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DISSOLVED GAS MONITORING PROGRAM
FISCAL YEAR 1973

Prepared for
Reaeration Research Program Management Team

By
Reaeration Methods and Devices Team

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ENGINEERING AND RESEARCH CENTER
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FOREWORD

The control and enhancement of water quality in Bureau of Reclamation reservoirs and reservoir releases have become increasingly important as a result of the expanded use of these impoundments not only for irrigation but for municipal and industrial water supply, recreation, and as an important fishery resource. As a result of this changing emphasis a multidisciplinary team was appointed to investigate water quality problems, principally reaeration needs, and recommend appropriate solutions. A Bureau-wide survey conducted by the team indicated dissolved oxygen deficiency and supersaturation of dissolved gases as priority subjects for investigation. A monitoring program to evaluate the aeration capabilities of the various types of outlet works and spillways employed by the Bureau to release water from its impoundments was initiated in May 1972. The program was also planned to identify related problems of dissolved gas deficiency or supersaturation and adverse temperature situations at each structure. This report records the results of the 1972 and early 1973 investigations.

ACKNOWLEDGEMENT

The studies discussed in this report were undertaken and supervised by the Reaeration Methods and Devices Team for the Reaeration Research Program Management Team. Field tests were conducted by peronnel from the Division of Design and personnel from the Division of General Research of the Engineering and Research Center. In this regard, special thanks go to Messrs. H. A. Salman and F. C. Heller, chemists from the Division of General Research, who were the most deeply involved with the field tests.

Valuable assistance was also given by the dam superintendents and members of their staffs. On occasion, assistance was also obtained from project and regional personnel. In addition, Mr. Bruce Haines of the New Mexico Department of Game and Fish assisted in the Navajo Dam tests and Dr. Ron Garton of the Western Fish Toxicology Station, U.S. Environmental Protection Agency, Corvallis, Oregon assisted in the Morrow Point tests. Assistance by personnel of the Upper Colorado, Upper Missouri, and Lower Missouri Regional Offices in test coordination is also gratefully acknowledged. This report has been compiled and written through the efforts of Mr. G. H. Austin, Hydraulic Structures Branch; Mr. F. C. Heller, Applied Sciences Branch; and Mr. P. L. Johnson, Hydraulics Branch.

The Reaeration Research Program Management Team is composed of:

Danny L. King, Manager

Dr. Dale A. Hoffman

Erwin T. Scherich

Robert F. Wilson

Members of the Methods and Devices Team are:

Garry H. Austin, Manager

Frank C. Heller

Cornelius Van Hoek

James C. Wadge

CONTENTS

CONCLUSIONS

The conclusions expressed here are based on the data presented in this report. These data are only a portion of that expected to be obtained in this ongoing study. These conclusions may therefore be altered and refined as additional insight is obtained. It appears that the phenomenon discussed in this report is quite complex with several significant parameters. This becomes especially true when biological effects and consequences are considered. The relative significance of these various parameters is as of now not completely understood. Conclusions that can be made are:

1. The dissolved gas problem is actually composed of two different aspects. One is the desire to aerate or oxygenate discharges that are low or completely depleted in dissolved oxygen. Water that is in this depleted state cannot support aquatic life. It does support an aerobic decomposition of organic matter. This type of decomposition, however, yields undesirable byproducts which include strong odors.

   Too much dissolved gas may also be a problem. Hydraulic structures may aerate discharges to the point that dissolved gas supersaturation may occur. This supersaturation can adversely affect fish life. It is therefore most desirable to release discharges that are neither depleted in oxygen nor supersaturated in oxygen or nitrogen. It appears that dissolved gas levels near saturation are the most desirable.

   The majority of the data collected dealt with supersaturated flows. No severely depleted situations were observed.

2. The pressure to which flow with entrained air is exposed, is a dominant factor in dissolving the gas. It appears to be especially critical with respect to dissolved gas supersaturation. The higher the pressure the more gas is dissolved. This pressure is generally dependent on the depth of penetration of the inflowing jet which is in turn dependent on the jet's momentum, organization, and orientation.

3. The amount of turbulence in the flow appears to be a significant factor. Highly turbulent flows tend to show lower supersaturation levels than less turbulent flows when they have comparable depths of penetration.

4. The amount of air entrained in the flow appears to be of only secondary importance. The highest supersaturation levels observed occurred in situations where relatively small quantities of air were entrained in the flow. An adequate supply of air must, of course, be present to increase gas saturation. In instances where

water is passed through a hydraulic structure without entraining air (such as through an unvented turbine), no increase in saturation levels was observed.

5. Vented turbine operation may or may not cause increased saturation or supersaturation levels. Instances were observed for both cases. Because of the complex flow conditions and geometries associated with turbine and draft tube discharges, it is hard to determine exactly why this is the case. It is realized that when dissolved gas levels are increased, the cause is probably exposure to higher pressures for longer periods of time.

INTRODUCTION

The monitoring program was designed to determine the change in dissolved gas content of impounded water produced by passage through reservoir release facilities in common use. First priority was accorded outlet works and powerplants with spillways reserved for later study because of their comparatively infrequent use. The various types of outlet works, regulating valves and gates, and energy dissipators were categorized. Listings were prepared of projects containing each category together with other pertinent data such as size, head, travel distance from Denver, etc. A selection of structures to be monitored during 1972 and 1973 was made from this list. Priority consideration was given to Navajo Dam because of previously reported problems of tailwater fish kill thought to be associated with the dissolved gas content of water passed through the auxiliary outlet works. After Navajo, testing progressed to Granby, Shadow Mountain, Willow Creek, Ruedi and Morrow Point Dams during 1972.

A minor fish kill below the Yellowtail Afterbay Dam in April of 1973 resulted in tests at that structure during the following month. A favorable spring runoff situation on the North Platte River with several spillways operating led to testing at Seminoe, Kortes, Pathfinder, Alcova, and Glendo Dams and Fremont Canyon Powerplant. Additional testing followed at Silver Jack Dam on Cimarron Creek, a tributary of the Gunnison River. Through cooperation with the Denver Board of Water Commissioners, tests were also conducted at Gross and Dillon Dams while spills were in progress.

TESTING METHODS

The monitoring program was initially planned to measure temperature and dissolved oxygen and nitrogen content of water impounded in or released from Bureau reservoirs. Additional chemical tests were made as special needs arose. By successive sampling in the reservoir at intake level, at the end of the energy dissipator, and at selected stations downstream the effect on water quality from passage through various structures could be identified. During the 1972 tests a mobile chemical laboratory was moved to each site. This was necessary because of the elaborate equipment needed for determining dissolved nitrogen content with the Van Slyke method or with the gas chromatograph. With the acquisition of a Weiss saturometer in late 1972, the testing equipment became more portable and it was no longer necessary to use the mobile laboratory.

A description of the testing methods and equipment follows:

1. Surface temperature, the most easily measured parameter, was read manually with a mercury thermometer. For taking temperatures at depth in situ a thermistor probe was used. A thermistor was incorporated in the dissolved oxygen probe so temperature data could be easily and quickly acquired.

2. The dissolved oxygen (DO) content of water depends on the physical, chemical, and biological activities of the water. DO was usually determined by Winkler titration or by electronic probe. The Winkler method is a direct wet chemical titration that depends on the oxidizing effect of the oxygen in solution. It is considered a standard, accurate and reliable titrimetric method.

The electronic method of determining DO is accomplished by a probe containing a semipermeable membrane. Dissolved oxygen in the water diffuses through the membrane changing the voltage output of the probe. This change is monitored by a meter which is calibrated in concentration units (ppm) of dissolved oxygen. The electronic method is fast, easy, accurate, and readily adaptable to field use. As the DO meter must be calibrated against a known concentration of dissolved oxygen, a Winkler titration is usually used for this purpose.

3. Dissolved nitrogen in water was measured by the Van Slyke manometric method[1] and the gas chromatographic method.[2]

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[1] Donald D. Van Slyke and James M. Neil, "The Determination of Gases in Blood and Other Solutions by Vacuum Extraction and Manometric Measurement," Journal of Biological Chemistry, Vol LXI, 1924.
[2] John W. Swinnerton, Victor J. Linnenbom, Conrad H. Cheek, Anal. Chem., Vol 34, No. 4, April 1962.

In the Van Slyke method the gases in a sample are extracted under reduced pressure and the reactive gases, carbon dioxide and oxygen, are absorbed with chemical reagents. The pressure of the remaining inert gases, nitrogen and a small percentage of argon, is read at a known volume. From these data the amount of nitrogen can be calculated.

The Van Slyke method is accurate but tedious and time consuming, requiring about an hour to run a sample and clean up the apparatus.

The gas chromatographic method is a much faster method but not quite as accurate as the Van Slyke. The gas chromatograph must also be standardized against a known concentration of gas. In the chromatographic technique, a sample is injected into a gas stripper in the carrier flow of the instrument. The dissolved gases are stripped from the sample, separated by the instrument's column, detected by the difference in thermal conductivity of the gases, and recorded as a peak on a chart recorder. By means of the peak area and the calibration factor, the quantity of gas present can be calculated. Most samples were determined by gas chromatography with the Van Slyke being used to standardize and check the gas chromatograph.

The Weiss saturometer,[3] a field instrument for measuring the total partial pressure of gases in supersaturated waters, has just recently become commercially available. The instrument is very simple, consisting of several hundred feet of gas-permeable silastic rubber tubing wound in small loops, and a pressure gage. The loops are submerged into the water to be sampled, and gases in the water permeate the tubing producing a pressure reading on the gage. From the total partial pressure reading, the barometric pressure, temperature, and an independent dissolved oxygen determination, the partial pressure and supersaturation percent of nitrogen can be calculated. One objective of this study was to evaluate the saturometer. Tests proved the data to be reproducible, accurate, and reliable. The saturometer provides a convenient means to collect data on surface or easily accessible waters.

4. Other chemical data were taken occasionally at various locations for specific reasons. A brief mention of these data follows:

Free carbon dioxide (CO_2) was determined by means of titration with sodium hydroxide to the characteristic phenolphthalein indicator color change at pH 8.3. This titration is a rapid field test that gives an approximation of the free CO_2 present.

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[3] Terrotec Division of Symlog Instruments, Overlake Park, Redmond, Washington 98052.

The pH or degree of acidity or basisity was measured electrometrically by means of a portable, battery-operated glass electrode-type pH meter. These portable meters are capable of measuring pH to an accuracy of well within 0.1 of a pH unit.

Hydrogen sulfide (H_2S) was tested for in some first-release waters by the sulfide-stain test method; however, none was detected.

The total alkalinity of a water is an indicator of its ability to accept protons and is generally attributed to the carbonate, bicarbonate, or hydroxyl components. Alkalinity was determined by titration with a strong proton-donating mineral acid.

TEST RESULTS

Test results are grouped by individual field trip. Descriptions of the testing for each trip is followed by figures providing general details of the structure, water levels, and sampling locations. Also included are the synopsis information about the tests, photographs of discharge conditions, and the data tabulations obtained. The test results are listed in chronological order.

Navajo Dam

As was previously stated, the Navajo Dam tests were given a high priority because of reported problems of tailwater fish kill. It had been speculated that these kills resulted from dissolved gas supersaturation created by discharges through the auxiliary outlet works. It was also noted that Navajo Dam has three very different types of outlet works structures which would yield significant information to the overall study. Navajo was thus chosen as the first site at which field monitoring would occur.

With respect to chemical analysis, dissolved oxygen and nitrogen were monitored for all conditions studied. As previously stated the Winkler titration was used as the standard in the dissolved oxygen monitoring; the majority of the data was obtained with the DO probe. Likewise, Van Slyke data on nitrogen saturation were used as a standard with the majority of the data taken with the gas chromatograph. In addition to oxygen (O_2) and nitrogen (N_2), CO_2 and H_2S were monitored for a few samples and in two cases complete chemical analyses were carried out. These extensive analyses resulted in part from speculation prior to the tests that the fish kills may have resulted from chemical factors other than dissolved gas. The results indicated that dissolved gas was the only critical factor. The total chemistry analyses showed high-quality water. The CO_2 supersaturation was in the normal range for natural waters and no H_2S was observed.

The various operating conditions studied included the following:

1. Reservoir. - Samples were taken at two depths in the reservoir corresponding to the auxiliary outlet works (240-foot depth) and river outlet works (130-foot depth) intake levels (Figure 1). The data generally indicated slight N_2 supersaturation (102 percent) and a somewhat depleted O_2 level (83 percent).

2. River outlets. - The centerline profile of the river outlets (or simply the outlet works) is shown in Figure 1. The hollow-jet valve basin at the end of this structure is of a modified USBR design. Figure 3 shows the basin operating at 2,000 cfs or approximately 50 percent of capacity. Discharges of 1,000 and 500 cfs were also observed. The lower discharges correspondingly caused less turbulence in the basin. It was determined from a previous hydraulic model study that the depth of penetration was approximately 33 feet at a discharge of 2,000 cfs and 20 feet at 1,000 cfs. The penetration would be less than this for yet smaller discharges.

3. Thirty-inch hollow-jet valve bypass. - Shown in Figure 4, discharges from the side into the spillway stilling basin. Its flow is directed downward at a 30° angle. Figure 4 shows the

bypass at a discharge of 400 cfs or 100 percent of capacity. At this discharge (the only data point) the jet probably penetrates 36 feet to the bottom of the basin.

4. Auxiliary outlet. - Also shown in Figure 1, directs a consolidated jet with only a relatively small amount of entrained air deep into the spillway stilling basin. Figure 5 shows the outlet operating at a discharge of 1,000 cfs or 60 percent of capacity. Observations indicate that the flow stays near the bottom of the basin for the basin's entire length. This is a depth of penetration of approximately 36 feet.

5. Downstream river. - Additional data were also taken on the river below the dam. These data were taken for flows with various initial saturation levels caused by different operating outlet works.

SYNOPSIS OF FIELD TRIP

1. Location: Navajo Dam

2. Period: May 15-19, 1972

3. Log:

May 16 - Salman and Heller traveled to Navajo Dam. Austin conferred with Mr. Lincoln in Project Construction Office, then traveled to Navajo Dam, arriving at same time as Salman and Heller. With assistance from Bernard Corder, Dam Superintendent, Leonard Trujillo, Navajo Dam, and Bruce Haines, New Mexico Department of Game and Fish, samples were obtained from reservoir, stilling basins, and downstream stations. River outlet works was operating at 500 cfs. Salman and Heller set up analysis equipment, calibrated, and made initial analysis. King traveled to Farmington in the evening.

May 17 - Samples were collected at two depths in the reservoir, in the stilling basins, and at downstream stations for the river outlet works operating at 500, 1,000, and 2,000 cfs, for the 30-inch bypass discharging approximately 400 cfs into the spillway stilling basin, and for the auxiliary outlet works discharging 1,000 cfs into the spillway stilling basin. All samples were analyzed for dissolved nitrogen, several for dissolved oxygen and carbon dioxide, and a few for dissolved hydrogen sulfide and total chemistry. Mr. Haines and Mr. Gary Herr, NMG&F, assisted in obtaining samples.

Mr. Nat Mahan, Durango Projects Office, observed the tests. Mr. Dave Nelson, Regional Office, Salt Lake City; Mr. Jim Harpster, E&R Center; and Mr. Monk Tyson, Denver Post, observed portions of the test.

4. Conclusions:

a. Operation of the auxiliary outlet works caused nitrogen supersaturation levels exceeding 130 percent in the stilling basin causing termination of the test.

b. The 30-inch bypass caused a nitrogen supersaturation level of about 120 percent.

c. The river outlet works contributed negligible nitrogen up to 1,000 cfs, and 115 percent supersaturation at 2,000 cfs.

d. Reservoir nitrogen levels were about 98 percent.

e. Oxygen analysis by the Winkler method showed oxygen supersaturation equal to that of nitrogen. DO probe data were unreliable.

f. CO_2 supersaturation was in the normal range for natural waters, not in sufficient absolute concentrations to affect fish.

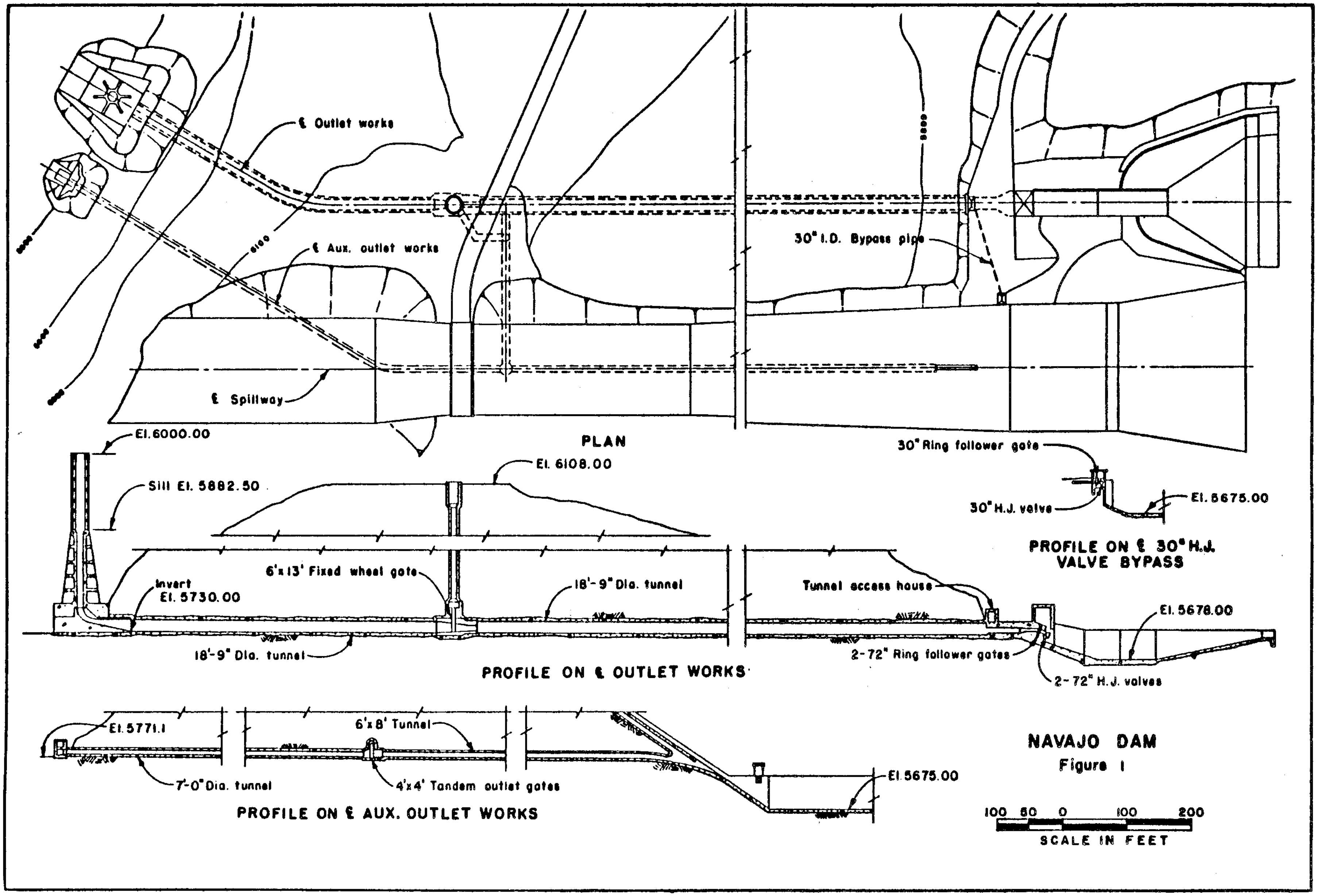
g. H_2S was not present in the reservoir or in the releases.

h. The initial auxiliary outlet works discharge was highly turbid.

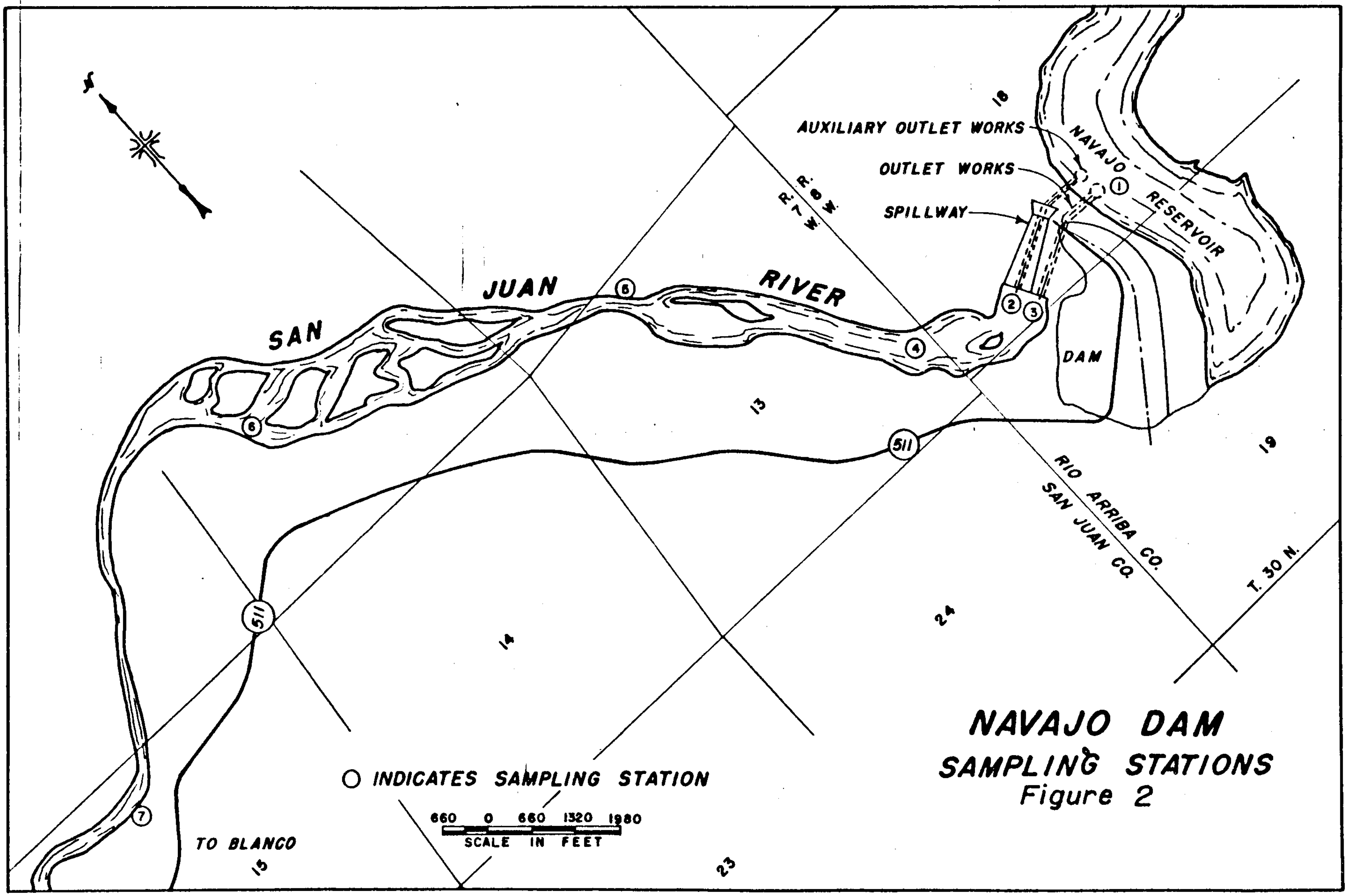
i. Total chemistry analyses showed high-water quality.

j. The auxiliary outlet works operated for 1 hour; no fish kill was observed.

k. Data at downstream stations were insufficient to determine the gas loss in the stream.



NAVAJO DAM
Figure 1



NAVAJO DAM
SAMPLING STATIONS
Figure 2

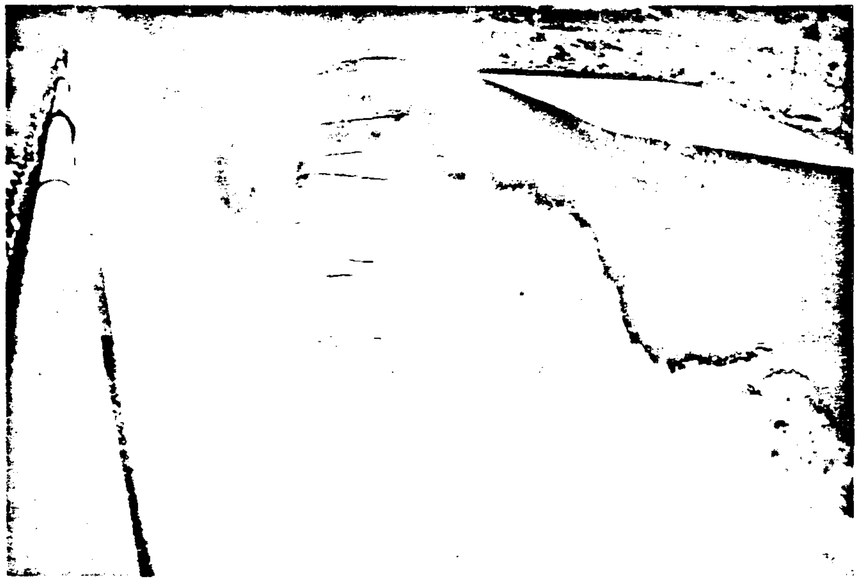


Figure 3. Navajo River outlet works at 2,000 cfs. Photo P711-D-74126

Figure 4. Navajo 30-inch bypass at 400 cfs. Photo P711-D-74127

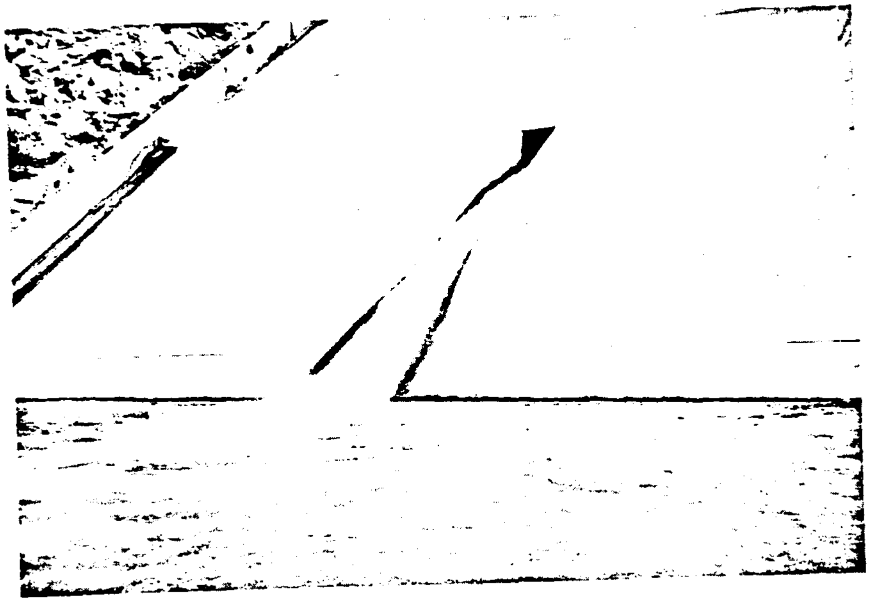


Figure 5. Navajo auxiliary outlet at 1,000 cfs.
Photo P711-D-74128

Table I

NAVAJO DAM - MAY 1972
(Barometric Pressure - 617–mm Hg)

Location[1]	Date	Time	Temp °C	N_2 ppm	N_2 per-cent sat.	O_2 ppm	O_2 per-cent sat.	CO_2 mg/ℓ	H_2S mg/ℓ	Remarks
River outlet basin	5-16-72	1155	6.0	-	-	-	-			River outlet alone Q = 500 cfs
Spillway basin		1335	8.1	17.1	111.5*	10.2	106.3	3.0	0.0	
		1335	8.1	-	-	10.2	106.3		0.0	
		1340	8.1	-	-	10.2	106.3			
River outlet basin		1355	5.7	-	-	9.6	94.2			
		1355	5.7	16.9	104.1*	9.6	94.2	2.5		
		1405	5.7	-	-	9.6	94.2			
Reservoir - 130-foot		1505	6.4	-	-	-	-			
depth		1510	6.4	20.5	101.1*	-	-	2.2	0.0	
		1515	6.5	-	-	-	-			
240-foot		1525	5.4	-	-	-	-	3.2	0.0	
depth		1530	5.4	-	-	-	-			
		1530	5.4	-	-	-	-			
		1535	5.4	-	-	8.5[2]	83.1			
0.6 mile downstream	5-17-72	0720	6.6	17.8	112.0	7.9	79.3			
		0720	6.6	17.1	107.5*	7.9	79.3	2.3		
		0725	6.6	-	-	7.9	79.3			
River outlet basin		0745	5.9	16.8	104.0	-	-			
		0745	5.9	16.1	100.0	-	-			
Spillway basin		0810	6.4	16.6	104.0*	-	-			
		0810	6.4	16.1	101.0	-	-			
1.3 miles downstream		1000	8.5	15.4	101.0	12.5	131.0			

Navajo Dam - May 1972 - Continued

Location[1]	Date	Time	Temp °C	N_2 ppm	N_2 percent sat.	O_2 ppm	O_2 percent sat.	CO_2 mg/ℓ	H_2S mg/ℓ	Remarks
3.0 miles downstream	5-17-72	1020	8.6	16.2	106.8*	6.8	71.7			River outlet alone Q = 500 cfs
		1020	8.6	15.5	102.0	6.8	71.7			
8.0 miles downstream		1035	7.6	19.9	101.0	6.6	68.0			
River outlet basin		1110	5.8	16.3	101.0	12.7	125.2			River outlet alone Q = 1,000 cfs
		1110	5.8	17.3	107.0	12.7	125.2			
Spillway basin		1150	8.0	17.4	113.0	-	-		0.0	River outlet - Q = 1,000 cfs Auxiliary outlet Q = 1,000 cfs (Auxiliary outlet opened at 1140)
0.6 mile downstream		1210	6.6	16.8	106.0	-	-			
		1210	6.6	-	-	11.0[2]	110.1			
		1210	6.6	17.3	109.0	10.2[2]	102.6			
Spillway basin		1220	6.0	20.5	127.0[3]	-	-			
		1220	6.0	-	-	13.1[2]	129.8			
1.3 miles downstream		1300	9.4	16.9	113.0	-	-			Auxiliary outlet closed at 1240 River outlets alone Q = 1,000 cfs
		1300	9.4	-	-	10.7[2]	119.2			
		1300	9.4	16.9	113.0	-	-			
Reservoir - 130-foot depth		1500	5.7	16.0	98.4*	-	-			
		1500	5.7	16.6	102.0	-	-			
240-foot depth		1515	4.6	17.0	102.0	-	-			
		1515	4.6	17.0	102.0	-	-			
Spillway basin		1600	6.9	21.1	134.0*	-	-			
		1600	6.9	23.8	151.0	-	-			
Spillway basin	5-17-72	1700	6.2	-	-	11.9[2]	118.0			River outlets Q = 1,000 cfs 30-inch bypass Q = 400 cfs (Bypass opened 1630 - closed 1700
		1700	6.2	-	-	12.2	121.3			
		1700	6.2	19.6	122.0	-	-			
		1700	6.2	20.4	127.0	-	-			
River outlet basin		1720	6.6	-	-	11.4[2]	114.1			River outlets alone Q = 2,000 cfs (opened 1710)
		1720	6.6	-	-	11.3[2]	113.6			
		1720	6.6	18.9	119.0	-	-			
		1720	6.6	18.7	118.0	-	-			

* Van Slyke procedure.
[1] See Figure 2.
[2] Measured by Winkler method - All others by DO probe.
[3] Gas bubbles escaping during withdrawal from sample bottle.

Granby, Shadow Mountain, and Willow Creek Dams

At these three structures only N_2, O_2, and CO_2 were monitored. Again the Winkler titration and Van Slyke data were used as standards with the majority of the data taken with the DO probe and the gas chromatograph.

At Granby Dam only flow through the outlet works was observed. The outlet works consist of a nearly horizontal tunnel with a 30-inch hollow-jet valve and a 12-inch needle valve for control (Figure 6). The valves are located about halfway through the tunnel. The flow continues below the valves with a free surface. It then enters the river channel with no distinct stilling basin (Figure 9). The probable maximum depth of penetration is 10 feet. The discharge of 110 cfs that was observed is 27 percent of the maximum possible. There was a moderate amount of turbulence and air entrainment.

At Shadow Mountain, spillway flow was observed. The spillway design is fairly common with a radial-gate-controlled crest leading to a chute that ends in a hydraulic jump basin (Figure 7). A very small discharge of only 106 cfs was observed. This is only about 1 percent of the spillway's total capacity. It was estimated that because of the fairly shallow basin and the small discharge the probable maximum depth of penetration was less than 10 feet. The small discharge also creates a fairly quiet flow in the basin (Figure 10).

At Willow Creek Dam, again, only flow through the outlet works was observed. As at Granby the outlet works is through a nearly horizontal tunnel (Figure 8). Again the flow is controlled part way through the tunnel, but this time the control is two high-pressure slide gates. The flow then continues with a free surface to the end of the tunnel where it is flipped into a basin. For the observed discharges of 191 cfs (10 percent of capacity) and 45 cfs (2 percent) the probable depth of penetration is less than 18 feet (the basin depth).

On all three structures at least some data were taken on the stream below and the reservoir above. The most extensive downstream data were collected at Willow Creek.

SYNOPSIS OF FIELD TRIP

1. Location: Lake Granby, Shadow Mountain, and Willow Creek Reservoirs.

2. Period: June 19 - 22, 1972.

3. Log:

June 19 - Salman, Hopkins, and Hjerstedt traveled to Granby Pumping Plant and set up the Mobile Water Quality Laboratory. Mr. Bob Barnes assisted us in locating the sampling sites at each reservoir.

June 20 - Samples were collected at the surface and at one depth in Shadow Mountain, in the stilling basins of Shadow Mountain and Willow Creek, and at several stations downstream from each reservoir. Samples from the stilling basin and downstream stations of Willow Creek Reservoir were collected at releases of 191 and 45 cfs. The samples were analyzed for dissolved N_2, O_2, and CO_2.

June 21 - Collected samples from a depth of 44 feet and at the surface of Lake Granby, in the outlet works below Lake Granby, and at several stations downstream. Samples were also collected at Willow Creek while 45 cfs of water were released at a depth of 50 feet, at the surface of the reservoir, and at several stations downstream. The samples were analyzed for dissolved N_2, O_2, and CO_2.

4. Conclusions:

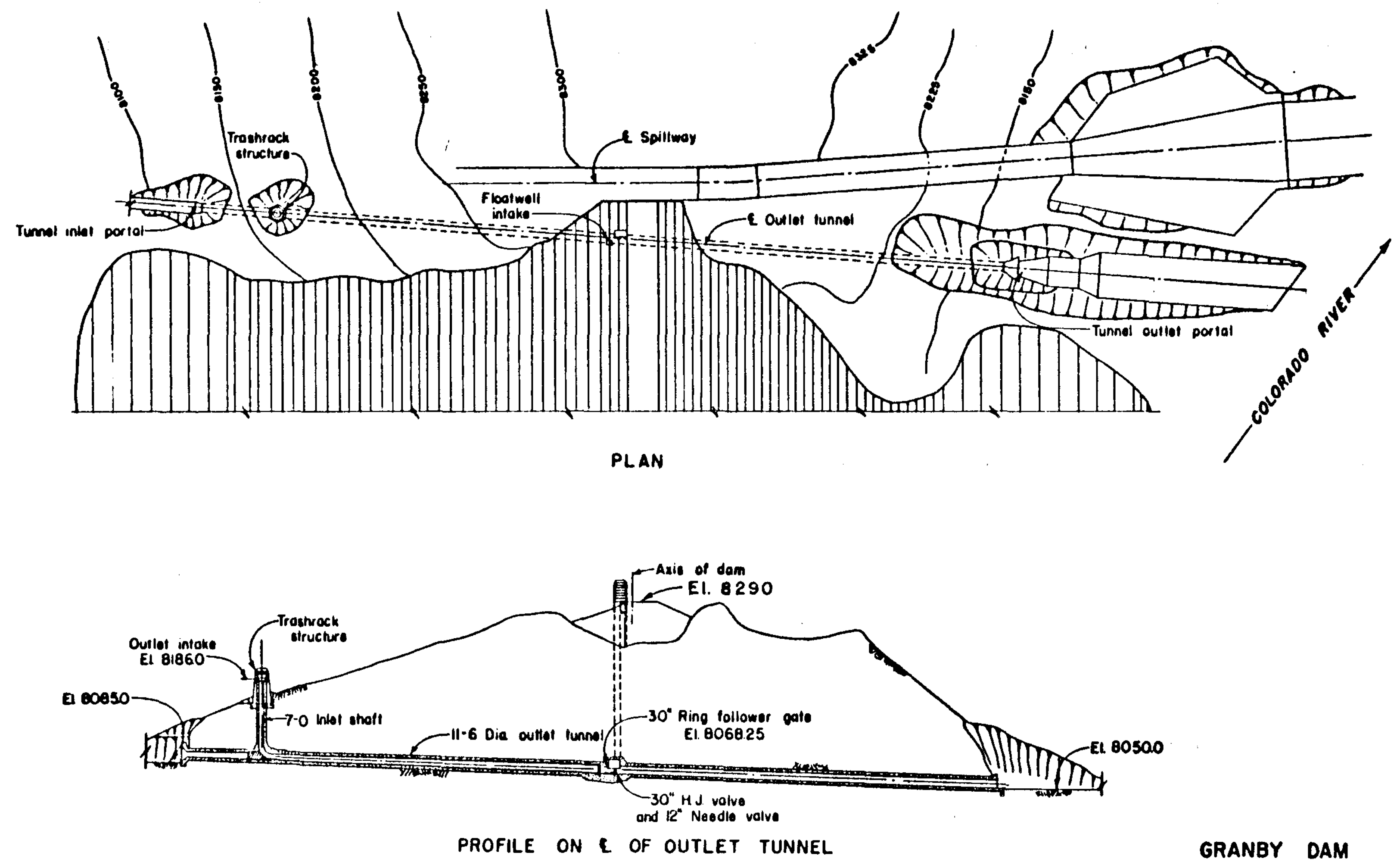
a. Reservoir nitrogen saturation levels were about 104 percent at all three reservoirs.

b. The nitrogen saturation levels at depths were about 101, 105, and 111 percent at Shadow Mountain, Lake Granby, and Willow Creek, respectively.

c. The nitrogen levels in the outlet basins were 99, 104, and 108 percent at Shadow Mountain, Lake Granby and Willow Creek, respectively.

d. At each gaging station below the reservoirs, the nitrogen saturation levels tended to increase.

e. Much higher flows occur at the outlet works of these reservoirs in April or May. Higher flows may produce increased nitrogen levels at these sites.

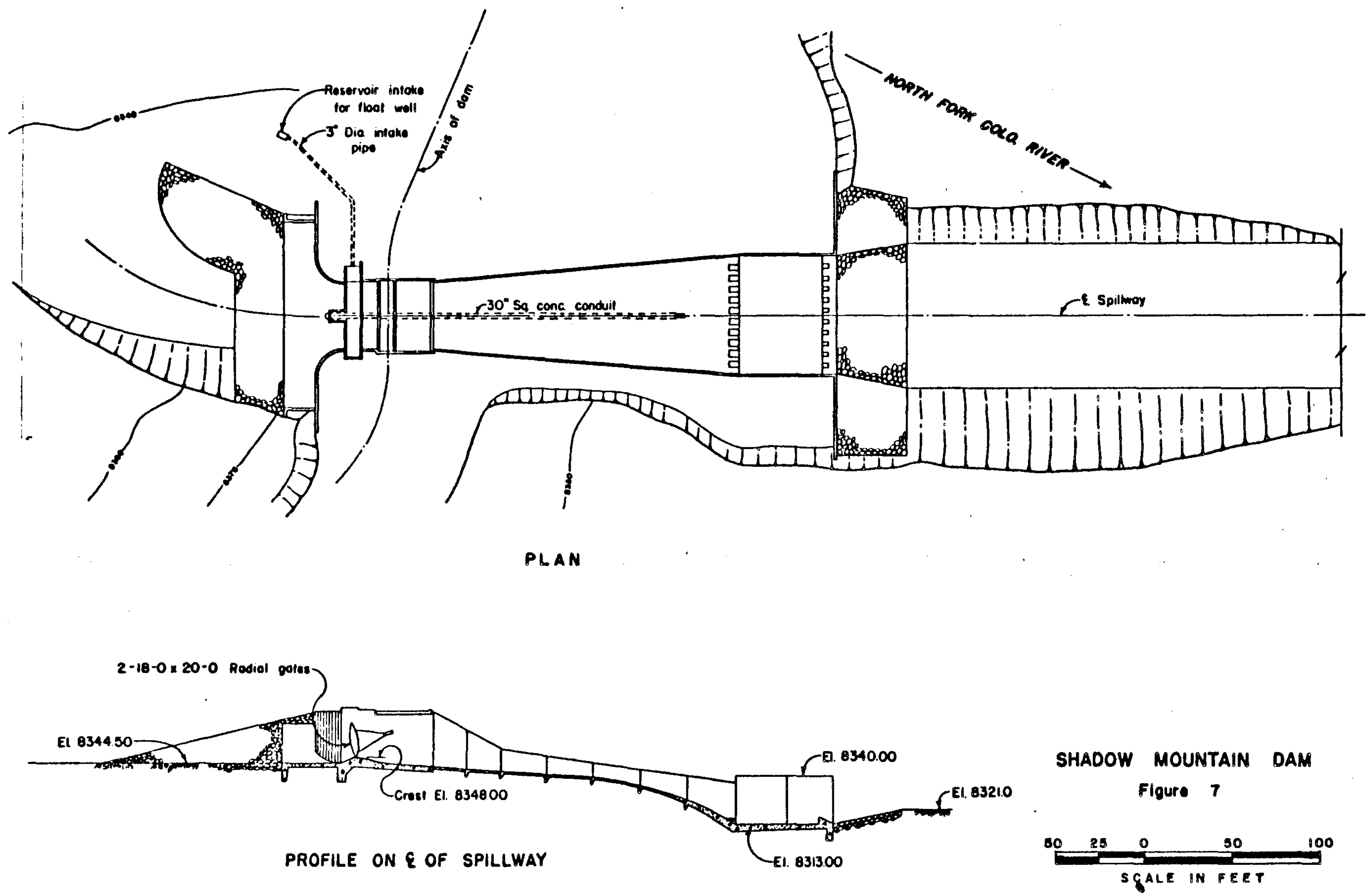


GRANBY DAM

Figure 6

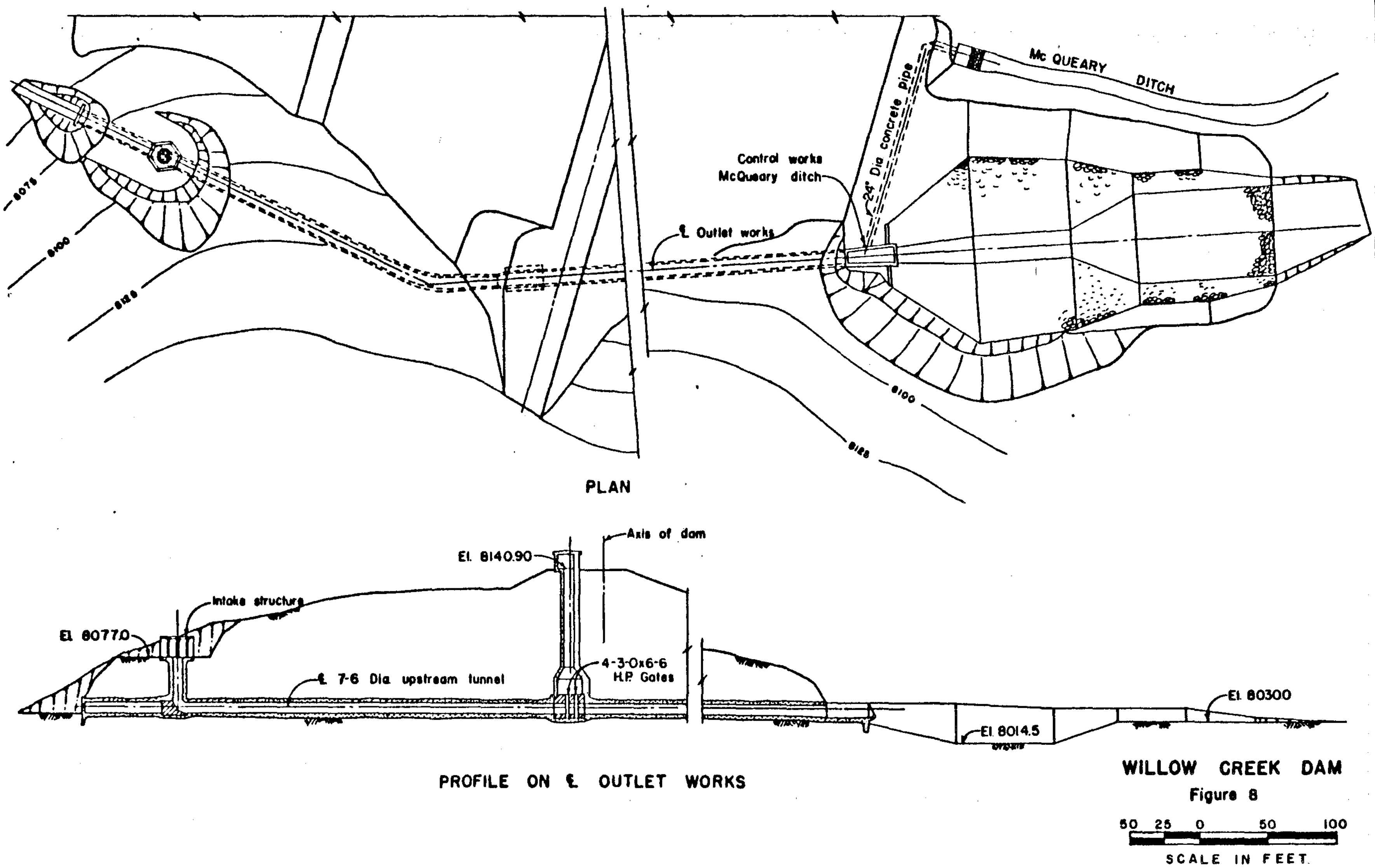
100 50 0 100 200

SCALE IN FEET



SHADOW MOUNTAIN DAM

Figure 7



WILLOW CREEK DAM

Figure 8

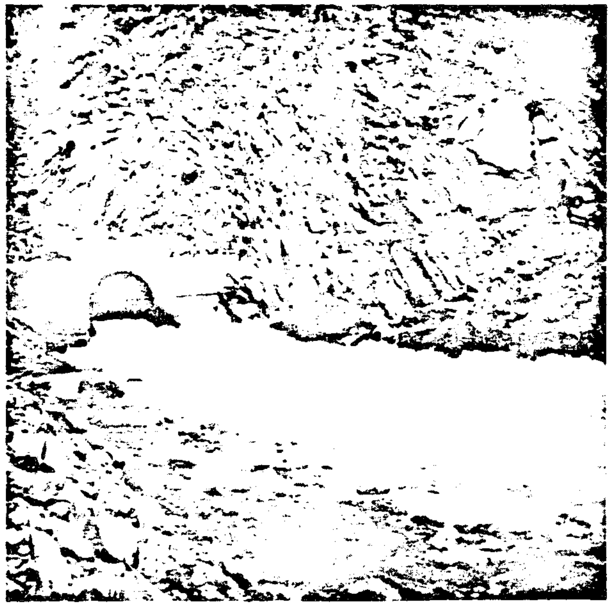


Figure 9. Granby outlet works at 430 cfs. Photo P245-D-74129

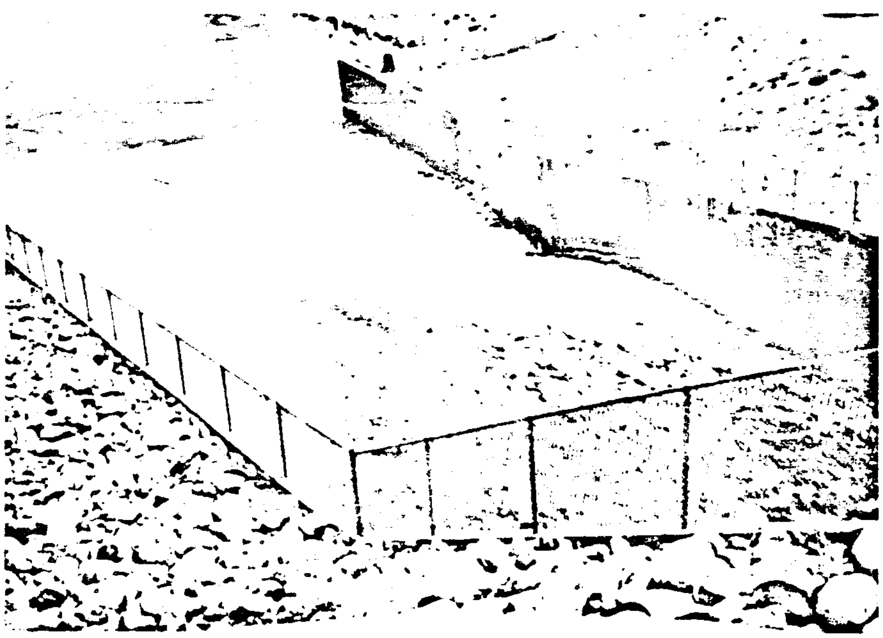


Figure 10. Shadow Mountain spillway at 1,150 cfs. Photo P245-D-74130

SHADOW MOUNTAIN
(Barometric pressure = 565-mm Hg)

Field identification	Date sampled (1972)	Flow (cfs)	Temper-ature (°C)	CO_2 (ppm)	DO (Percent saturation)	DO (ppm)	Percent N_2 saturation	N_2 ppm
Reservoir surface at dam	6-20	-	12.9	2.4	95.0	7.45	105	13.3
Reservoir 18 feet at dam	6-20	-	11.5	3.0	85.9	6.96	103	13.4
Spillway basin	6-20	106	11.6	3.0	90.4	7.30	101.9*	13.3
Gaging station	6-20	106	11.5	2.5	90.5	7.33	104	13.6
LAKE GRANBY (Barometric pressure = 568-mm Hg)								
Surface at dam	6-21	-	14.4	1.0	102.4	7.80	105 (107)*	13.0 13.2
Reservoir 44 feet at dam	6-21	-	9.5	2.5	86.8	7.40	106	14.5
Outlet basin	6-21	110	6.6	3.2	96.8	8.87	105	15.4
Gaging station (1/4 mile downstream)	6-21	110	6.9	3.0	96.9	8.80	115	16.7
Bridge downstream (1-1/4 miles downstream)	6-21	110	8.8	1.8	102.6	8.90	109	15.2

* Van Slyke procedure.

WILLOW CREEK
(Barometric pressure = 565-mm Hg)

Field identification	Date sampled (1972)	Flow (cfs)	Tem-per-ature (°C)	CO_2 (ppm)	DO (Per-cent sta-uration)	DO (ppm)	Percent N_2 saturation	N_2 ppm
Surface at dam	6-20	-	14.5	1.5	93.0	7.42	106	13.0
Outlet basin (1/4 mile downstream)	6-20	191	9.20	-	100.7	8.60	110 (109)*	15.1 15.0
Gaging station	6-20	191	9.55	1.2	103.4	8.76	116	15.8
Downstream (1 to 2 miles)	6-20	191	9.60	1.5	103.0	8.71	113	15.4
Outlet basin	6-20	45	9.05	2.4	101.5	8.70	114	15.7
Surface at dam	6-21	-	15.7	1.7	102.4	7.55	113	13.5
Outlet basin	6-21	45	8.7	2.0	100.9	8.73	115	16.0
Gaging station (1/4 mile downstream)	6-21	45	8.95	1.9	105.7	9.08	118	17.2
Reservoir 50 feet at dam	6-21	-	15.5	2.5	101.5	7.51	113	13.6

* Van Slyke procedure.

Ruedi, Morrow Point, and Blue Mesa Dams

Efforts were made in the study of these structures to obtain comparative data from the various analytical techniques. This information could be used in a generalized evaluation of these various methods. In addition, the Weiss saturometer was used for the first time. The comprehensive data from the other techniques thus significantly aided in evaluation of this new device. Comparative data were taken at all three structures. In addition a second series of tests were run at Ruedi. Data for this second series were taken in the traditional manner with Winkler and Van Slyke data as standards and with the DO probe and the gas chromatograph supplying the majority of the information. In addition to the dissolved gas data, pH and total alkalinity were also measured.

In the two sets of tests run at Ruedi, three outlet works structures were studied. They are:

1. The river outlet works which consist of a near horizontal tunnel controlled by two gates at its downstream end (Figure 12). Flow from these gates is directed downward into a conventional hydraulic jump basin with a center dividing wall. Discharges of 270 cfs (15 percent) and 134 cfs (8 percent) were observed. It is estimated that the jet penetrates to the bottom of the basin, a depth of approximately 19 feet. The observed flow was moderately rough with fairly high air entrainment (Figure 15).

2. The 12-inch jet-flow gate bypass releases a free jet into the previously described outlet works basin (Figure 15). A discharge of 80 cfs was observed. The depth of penetration could not be greater than 19 feet (the basin depth).

3. The auxiliary outlet works is quite similar to the auxiliary outlet works at Navajo Dam. It consists of a nearly horizontal tunnel with slide gate control approximately halfway through its length (Figure 12). The outlet is arranged so that a fairly solid jet dives deep into the spillway stilling basin with relatively low turbulence and air entrainment (Figure 16). The jet appears to stay at the bottom of the basin (a depth of about 30 feet) for the basin's entire length.

At Morrow Point, flows through both the turbines and the outlet works were observed:

1. The turbines were studied under both full production and offpeak conditions (Figure 14). When they are run at offpeak efficiency, they are vented to reduce draft tube surges. This is a common operational technique at Bureau powerplants. In effect, what happens is that at offpeak efficiencies a high amount of angular velocity exists in the draft tube flow. This

is not the case at peak efficiency. This high angular velocity creates a situation where flows in the core of the draft tube become hydrodynamically unstable. This instability causes fluctuations in the head on the turbine and therefore fluctuations in the power output. Now, as previously stated, these fluctuations or surges can be reduced or eliminated by venting. This venting generally consists of opening valves to allow atmospheric air to be drawn into negative pressure regions of the turbine flow. It appears, however, that the venting also may cause significantly higher gas supersaturation. In this case maximum submergence of bubbles in the flow was on the order of 37 feet.

2. In addition to turbine flows, flow through the outlet works was also observed. The outlet works consist of a 3.5- by 3.5-foot gate that discharges a free jet (directed downward at an angle of 30°) into a fairly deep pool (Figure 11). The jet drops approximately 30 feet to the tailwater surface. A discharge of 1,200 cfs (80 percent) was monitored. The jet breaks up somewhat in its free trajectory. It also entrains large amounts of air (Figure 13). The maximum depth of penetration can be no more than 50 feet (the approximate basin depth).

Again, data were taken both in the reservoirs above and on the rivers at various distances below these two dams. The river data were taken for various initial supersaturation levels. At Ruedi, data were also taken above the reservoir on a stream that is not affected by hydraulic structures.

SYNOPSIS OF FIELD TRIP

1. Location: Ruedi Reservoir.

2. Period: June 26 - 29, 1972

3. Log:

June 27 - The analytical equipment in the Mobile Water Quality Laboratory was set up and calibrated. With assistance from Reservoir Superintendent Cliff Held, samples were collected at two depths in the reservoir, at the reservoir surface, in the regular outlet works basin, and at several stations downstream.

The 12-inch bypass was opened to 80 cfs with the regular outlet works closed. After several hours, samples were collected in the regular outlet works basin, and at several downstream stations. Sample temperatures were recorded and the samples analyzed for dissolved nitrogen, oxygen, and carbon dioxide.

June 28 - Since high dissolved nitrogen levels were measured June 27 downstream from the regular outlet works, samples were collected at distances of 0, 0.7, 3, 8, and 12 miles downstream from Ruedi Reservoir while the regular outlet works were discharging 236 cfs. Samples were collected in the river above Ruedi and 0.25 miles below the inlet. The auxiliary outlet works were opened to 236 cfs. After several hours, samples were collected in the auxiliary outlet works basin and at several stations downstream. The samples were analyzed for dissolved nitrogen, oxygen, and carbon dioxide.

4. Conclusions:

a. The stream flowing into Ruedi Reservoir contained 118.9 percent dissolved nitrogen saturation.

b. The reservoir surface samples contained about 99 percent nitrogen saturation.

c. Depth reservoir samples at 185 and 200 feet were 99.1 and 93.7 percent nitrogen saturated, respectively.

d. All outlet works supersaturated the stilling basins with dissolved nitrogen.

e. In general, dissolved nitrogen saturation equaled or exceeded 110 percent saturation at all stations downstream.

f. The Van Slyke dissolved gas analyzer did not function properly, especially with supersaturated waters, and therefore, could not support completely the gas chromatographic data. Due to the high levels of nitrogen observed, further tests should be conducted.

SYNOPSIS OF FIELD TRIP

1. Location: Ruedi and Morrow Point Reservoirs.

2. Period: September 11 - 16, 1972

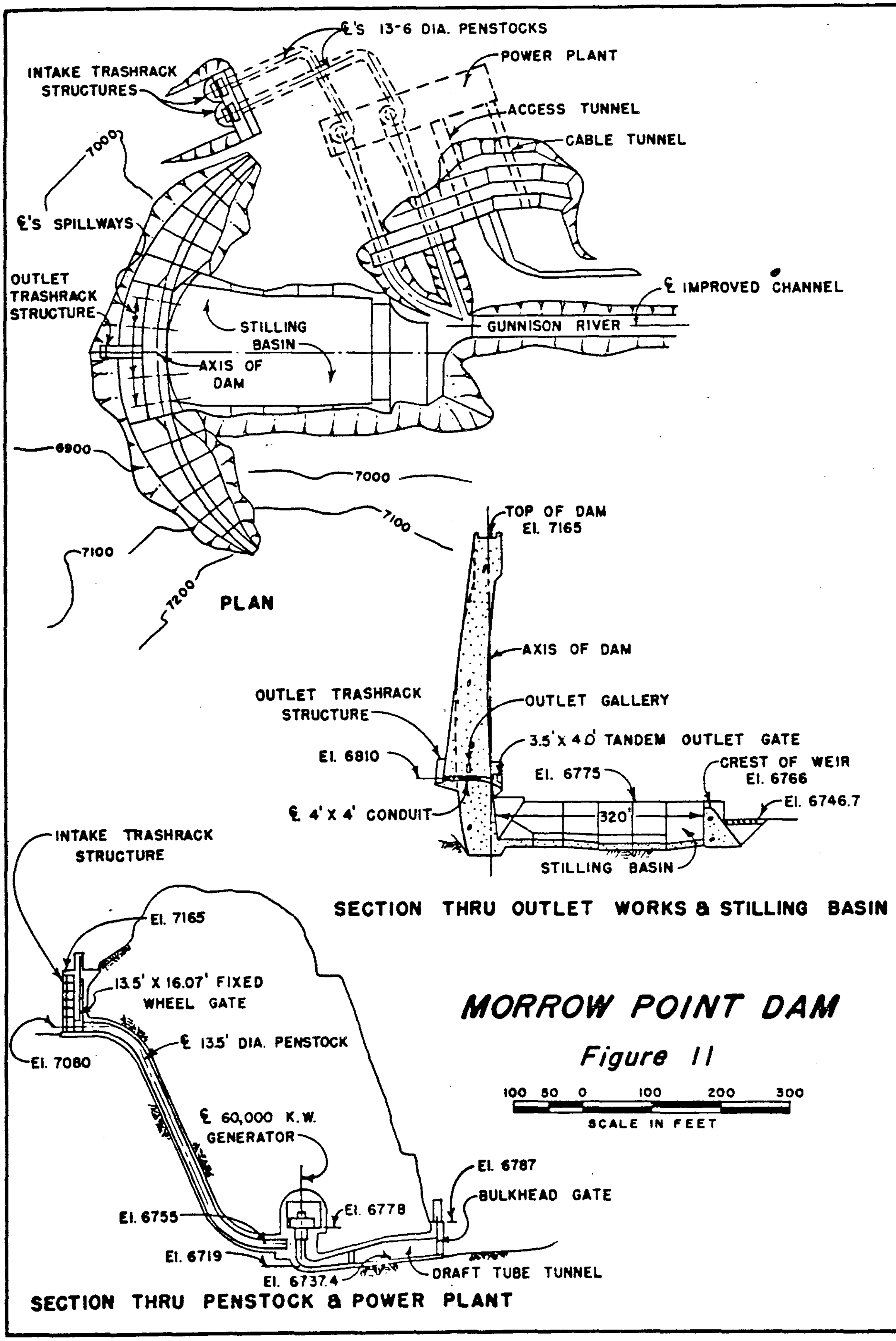
3. Log:

Dissolved oxygen, dissolved nitrogen, pH temperature, and total alkalinity measurements were conducted at Ruedi and Morrow Point Reservoirs. Dr. Ron Garton of the Western Fish Toxicology Station, U.S. Environmental Protection Agency, Corvallis, Oregon, recorded saturometer readings in conjunction with our tests. Nitrogen saturation values of 130 percent were measured at Morrow Point when the turbine outlets were running at 15 and 31 megawatts.

Several fish were caught immediately below the turbines and within one-half mile of the dam. The fish had no evidence of gas bubble disease.

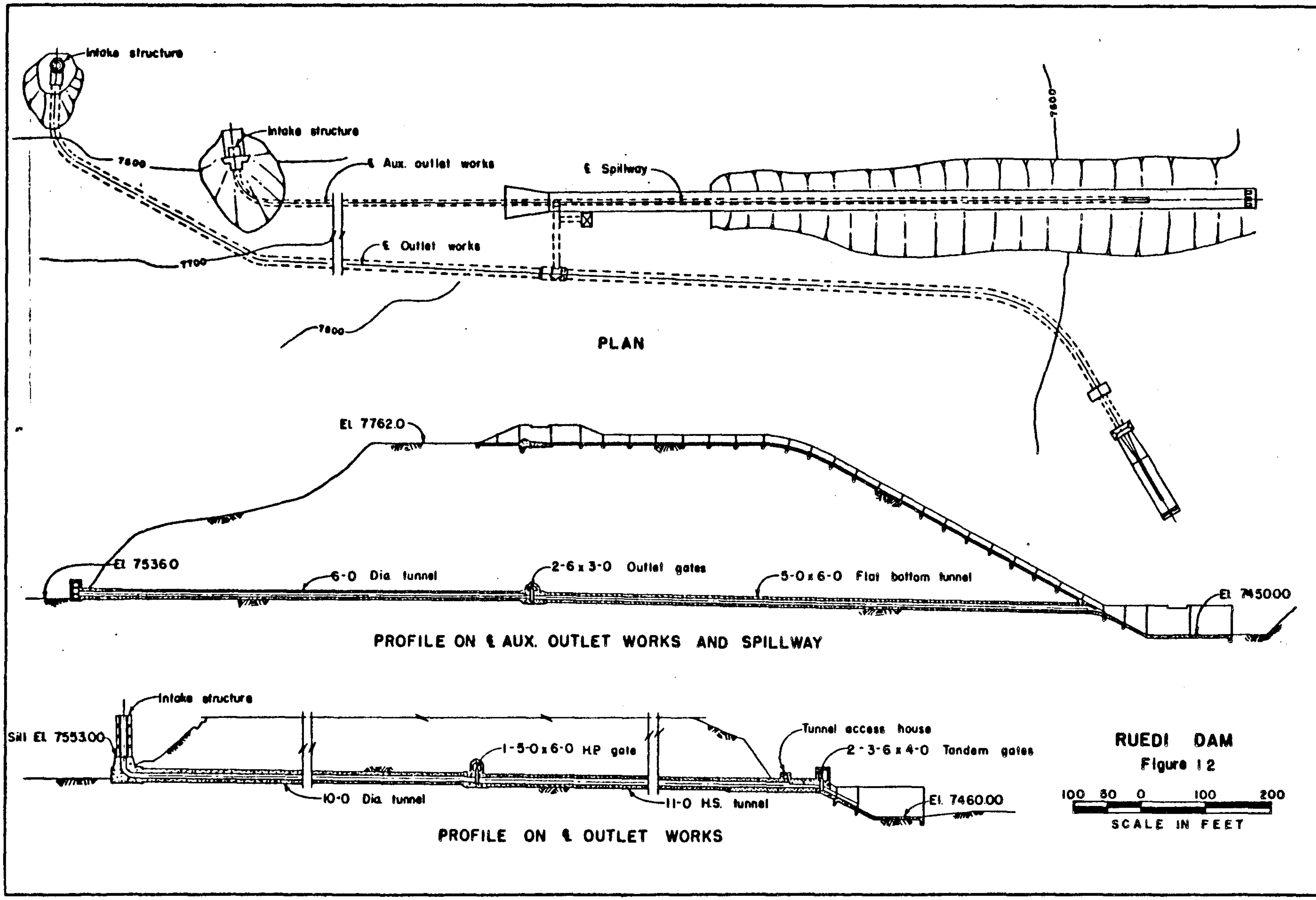
4. Conclusions:

Dissolved gas supersaturation tests were performed at Ruedi and Morrow Point Reservoirs. A question Dr. Garton raised was how did these trout live in highly supersaturated waters without showing evidence of gas bubble disease?



MORROW POINT DAM

Figure 11



RUEDI DAM
Figure 12

Figure 13. Morrow Point outlet works at 1,580 cfs. Photo P622-D-74131

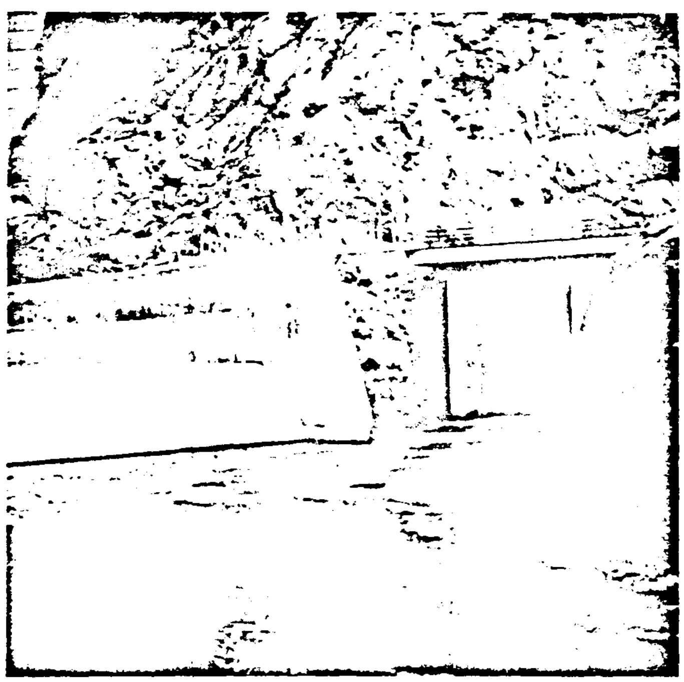


Figure 14. Morrow Point powerplant flow. Photo P622-D-74132

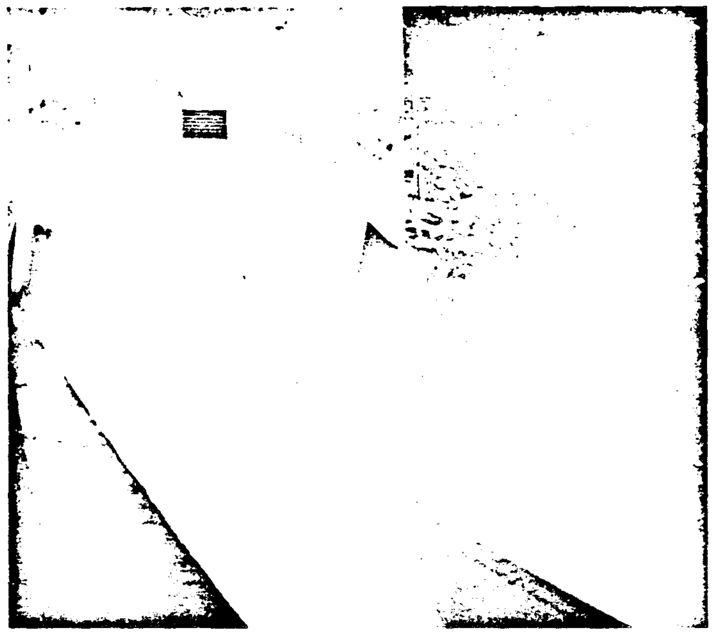


Figure 15. Ruedi outlet works at 270 cfs and 12-inch bypass at 80 cfs. Photo P382-D-74133

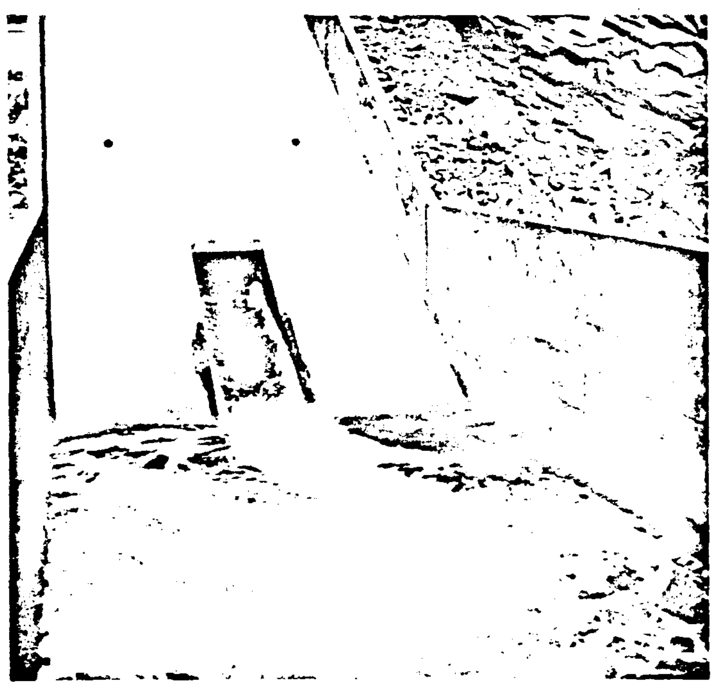


Figure 16. Ruedi auxiliary outlet works at 150 cfs. Photo P382-D-74134

RUEDI RESERVOIR DISSOLVED GAS MEASUREMENTS

Field identification	Date sampled (1972)	Temp. (°C)	CO_2 (ppm)	DO (ppm)	DO (percent saturation)	Percent N_2 saturation	N_2 (ppm)	Remarks
Surface res	6-27	13.8	1.5	7.75	97.7	94	12.1	Regular outlet
Surface res	6-27	14.0	1.0	7.76	98.4	91	11.6	works at
Depth (185 feet)	6-27	7.5	5.6	6.66	72.5	94	13.8	Q = 270 cfs
Depth (200 feet)	6-27	7.5	3.5	6.36	69.3	89	13.1	
Regular outlet works basin	6-27	5.5	3.0	11.17	115.6	117.7*	18.0	
Regular outlet works basin	6-27	5.8	3.0	-		115	17.6	
Regular outlet works basin	6-27	6.4	2.5	11.20	118.6	111	16.7	Bar Press
0.2 mile downstream	6-27	7.0	2.2	11.35	122.0	115	17.1	583-mm Hg
Gaging station (0.7 mile) downstream	6-27	6.8	2.0	11.35	121.5	111	16.6	
Gaging station (0.7 mile) downstream	6-27	6.7	2.0	11.22	119.7	119	17.8	
0.9 mile downstream	6-27	7.0	2.0	11.10	119.4	109	16.2	
1.1 mile downstream	6-27	7.1	2.0	11.29	121.8	115	17.1	
12-inch bypass - regular outlet works basin	6-27	6.4	2.6	10.40	110.2	112	16.9	12-inch bypass at Q = 80 cfs
12-inch bypass - regular outlet works basin	6-27	6.1	3.0	10.31	108.4	112	17.0	
Gaging station (0.7 mile) downstream	6-27	6.5	1.8	10.45	97.1	111	16.7	
2.0 miles downstream	6-27	7.9	-	9.15	100.5	100	14.2	
Regular outlet works basin	6-28	5.8	2.5	11.27	117.4	133	20.3	Regular outlet works at
Gaging station (0.7 mile) downstream	6-28	6.0	3.0	10.82	113.3	132	20.1	Q = 238
3 miles downstream	6-28	6.0	2.0	9.32	97.6	113	17.2	
8 miles downstream	6-28	6.3	2.5	9.25	97.6	116	17.5	
12 miles downstream	6-28	6.3	2.0	9.50	100.2	113	17.1	
River at bridge above dam	6-28	8.2	2.0	8.55	94.6	122	17.7	Auxiliary outlet works at
0.25 mile below inlet (surface)	6-28	16.1	1.5	7.92	104.9	102.5*	12.6	Q = 236 cfs
Auxiliary outlet basin	6-28	7.8	4.0	-		132	19.3	Bar press
Auxiliary outlet basin	6-28	7.4	4.0	10.73	116.3	129	19.0	584-mm Hg
0.2 mile downstream	6-28	10.3	-	9.72	101.4	110	15.2	
Gaging station (0.7 mile)	6-28	7.1	-	10.74	115.6	120	17.8	
0.9 mile downstream	6-28	7.3	-	10.68	115.6	115	17.0	
1.1 mile downstream	6-28	7.4	-	10.44	113.2	122	18.0	
2.0 miles downstream	6-28	9.6	2.0	8.78	100.4	102.9*	14.5	

* Van Slyke procedure.

RUEDI
September 12, 1972
Barometric Pressure = 584 mm Hg

Field identification	Temp °C	pH	DO (ppm)	DO percent saturation	Total alkalinity as $CACO_3$ (ppm)	Percent N_2 saturation (gas chromato.)	N_2 (GC) (ppm)	Percent N_2 saturation (Van Slyke)	N_2 (VS) (ppm)	Total percent saturation (saturometer)
Outlet works at 134 cfs	8.3	8.1	9.88	109	-	120	17.4	110.5	16.0	112.0
Gaging station (1/4 mile)	8.4	8.1	10.44	116	45.4	117	16.9	-	-	112.0
with outlet works at 134 cfs						119	17.2			
3 miles downstream with	8.3	8.0	8.95	99	45.7	101	14.6	-	-	101.2
outlet works at 134 cfs						105	15.2			
8 miles downstream with	8.1	7.9	8.85	97	54.2	111	16.1	-	-	100.3
outlet works at 134 cfs						105	15.3			
12 miles downstream with	8.4	7.9	8.88	98	56.7	-	-	101.9	14.7	100.5
outlet works at 134 cfs										
Reservoir at 200-foot depth	9.7	8.0	5.20	59	43.0	105	14.7	106.3	14.9	-
(opposite intake tower)						108	15.1			
Reservoir at 215-foot depth	9.9	7.8	4.78	55	43.7	108	15.1	-	-	-
(opposite intake tower)										
12-inch bypass at 80 cfs	8.6	8.0	9.30	104	40.5	118	17.0	102.4	14.7	106.3
Gaging station (1/4 mile)	9.4	8.2	10.88	123	44.8	113	16.0	-	-	109.8
with 12-inch bypass at 80 cfs						116	16.4			
and auxiliary at 55 cfs										
3 miles upstream from	10.2	8.2	8.32	96	35.1	96	13.3	96.9	13.4	101.5
Ruedi inlet										
Ruedi inlet lake surface	16.3	7.8	7.25	96	42.8	113	13.8	-	-	101.2
						110	13.5			
Auxiliary outlet works	8.4	7.8	10.05	111	37.3	129	18.6	116.2	16.8	114.6
at 150 cfs						131	18.9			
Gaging station with auxiliary	9.1	8.2	10.55	119	45.4	122	17.3	-	-	115.2
outlet at 150 cfs						125	17.8			
3 miles downstream with	-	-	-	-	-	-	-	-	-	101.7
auxiliary at 150 cfs										

MORROW POINT
September 14 and 15, 1972
Barometric pressure = 604 on September 14
Barometric pressure = 601 on September 15
15 megawatts on each turbine = minimum load 700 cfs/unit
31 megawatts on each turbine = normal load 1,227 cfs/unit
60 megawatts on each turbine = maximum load 2,078 cfs/unit

Field identification	Temp °C	pH	DO (ppm)	DO percent saturation	Total alkalinity as $CACO_3$ (ppm)	Percent N_2 saturation (gas chromato.)	N_2 (GC) (ppm)	Percent N_2 saturation (Van Slyke)	N_2 (VS) (ppm)	Total percent saturation (saturometer)
Turbine No. 1 outlet,	10.9	7.3	9.97	114	78.4	137	19.4	135.6	19.2	-
31 megawatts*						137				
Reservoir, 75 feet, opposite	11.4	6.9	5.55	64	67.8	99.3	13.9	99.8	13.9	-
turbine intake (depth)						99.3				
Reservoir, 345 feet, opposite	6.5	6.8	0.10	1.03	91.3	113	17.6	-	-	-
outlet intake (depth)						118	18.4			
Boat landing (1/4 mile)	11.3	7.7	9.42	109	81.5	133	18.7	-	-	131.5
31 megawatts*						129	18.1			
1/2 mile downstream	-	-	-	-	-	-	-	-	-	128.0
31 megawatts*										
Across from turbines,	11.2	7.7	9.65	111	74.0	132	18.5	129.5	18.2	131.0
31 megawatts*						131	18.4			
Blue Mesa turbine outlet	10.8	6.8	4.48	51	80.1	100	14.2	97.2	13.8	-
(2,400 cfs)										
Blue Mesa 1/4 mile	10.8	6.5	4.48	51	80.5	96.4	13.7	-	-	-
downstream						97.2	13.8			
Boat dock above dam	-	-	-	-	-	-	-	-	-	100.5
(water surface)										
Turbine No. 1 outlet	11.0	6.9	9.90	114	78.3	148	20.9	-	-	-
15 megawatts*						144	20.3			
Turbine No. 2 outlet	10.9	7.0	10.15	116	77.4	146	20.6	-	-	-
15 megawatts*						148	20.9			
Across from turbines	10.9	7.1	9.67	111	78.0	136	19.2	129.2	18.2	130.6
each at 15 megawatts*						140	19.8			

MORROW POINT - Continued

Field identification	Temp °C	pH	DO (ppm)	DO percent saturation	Total alkalinity as $CACO_3$ (ppm)	Percent N_2 saturation (gas chromato.)	N_2 (VS) (ppm)	Percent N_2 saturation (Van Slyke)	N_2 (VS) (ppm)	Total percent saturation (saturometer)
Boat landing (1/4 mile) each at 15 megawatts*	10.9	7.2	9.80	112	76.7	145 141	20.5 19.9	-	-	-
Turbine No. 1 outlet 60 megawatts	11.4	7.1	6.35	74	78.8	98	13.7	99.6	13.9	-
Across from turbines, each at 60 megawatts	11.4	7.4	6.40	74	81.0	99.6	13.9	102.8	14.3	98.3
Boat landing (1/4 mile) each at 60 megawatts	12.0	7.6	6.65	78	80.5	99.2	13.7	-	-	-
Outlet works basin at 1,200 cfs above weir	5.4	7.1	10.80	108	94.5	113 114	18.1 18.2	109.3	17.4	-
Outlet works at 1,200 cfs below weir	5.4	7.6	10.75	108	97.2	117	18.7	112	17.8	113.6
Boat landing (1/4 mile) outlet works at 1,200 cfs	5.6	7.6	10.95	110	96.7	115 112	18.3 17.8	-	-	115.0
Turbine No. 1 outlet, 31 megawatts with air valve closed	11.1	7.7	5.65	65	81	97.3 96.5	13.7 13.6	-	-	-
Across from turbines, 31 megawatts with air valve closed	11.1	7.6	5.82	67	80.5	102 101	14.4 14.2	102	14.3	93.5
Boat landing (1/4 mile) 31 megawatts with air valve closed	11.2	7.6	6.05	70	79.4	103 105	14.5 14.8	-	-	97.0
Crystal damsite 8 miles downstream, 31 megawatts	-	-	-	-	-	-	-	-	-	101.7

* Air valve open.

Yellowtail Dam

As was mentioned in the introduction, a minor fish kill was observed below Yellowtail Afterbay Dam in April of 1973. This observation precipitated the monitoring of not only the flow through the Afterbay Dam but also through the powerplant turbines. Turbine flow was monitored for both offpeak vented conditions and full-load conditions. No additional supersaturation was found to result from the vented condition. The probable maximum submergence of bubbles in the vented flow is 22 feet (Figure 17). At the Afterbay Dam only flow through the sluiceway was observed. The sluiceway consists of a low, slide-gate-controlled chute that discharges into a conventional hydraulic jump basin (Figure 18). Discharges of between 2,500 and 5,000 cfs were observed through this structure. The probable maximum depth of penetration is 13 feet which is approximately the basin depth. The observed flow had a moderate amount of turbulence and air entrainment (Figure 19). In addition, a considerable amount of data was collected on the river below the afterbay dam. These data came from six stations ranging from 1/4 mile to 20 miles downstream from the structure.

SYNOPSIS OF FIELD TRIP

1. Location: Yellowtail Dam.

2. Period: May 13 - 15, 1973

3. Log:

Dissolved oxygen, dissolved nitrogen, and total gas saturation measurements were conducted at Yellowtail Dam, at the Afterbay Dam, and at several stations downstream.

Total gas saturation measured in the Yellowtail Powerhouse tailrace (Station 8) was 99 percent for the turbines discharging 1,814 cfs at 60 megawatts. One turbine discharging 946 cfs at 30 megawatts measured 100 percent total gas saturation. This turbine was vented but caused no supersaturation.

The discharges through the Afterbay Dam sluiceway gates were varied and the total gas saturation levels downstream monitored. At Station 2, total gas saturation was 110 and 113-115 percent at 3,550 cfs when the Afterbay Reservoir elevation was 3178.9 and 3186.4 feet, respectively. Total gas saturation at Station 2 (elevation 3186.4 feet) varied from 115 percent at 2,500 cfs to 111 percent at 5,000 cfs.

The Big Horn River below the Afterbay Dam is quite tranquil at flows over 2,500 cfs. At a discharge of 3,550 cfs through the sluiceway gates, total gas saturation measured 8 and 20 miles downstream was 109 and 108 percent, respectively.

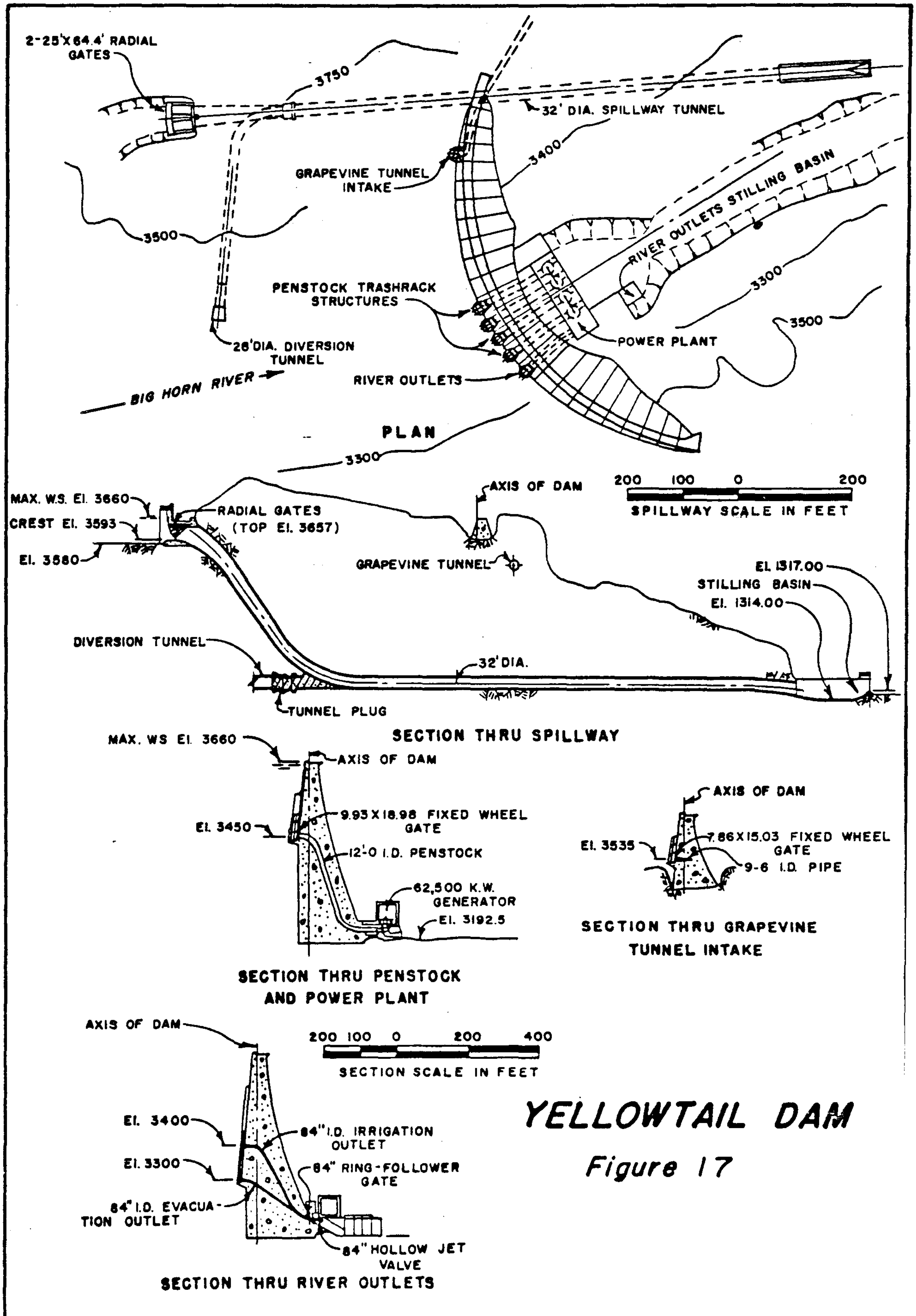
Mr. Eley Denson of the UMR was trained in the use of the Weiss saturometer and is currently using it to obtain additional measurements. Several fish caught approximately one-fourth mile below the sluiceway gates by personnel of the Montana Park Service showed signs of gas bubble disease.

4. Conclusions:

As the flow through the sluiceway gates is increased above 2,500 cfs, the total gas saturation decreases. However, all values are greater than the total gas saturation values currently being recommended by the Environmental Protection Agency.

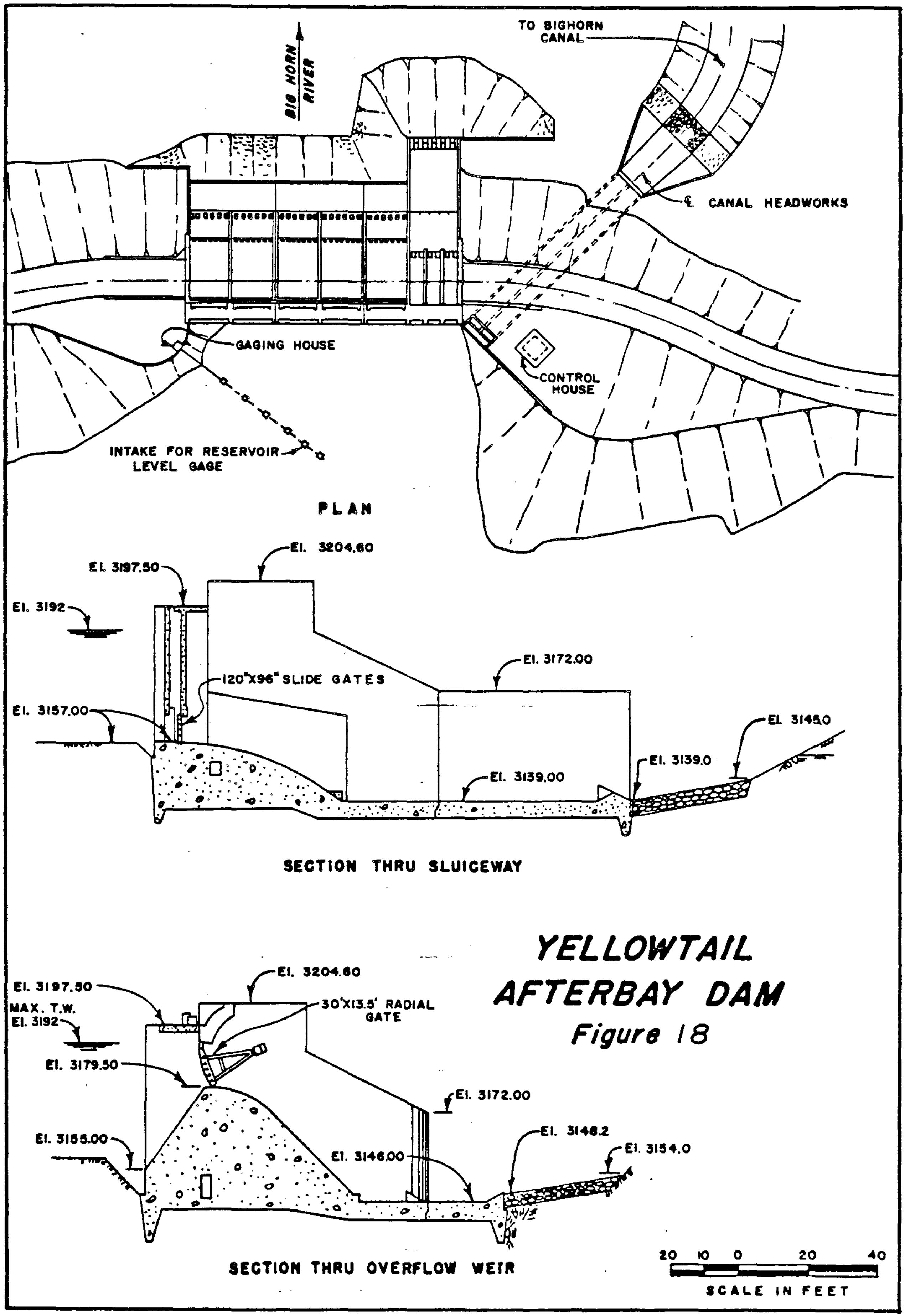
Further biological examination of the fish downstream from the Afterbay Dam during periods of supersaturation should be made.

Station	Field Identification
1	North side of Afterbay Dam immediatley downstream
2	South side of Afterbay Dam immediately downstream from sluiceway
3	Gaging station - ∿ 1/4 mile downstream from Afterbay Dam
4	∿ 1/2 mile downstream from Afterbay Dam
5	∿ 1-1/4 miles downstream from Afterbay Dam
7	Reservoir side of Afterbay Dam
8	Immediately below Yellowtail Powerhouse
10	Yellowtail Reservoir taken from dam boat landing



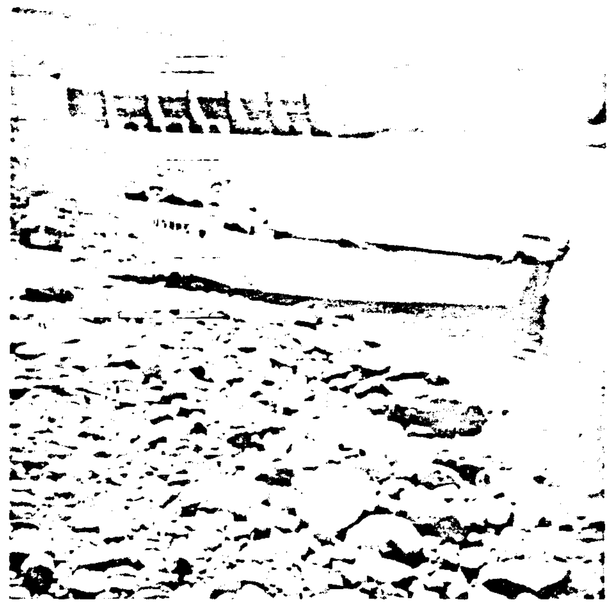
YELLOWTAIL DAM

Figure 17

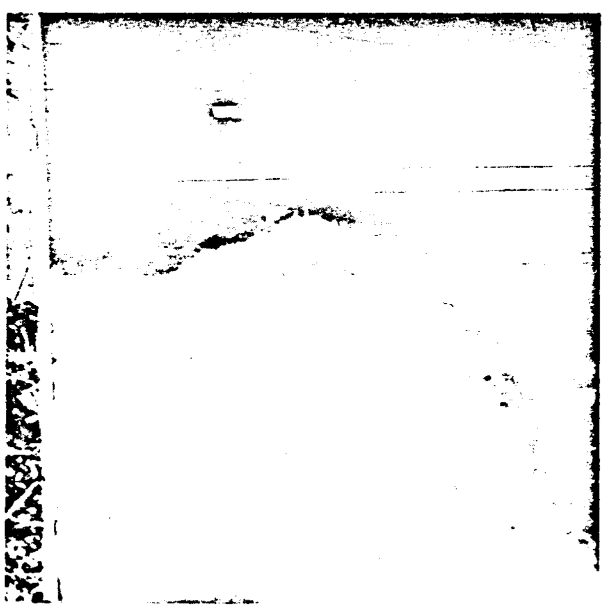


YELLOWTAIL AFTERBAY DAM

Figure 18



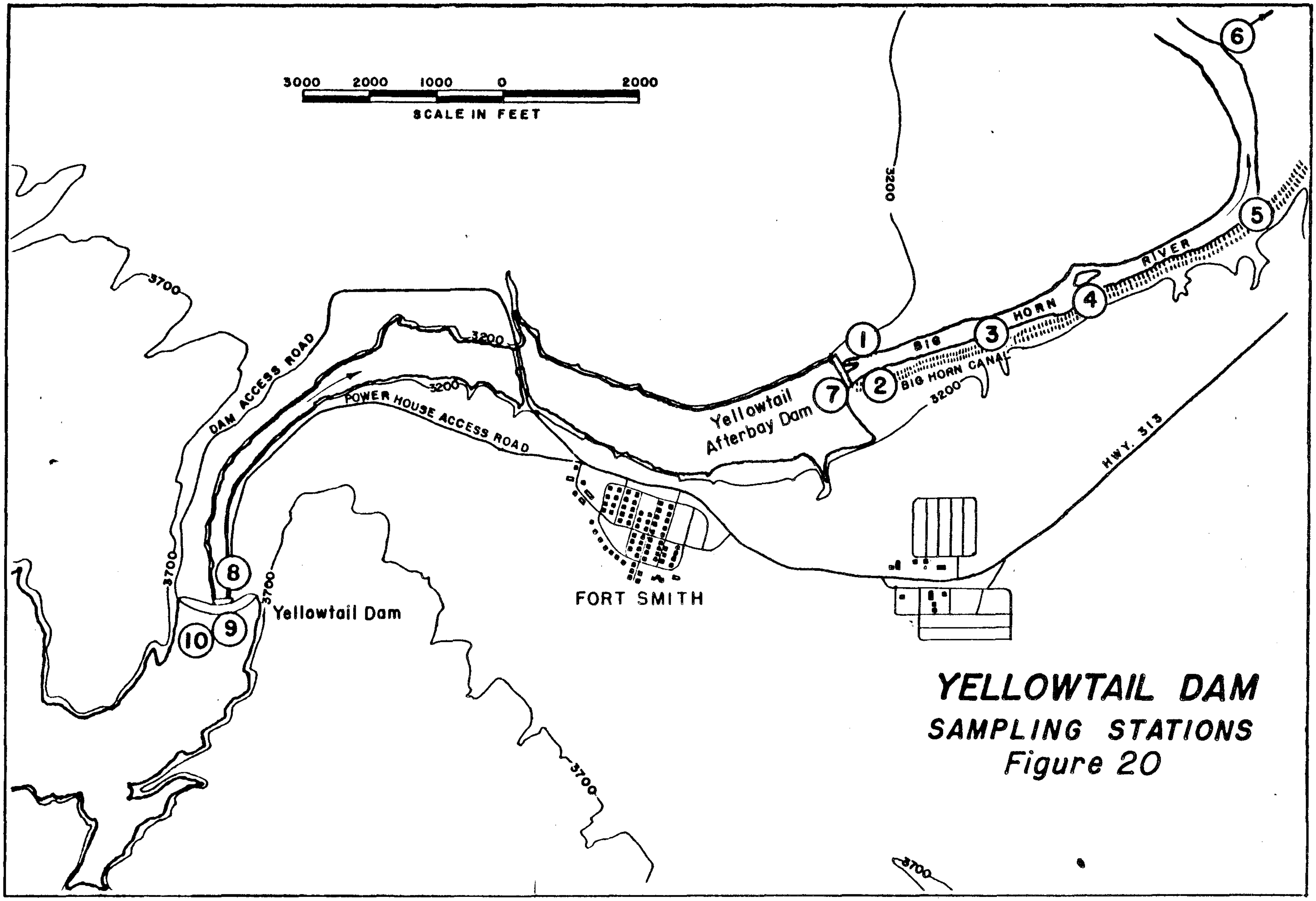
Afterbay Dam. Photo P459-D-74135



Flow beneath slide gates.
Photo P459-D-74136

Flow in sluiceway hydraulic jump basin. Photo P459-D-74137

Figure 19. Yellowtail Afterbay sluiceway at 5,000 cfs.



YELLOWTAIL DAM
SAMPLING STATIONS
Figure 20

YELLOWTAIL DISSOLVED GAS MEASUREMENTS

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Percent sat. N_2+AR	ppm N_2	Percent sat. O_2	ppm O_2**	Total percent sat.
8 - Turbine No. 2 30 mw, venting		946		5.0	105		78.4	8.95	100
8 - Turbines No. 3 and 4 60 mw, air valve closed		1,814		5.0	105		78.3	8.94	100
10			8:00 am	6.6	107		95.7	10.49	104
10 - Depth of 214 feet			8:30 am	5.0	105		76.0	8.67	99
10 - Depth of 214 feet			8:30 am	5.0	103*	18.62	76.0	8.67	
2	3178.9	3,550	10:45 am	4.1	112*	20.85	96.2	11.25	110
2	3178.9	3,550	10:45 am	4.1	114		96.2	11.25	
2	3186.4	2,500	2:15 pm	4.8	117		104	11.87	114
2	3186.4	2,500	2:15 pm	4.8	113*	20.68	104	11.87	

YELLOWTAIL DISSOLVED GAS MEASUREMENTS - Continued

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Percent sat. N_2+AR	ppm N_2	Percent sat. O_2	ppm O_2**	Total percent sat.
2	3186.7	3,550	7:10 pm	4.8	110*	20.19	100	11.45	
2	3186.7	3,550	7:10 pm	4.8	117		100	11.45	113
2	3186.4	3,000	3:30 pm	5.0	118		103.4	11.8	115
2	3186.7	5,000	6:20 pm	4.8	110*	20.19	98.9	11.35	
2	3186.7	5,000	6:20 pm	4.8	115		98.9	11.35	111
7	3186.4		3:45 pm	6.5	103		85.7	9.42	100
7	3186.4		3:45 pm	6.5	105*	18.41	85.7	9.42	
8 - Turbine No. 1 40 mw Turbine No. 2 60 mw			8:45 am	3.5	100		72.5	8.60	94
8 - Turbine No. 1 40 mw Turbine No. 2 60 mw			8:45 am	3.5	96*	18.25	72.5	8.60	

YELLOWTAIL DISSOLVED GAS MEASUREMENTS

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Percent sat. N_2+AR	ppm N_2	Percent sat. O_2	ppm O_2**	Total percent sat.
8 - Turbine No. 2 30 mw, venting		946		5.0	105		78.4	8.95	100
8 - Turbines No. 3 and 4 60 mw, air valve closed		1,814		5.0	105		78.3	8.94	100
10			8:00 am	6.6	107		95.7	10.49	104
10 - Depth of 214 feet			8:30 am	5.0	105		76.0	8.67	99
10 - Depth of 214 feet			8:30 am	5.0	103*	18.62	76.0	8.67	
2	3178.9	3,550	10:45 am	4.1	112*	20.85	96.2	11.25	110
2	3178.9	3,550	10:45 am	4.1	114		96.2	11.25	
2	3186.4	2,500	2:15 pm	4.8	117		104	11.87	114
2	3186.4	2,500	2:15 pm	4.8	113*	20.68	104	11.87	

YELLOWTAIL DISSOLVED GAS MEASUREMENTS - Continued

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Percent sat. N_2+AR	ppm N_2	Percent sat. O_2	ppm O_2**	Total percent sat.
2	3186.7	3,550	7:10 pm	4.8	110*	20.19	100	11.45	
2	3186.7	3,550	7:10 pm	4.8	117		100	11.45	113
2	3186.4	3,000	3:30 pm	5.0	118		103.4	11.8	115
2	3186.7	5,000	6:20 pm	4.8	110*	20.19	98.9	11.35	
2	3186.7	5,000	6:20 pm	4.8	115		98.9	11.35	111
7	3186.4		3:45 pm	6.5	103		85.7	9.42	100
7	3186.4		3:45 pm	6.5	105*	18.41	85.7	9.42	
8 - Turbine No. 1 40 mw Turbine No. 2 60 mw			8:45 am	3.5	100		72.5	8.60	94
8 - Turbine No. 1 40 mw Turbine No. 2 60 mw			8:45 am	3.5	96*	18.25	72.5	8.60	

YELLOWTAIL DISSOLVED GAS MEASUREMENTS - Continued

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Percent sat. N_2+Ar	ppm N_2	Percent sat. O_2	ppm O_2**	Total percent sat.
12 miles downstream		3,550	11:30 am	7.2	108		115	12.4	109
12 miles downstream		3,550	11:30 am	7.2	109*		115	12.4	
20 miles downstream		3,550	12:30 am	7.0	106		113	12.27	108
2	3186.4	4,250	5:15 pm	5.0	116		99.4	11.34	113
1	3186.4	4,250	5:00 pm	5.0	115		100.8	11.50	
1	3186.4	4,250	5:00 pm	5.0	111*	20.24	100.8	11.5	
1	3186.7	5,000	6:00 pm	4.9	115		98.9	11.42	
3	3178.9	3,550	10:45 pm	4.2	113		95.4	11.12	109
3	3186.4	3,000	3:20 pm	5.2	119		102.6	11.65	115
3	3186.4	3,500	4:25 pm	5.1	118		102.8	11.70	115
3	3186.7	5,000	6:40 pm	5.0	114		99.9	11.40	111

YELLOWTAIL DISSOLVED GAS MEASUREMENTS - Continued

Station and conditions[1]	Afterbay reservoir elev	cfs	Time	Temp °C	Per-cent sat. N_2+Ar	ppm N_2	Per-cent sat. O_2	ppm O_2**	Total per-cent sat.
4	3178.9	3,550	10:10 am	4.2	112		98.3	11.45	109
4	3186.4	2,500	2:30 pm	4.8	118		109	12.45	116
5	3178.9	3,550	9:30 am	4.3	112		98.7	11.47	110
5	3178.9	3,550	9:30 am	4.3	111*	20.72	98.7	11.47	
5 - On bank	3178.9	3,550	9:45 am	4.2	111		100	11.65	109
5	3186.4	2,500	2:45 pm	4.9	117		110	12.60	115

* Van Slyke, other N_2+Ar measurements by Saturometer.
** Winkler method.
[1] See Figure 20.

Silver Jack Dam

At Silver Jack, only spillway flow was observed. The spillway consists of a morning-glory intake which feeds a sloped tunnel that discharges its free surface flow into a shallow, highly baffled basin (Figure 21). Discharges from 740 to 800 cfs were observed. The maximum depth of penetration is 17 feet. Moderate to high turbulence and air entrainment were observed in the basin (Figure 22).

SYNOPSIS OF FIELD TRIP

1. Location: Silver Jack Dam.

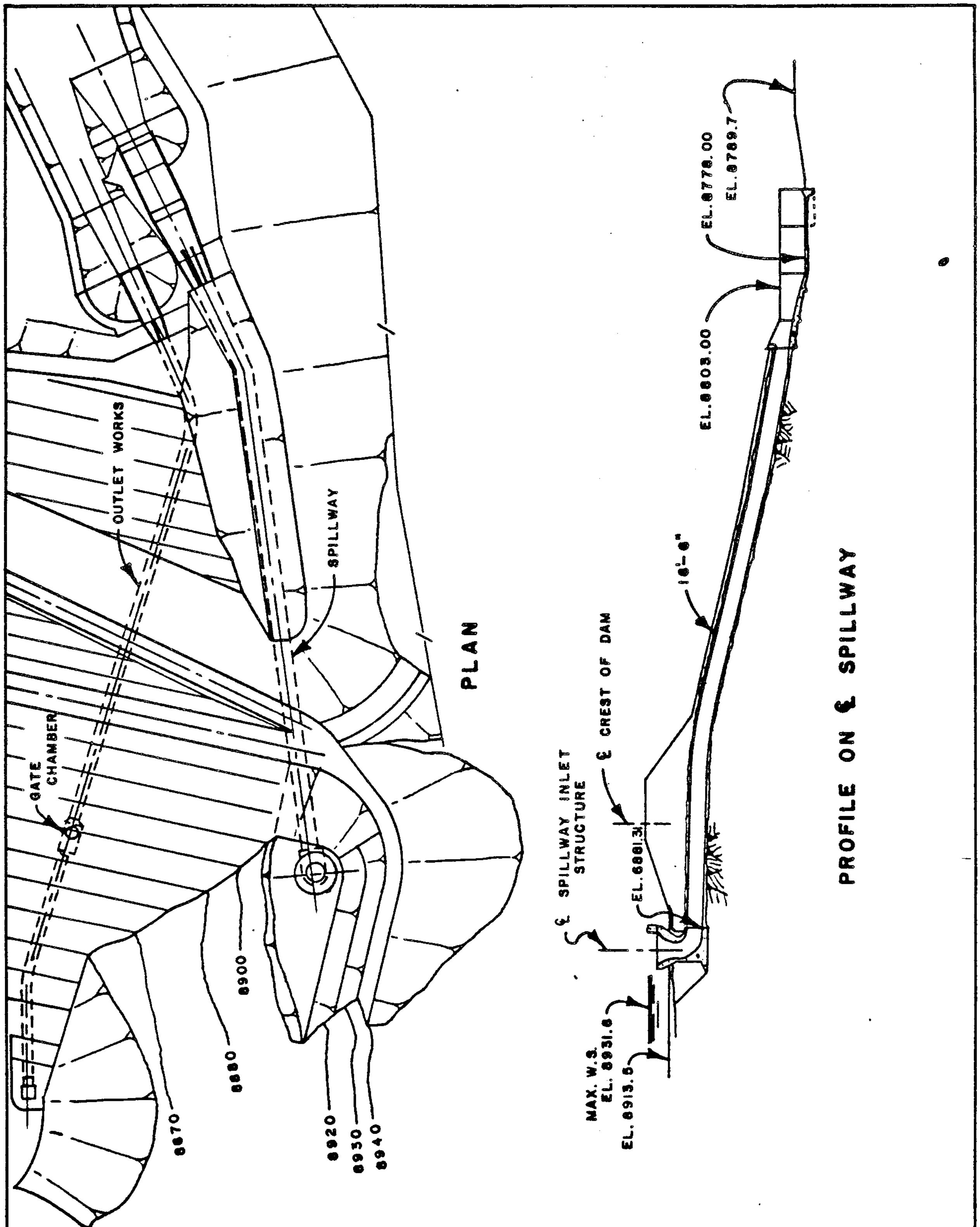
2. Period: June 13 - 14, 1973

3. Log:

   Tests were conducted in the reservoir, at the end of the spillway stilling basin, in the river one-fourth mile downstream to determine the quantity of dissolved oxygen and dissolved nitrogen present in the water. The data indicate an increase of 2 percent in dissolved nitrogen and a maximum increase of 6 percent in dissolved oxygen of the water traveling through the spillway structure. Data were not obtained for the regular outlet works as necessary repairs prevented its operation.

4. Conclusions:

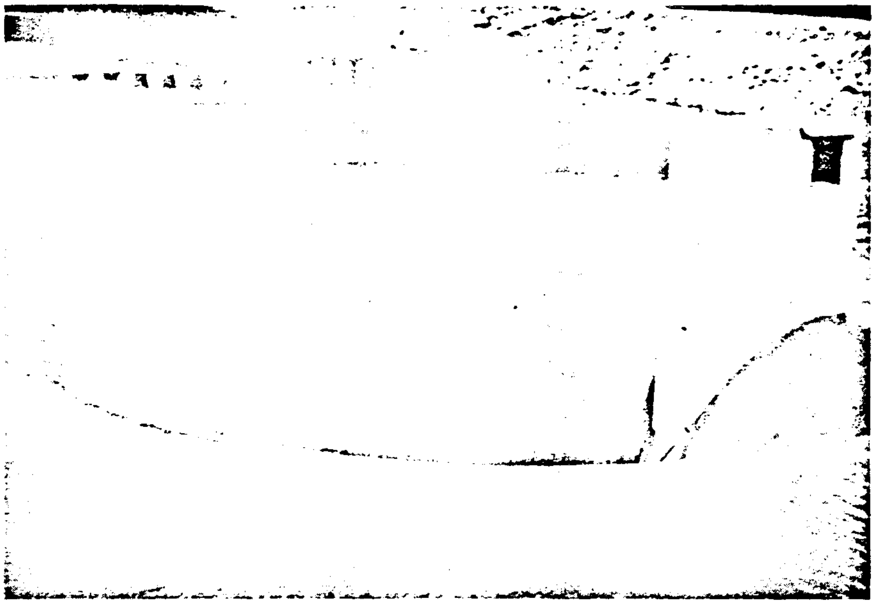
   Increase in dissolved gas through the spillway structures was minimal; total dissolved gas supersaturation was well within limits of safe operation and in the same order as for natural streams.



SILVER JACK DAM

FIGURE 21

100 50 0 100 200
SCALE IN FEET



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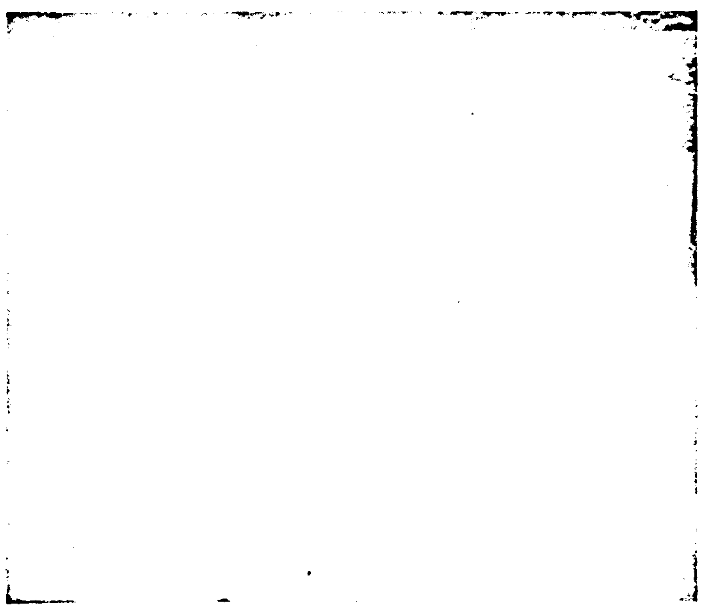


Photo P860-D-74139

Figure 22. Silver Jack spillway at 800 cfs.

SILVER JACK DAM
June 13, 1973
Reservoir elevation 8927.05 feet
Spillway discharge 740 cfs
Tailrace elevation 8792.6 feet

Location	Time	Temp °C	DO (ppm)	Per-cent sat. DO	Per-cent sat. total	Per-cent sat. N_2+AR	N_2 (ppm)
Reservoir surface	1450	6.0	9.15	92	104	107	17.1
End of spillway	1545	5.5	9.87	98	106	109	17.6
1/4 mile downstream	1610	5.7	9.75	97	106	108	17.4

June 14, 1973
Reservoir elevation 8927.15 feet
Spillway discharge 800 cfs
Tailrace elevation 8792.6 feet

Location	Time	Temp °C	DO (ppm)	Per-cent sat. DO	Per-cent sat. total	Per-cent sat. N_2+AR	N_2 (ppm)
End of spillway	1045	7.0	9.66	99	107	109	17.0
1/4 mile downstream	1110	7.0	9.47	97	106	108	16.8
Reservoir manometer tap	1145	5.0	8.93	87	102	106	17.3
Reservoir surface	1300	8.0	9.27	98	105	107	16.3
Reservoir 10 feet	1345	7.2	9.25	95	105	107	17.0

Seminoe, Kortes, Pathfinder, Alcova, Gray Reef, and Glendo Dams and Fremont Canyon Powerplant

As stated in the introduction, high discharges on the North Platte River created a situation where many spillways operated. Since spillway operation, especially with relatively high discharges, is not common, it was decided that monitoring of these flows should be undertaken. In addition, this supplied an opportunity to monitor various outlet works and powerplant discharges that might be of interest.

At Seminoe Dam, spillway and turbine discharges were observed. The turbine discharges were at somewhat offpeak levels but no information as to whether turbine venting was or was not occurring was obtained. No apparent increase in gas saturation was observed as the flow passed through these turbines. The spillway is a fixed-wheel gate-controlled tunnel (Figure 23). As Figure 23 shows, the tunnel has a fairly long horizontal reach prior to its end at the river channel. This establishes a horizontal free jet that drops about 10 feet from the tunnel outlet to the river water surface. The observed spillway discharge was 6,360 cfs or about 15 percent of capacity. The flow at the river channel was very turbulent with a high degree of air entrainment (Figure 29).

At Kortes Dam the turbine and spillway flows were again monitored. The turbine flows were at peak efficiency. No increase in supersaturation was observed through them. The spillway is quite similar to Seminoe except that its crest is not controlled (Figure 24). At the observed discharge of 5,410 cfs the flow at the river channel was again very turbulent with a high degree of air entrainment (Figure 30). As at Seminoe, the situation is one in which the probable maximum jet penetration is quite shallow.

At Pathfinder the spillway and two 58-inch needle valves were operating. The spillway consists of an uncontrolled flat-crested weir with a waterfall-type flow down the canyon wall (Figure 25). The observed flow of 3,900 cfs was very turbulent with a great deal of air entrainment (Figure 31). The needle valves (the north outlet in Figure 25) were discharging at their maximum capacity of 1,000 cfs each. The free jet from these valves is likewise very turbulent with a great deal of air entrainment (Figure 31).

Fremont Canyon Powerplant is supplied by a 3-mile-long tunnel from Pathfinder Reservoir. Its turbine releases were monitored for peak efficiency conditions. Samples of the flow above the units were taken from taps in the penstocks.

At Alcova Dam, turbine and spillway flows were again monitored. The turbine flows were only observed at maximum capacity. The spillway is a fixed-wheel gate-controlled chute with a conventional hydraulic jump basin (Figure 26). A relatively small discharge of 2,100 cfs or 4 percent of capacity was observed. The basin depth, and therefore the deepest possible penetration is 29 feet. The small relative discharge may, however, result in a penetration less than this maximum. The flow in the basin had only moderate turbulence and air entrainment (Figure 32).

Gray Reef is a low-head river regulation structure. It has a radial-gate-controlled spillway with a conventional hydraulic jump basin (Figure 27). It was observed passing a discharge of 5,950 cfs. The probable depth of penetration was approximately 20 feet. Flow in the stilling basin had moderate turbulence and air entrainment (Figure 33).

The final structure observed in this series of tests was the outlet works at Glendo Dam. These outlet works consist of a nearly horizontal tunnel with high-pressure slide-gate control on the downstream end (Figure 28). The gates are tilted so that the outflow will penetrate the fairly shallow, highly baffled, hydraulic jump basin. The probable deepest penetration of the jet is 24 feet. The flow in the basin was highly turbulent with a great deal of air entrainment (Figure 34).

In addition to this information, data were taken in all reservoirs involved with these tests. Data were also taken at various locations along the river as time and access allowed.

SYNOPSIS OF FIELD TRIP

1. Location: Fremont Powerplant and Seminoe, Kortes, Pathfinder, Alcova, Gray Reef, and Glendo Dams.

2. Period: May 30 to June 1, 1973

3. Log:

Dissolved oxygen, dissolved nitrogen, and total gas saturation measurements were conducted at Seminoe, Kortes, Pathfinder, Fremont Powerplant, Alcova, Gray Reef, and Glendo Dams.

All of the following values are total percent gas saturation.

The reservoir surface of Seminoe Dam was 101 percent while the spillway discharge increased to 108 percent. Listed in downstream order from Seminoe, all reservoir surfaces remained supersaturated with Kortes having 107 percent, Pathfinder 107 percent, Alcova 108 percent, Gray Reef 111 percent, and Glendo, much further downstream, 102 percent.

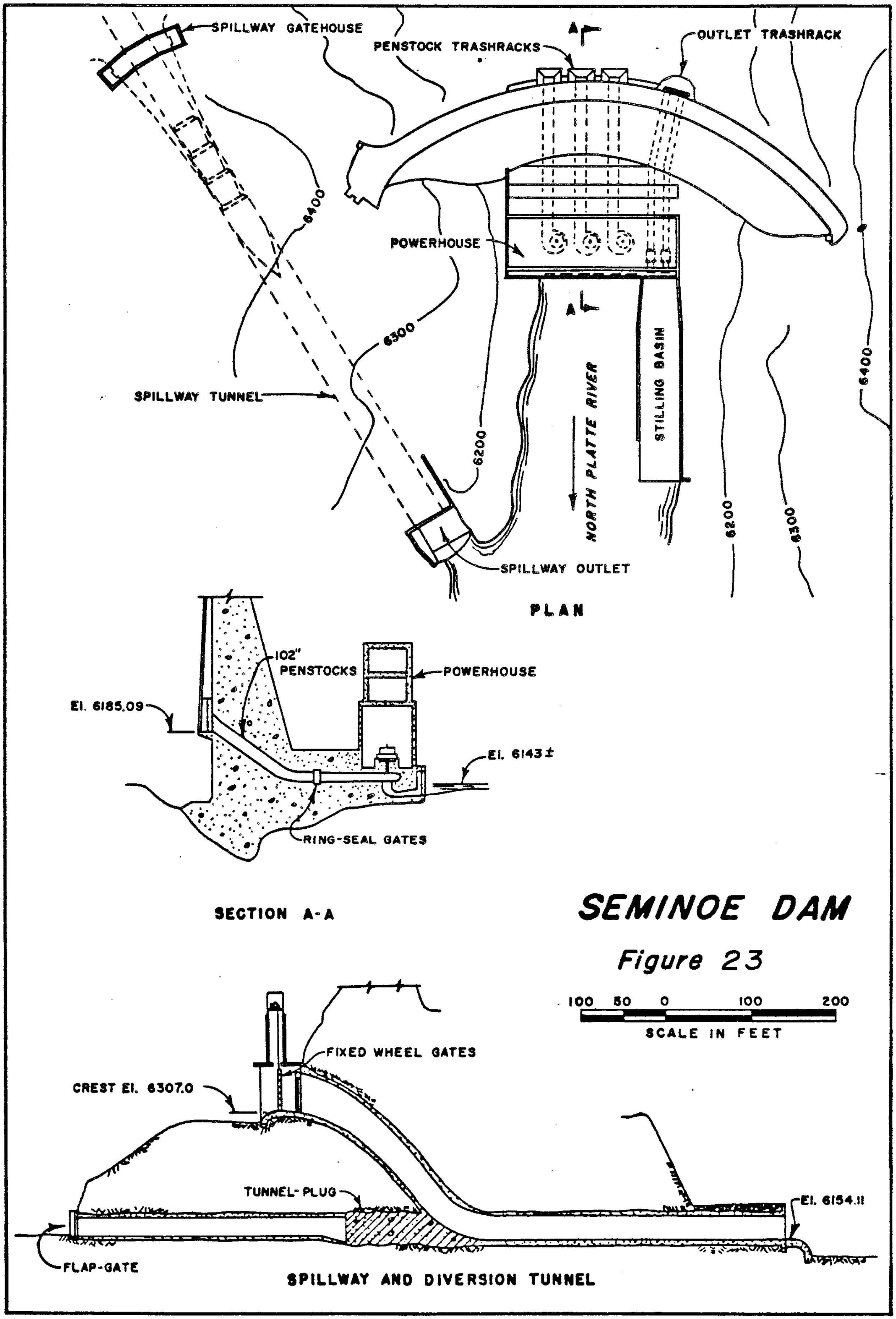
Below the spillways, total gas saturation measured 107 percent at Kortes, 110 percent at Pathfinder, 112 percent at Alcova, and 112 percent at Gray Reef. The outlet works at Glendo measured 102 percent.

All turbine releases were 105 percent or less.

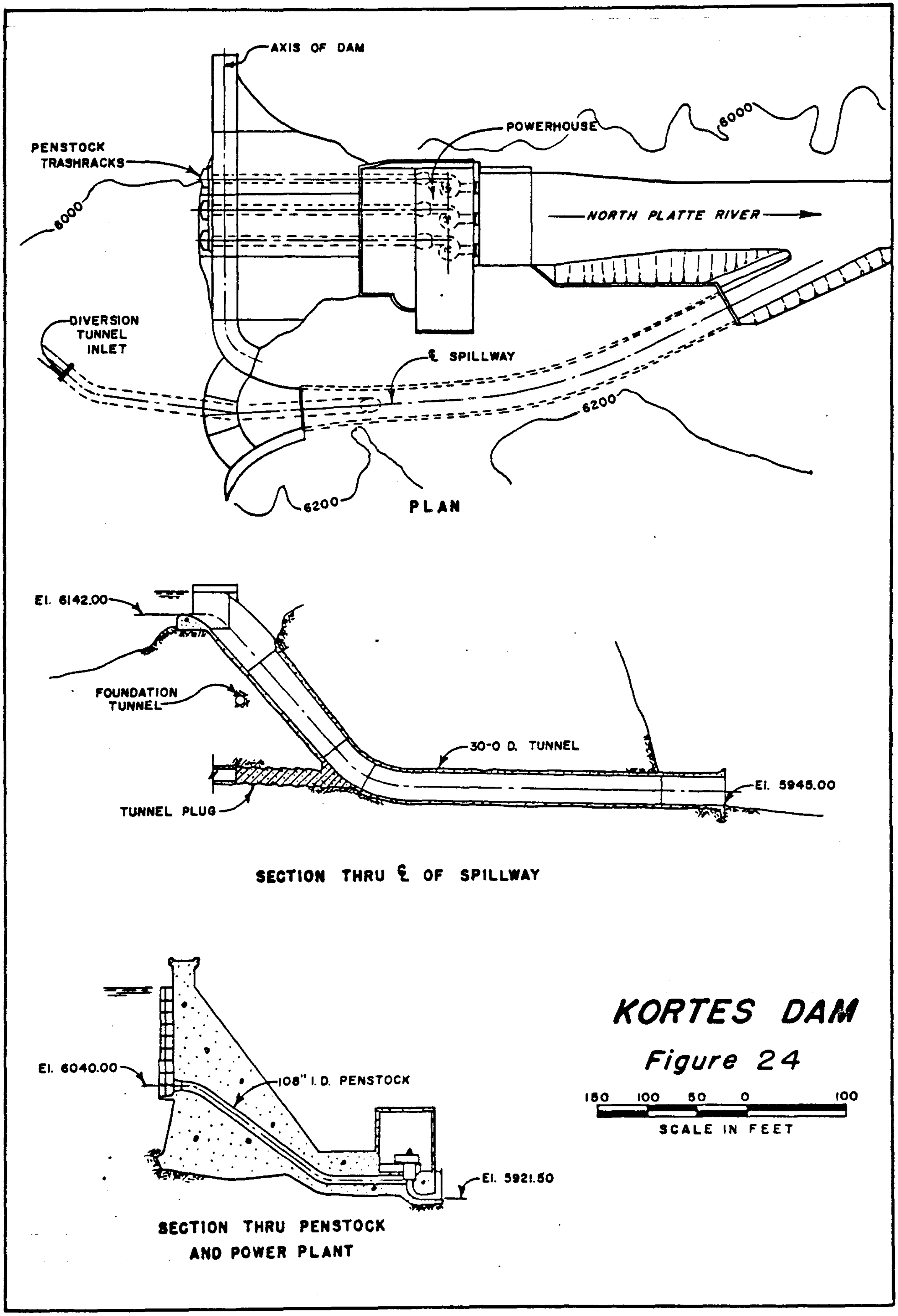
Below Gray Reef, total percent gas saturation was measured to determine the gas dissipation rate. At Bolton Creek Road, ~8 miles downstream, total gas saturation values were 113 percent, at Casper ~32 miles, 105 percent, and at Olin Bridge, close to headwaters of Glendo, 99 percent.

4. Conclusions:

After the first spill at Seminoe Dam, total gas saturation downstream remained between 107 and 112 percent. Dissipation of the dissolved gases required approximately 33 miles below the last dam, Gray Reef, to drop to levels below which fish embolism disease is not considered to be a problem. These values are low compared to spills measured on the Columbia River of greater than 130 percent.

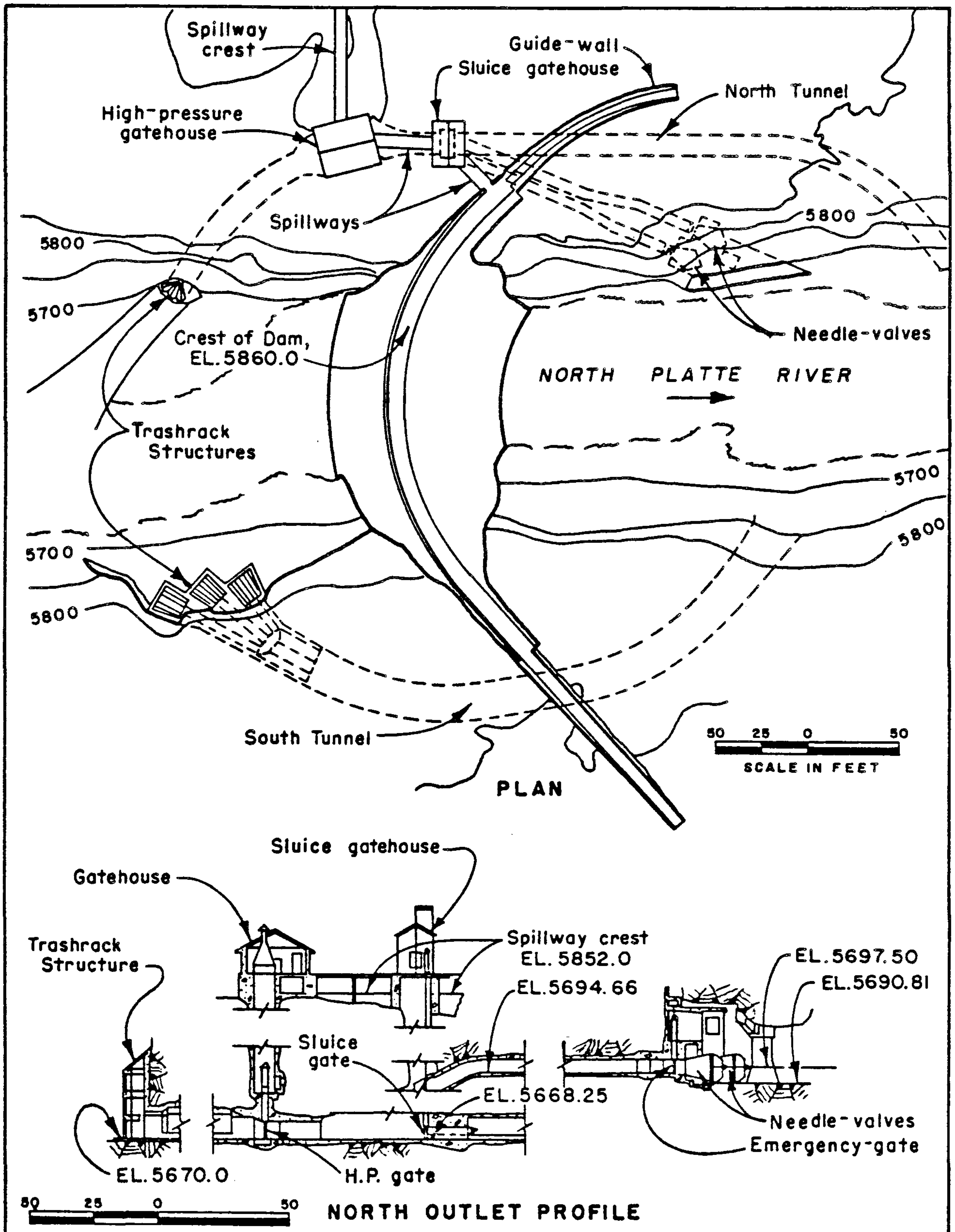


SPILLWAY GATEHOUSE
PENSTOCK TRASHRACKS
OUTLET TRASHRACK
A
POWERHOUSE
6400
6300
6200
SPILLWAY TUNNEL
STILLING BASIN
NORTH PLATTE RIVER
SPILLWAY OUTLET
PLAN
102" PENSTOCKS
POWERHOUSE
El. 6185.09
El. 6143±
RING-SEAL GATES
SECTION A-A
SEMINOE DAM
Figure 23
100 50 0 100 200
SCALE IN FEET
FIXED WHEEL GATES
CREST El. 6307.0
TUNNEL-PLUG
El. 6154.11
FLAP-GATE
SPILLWAY AND DIVERSION TUNNEL

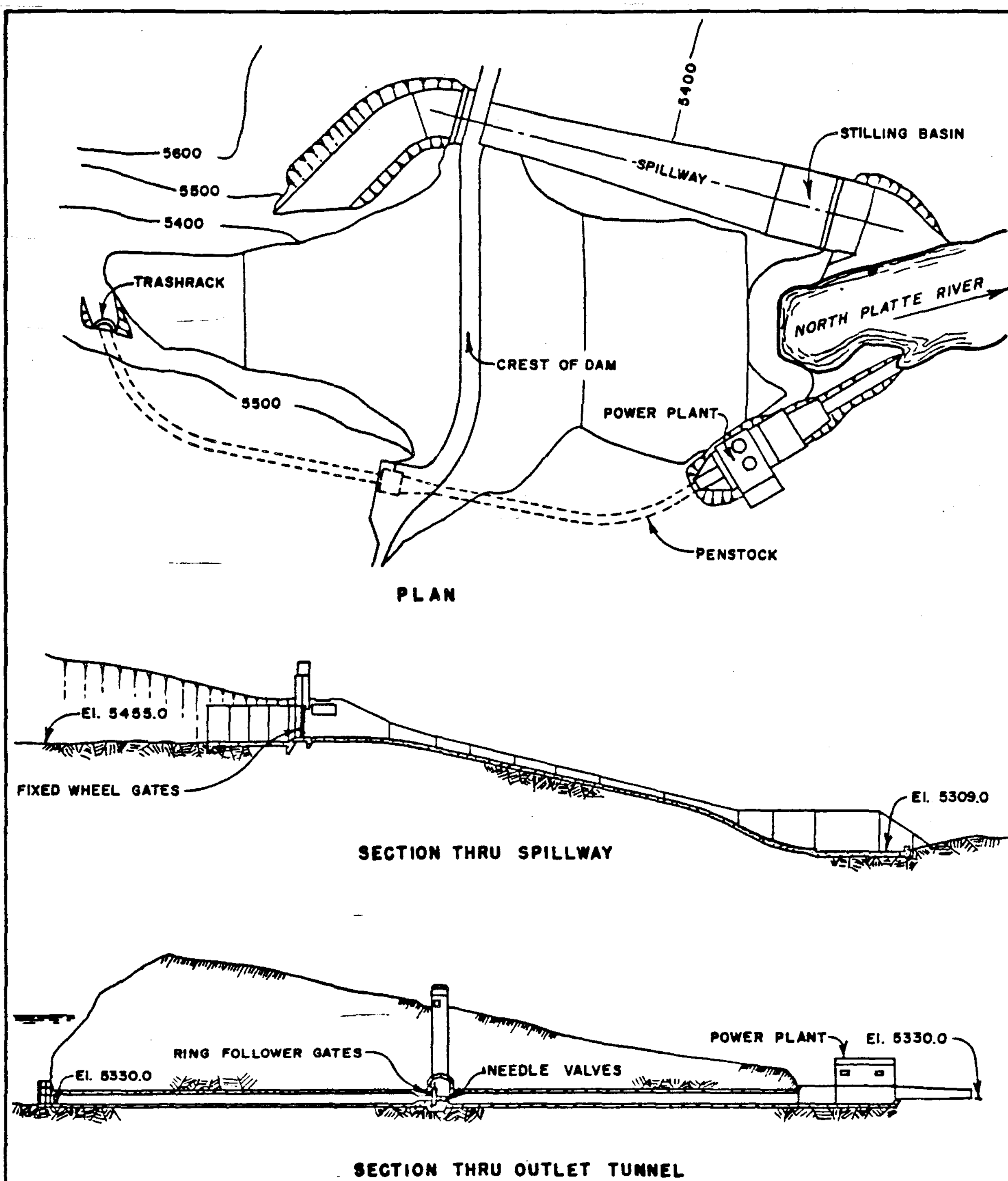


KORTES DAM

Figure 24

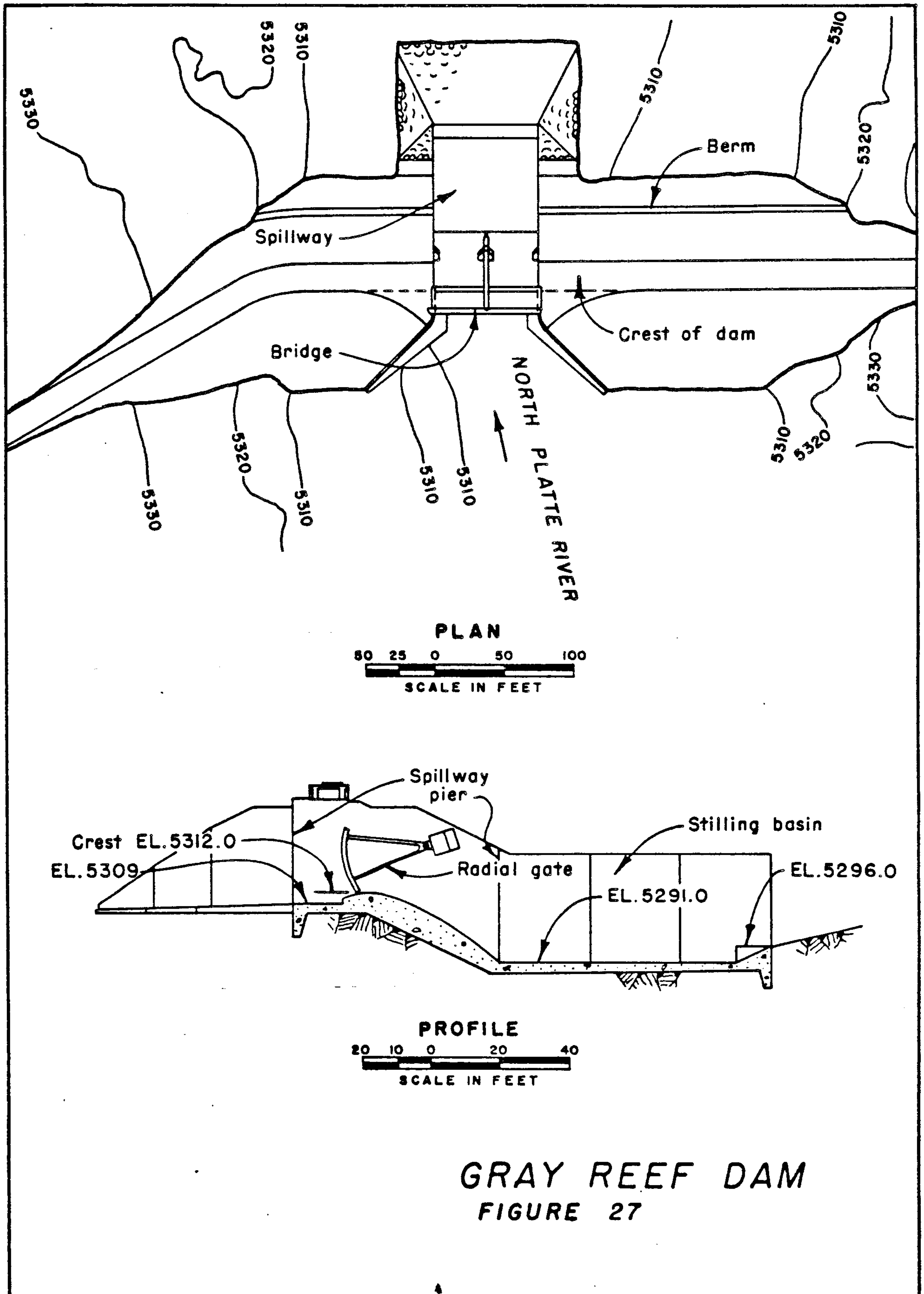


PATHFINDER DAM
FIGURE 25



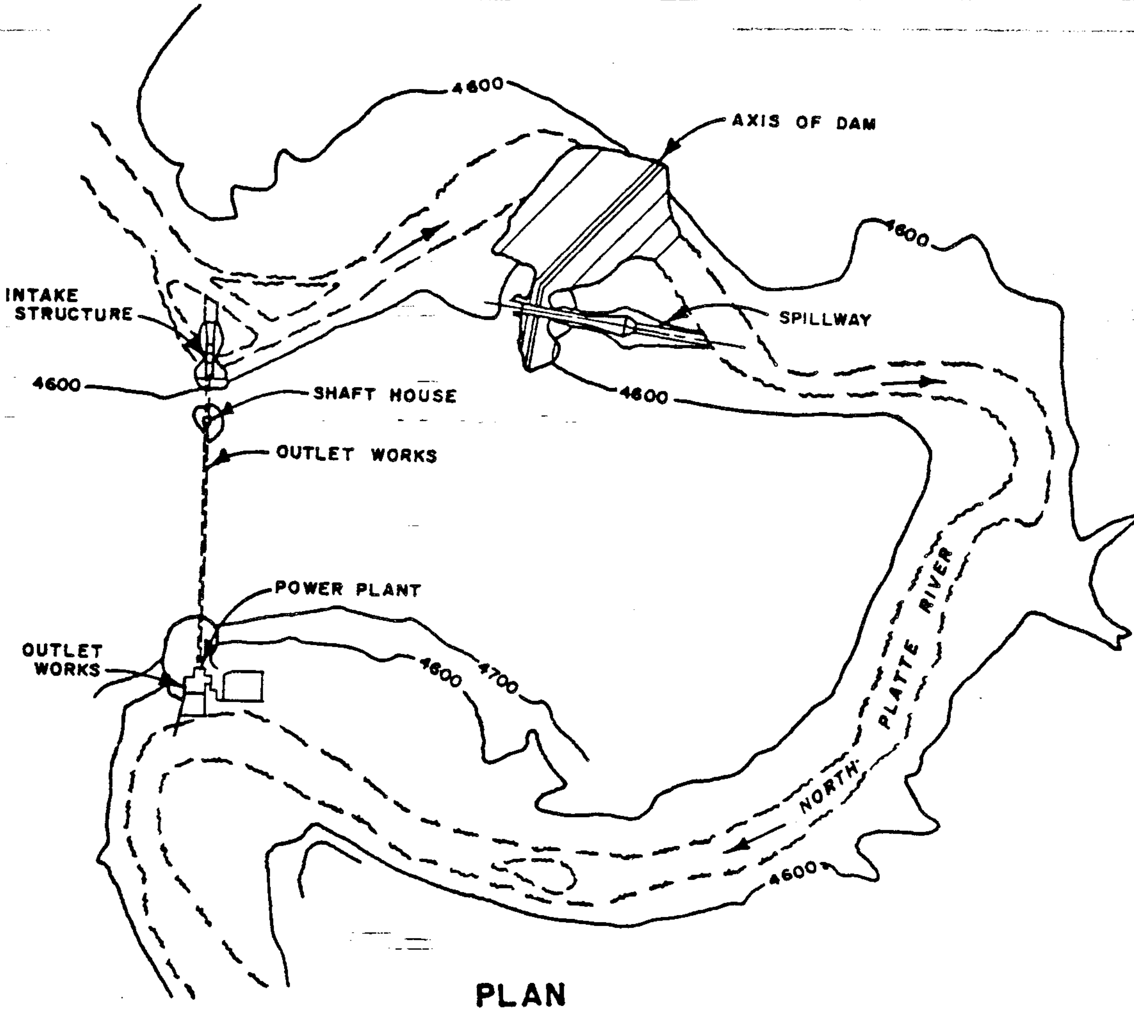
ALCOVA DAM

Figure 26



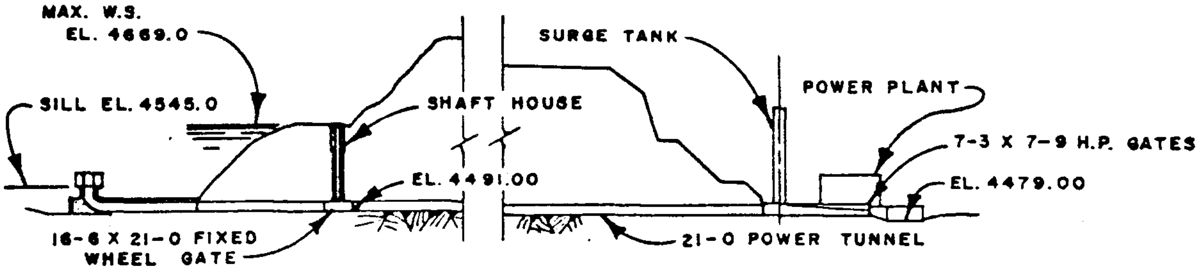
GRAY REEF DAM

FIGURE 27



PLAN

800 400 0 800 1600
SCALE IN FEET



PROFILE ON ℄ POWER TUNNEL AND OUTLET WORKS

200 100 0 200 400 600
SCALE IN FEET

GLENDO DAM
FIGURE 28

Photo P634-D-74140 Photo P634-D-74141

Figure 29. Seminoe spillway at 6,360 cfs.

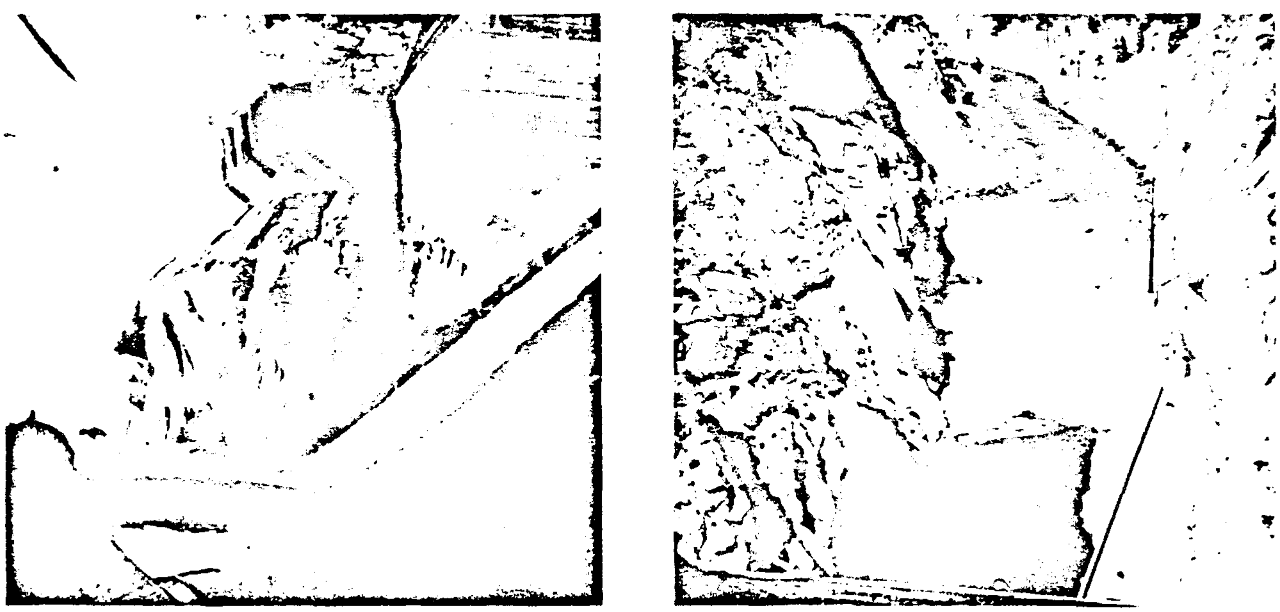
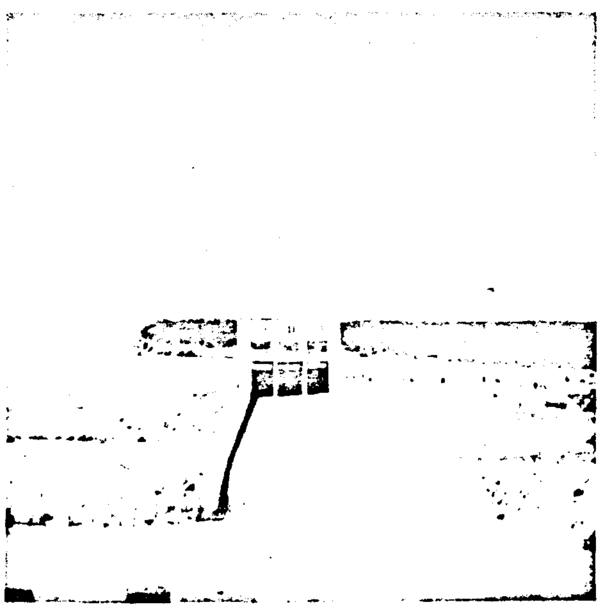


Photo P545-D-74142 Photo P545-D-74143

Figure 30. Kortes spillway at 5,410 cfs.

Photo P20-D-74144

Figure 31. Pathfinder spillway at 3,900 cfs and needle valves at 1,000 cfs each.



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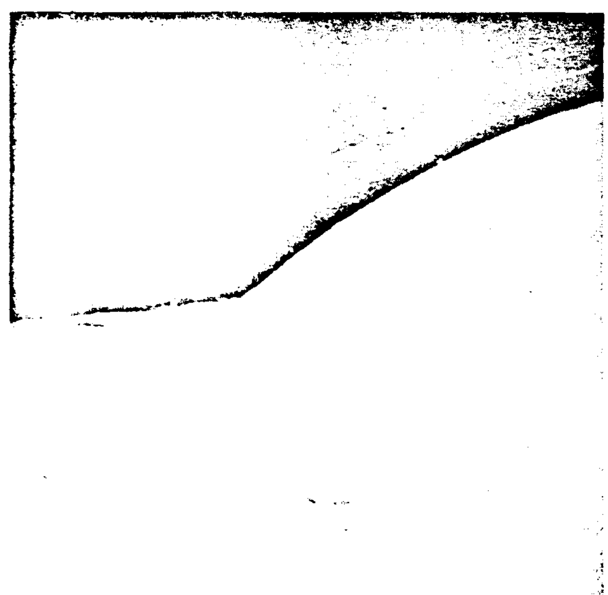


Photo P144-D-74146

Figure 32. Alcova spillway at 2,100 cfs.

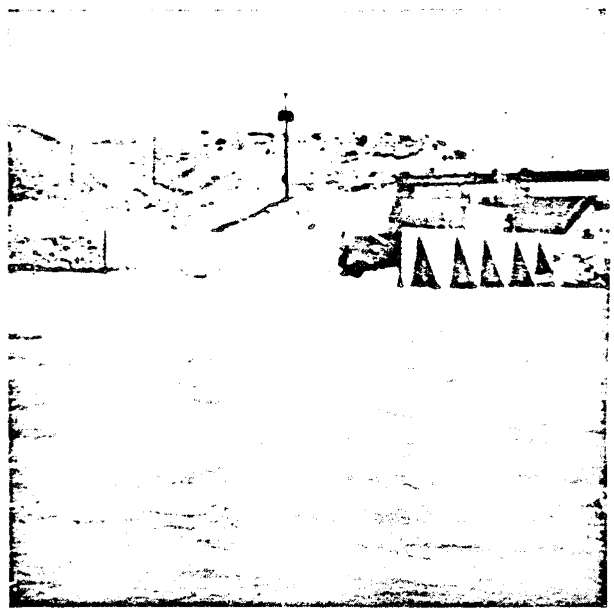


Photo P449-D-74147

Photo P449-D-74148

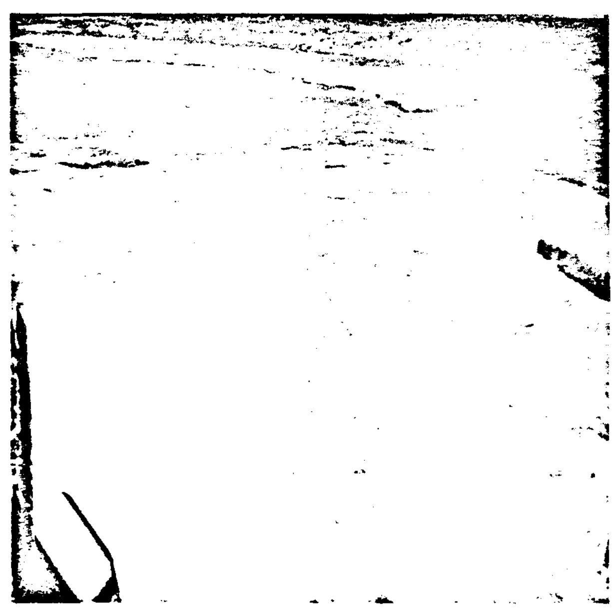


Photo P449-D-74149

Figure 33. Gray Reef spillway at 5,950 cfs.

Photo P449-D-74160

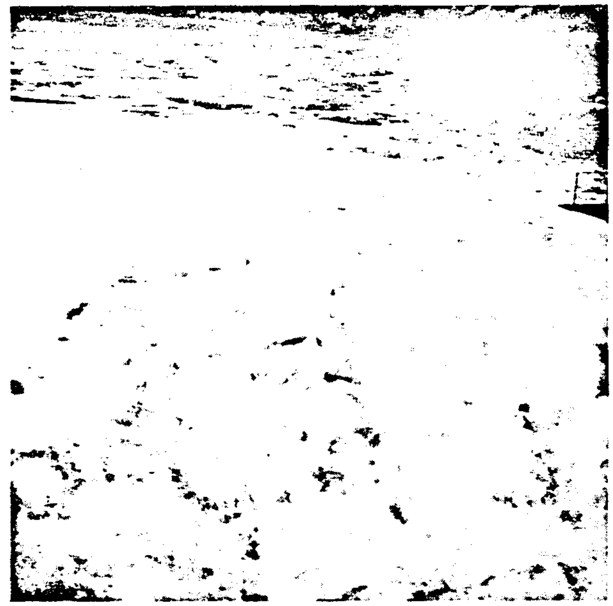


Photo P449-D-74161

Figure 34. Glendo outlet works at 6,500 cfs.

NORTH PLATTE DISSOLVED GAS MEASUREMENTS
June 1973

Field identification: Dam	Field identification: Sampling site	Barometric pressure (mm)	Temp °C	Percent saturation N_2+Ar (saturometer)	N_2 (ppm)	Percent saturation O_2	O_2 (ppm)	Total percent saturation (saturometer)
Seminoe	Reservoir surface	600	10.0	-	-	-	-	101
	Turbine outlet	600	6.8	103	15.84	92.1	8.86	101
	Spillway outlet	600	7.8	107	16.08	109	10.25	108
Kortes	Reservoir surface	608	8.8	105	15.64	115	10.64	107
	Turbine outlet	608	7.2	103	15.90	112	10.80	105
	Gaging station (1/4 mile)	608	7.8	106	16.15	107	10.20	107
	Miracle Mile Bridge (2 miles)	608	8.4	104	15.63	112	10.45	106
Fremont	Penstock above turbines	615	9.5	102	15.13	97.1	8.96	101
	Turbine outlet	615	8.9	-	-	-	-	101
Pathfinder	Reservoir surface	615	12.0	107	15.05	106	9.25	107
	Spillway basin	615	8.6	107	16.19	106	10.00	107
	Gaging station (1/4 mile)	615	10.1	110	16.11	108	9.80	110
Alcova	Reservoir surface	620	12.9	106	14.75	119	10.25	108
	Spillway basin	620	11.5	112	16.04	115	10.20	112
	Turbine outlet	620	7.5	103	16.11	102	10.00	103
	Penstock above turbine	620	8.0	102	15.77	101	9.11	102
Gray Reef	Reservoir surface	620	13.4	112	15.42	111	9.42	111
	Below stilling basin	620	10.1	112	16.54	115	10.58	112
Boston Creek Road	8 miles below Gray Reef	620	11.5	110	15.76	122	10.80	113
Casper	33 miles below Gray Reef	620	11.5	107	15.33	102	9.02	105
Olin Bridge	Above Glendo Dam	640	13.7	102	14.41	88	7.70	99
Glendo	Reservoir surface	640	14.0	103	14.47	100	8.62	102
	Outlet works	640	13.0	103	14.76	98	8.65	102

NORTH PLATTE DISSOLVED GAS MEASUREMENTS

Dam	Date 1973	Res el (ft)	Tailwater el (ft)	Spillway discharge	Spillway gate settings (ft)			Turbine discharge (cfs)			Turbine gate settings (ft)		
					1	2	3	1	2	3	1	2	3
Seminoe	5-30	6354.07	6142.30	6,360	4.0	2.5	4.0	800	-	800	6.8	-	3.0
Kortes	5-30	6147.10	5942.30	5,410	7.1	8.6	8.4	850	850	850	Wide open		
Pathfinder and Fremont Powerplant	5-31	5851.50	5473.08	3,900	Wide open			1,000	1,000	-	Wide open		
Alcova	5-31	5493.08	5337.62	2,100	3.0	-	-	1,800	1,800		Wide open		
Gray Reef	5-31	No data											
Glendo	6-1	4650.45	4503.50	6,500 (outlet works)	-	-	-	1,500	1,500		-	-	-

Gross and Dillon Dams

The final two structures to be included in this report are Gross and Dillon Dams. These structures belong to the Denver Water Board. At both structures only spillway flows were monitored. Gross is a concrete gravity dam with the spillway down the center of its face (Figure 35). At the base of the spillway is a deflector with no distinct energy dissipation basin. The spill observed at this structure was very small (266 cfs) and there was very little jet penetration (Figure 38). Dillon Dam on the other hand has a conventional morning-glory spillway (Figure 36). The observed discharge was 1,273 cfs. Flow in the stilling basin was only of moderate turbulence and air entrainment (Figure 37). Again, data were also collected on the streams below these structures.

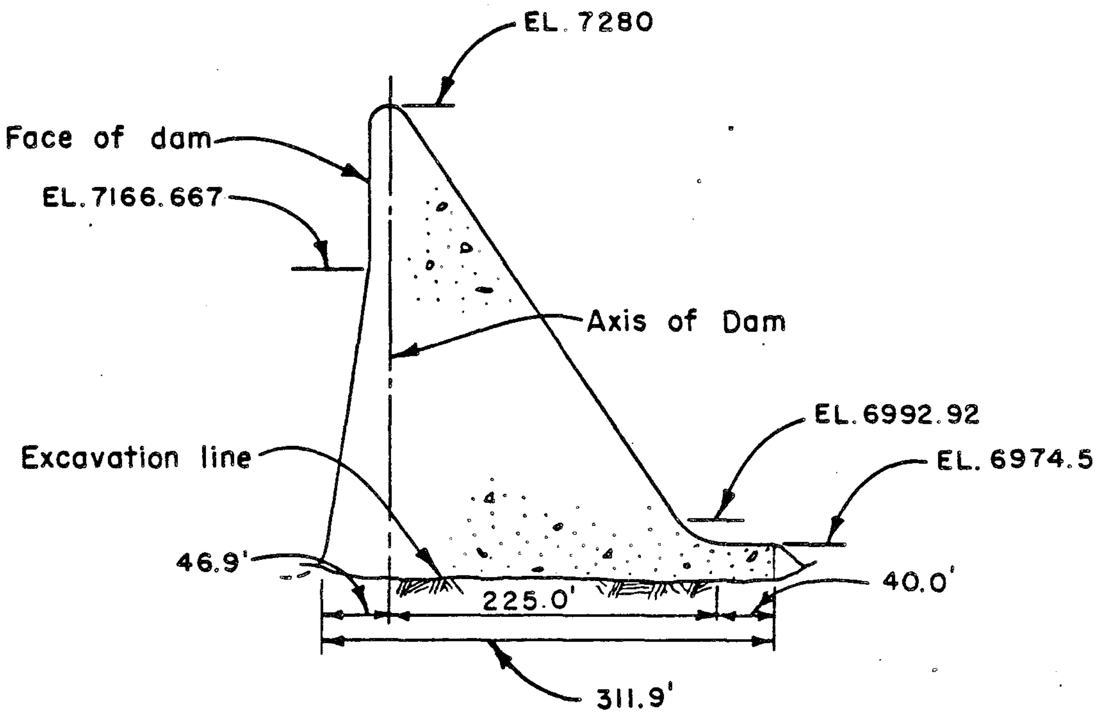
SYNOPSIS OF FIELD TEST

1. Location: Gross and Dillon Dams.

2. Period: June 5, 1973 and July 3, 1973

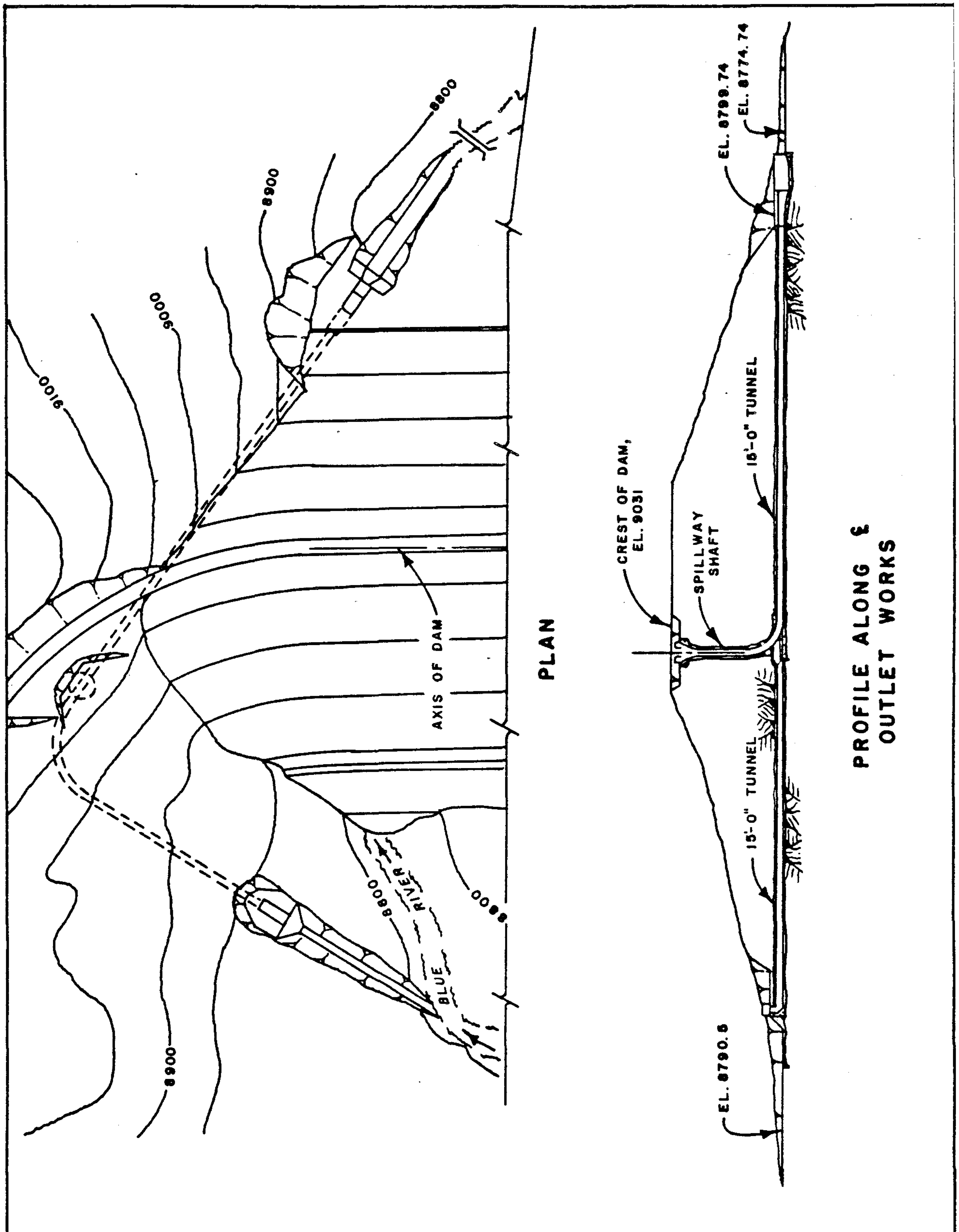
3. Log:

   One-day trips were taken to these two structures. Data was taken in the reservoir, in the spillway stilling basin, and on the stream below the structures. Photographs of the hydraulic action were taken.



MAXIMUM SPILLWAY SECTION

GROSS DAM
FIGURE 35



DILLON DAM

FIGURE 36

200 100 0 200 400

SCALE IN FEET

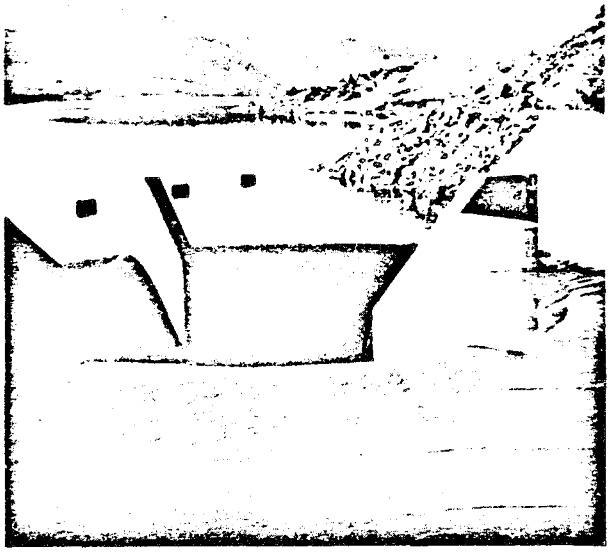


Photo P255-D-74162

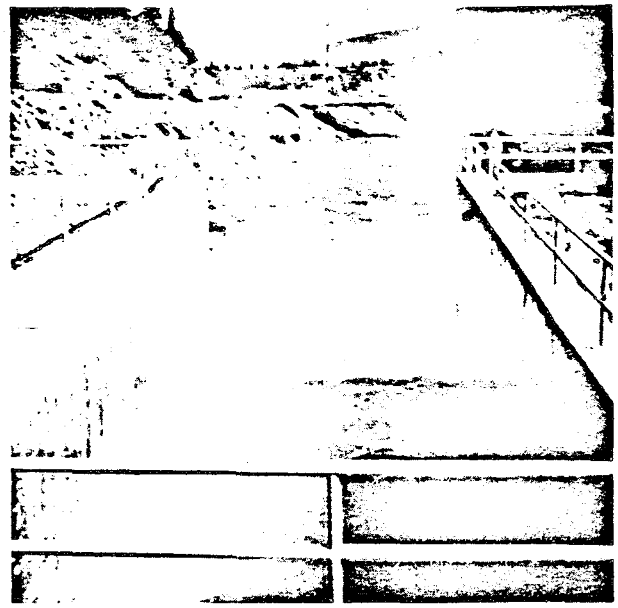


Photo P255-D-74163

Figure 37. Dillon spillway at 1,273 cfs.

Photo PX-D-74164

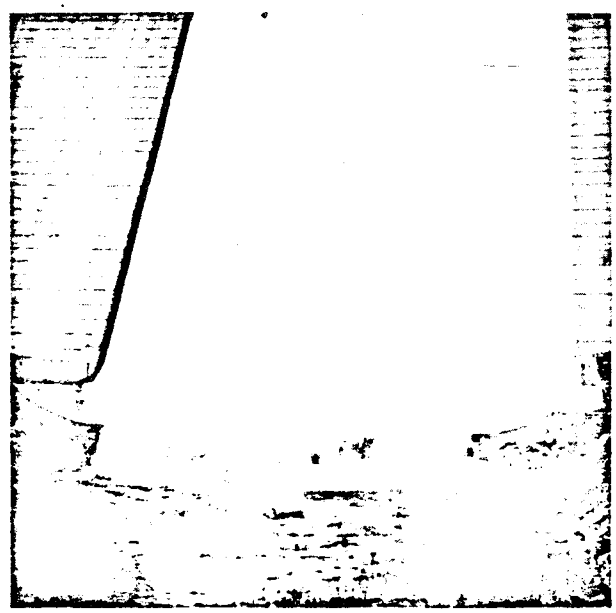


Photo PX-D-74165

Figure 38. Gross spillway at 266 cfs.

GROSS DAM
282.62 ft Reservoir Depth
266 cfs Spilling
Bar. - 625.3-mm hg

June 5, 1973

Location	Time	Temp °C	DO (ppm)	Percent DO sat.	Percent total sat.	Percent N_2+Ar sat.	N_2 (ppm)
Reservoir surface	10:00 am	9.2	9.00	95.1	103.7	105.9	16.1
Toe of spill	10:55 am	9.8	8.68	93.1	101.8	104.0	15.6
1/4 mile downstream	11:35 am	9.8	8.77	94.1	102.1	104.2	15.6
1/2 mile downstream	12:00 noon	9.9	8.85	95.2	102.6	104.5	15.6
Above weir	12:20 pm	10.1	8.80	95.0	102.4	104.3	15.5
Below weir	12:55 pm	10.2	8.78	95.1	102.4	104.3	15.5

DISSOLVED GAS MEASUREMENTS - DILLON RESERVOIR JULY 3, 1973*

Field identification	Temperature °C	DO (ppm)	Percent O_2 saturation	Percent total saturation	Percent N_2+Ar saturation	N_2 (ppm)
Reservoir surface at the Glory Hole	14.4	8.31	115	107	105	12.28
Stilling basin	14.1	8.28	114	116	117	13.72
1 mile downstream at Silverthorne	14.3	7.82	108	109	109	12.75

* Reservoir elevation = 9,018 feet
Spill = 1,273 cfs
Bar. pres. = 535-mm Hg

ANALYSIS OF RESULTS

In analyzing this first year's results there appears to be three major areas in which some insight was obtained. The first of these is the evaluation of the various chemical analysis techniques that have been applied. This includes an evaluation of the Weiss saturometer with respect to its accuracy and usefulness in field studies. Regarding dissolved oxygen monitoring, the DO probe was relied on to supply the majority of the data in these tests. This is because of the unit's compactness and ease of use. The Winkler method was used in a majority of the tests as a standard. For dissolved nitrogen analysis a saturometer was not available for the earlier tests so they were run using the Van Slyke analysis as the standard and using the gas chromatograph for the majority of the data. This method proved satisfactory although it was somewhat awkward. When the Weiss saturometer was initially used at the Morrow Point and Ruedi tests, it was used in conjunction with both the Van Slyke and the gas chromatograph methods. At Yellowtail the majority of the data was taken with only the saturometer, although the Van Slyke method was still maintained as a standard. The comparative data from these tests indicated that the saturometer yielded satisfactorily accurate results. The relative ease of use and mobility of the saturometer were found to make it very convenient. For these reasons the saturometer was used alone to evaluate the saturation levels in later tests.

The second, and probably most significant, area of insight is that dealing with capability of the various hydraulic structures to dissolve gases. This, of course, was the main objective of the study. Concerning outlet works structures, it can be observed that the highest gas supersaturation levels were created by the Ruedi auxiliary outlet works, the Navajo 30-inch hollow-jet valve bypass, and the Navajo auxiliary outlet works. Dissolved gas levels of above 120 percent were observed in the releases from all three. It should be noted that the Navajo and Ruedi auxiliary outlet works structures are quite similar to each other. To generalize on the flow from these three structures, it could be said that:

1. All three jets are fairly compact and organized when they enter the stilling basin pool. The flow from the 30-inch bypass is more disorganized than the other two but it still enters the pool a fairly short distance from the valve and therefore has little chance to disintegrate.

2. All three jets discharge into fairly deep pools without energy dissipating baffles.

3. The flow in all three basins was fairly quiet with moderate to low surface turbulence. The 30-inch bypass again showed more turbulence than the other two but even this was relatively weak.

4. In two of the three cases the amount of air entrained by the jet was small. Both of the auxiliary outlets entrained relatively little air and yet created quite high supersaturation levels. This indicates that a fairly small quantity of air is all that is needed.

Outlet works that were observed to create moderately high supersaturation levels (110 to 120 percent) include the Navajo 72-inch hollow-jet valves discharging at from 25 to 50 percent of capacity; the 12-inch jet-flow gate at Ruedi; and the main outlet works at Willow Creek, Ruedi, and Morrow Point. The jet flows at these structures were generally less organized than the flows at the three high supersaturation level structures. The stilling basins were also generally shallower and the turbulence and air entrainment in these basins were generally higher. The degree to which these various structures followed this pattern varied with the specific situation but the pattern generally describes what was observed. If a structure did not correctly follow one of these points (i.e., more turbulent flow), it was generally found that changes in the others were more severe (i.e., basin depth). These opposing factors thus compensated for each other in the overall picture.

Three operating outlet works were observed producing low supersaturation levels (below 105 percent). They were Glendo, operating at 55 percent of capacity; Granby, operating at 27 percent of capacity; and the Navajo 72-inch hollow-jet valves, operating at 13 percent of capacity. At Glendo the flow passes beneath high-pressure slide gates and into a relatively shallow, highly baffled stilling basin. The resulting flow in the basin was highly turbulent with a great deal of air entrainment. At Granby, on the other hand, only a moderate amount of turbulence and air entrainment was observed but the physical arrangement of the outlet works was such that the flow could not penetrate to any substantial depth. At the other structure (Navajo 72-inch hollow-jet valves), one other important point becomes clear. It is that discharge is a critical factor in evaluating the gas-saturating capabilities of a hydraulic structure. This structure was found to create saturation levels of 118 percent at 2,000 cfs (50 percent of capacity), 111 percent at 1,000 cfs (25 percent of capacity), and 101 percent at 500 cfs (12 percent of capacity). Lower discharges appear to create less supersaturation. It can be reasoned that lower discharges would cause less jet penetration, less turbulence, and less air entrainment. These factors apparently combine to cause lower gas saturation levels. Since the total data indicates that less air entrainment and less turbulence correspond to higher supersaturation levels, it appears that the reduced penetration must be the critical factor in reducing the supersaturation levels. It should be observed that the maximum depth of penetration is limited by the actual physical size of the stilling basin and thus discharge would not affect the penetration depth once its maximum was reached. Nevertheless when evaluating a structure's performance, discharge should definitely be a consideration.

It can, therefore, be generally said that structures which produce low dissolved gas supersaturation levels first of all have relatively shallow penetration depths for the inflowing jet. Deep penetration means that the water-entrained air mixture is put under higher pressure. As Henry's Law indicates, significantly more gas can be dissolved into the flow at higher pressures than at lower. If penetrations are to be held relatively shallow, one or more of the following situations must hold:

1. The entering jet would have little consolidated mass; thus, the jet is either highly disintegrated or has been spread into thin sheets. When this is the case, the jet's velocity will be quickly dispersed and reduced. The jet is therefore unable to penetrate to significant depth.

2. The entering jet would have little vertical velocity when the jet strikes the stilling basin's water surface. Thus the jet will have little velocity causing it to penetrate the pool. There are two ways that a jet could be in this situation. The first is that the total velocity of the jet is small (low-head structure) and thus the vertical component of that velocity is also small. The second is that the jet is near a horizontal trajectory when it enters the pool and thus the vertical component of the velocity is small even though the total velocity may be quite high.

3. The stilling basin could have the physical dimensions such that the jet would not be allowed to penetrate to a depth of any significance.

It appears that relatively small quantities of entrained air can cause high gas supersaturation levels. This indicates that although some air must be entrained by the flow, the actual quantity is not of great significance. Finally, observations have indicated that structures with highly turbulent stilling basin flows tend to have somewhat reduced gas supersaturation levels. These levels were observed up to 115 percent. It might be concluded that even though some of these structures do have flows with entrained air that penetrate to moderate depths the flow is quickly brought to the surface (reduced pressure) and violently agitated. The agitation would tend to reduce the high supersaturation created in initial penetration.

If this analysis is now continued to consider the spillway flow data obtained, very similar observations can be made. It should be first noted that of all the spillway flows observed, none had dissolved gas levels above 116 percent. This may in part be due to the fact that the observed spillway discharges were small in comparison to the maximum capacities of the facilities. Percentage-wise the largest spill observed was approximately 20 percent of capacity. The maximum capacities of spillways are based on discharges that would very rarely be encountered. Again, the worst conditions observed (with respect to dissolved gas) were when uniform, organized flows entered conventional stilling basins. Two of the worst contributors, Gray Reef at 4,000 cfs (20 percent of capacity) and Yellowtail Afterbay Sluiceway at 2,500 to 5,000 cfs, are low-head structures at which the flow has relatively short drops from crest to tailwater surface. The flows therefore had little chance to break up before they entered the tailwater pool. In both these cases the basins were of medium depth and the flows in them were moderately turbulent. A third structure at which similar saturation levels were observed is Alcova spillway where the flow passes down a long chute and into a deep, conventional stilling basin. A discharge of only 2,100 cfs, or 4 percent of capacity, was observed. The flow had low to moderate turbulence and air entrainment. One other spillway, Dillon, was observed to create these relatively high saturation levels. The Dillon spillway consists of a morning-glory intake to a vertical shaft which then goes through a vertical bend to a nearly horizontal tunnel. It is approximately a 225-foot drop from the crest to the tunnel invert. The stilling basin is a combination hydraulic jump-flip bucket structure and therefore contains no baffles. At the observed discharge of 1,273 cfs (11 percent of capacity), it was functioning as a hydraulic jump basin. The probable maximum depth of penetration was 17 feet. The basin flow had moderate turbulence and air entrainment. At all four of these structures the stilling basin flow had relatively low turbulence as compared to the others observed. Also, the probable depths of penetration at the four are as deep as, or deeper than, any others observed. It therefore appears that spillway flows follow the same pattern as that observed for outlet works. That is that deeper penetration with lower turbulence and some air entrainment causes high dissolved gas saturation.

Now, if the best spillway flows are analyzed, it can be observed that they also fit this pattern. By far the lowest contributors observed were Shadow Mountain and Gross. Both of these structures were observed at very small discharges (106 cfs or 1 percent of capacity at Shadow Mountain and 266 cfs at Gross). Gross has a flip-type structure at the base of its spillway with no distinct stilling basin. The penetration of the flow was therefore quite small. The reduced flow that it did have was quite turbulent with a great deal of air entrainment. On the other hand, Shadow Mountain has a radial-gate-controlled crest with a chute leading to a conventional hydraulic jump basin. The very small discharge did, however, create only a shallow penetration. There was only moderate to low turbulence and air entrainment in the flow. The flows at

Silver Jack, Seminoe, Kortes, and Pathfinder spillways all showed higher saturation levels but they were still below 110 percent. All four, each in its own way, had very turbulent flows with high air entrainment and moderately shallow penetration. It thus again appears that high turbulence and shallow penetration cause lower supersaturation levels.

Hydraulic turbines in the various powerplants have flow conditions quite different from those previously discussed. These turbines have two basic operational modes that are of concern in this report. These two modes are vented and unvented operation. As discussed previously, when turbines are run under offpeak conditions (reduced discharge and efficiency), air is often injected below the runner cone into the draft tube flow. This air reduces or eliminates draft tube surging which exists under these operating conditions. It was observed at Morrow Point that this air, which is carried to fairly high pressures deep in the draft tubes, also caused high supersaturation levels. Considering previous observations, this result is not surprising. What is surprising is that when the turbines at Yellowtail were observed operating under similar conditions, no additional supersaturation above the level in the reservoir was noted. These are the only two facilities at which vented turbine operation was studied. Just why one would cause increased supersaturation and the other would not is uncertain. The difference probably results from variations in the draft tube flow conditions to which the aerated discharge is exposed. These differences would result from three factors. The first is that the flow leaving vented turbines is fairly complex in nature. This flow could generally be expected to have strong swirling with a stall or dead area around the draft tube centerline. The exact conditions would be dependent on the individual turbine and specific operating condition. The air vented into the turbine would enter the stalled area in the flow (a low pressure region that would draw in the air without the use of compressors) where it would then be entrained by the flow and carried downstream. These flow conditions would then be interacting with the second factor which is the complex flow passage geometries in the draft tubes. Again, generally, draft tube geometries also vary from powerplant to powerplant. This, combined with variable tailwater elevations which influence overall pressures in the draft tube, yields very complex flow conditions. The flow could be expected to have both high- and low-velocity regions and high- and low-pressure regions. The specific conditions to which the flow with entrained air is exposed would determine what levels of supersaturation are created.

Unvented operation (at maximum capacity and peak efficiency) was observed at several powerplants. In all cases no increase in dissolved gas was noted through the turbine and draft tube. This would be expected in that the flow is not exposed to additional free air. These findings indicate that unvented turbine operation and submerged outlet works may offer some solution to the dissolved gas supersaturation problem.

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