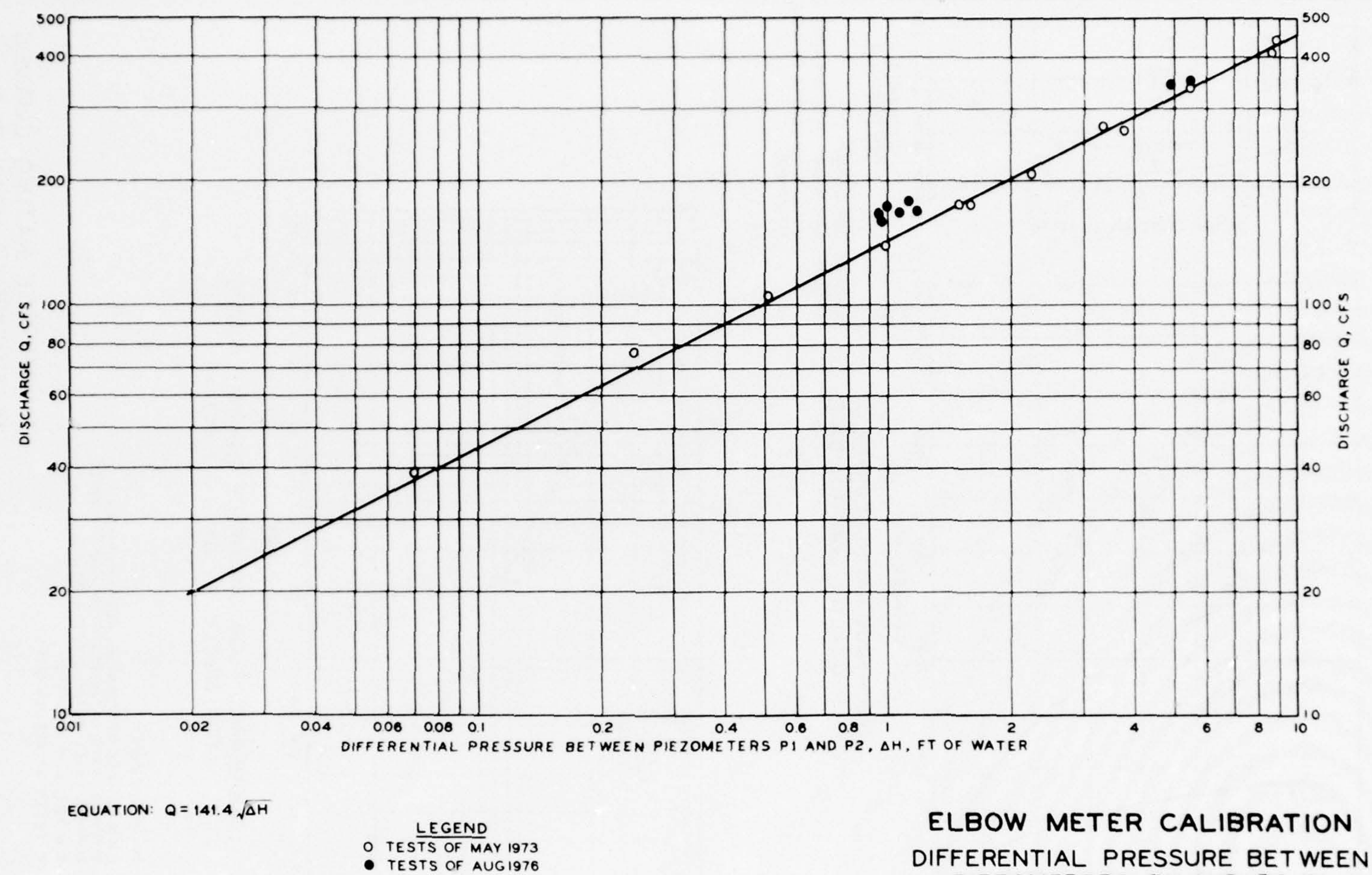


TEST CONDITIONS

TEST: 12
INTAKE: 1
WQ GATE OPENING: 50%
DISCHARGE: 155.0 CFS

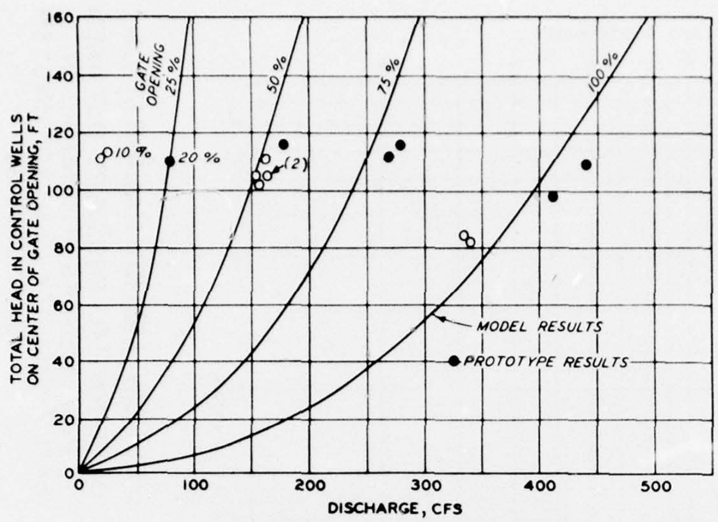
WATER-QUALITY MEASUREMENTS

TEST 11 AND 12

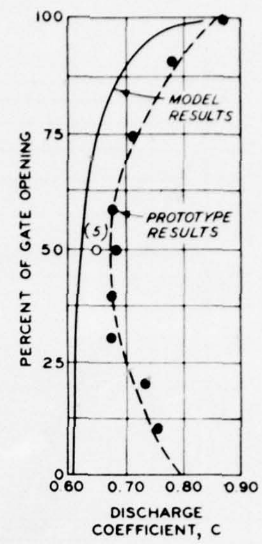


ELBOW METER CALIBRATION

DIFFERENTIAL PRESSURE BETWEEN PIEZOMETERS P1 AND P2 IN WATER-QUALITY CONTROL SYSTEM VS DISCHARGE



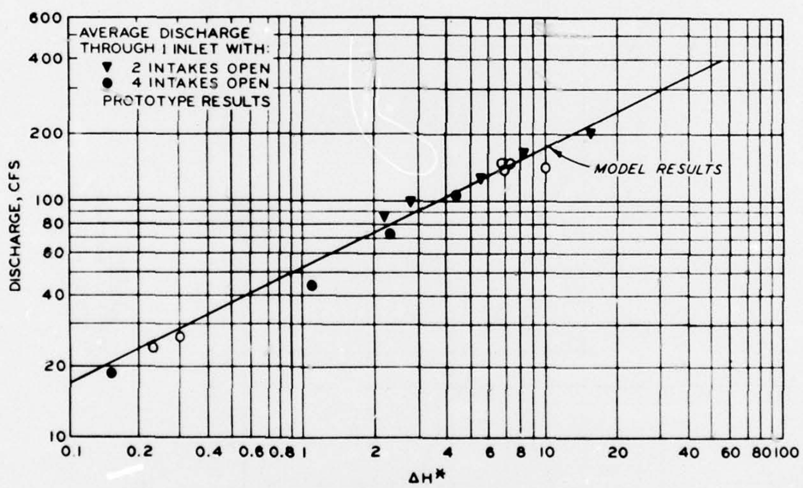
DISCHARGE RATING CURVES, WATER-QUALITY CONTROL GATE



EQUATION: $Q = CA\sqrt{2gH}$

WHERE: A = AREA OF GATE OPENING

H = HEAD TO CENTER OF GATE OPENING



SUBMERGED FLOW DISCHARGE CHARACTERISTICS FOR SINGLE 4- BY 2-FT INTAKE

EQUATION: $Q = 52.76(\Delta H)^{0.511}$

NOTE: ΔH* IS HEAD DIFFERENTIAL BETWEEN WATER SURFACE LEVEL IN THE RESERVOIR AND THE WATER SURFACE LEVEL IN THE CONTROL WELLS.

▼,● TESTS OF MAY 1973.

O TESTS OF AUGUST 1976.

DISCHARGE RATING CURVES
PROTOTYPE VS MODEL RESULTS

APPENDIX A: DETERMINATION OF DISSOLVED OXYGEN CONTENT WITH AZIDE MODIFICATION OF THE STANDARD WINKLER TITRATION*

1. This iodometric method of analyzing for dissolved oxygen (DO) is based on the oxidizing property of DO. Improved by variations in techniques and equipment, the iodometric test is the most precise and reliable titrimetric procedure for DO determination.

2. The test is based on the addition of divalent manganese (manganous sulfate, $MnSO_4$), followed by a strong alkali (alkaline iodine-azide: $NaOH + NaI + NaN_3$), to the water sample in a glass-stoppered bottle. DO present in the sample rapidly oxidizes an equivalent amount of the manganous hydroxide precipitate ($Mn(OH)_2$) to hydroxides of higher valency states. In the presence of iodide ions and upon the addition of concentrated sulfuric acid, the oxidized manganous hydroxide reverts to the divalent state, liberating iodine equivalent to the original DO content of the sample. The iodine is then titrated with a standard solution of PAO (phenylarsine-oxide) or thiosulfate.

3. The titration end point is then detected visually using a starch indicator. The minimum amount of titrant used to make the sample colorless is proportional to the DO content.

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* This method of determination of dissolved oxygen comes from References 8 and 9 (reference numbers refer to similarly numbered items in the References at the end of the main text).

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Hart, Ellis Dale

Reaeration tests, outlet works, Beltzville Dam, Pohopoco Creek, Pennsylvania, by E. Dale Hart [and] Steven C. Wilhelms. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.

1 v. (various pagings) illus. 27 cm. (U. S. *Waterways Experiment Station.* Technical report H-77-14)

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Includes bibliography.

1. Beltzville Dam. 2. Outlet works. 3. Pohopoco Creek, Pa. 4. Prototype tests. 5. Reaeration. I. Wilhelms, Steven C., joint author. II. U. S. Army Engineer District, Philadelphia. III. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report H-77-14)

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