ERDC/CHL TR-02-2

Coastal and Hydraulics Laboratory

US Army Corps
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Bluestone Lake Dam, West Virginia, Rating Curve and Overtopping Study

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Final report

Prepared for U.S. Army Engineer District, Huntington
Huntington, WV 25701-2070

Contents

Preface

The study was authorized by the Office, Chief of Engineers, U.S. Army, at the request of the U.S. Army Engineer District, Huntington. Points of contact for the Huntington District were Messrs. Coy Miller, Dave Margo, and Ken Halstead.

The work was conducted during the period April 1999 to December 2000 in the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC). The study was under the direction of Mr. Thomas W. Richardson, Acting Director, CHL, and under the general supervision of Mr. James R. Leech, Chief of the Spillways and Channels Branch. The principal investigator for the model study was Mr. Billy D. Fuller, assisted by Messrs. Kevin Pigg, Bill Katzenmeyer, John Williams, and Douglas White all of CHL, and Mr. Ed Johnson of Mevatec Corp. The model was constructed by personnel of the Department of Public Works under the direction of Mr. Cecil Dillon. Messrs. Fuller, Pigg, and Katzenmeyer prepared this report.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
pounds (force) per square inch	0.006894757	megapascals

1 Introduction

Prototype

The Bluestone Lake Dam was constructed as a multipurpose concrete gravity dam and is located on the New River, near Hinton, WV (Figure 1). Completed in 1949, the structure consists of a 21-bay spillway, nonoverflow and intake sections (Figure 2). The spillway is 790 ft long with a crest elevation of 1,490[1] and contains 16 sluices to pass low pool flows. A stilling weir with crest elevation of 1,392 is located just downstream of the spillway to maintain tailwater for energy dissipation. The intake section contains six penstocks for possible future hydropower generation. The top elevation of the dam is 1,535.

As a result of the new Probable Maximum Flood (PMF) criteria developed by the National Weather Service, the dam must be modified to pass a discharge higher than the original design. In an effort to meet the PMF criteria, the top elevation of the dam will be raised, via a parapet wall, to el 1,549. A higher head will be induced on the dam, which will increase spillway and sluice discharge to a level over their original design capacities. The penstocks will be used to further increase total discharge capacity of the dam during extremely high discharge events.

Purpose of Model Study

The purpose of this model study is to verify the discharge capacity of the Bluestone Lake Dam after it is modified to provide flood control for the new PMF. The modifications that will affect the hydraulics of the structure are adding a 14-ft-high parapet wall (head increase on the dam) and using the penstocks for emergency discharge.

Other areas to be investigated are: pressures along the spillway and in the stilling basin, erosion potential of the east abutment due to penstock

[1] Unless stated otherwise, all elevations (el) cited herein are in feet as referred to in the National Geodetic Vertical Datum (NGVD) of 1929. To convert feet to meters, multiply by 0.3048.

discharge, determination of the necessary training wall height increase to contain the increased spill discharge, and to investigate the option of overtopping the intake section of the structure to increase discharge capacity.

2 Physical Model

Description

A flume was designed to accommodate reproduction of the structures, a 2,200-ft reach of the tailrace and a 1,000-ft reach of the upper pool topography at an undistorted linear 1:65 scale. All pertinent topography was reproduced with molded cement mortar over sand. The structures were constructed of sheet metal, acrylic, and wood. The model layout is shown in Figure 3.

The discharges were established using Data Industrial flow meters. These meters were calibrated using the U.S. Army Engineer Research and Development Center (ERDC) calibration flume. Water-surface elevations were measured with point gages. The point gages were located 800 ft upstream of the dam axis and 1,000 ft downstream of the dam axis. The tailwater was maintained with an adjustable tailgate.

Pressures were measured using piezometer taps and a stilling well system. Piezometer taps were located on 10-ft (prototype) intervals along the center of spillbay 5 and extended through the stilling basin. The stilling basin locations were duplicated laterally three bays over (downstream of spillbay 8). These locations are shown in Figure 4. Pressure cells were used for time-history recordings in six locations in the stilling basin. Pressure cells locations were determined from the piezometric pressure variances.

Velocities were measured with Acoustic Doppler Velocity (ADV) probes, pitot tubes, and a video tracking system (VTS). The VTS and dye streaks were used in documenting surface current patterns.

Interpretation of Model Results

The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. The general relations expressed in terms of the model's scale or length ratio, L_r, are expressed in Table 1.

Table 1
Scale Relations

Dimension	Ratio	Scale Relation
Length	L_r	1:65
Area	$A_r = L_r^2$	1:4,225
Velocity	$V_r = L_r^{1/2}$	1:8.062
Discharge	$Q_r = L_r^{5/2}$	1:34,063
Time	$T_r = L_r^{1/2}$	1:8.062
Force	$F_r = L_r^3$	1:274,625
Frequency	$f_r = 1/L_r^{1/2}$	1:0.124

Measurements of each of the dimensions or variables can be transferred qualitatively from model to prototype equivalents by means of the scale relations (Table 1). All model data are presented in terms of prototype equivalents.

3 Experiments

Phase A

Rating curves

Spillway and sluice rating curve. Flow through the spillway of the Bluestone Lake Dam is controlled by a series of slide gates. Due to the original design of the gate machinery, the fully open gates provide 33-ft above the spillway crest. The higher pool elevation required to pass the new PMF will cause the spillway nappe to contact the bottom of the gate. When this occurs, the control of discharge through the spillway transitions from free overflow to an orifice flow. Thus, an extension of the spillway discharge rating curve cannot be accomplished by analytical methods.

In order to develop an extension of the discharge rating curve for the modified Bluestone Dam, the model response had to be verified. This verification consisted of validating the spillway and sluice discharge capabilities individually.

The model spillway was verified using data from the design model (Carnegie 1937)[1]. The original study produced a discharge rating curve for flows up to a 388.5 kcfs spillway discharge. Figure 5 shows the verification rating curve for the spillway.

Because geometric scaling of trash racks at a 1:65 scale will not accurately reproduce the head loss, the sluices were constructed without trash racks and calibrated in place. Calibration of sluice flow required installing expanded metal screens at the inlet of the sluices to simulate the appropriate amount of head loss. Figure 6 shows the verification rating curve for all 16 sluices.

Once the rating curves for the spillway and sluices were verified, the rating curve was extended for flows to a maximum pool elevation of 1,546.8

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1 Carnegie Institute of Technology. (1937). "Laboratory test on hydraulic models of Bluestone Dam, New River, Hinton, WV," Hydraulic Laboratory, Carnegie Institute of Technology, Pittsburgh, PA.

(the original maximum pool elevation was 1,520.0). The model data is presented in Table 2. The extended rating curve is presented in Figure 7.

Table 2
Spillway and Sluice Rating Curve

Discharge, kcfs	Pool Elevation, NGVD	Comment
38.0	1,430.19	No spillway gates
49.0	1,452.55	
57.9	1,475.89	
79.5	1,493.44	
88.1	1,494.61	
192.4	1,504.88	
193.8	1,504.68	
284.3	1,510.68	
354.6	1,515.21	
355.4	1,515.08	
450.4	1,520.15	
450.8	1,520.15	
557.0	1,524.84	
563.7	1,525.61	
672.5	1,528.41	
728.9	1,530.75	
730.9	1,531.21	
997.6	1,542.90	
1,008.1	1,542.90	
1,100.3	1,546.80	
1,104.2	1,546.80	
849.7	1,537.83	33-ft gate opening
855.1	1,538.94	
856.1	1,538.42	
891.7	1,546.80	
898.7	1,546.80	

Spillway, sluice, and penstock rating curve. The penstocks were originally constructed for power generation. However, interest in hydropower declined and the powerhouse was never constructed. Subsequently, the recent dam safety assurance studies determined that it would be feasible to use the penstocks to accommodate passage of the PMF. Therefore, physical modeling was determined to be the best means for developing a reliable discharge rating. Table 3 and Figure 8 present flow conditions used and resulting rating curve for passage of flow through the spillbays, sluices, and penstocks.

Table 3
Spillway, Sluice, and Penstock Rating Curve

Discharge, kcfs	Pool el, NGVD	Tailwater el	Comment
88.3	1,452.8	1,379	With air vents open
109.4	1,474.0	1,380	
602.5	1,520.0	1,398	
602.8	1,520.0	1,398	
963.6	1,535.0	1,408	
963.8	1,535.0	1,408	
1,040.8	1,546.8	1,410	
1,060.4	1,546.8	1,414	
88.3	1,448.6	1,379	With air vents closed
109.4	1,470.8	1,380	
604.5	1,519.0	1,398	
983.9	1,535.8	1,408	
1,049.1	1,546.8	1,414	

Figure 8 shows information for vented and nonvented penstock flow. No significant change in discharge capacity resulted from penstock ventilation.

Spillway and stilling basin pressures

Spillway pressures. The ogee shape of the spillway is designed to reduce the probability of cavitation by maintaining pressures along the spillway face of a negative 15 ft of water or greater (HQUSACE 1990).[1] An increased head on the spillway will reduce the pressures on its face, thus increasing the cavitation potential. Pressures along the spillway face were measured for discharges up to 890,000 cfs (spillway and sluice discharge, at pool el 1,546.8). These pressures are presented in Figures 9 and 10.

Stilling basin pressures. The pressures in the stilling basin were measured using piezometer taps and with pressure cells (Kulite 1994).[2] The piezometer taps are in two arrays, one along the center line of spillbay 5 and the other along the center line of spillbay 8. The piezometer taps were located on 10-ft intervals, beginning just downstream of the baffle blocks (175 ft from the axis of the dam) to just upstream of the stilling weir (345 ft from the axis of the dam). The flow conditions used for the stilling basin

[1] Headquarters, U.S. Army Corps of Engineers. (1990). “Hydraulic design of spillways,” EM 1110-2-1603, January 1990.

[2] Kulite Semiconductor Products, Inc. (1994). “Pressure transducers, Model XTM-190,” Kulite Product Data Sheet, Leonia, NJ.

evaluation are shown below in Table 4. These data are presented in tabular and graphical form in Appendix A.

Pressure cells were used to record time-history pressures at three locations in each array. These locations were determined from the piezometric data. The locations showing the highest variance in piezometric pressure were chosen for pressure cell locations. They were locations 2, 11, and 18. The pressure cell data are presented in Figures 11-24. The model data are in Appendix B.

Table 4
Stilling Basin Evaluation Flows

Condition Number[1]	Discharge, kcfs[2]	Pool el, NGVD	Tailwater el
1	28.0	1,415	1,374
2	49.5	1,455	1,376
3	87.0	1,480	1,379
4	193.0	1,505	1,384
5	355.0	1,515	1,390
6	450.0	1,520	1,394
7	560.0	1,525	1,397
8	730.0	1,530	1,402
9	855.0	1,539	1,410
10	895.0	1,547	1,414

[1] Conditions 1, 2, and 3 do not have spillway discharge (sluices only).
[2] Total river discharge. All spillways and sluices are in operation.

Abutment erosion potential

Erosion of the east abutment is a concern during events with penstock release. The penstock discharge forms an eddy near the toe of the east abutment. With low tailwater, the flow is not in contact with the abutment, but at high tailwaters (those likely to be present during flows approaching the PMF) the eddy is a potential cause of erosion. The velocity and size of the eddy was documented using a video tracking system. The flow conditions used for this evaluation were a maximum pool (el 1,546.8, 1,050 kcfs) and a high tailwater (el 1,414.0). The data for this condition are presented in Figure 25.

In an effort to reduce the velocities in the eddy, several outlet deflector configurations were investigated. A deflector was attached to the outlet of each penstock. The six-penstock outlet deflectors had the same orientation during a test (i.e., all deflectors were affixed to the outlets in the same direction and had the same amount of deflection). There were six tests conducted on the deflectors. The deflector orientations were 15 and 30-deg deflections into and away from the channel and 15- and 30-deg deflections up. These data are presented in Figures 26-31.

Training wall height

The height of the stilling basin training walls were evaluated for a range of river flows up to the PMF. Training wall extensions were installed in the model as seen in Photos 1 and 2. The resulting necessary wall heights for infrequent overtopping are presented in Table 5.

Table 5
Training Wall Height

Discharge, kcfs	Tailwater el, NGVD	East Wall Height, NGVD	West Wall Height, NGVD	Comment
193.4	1,385.0	—	—	No extension needed
357.6	1,392.0	1,420	1,420	
456.9	1,398.0	1,440	1,440	
567.1	1.398.5	1,450	1,450	Estimate, overtopped extended walls
733.4	1,406.0	1,430	1,430	No jump in basin, spill discharge impacts the stilling weir
858.2	1,412.5	1,435	1,435	No jump in basin, spill discharge impacts the stilling weir
917.5	1,414.0	1,435	1,435	No jump in basin, spill discharge impacts the stilling weir

After onsite observation with district personnel, it was determined that a more frequent overtopping would be acceptable. The training wall heights were modified as shown in Photos 3 and 4. The final training wall dimensions are shown in Figure 32.

Dynamic Loading

Spill gate and spillway pier

The additional head on the spill gates, resulting from changing the maximum upper pool, will increase the loads on the supporting piers. Because some of the pier support structure (Figure 33) will be inundated during the PMF, it was uncertain if the dynamic loading would be higher than the static loading. Pressure cells (Druck 2000)[1] were installed in a spill gate and a pier to measure the dynamic pressures (Figures 33 and 34).

[1] Druck, Inc. (2000). "Pressure transducers, Type PDCR 800 Series," Druck Product Data Sheet, New Fairfield, CT.

Dynamic pressures

These pressures are intended to provide information to design engineers that will assist in the analysis of the structural stability of the existing spillway piers and gates. The data summary sheets and waveforms are in Appendix C.

Phase B (Overtopping)

Rating curve

Phase B of the model study was to investigate the effects of overtopping the intake section of the dam (Figure 35). The rating curve, developed for Phase A of this study, was extended to include data for the overtopped intake section. Figure 36 shows the extended rating curve with the intake overtopping data.

Abutment erosion potential

The flow conditions near the east abutment were again investigated. The discharge used was the same as used for Phase A of this study (upper pool el 1,546.8 and lower pool el 1,414.0). Overtopping of the intake section did not significantly change the eddy size or intensity near the east abutment.

Phase A experiments indicated that installation of penstock deflectors was not an effective means of reducing the eddy. Therefore, a training wall was investigated to determine a minimum wall length and height necessary to reduce velocities near the east abutment. Figures 37-40 show data for wall lengths of 100 to 200 ft. The wall height should be equal to the highest expected tailwater elevation.

Overtopping pressures at intake

Pressures resulting from overtopping were a concern at two locations on the intake structure. They were at the toe of the structure where overtopping flow impacts and at the top of the structure, a possible low-pressure zone (Figure 41).

Pressure cells (Druck)[1] were installed at these two locations to provide time-history records of pressure. Pressures were recorded for two flow conditions, upper pool el 1,546.8 and 1,542.0 with lower pool el 1,414.0 and 1,409.0 respectively. These data are included in Appendix E.

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[1] Druck, Inc. (2000). "Pressure transducers, Type PDCR 800 Series," Druck Product Data Sheet, New Fairfield, CT.

4 Summary

Rating Curves

The additional head in the upper pool, provided by the 14-ft-high parapet wall, increased the total discharge that the dam is required to pass. The original upper pool elevation of 1,520.0 was initially increased to 1,546.8. The corresponding increase in discharge for combined spillway and sluice operation was approximately 100 percent with the spill gates in the full-open position of 33-ft (450,000 cfs to 900,000 cfs). For discharges that were combined spillway, sluice, and penstock operations, the increase was approximately 75 percent (600,000 cfs to 1,050,000 cfs).

By utilizing the penstocks for emergency release, the new PMF (approximately 950,000 cfs) could be passed with the parapet wall installed and reduced in height to produce a maximum pool el of 1,542.0.

The second phase (Phase B) of this study investigated the overtopping of the intake section of the structure. This allowed river flow passage through the spillway, sluices, penstocks and the overtopping flow. The capacity was increase of approximately 1,100,000 cfs at upper pool elevation of 1,546.8.

Spillway Pressures

The cavitation safety curves in EM 1110-2-1603, “Hydraulic design of spillways,” indicate the upper limit of acceptable low pressures on the spillway face is -15 ft. This limit was reached at a discharge of approximately 900,000 cfs (spillway and sluice discharge only). If emergency penstock release is utilized during the PMF, the spillway and sluice discharge will be reduced to approximately 850,000 cfs. The corresponding spillway face pressure is approximately -14 ft. While this is on the edge of the limit, it is within design criteria.

Abutment Erosion

During discharges that require penstock release, an eddy is formed adjacent to the east dam abutment. The velocities in the eddy approach 30 fps next to the bank. This velocity magnitude can cause severe erosion and reduce the structural integrity of the dam. In an effort to reduce the velocities in this area, several penstock deflector configurations were investigated. These deflectors were 15 and 30 deg into and away from the bank and 15 and 30 deg upward. None of these configurations improved flow conditions.

A vertical wall was placed on the east abutment side of the intake structure. The wall length was varied from 100 to 200 ft. The minimum length required to reduce velocities to a manageable level (less than 20 fps) was 175 ft. The wall height should be equal to the highest expected tailwater elevation.

Pressures

Several pressures were recorded throughout this study. These measurements are intended to aid in the design of anchoring systems and structural component design verification. They are to be used as needed by the design engineers. These data are presented in Appendices B-E.

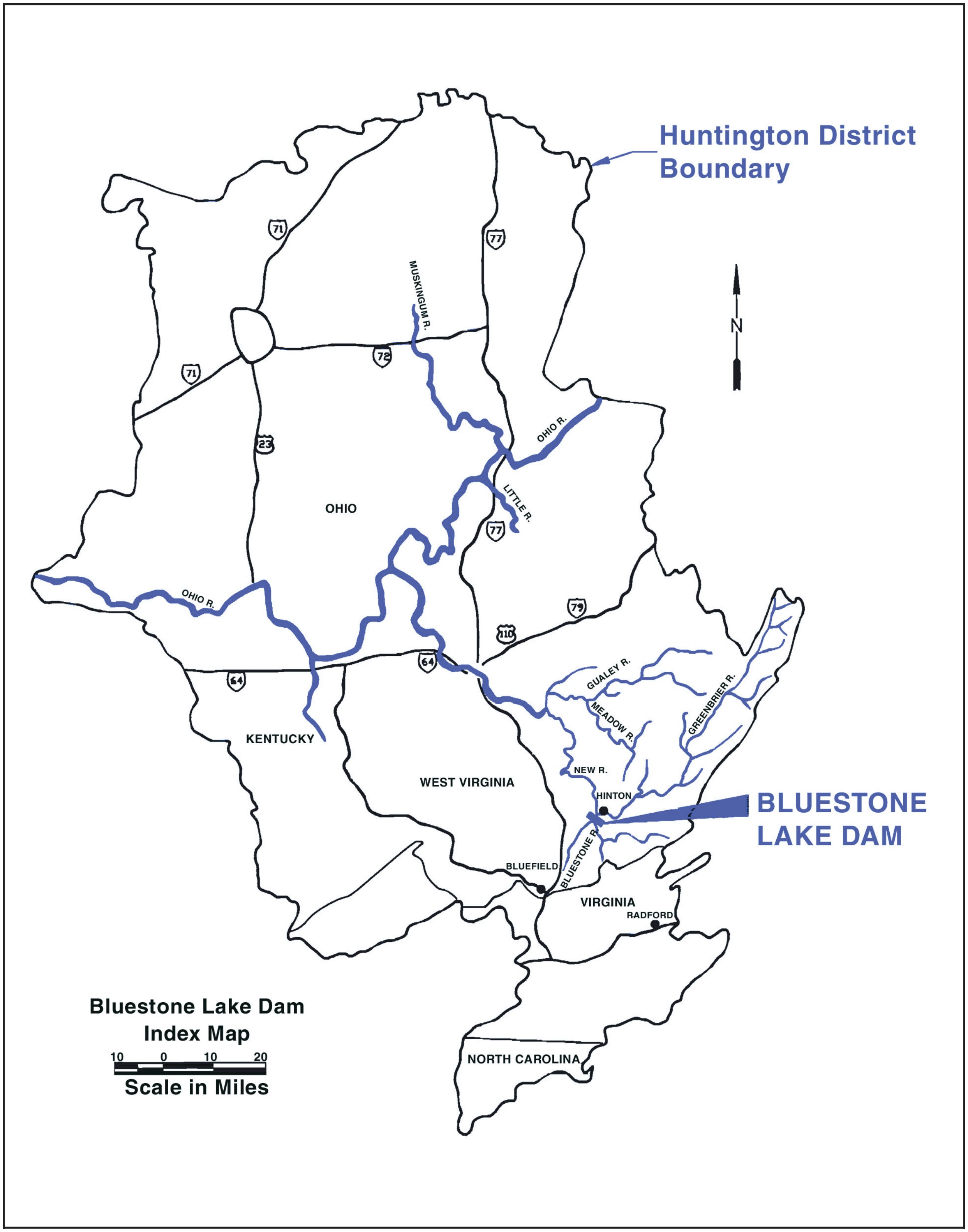


Figure 1. Site location

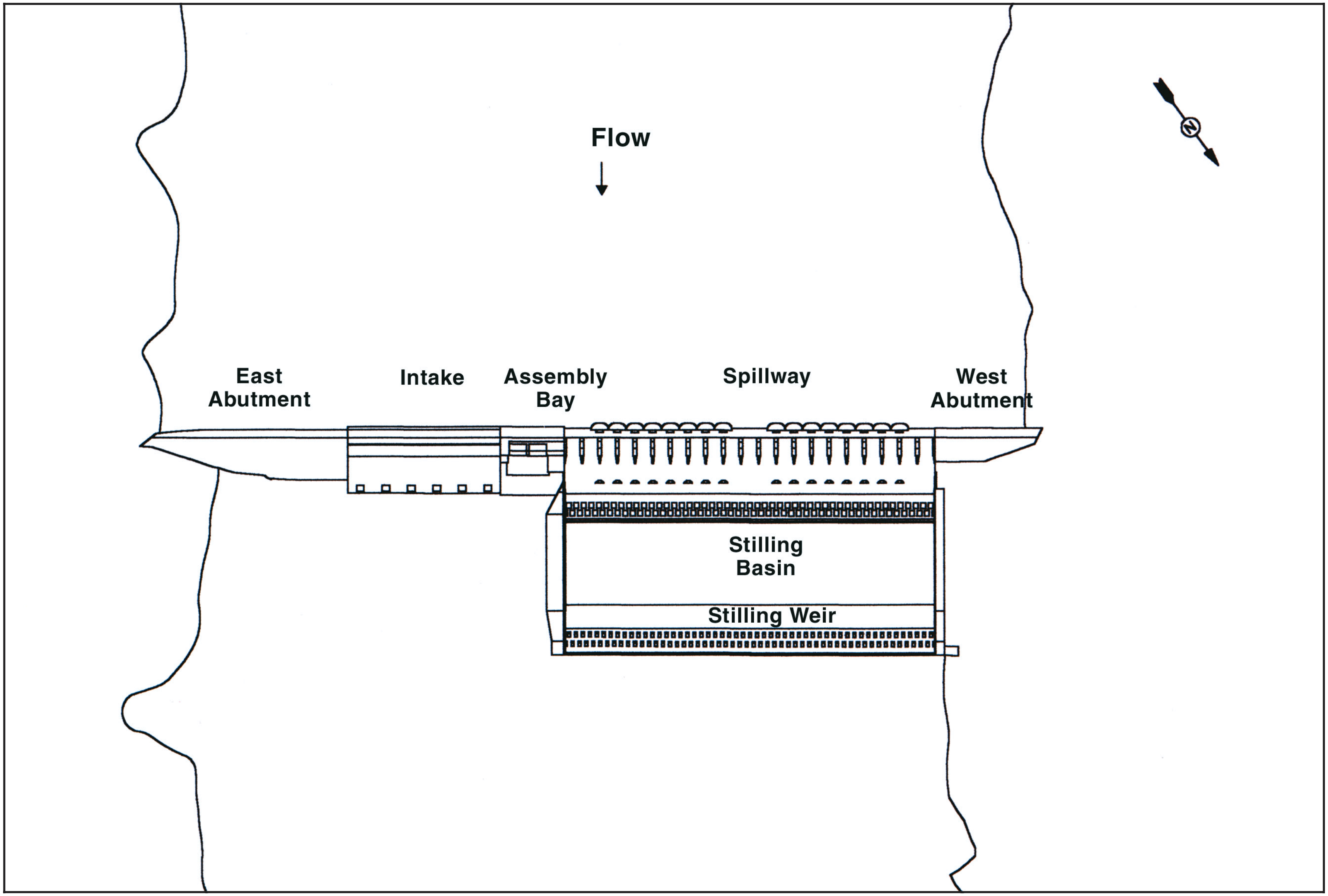


Figure 2. Bluestone Lake Dam layout

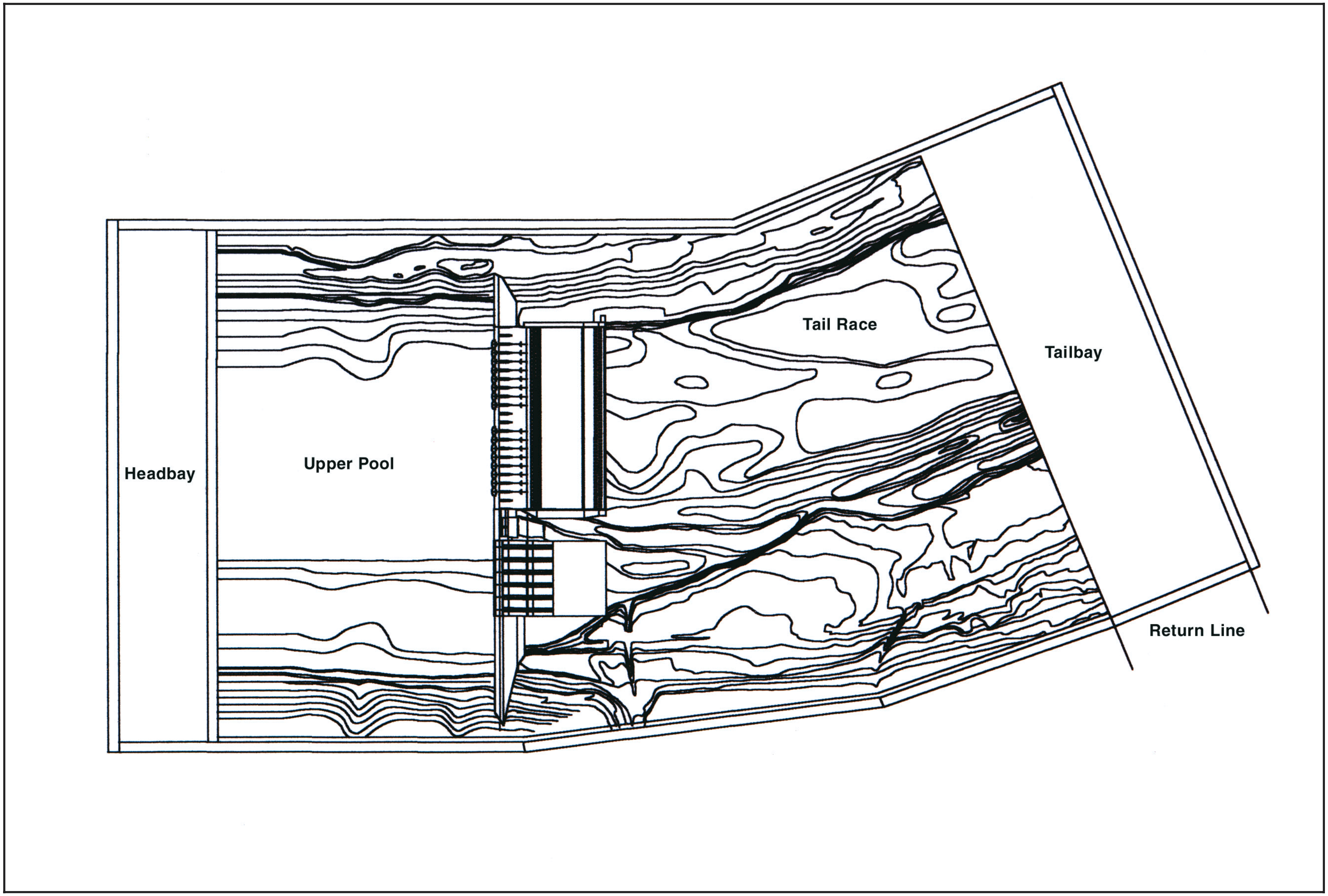


Figure 3. Bluestone 1:65 scale, model layout

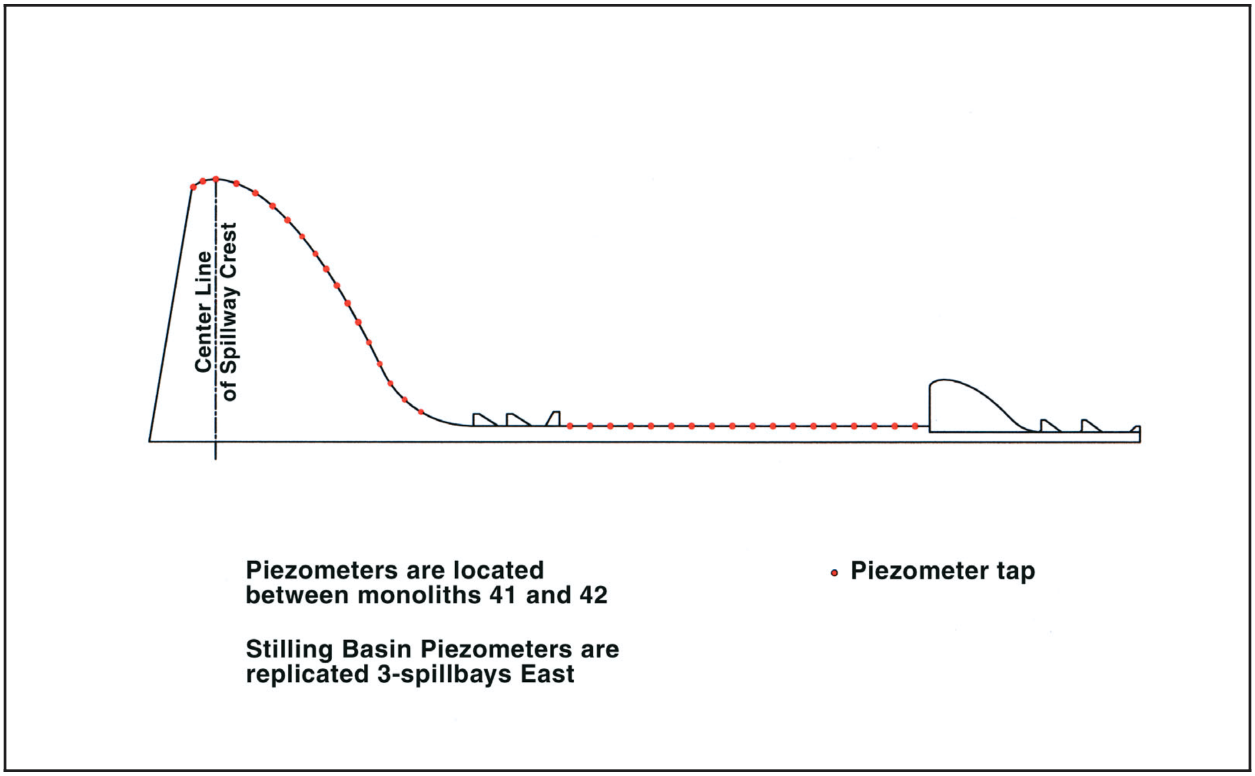


Figure 4. Piezometer tap locations, spillway, and stilling basin

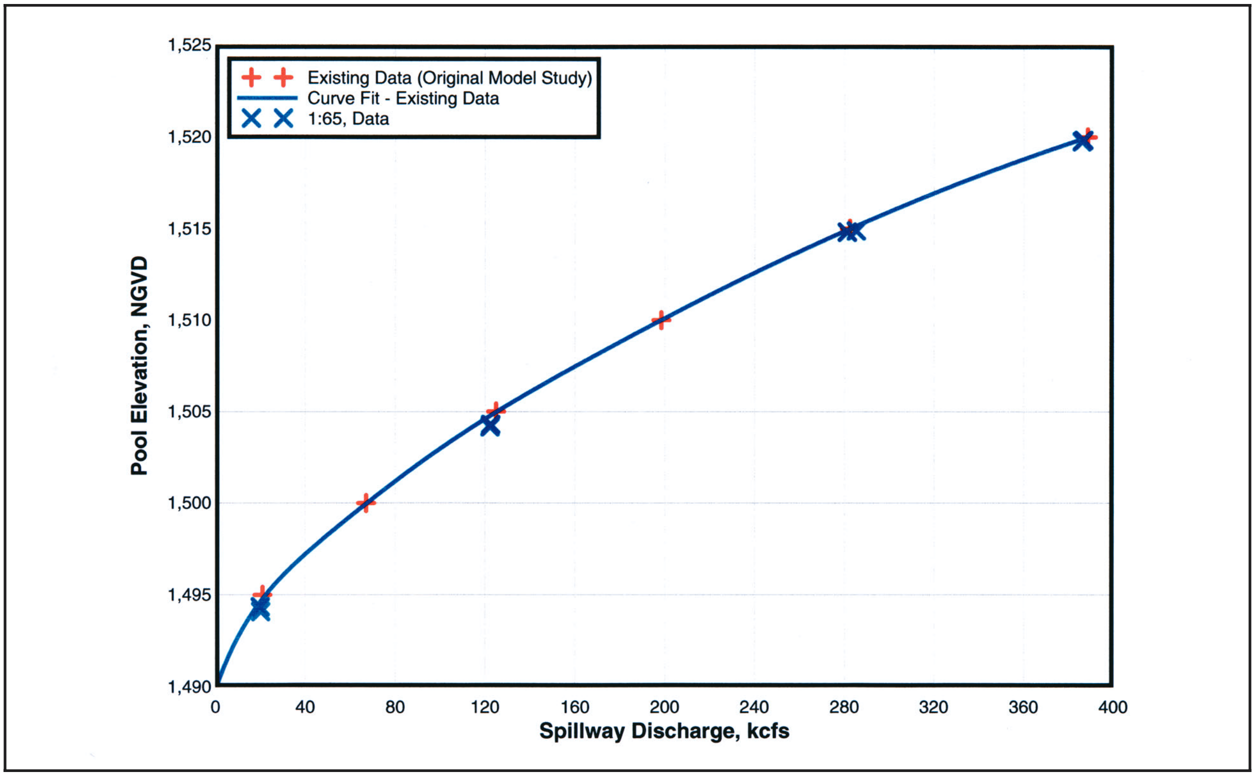


Figure 5. Spillway rating verification curve

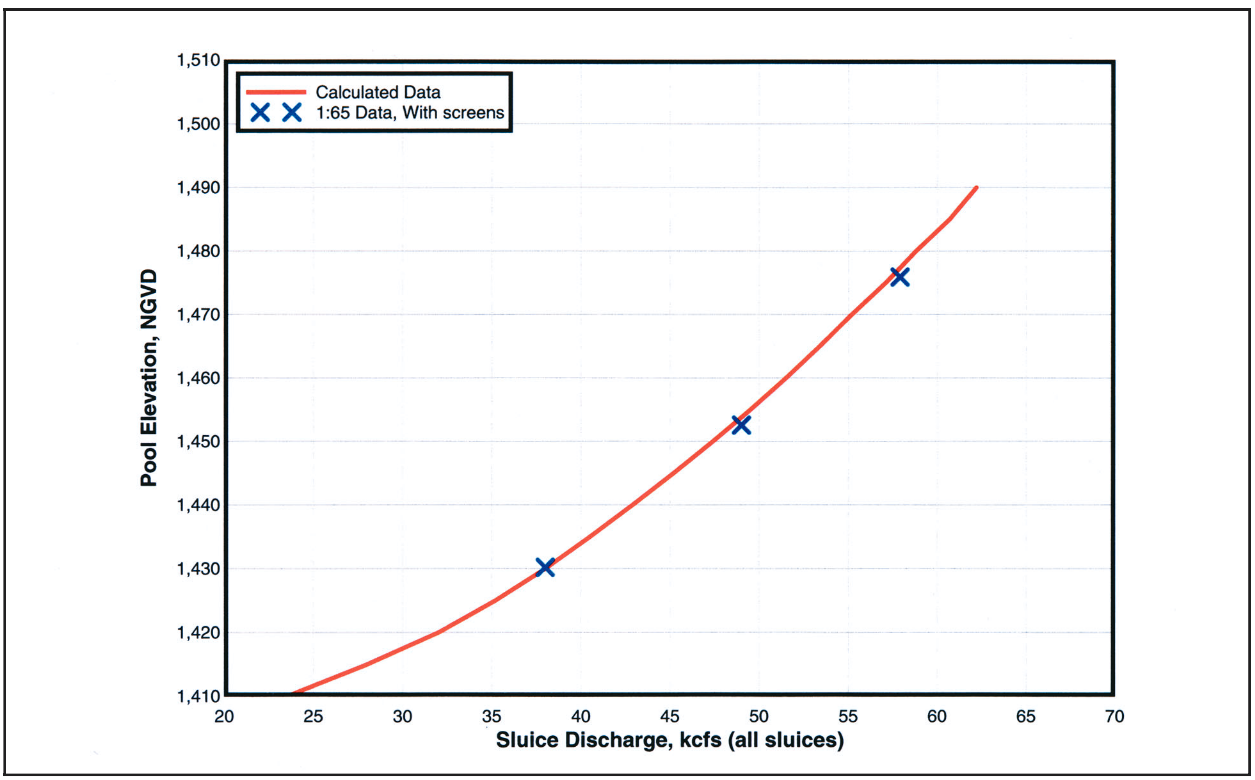


Figure 6. Sluice rating verification curve

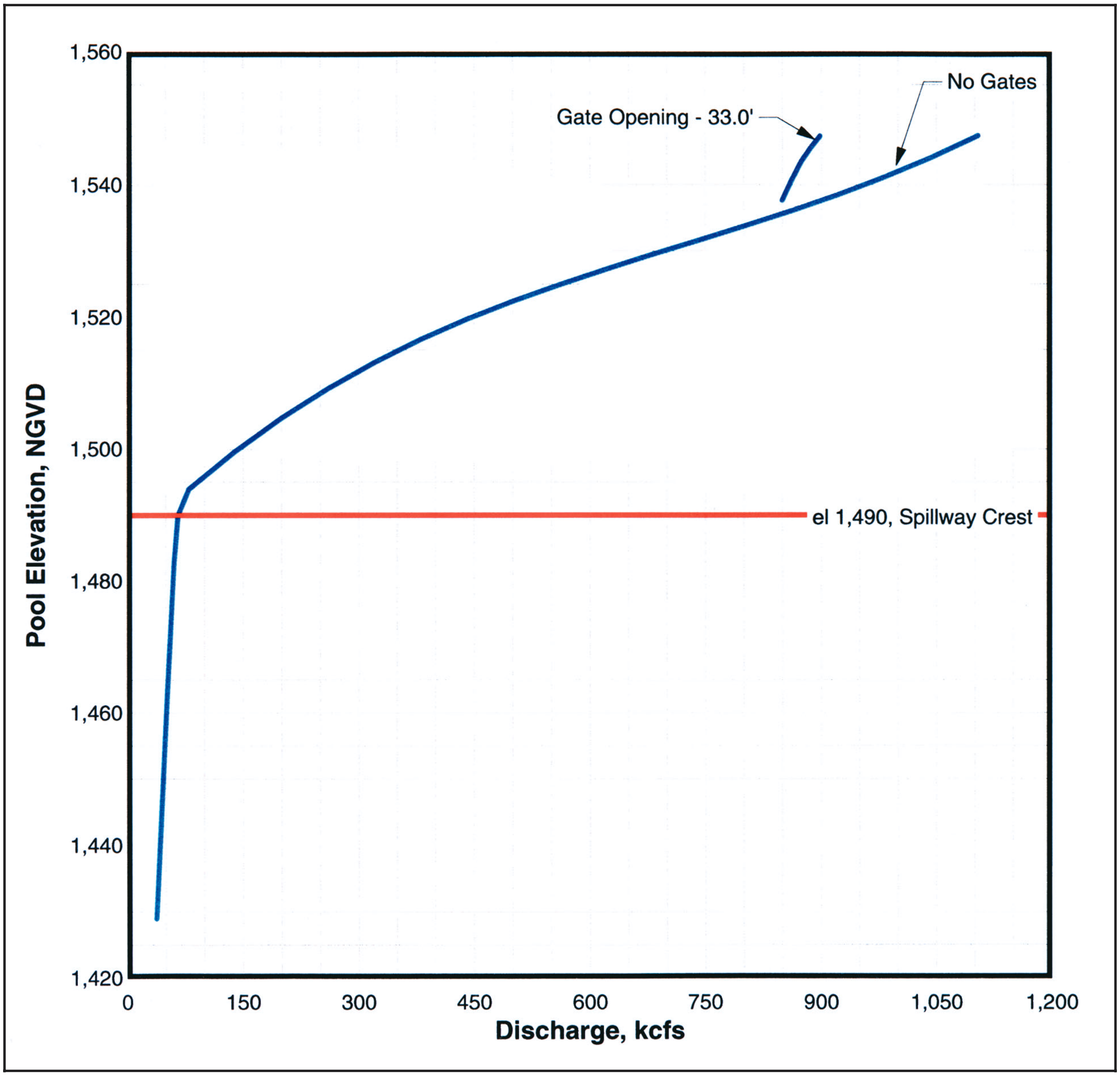


Figure 7. Extended rating curve, spillway, and sluice discharge only

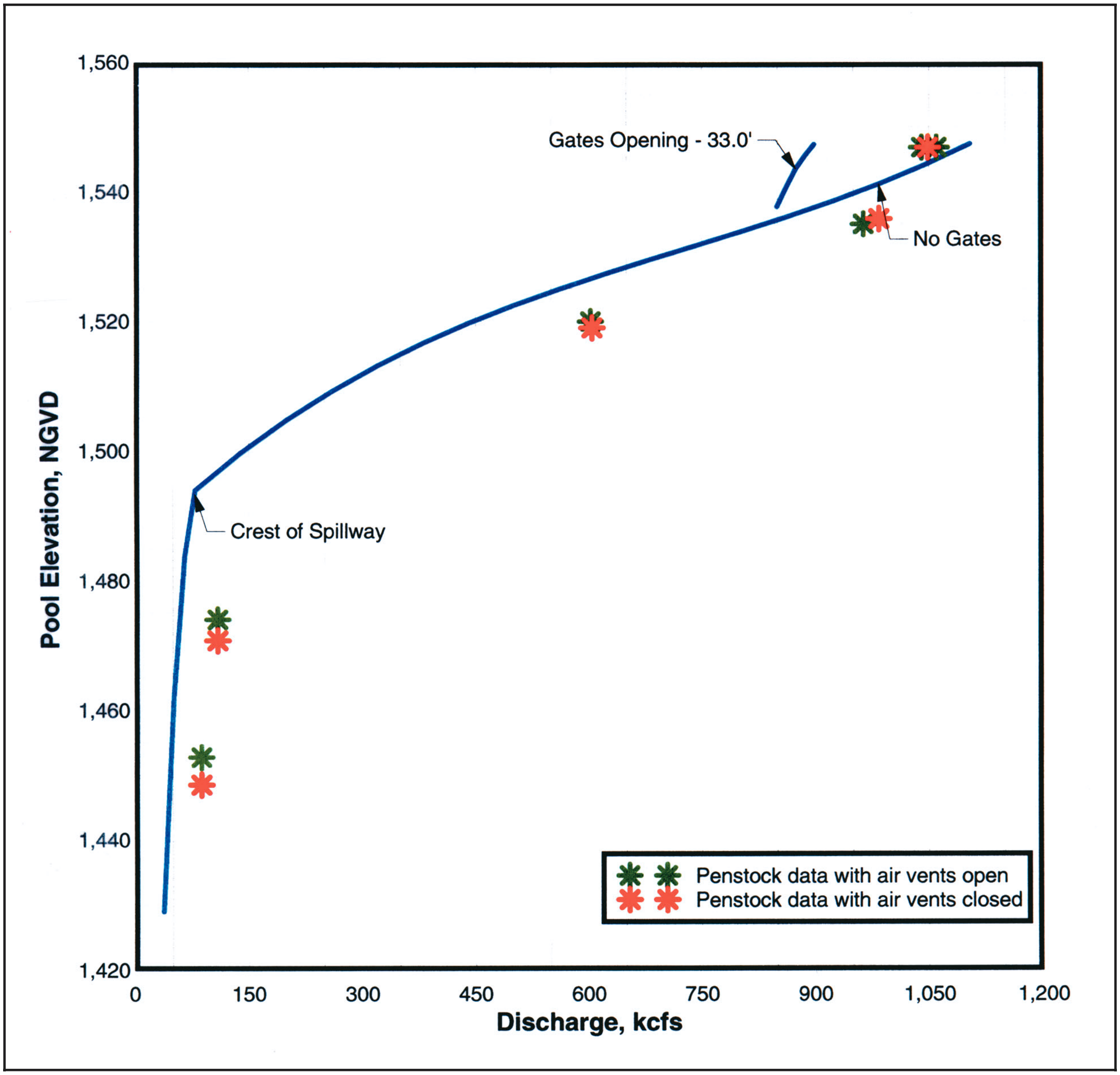
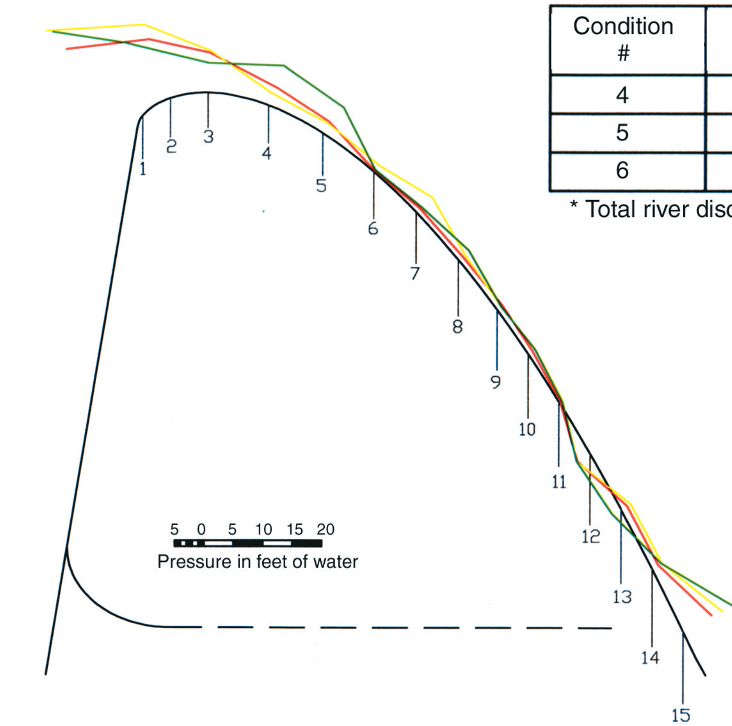


Figure 8. Extended rating curve, spillway, sluice, and penstock discharge

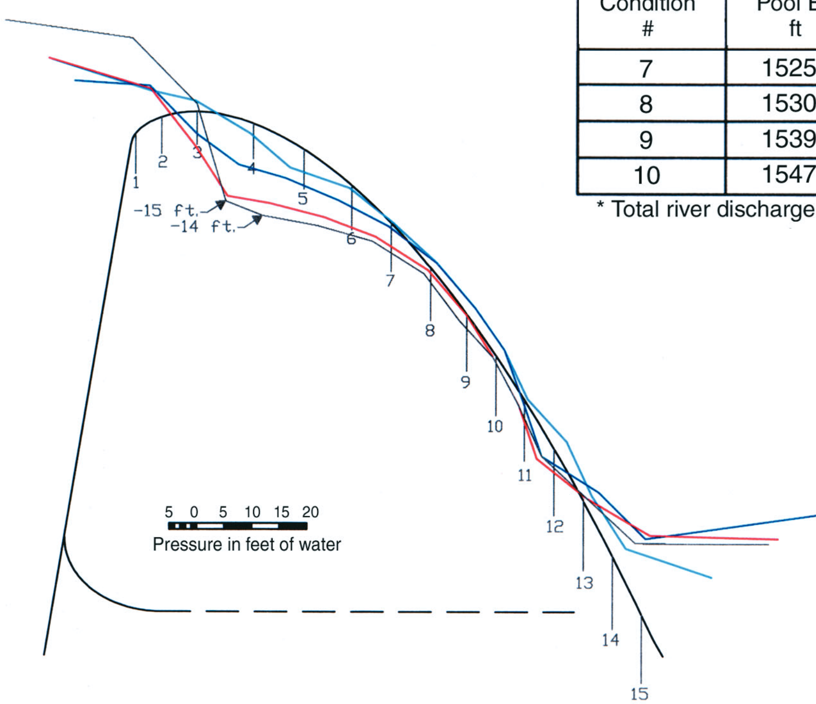


Condition #	Pool El. ft	Head ft	Discharge cfs	Line Color
4	1505	15	193,000	
5	1515	25	355,000	
6	1520	35	450,000	

* Total river discharge. All spillbays and sluices in operation.

Location #	Dist. from crest, ft	Measurement Direction
1	11.12	U/S CL Crest
2	6.37	U/S CL Crest
3	0	CL Crest
4	10.27	D/S CL Crest
5	19.50	D/S CL Crest
6	28.21	D/S CL Crest
7	35.43	D/S CL Crest
8	42.58	D/S CL Crest
9	49.21	D/S CL Crest
10	54.47	D/S CL Crest
11	59.80	D/S CL Crest
12	65.00	D/S CL Crest
13	70.40	D/S CL Crest
14	75.73	D/S CL Crest
15	80.99	D/S CL Crest

Figure 9. Spillway pressure for conditions 4 through 6



Condition #	Pool El. ft	Head ft	Discharge cfs	Line Color
7	1525	35	560,000	
8	1530	41	730,000	
9	1539	49	855,500	
10	1547	57	895,000	

* Total river discharge. All spillbays and sluices in operation.

Location #	Dist. from crest, ft	Measurement Direction
1	11.12	U/S CL Crest
2	6.37	U/S CL Crest
3	0	CL Crest
4	10.27	D/S CL Crest
5	19.50	D/S CL Crest
6	28.21	D/S CL Crest
7	35.43	D/S CL Crest
8	42.58	D/S CL Crest
9	49.21	D/S CL Crest
10	54.47	D/S CL Crest
11	59.80	D/S CL Crest
12	65.00	D/S CL Crest
13	70.40	D/S CL Crest
14	75.73	D/S CL Crest
15	80.99	D/S CL Crest

Figure 10. Spillway pressures for conditions 7 through 10

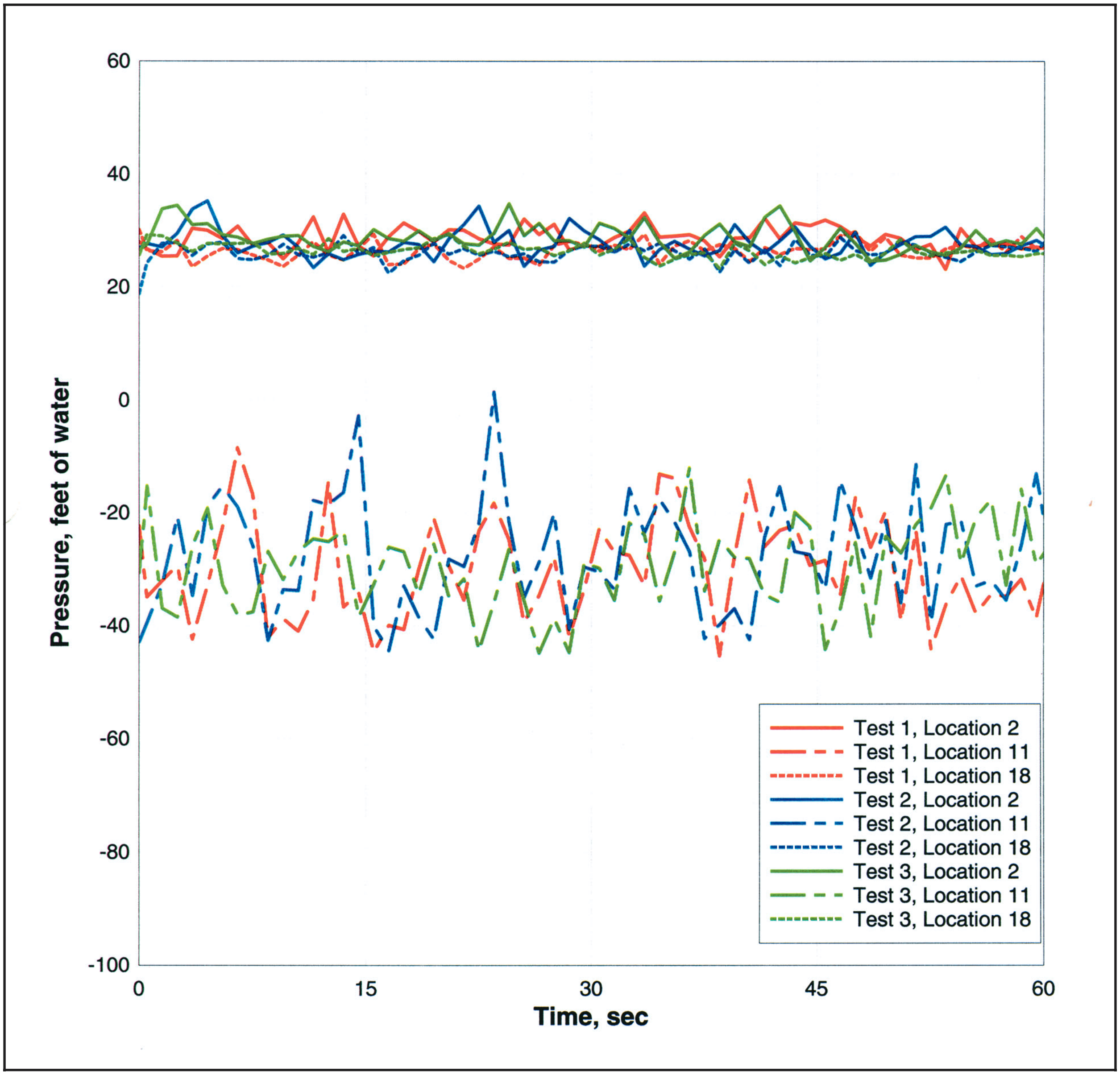


Figure 11. Pressure cell data, stilling basin, condition 4, downstream of spillbay 5

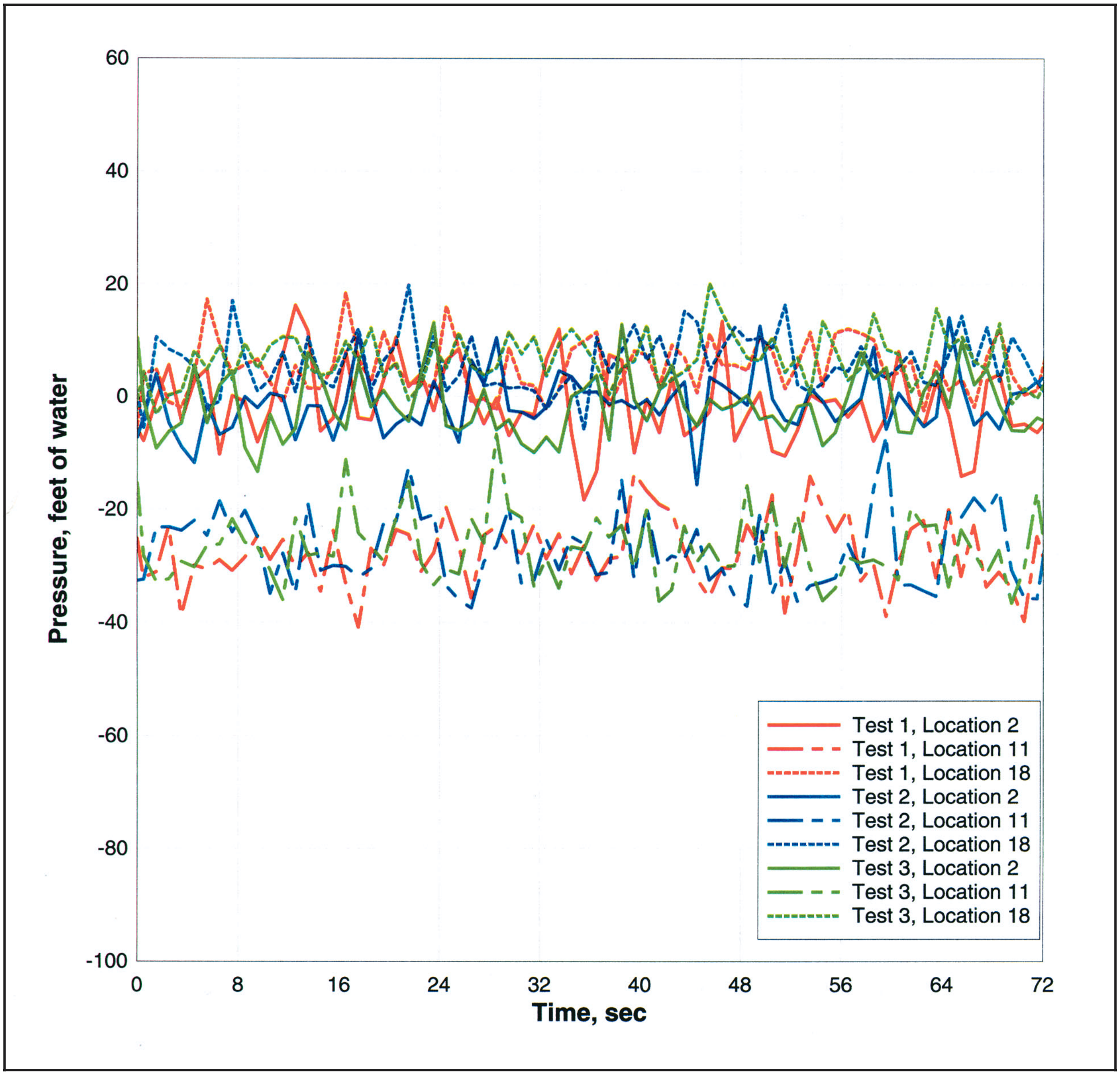


Figure 12. Pressure cell data, stilling basin, condition 4, downstream of spillbay 8

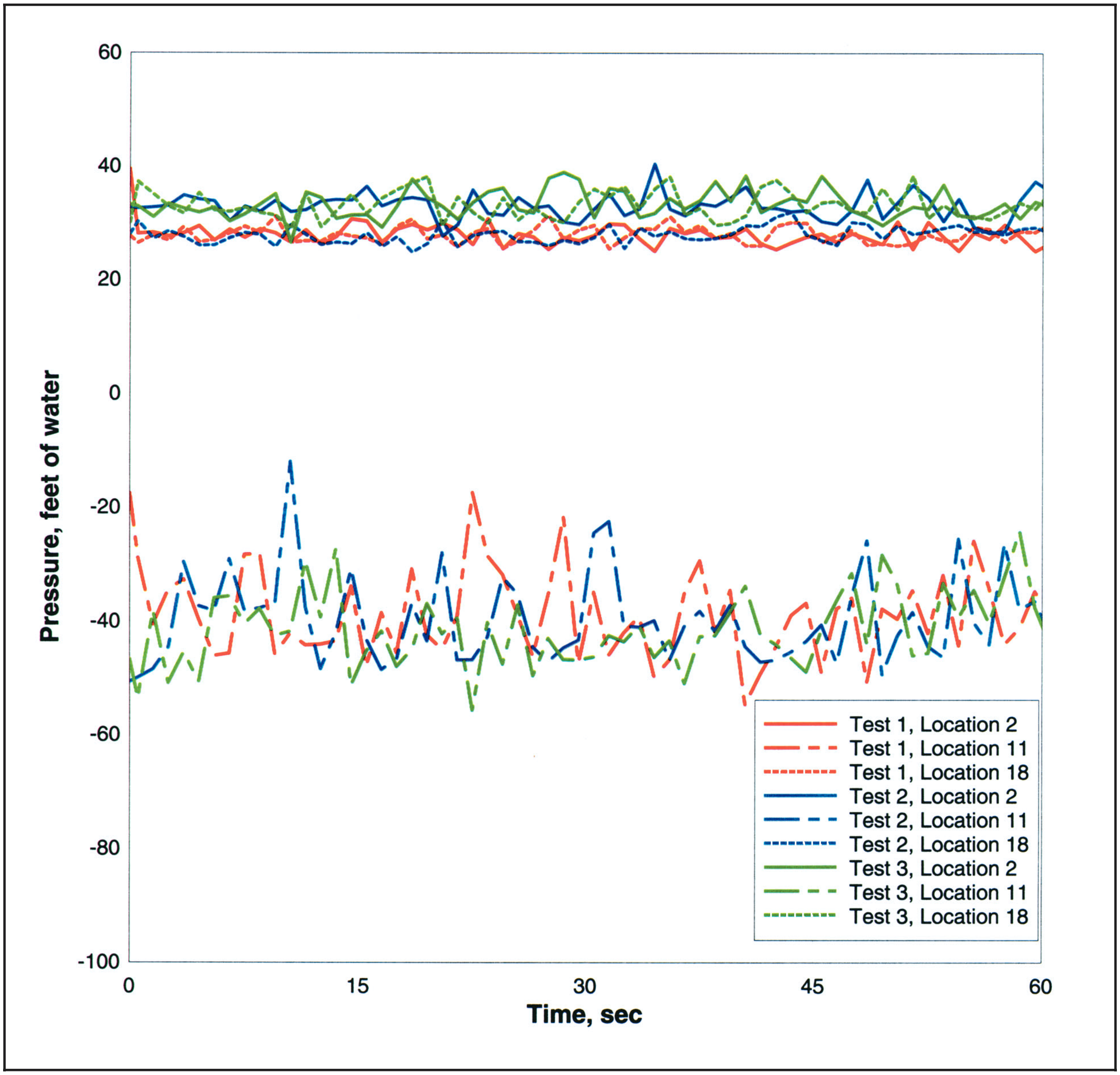


Figure 13. Pressure cell data, stilling basin, condition 5, downstream of spillbay 5

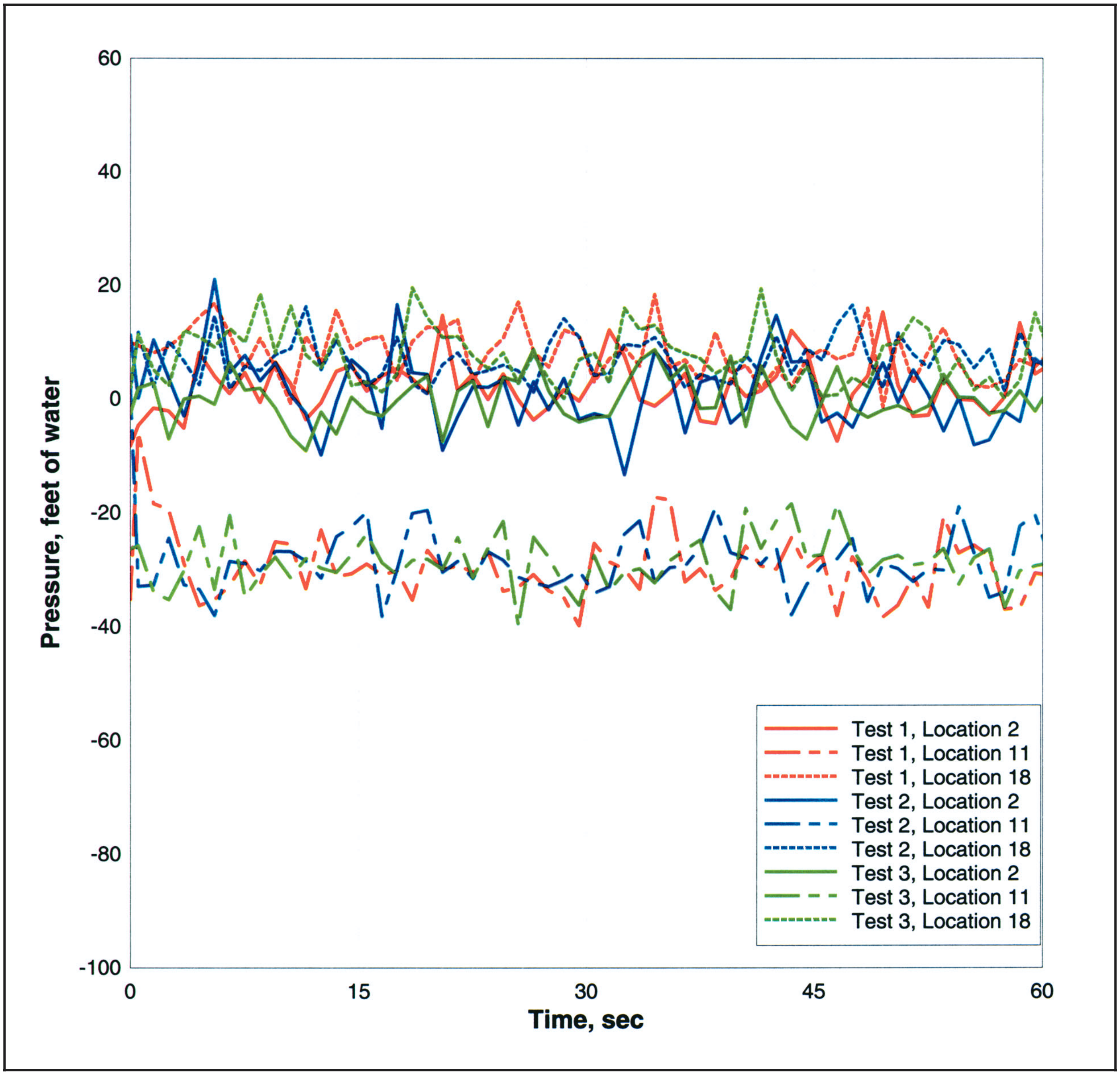


Figure 14. Pressure cell data, stilling basin, condition 5, downstream of spillbay 8

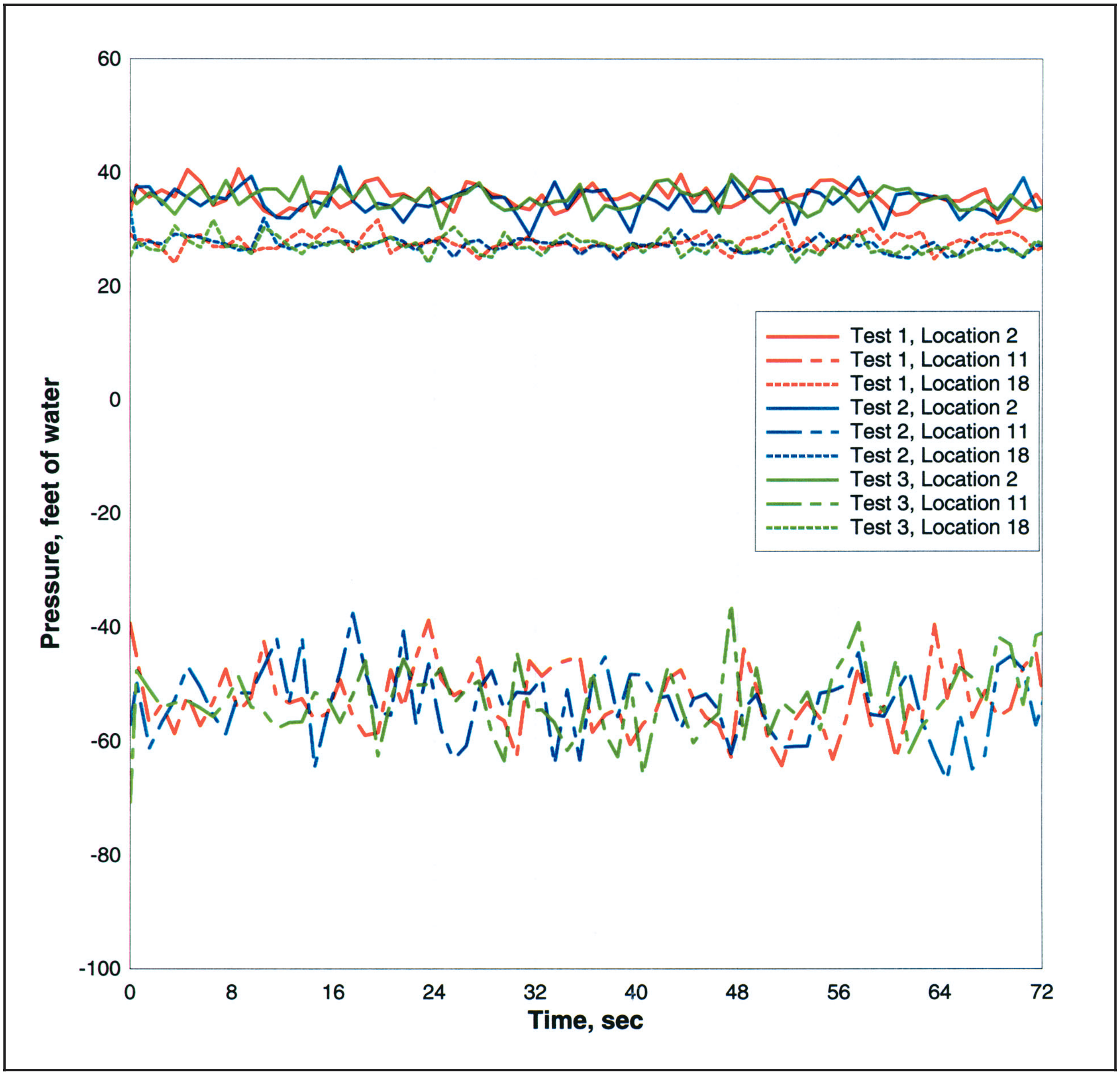


Figure 15. Pressure cell data, stilling basin, condition 6, downstream of spillbay 5

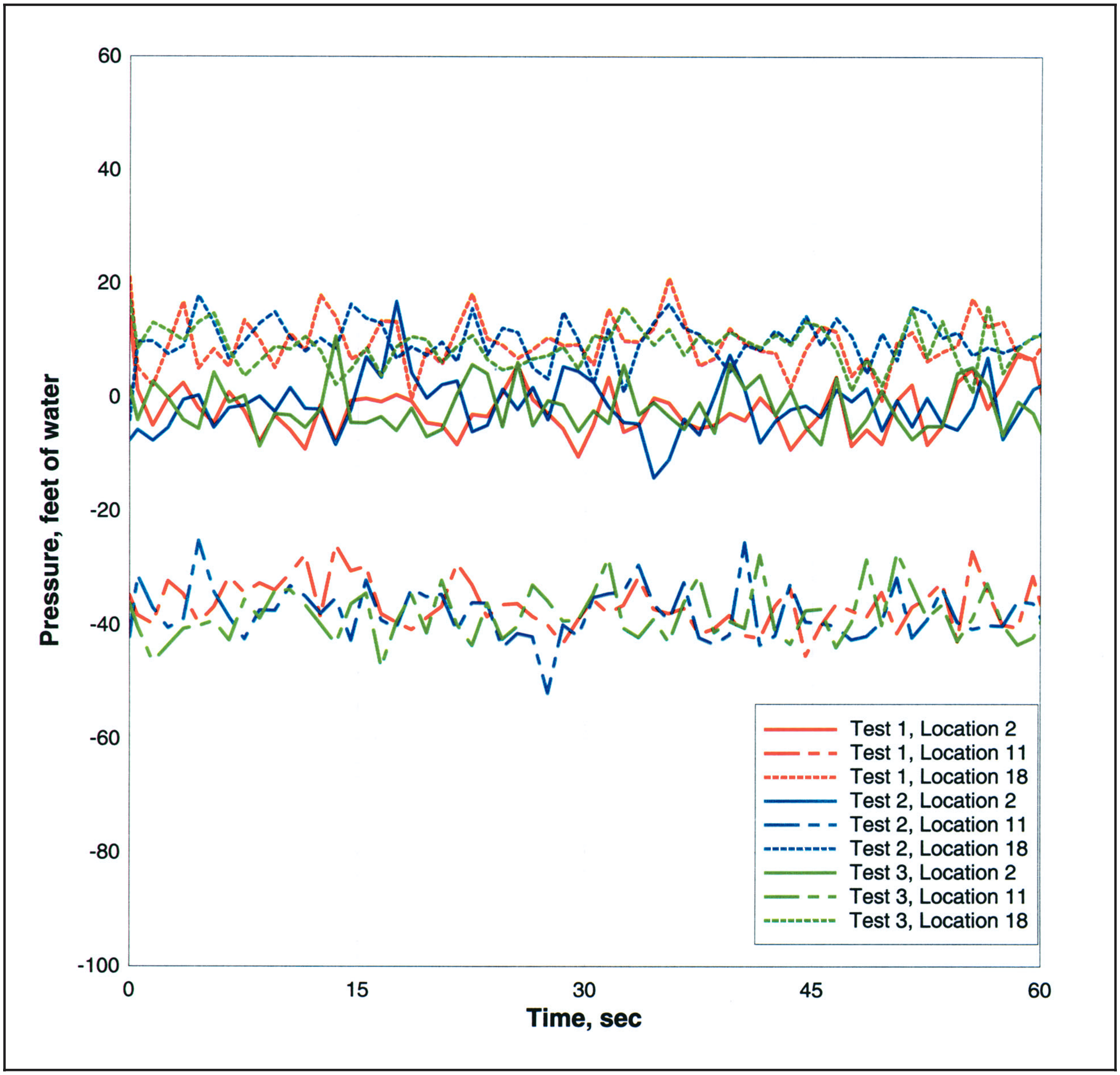


Figure 16. Pressure cell data, stilling basin, condition 6, downstream of spillbay 8

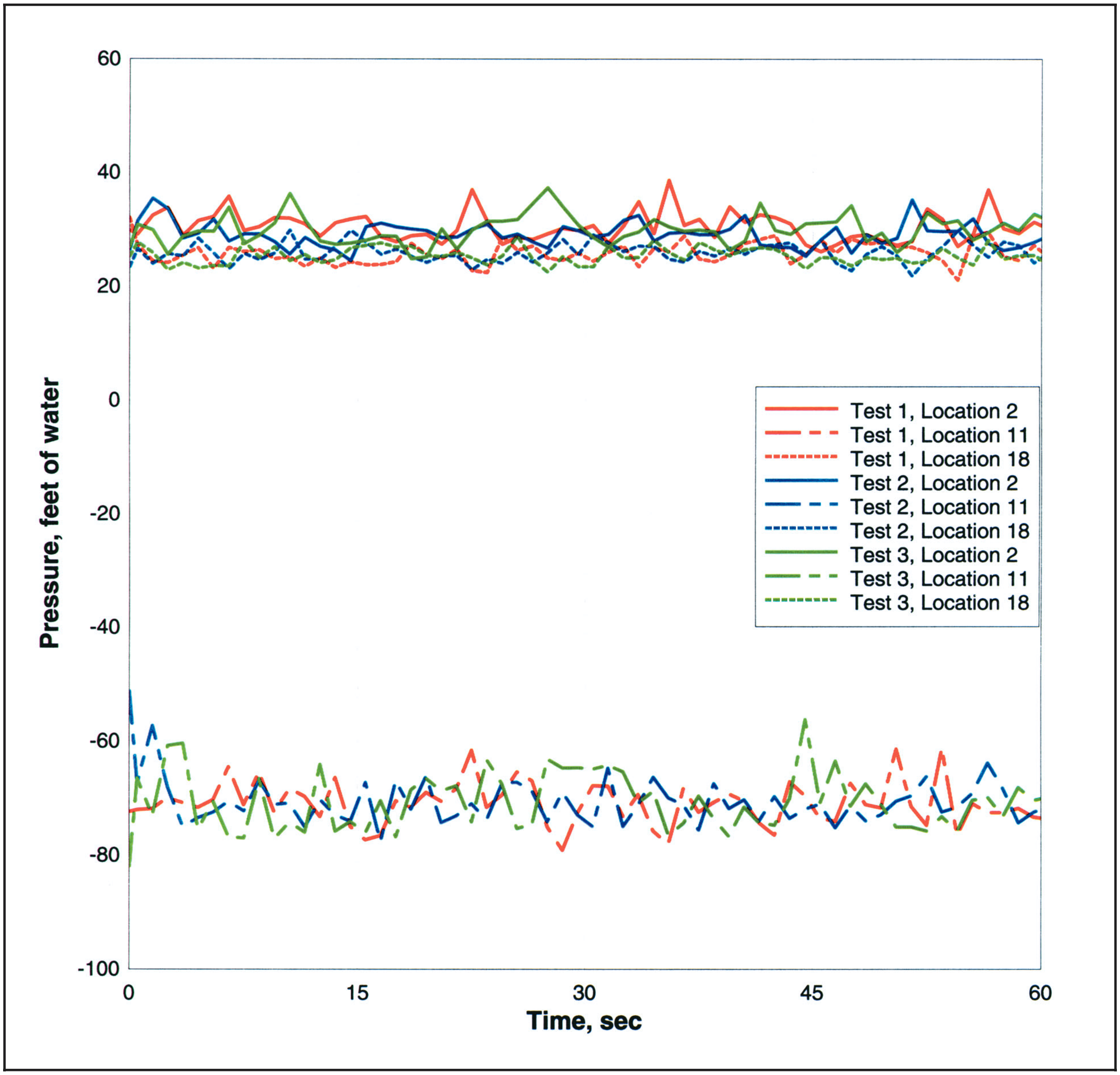


Figure 17. Pressure cell data, stilling basin, condition 7, downstream of spillbay 5

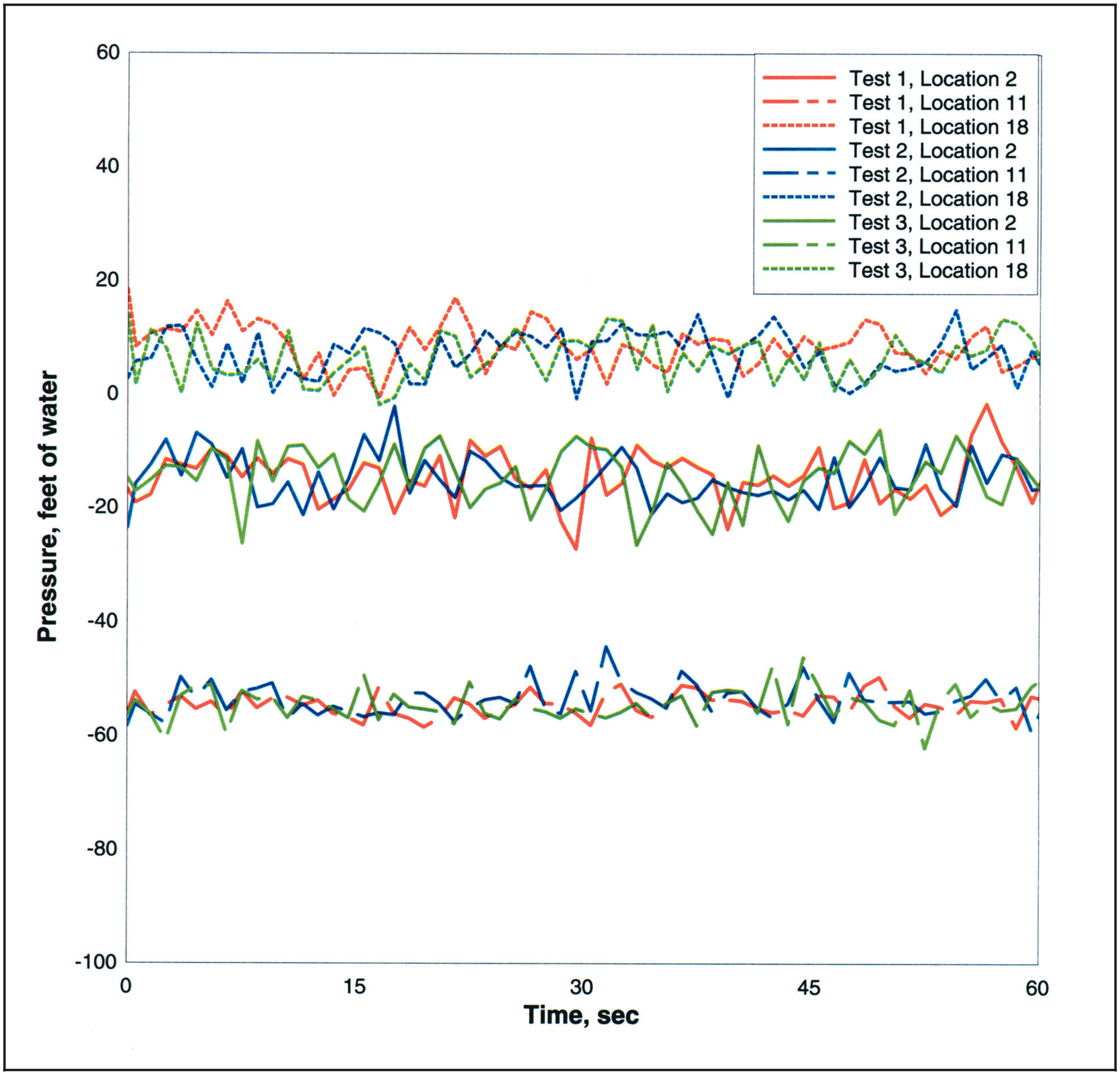


Figure 18. Pressure cell data, stilling basin, condition 7, downstream of spillbay 8

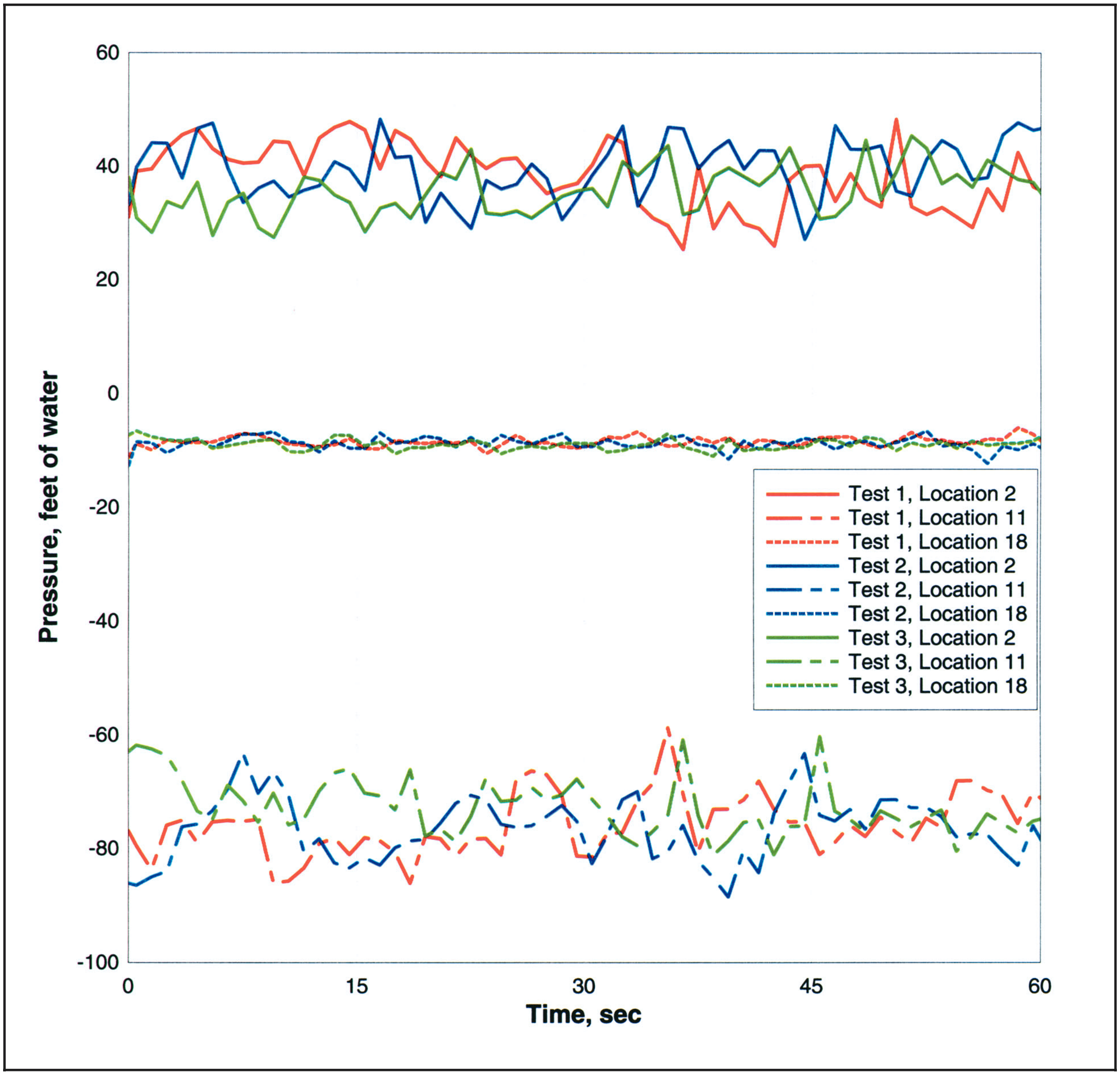


Figure 19. Pressure cell data, stilling basin, condition 8, downstream of spillbay 5

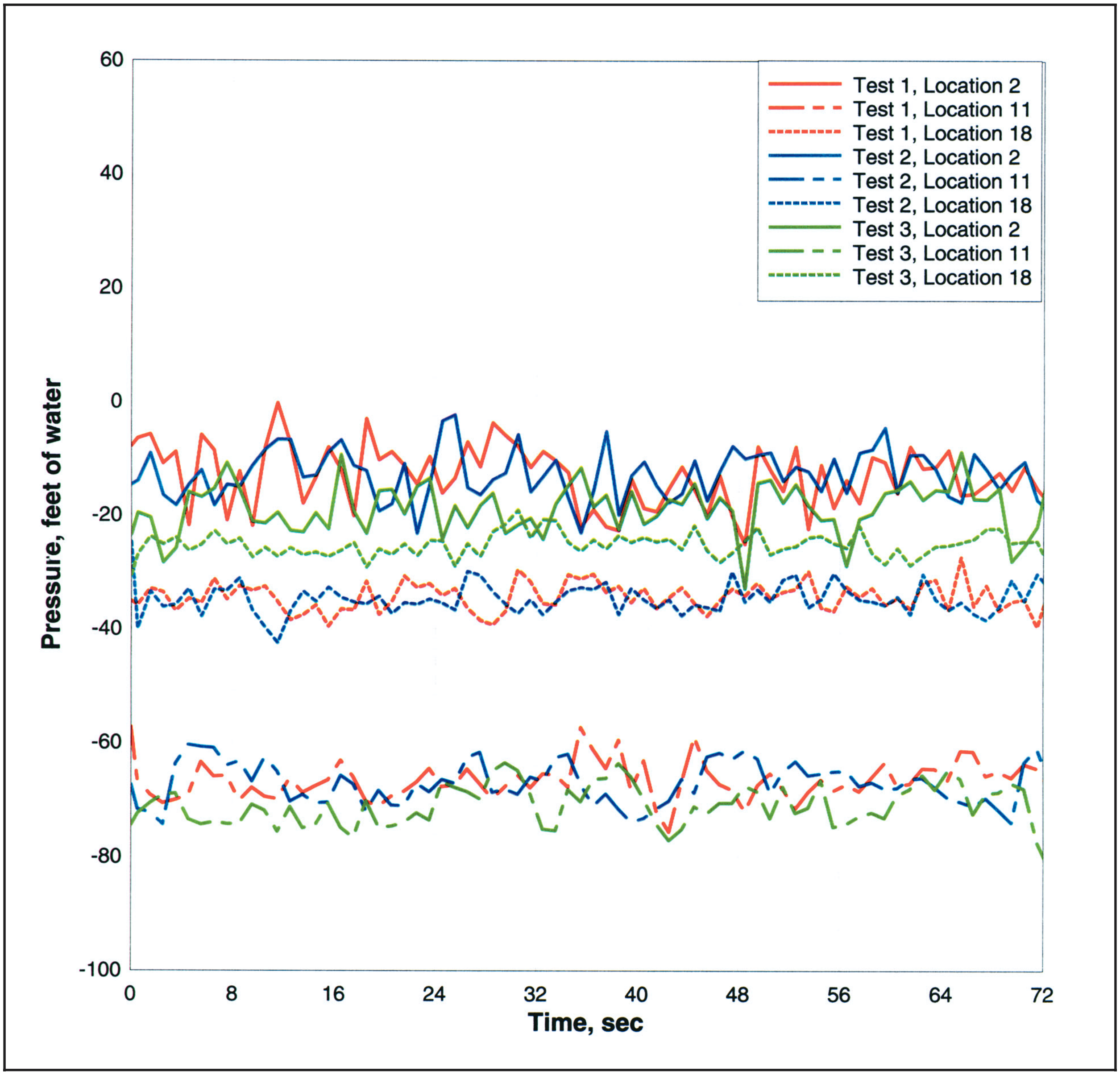


Figure 20. Pressure cell data, stilling basin, condition 8, downstream of spillbay 8

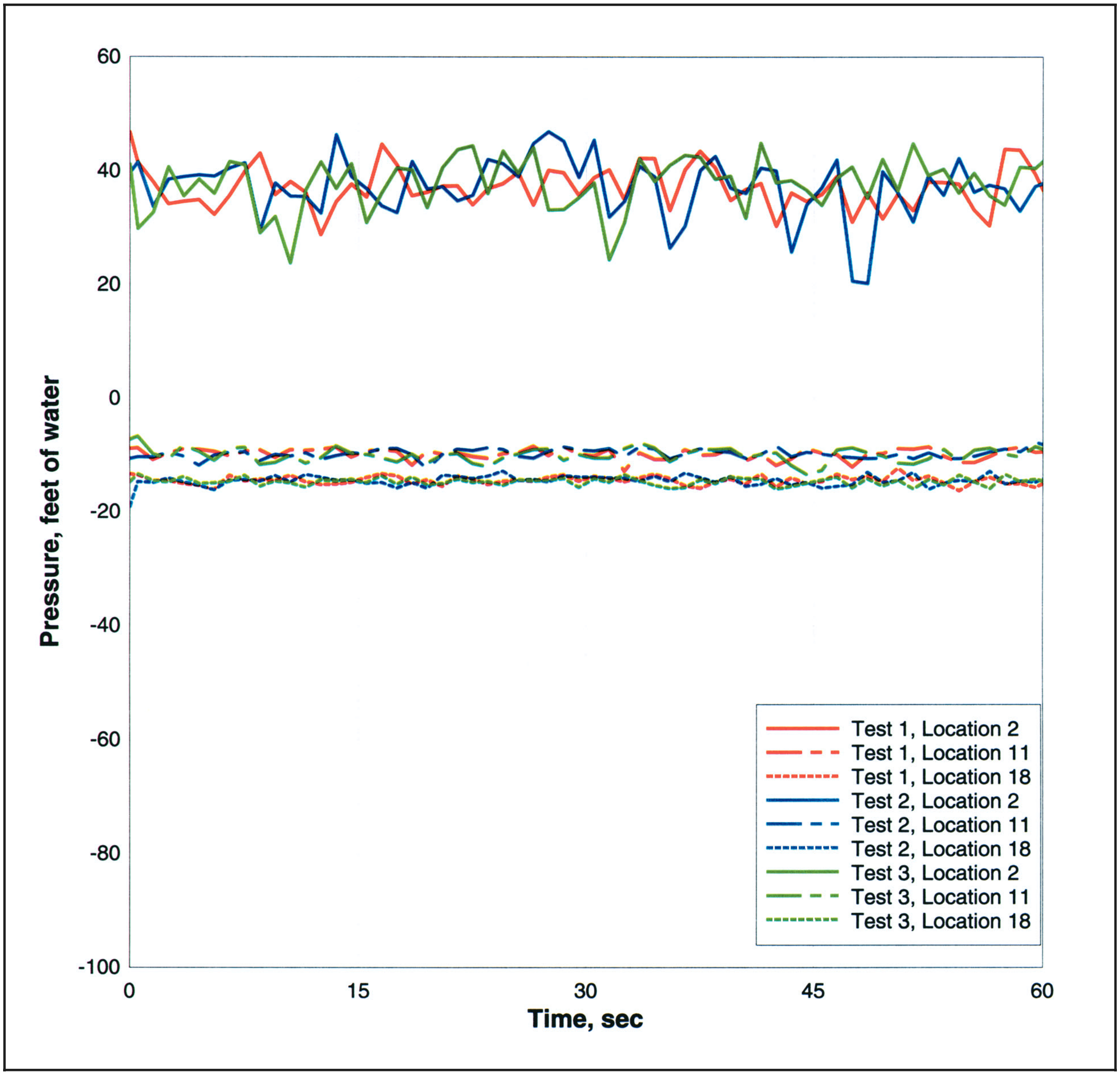


Figure 21. Pressure cell data, stilling basin, condition 9, downstream of spillbay 5

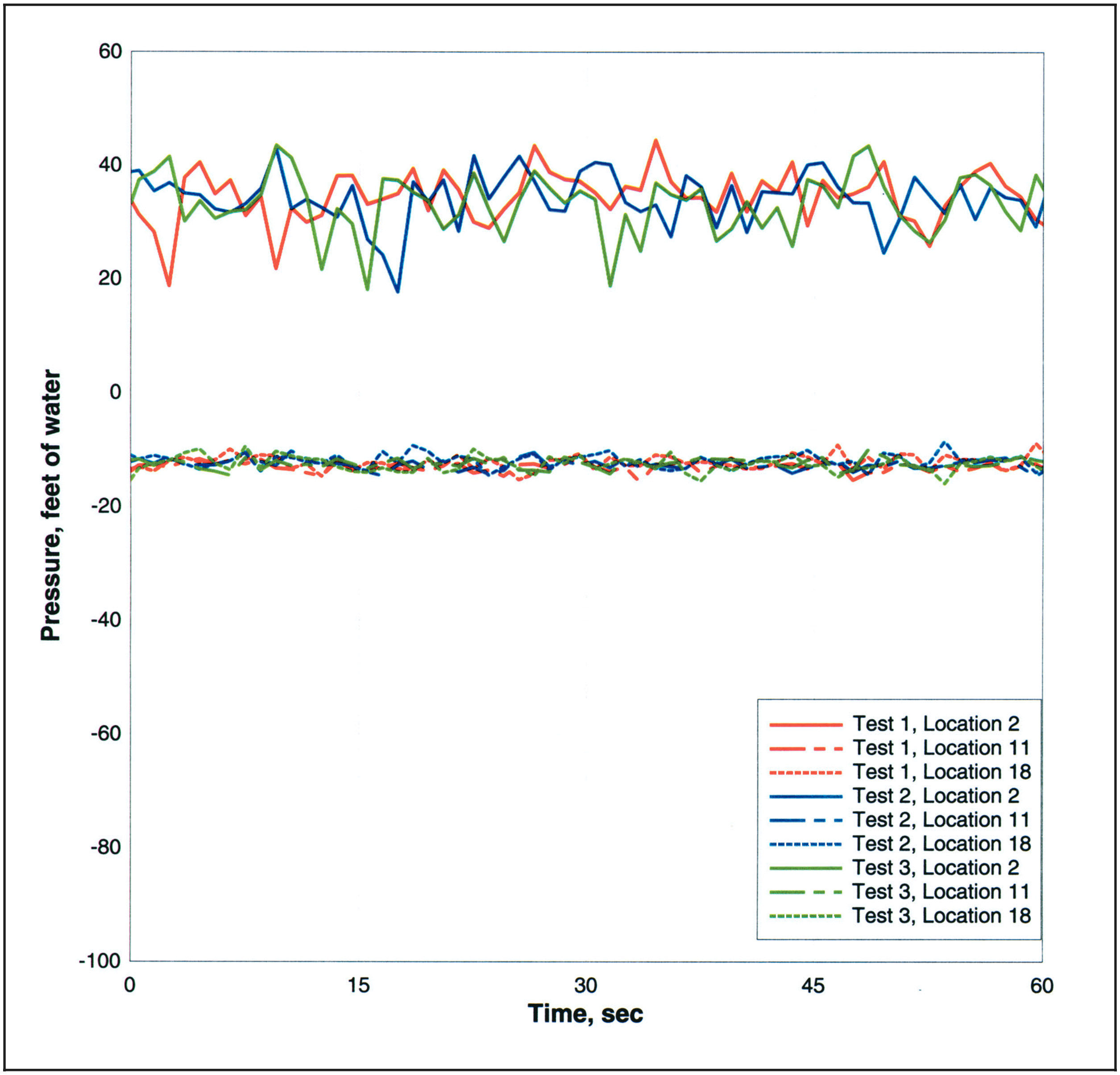


Figure 22. Pressure cell data, stilling basin, condition 9, downstream of spillbay 8

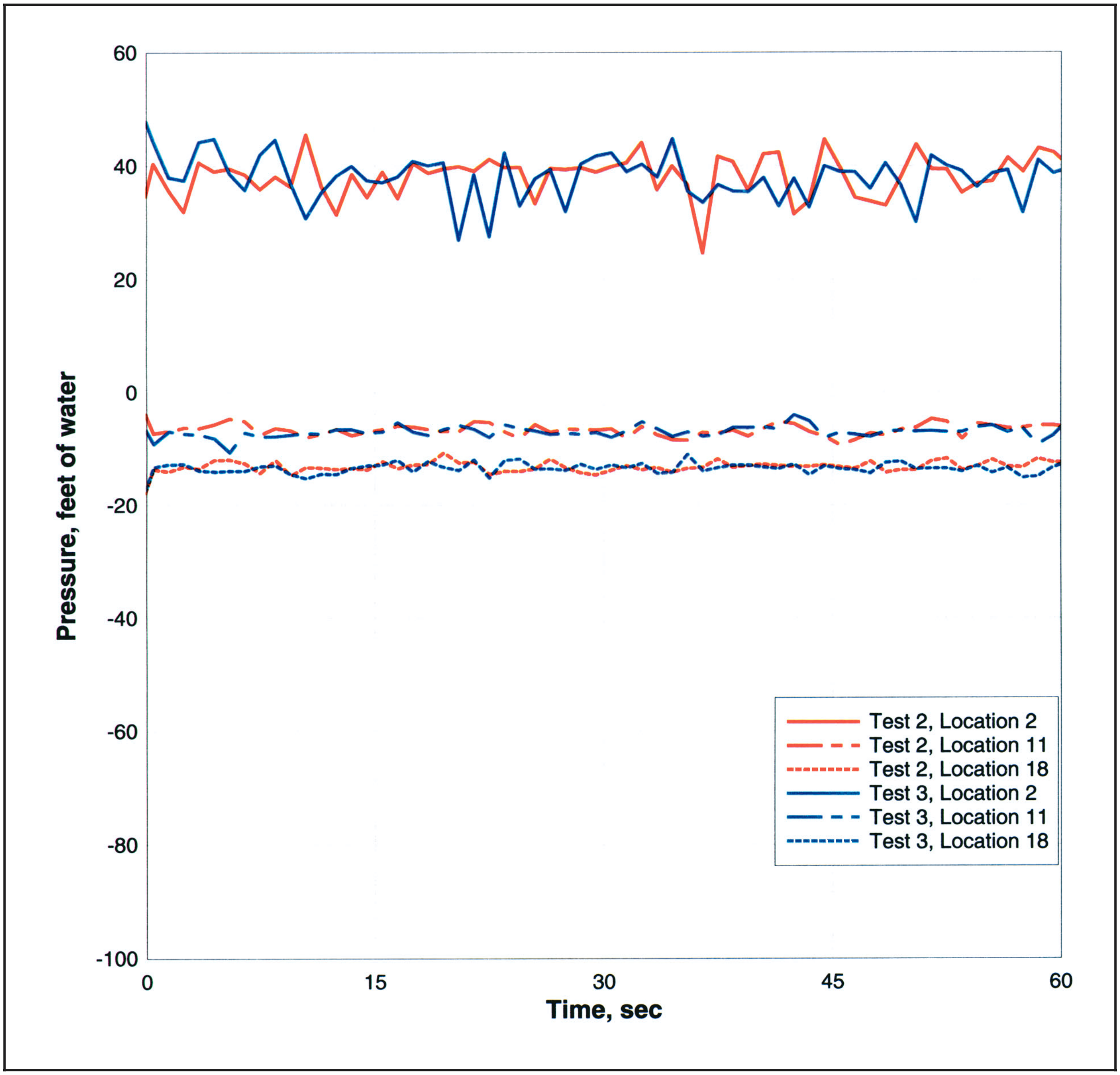


Figure 23. Pressure cell data, stilling basin, condition 10, downstream of spillbay 5

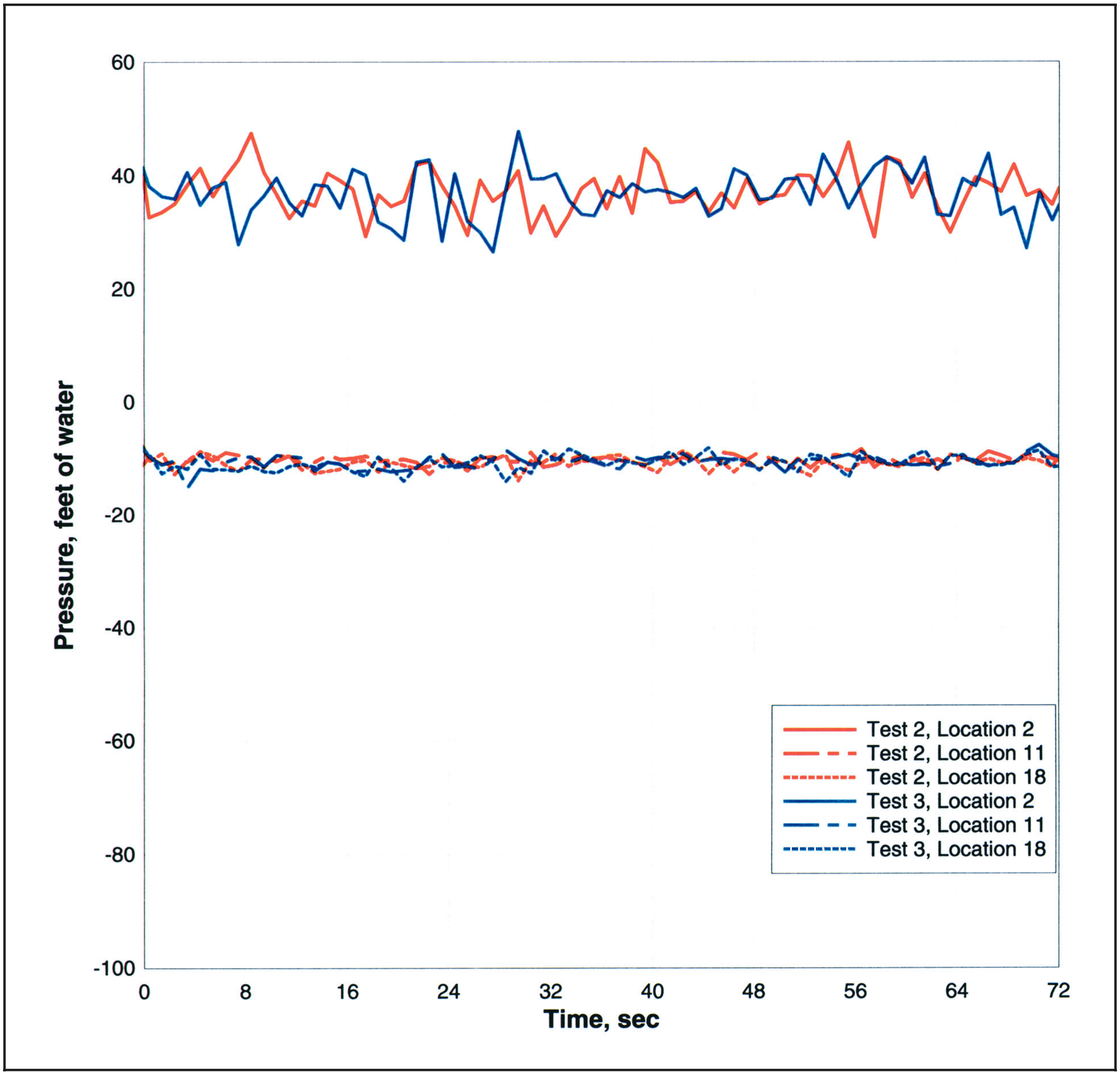


Figure 24. Pressure cell data, stilling basin, condition 10, downstream of spillbay 8

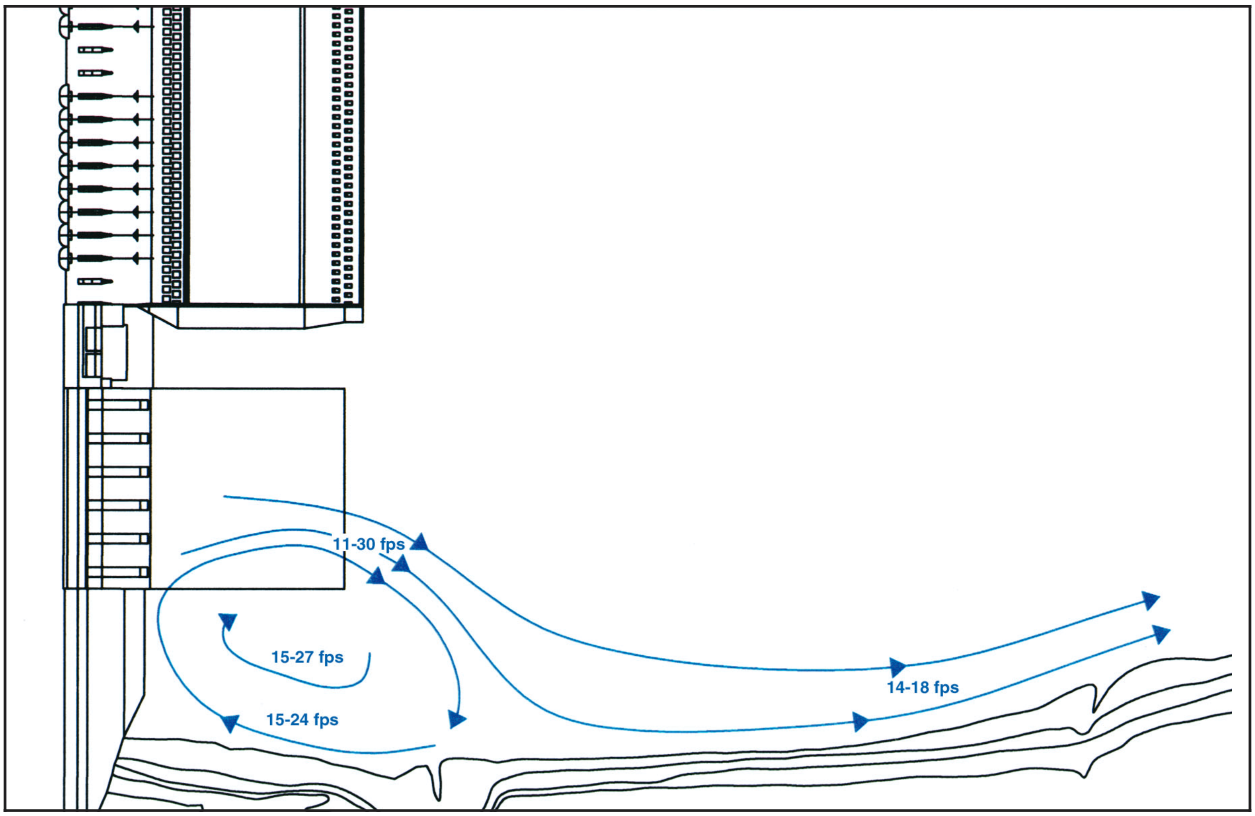


Figure 25. Size and intensity of eddy downstream of penstocks during PMF

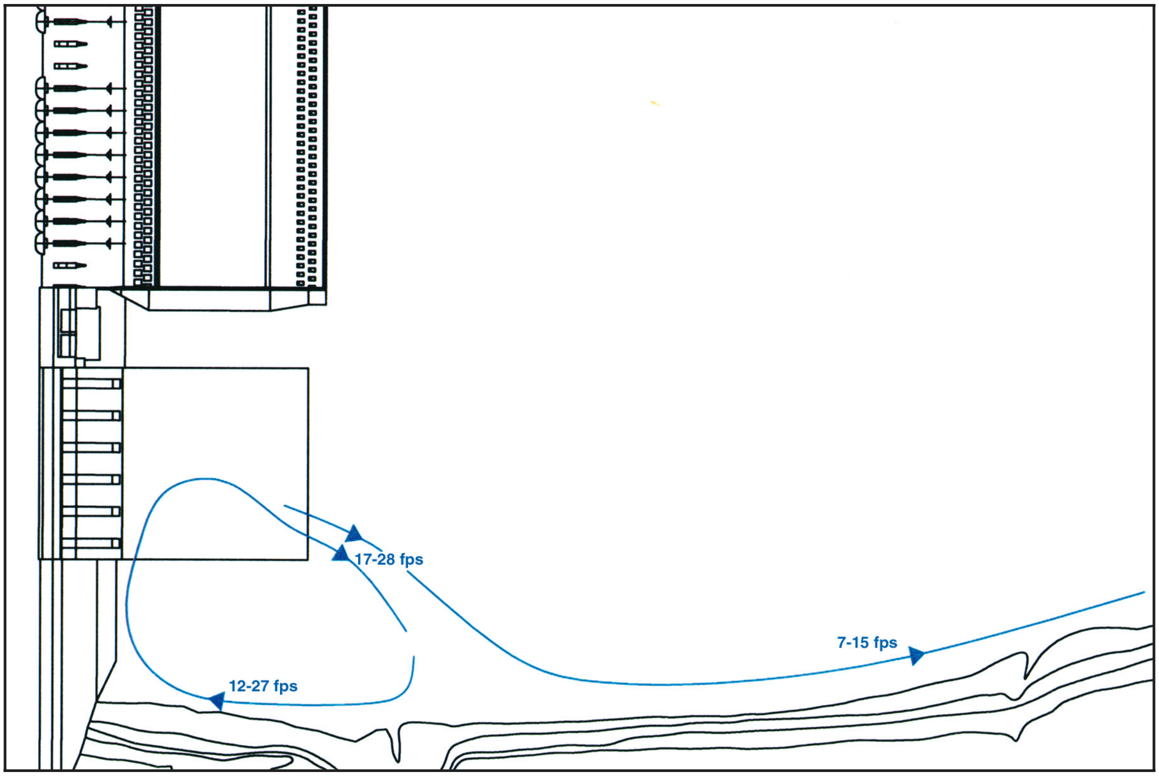


Figure 26. Size and intensity of eddy downstream of penstocks during PMF with 15 deg of deflection toward right bank

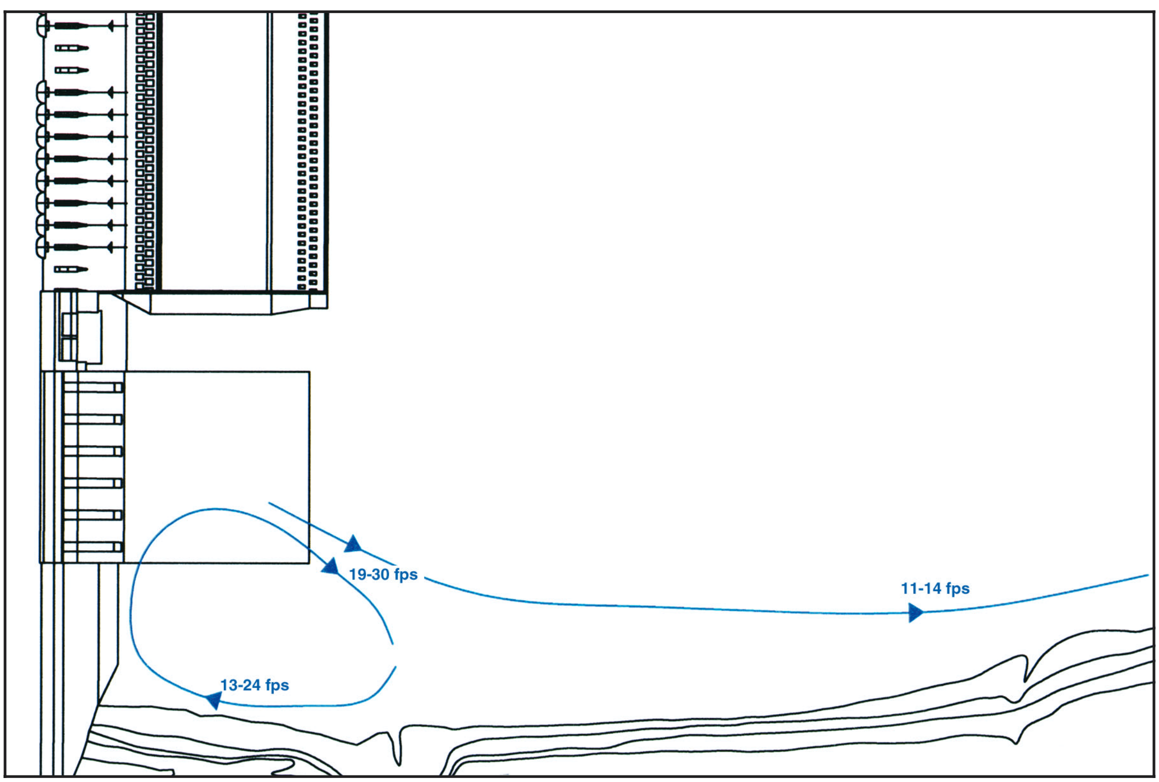


Figure 27. Size and intensity of eddy downstream of penstocks during PMF with 30 deg of deflection toward right bank

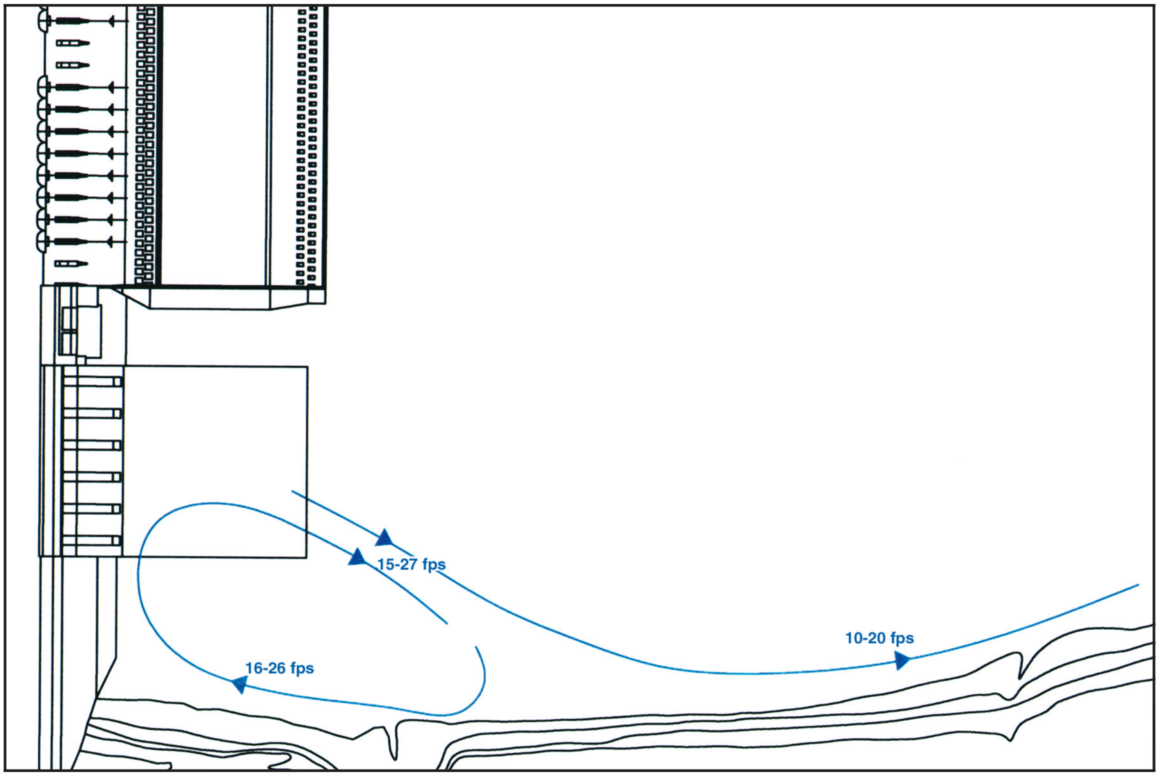


Figure 28. Size and intensity of eddy downstream of penstocks during PMF with 15 deg of deflection toward channel

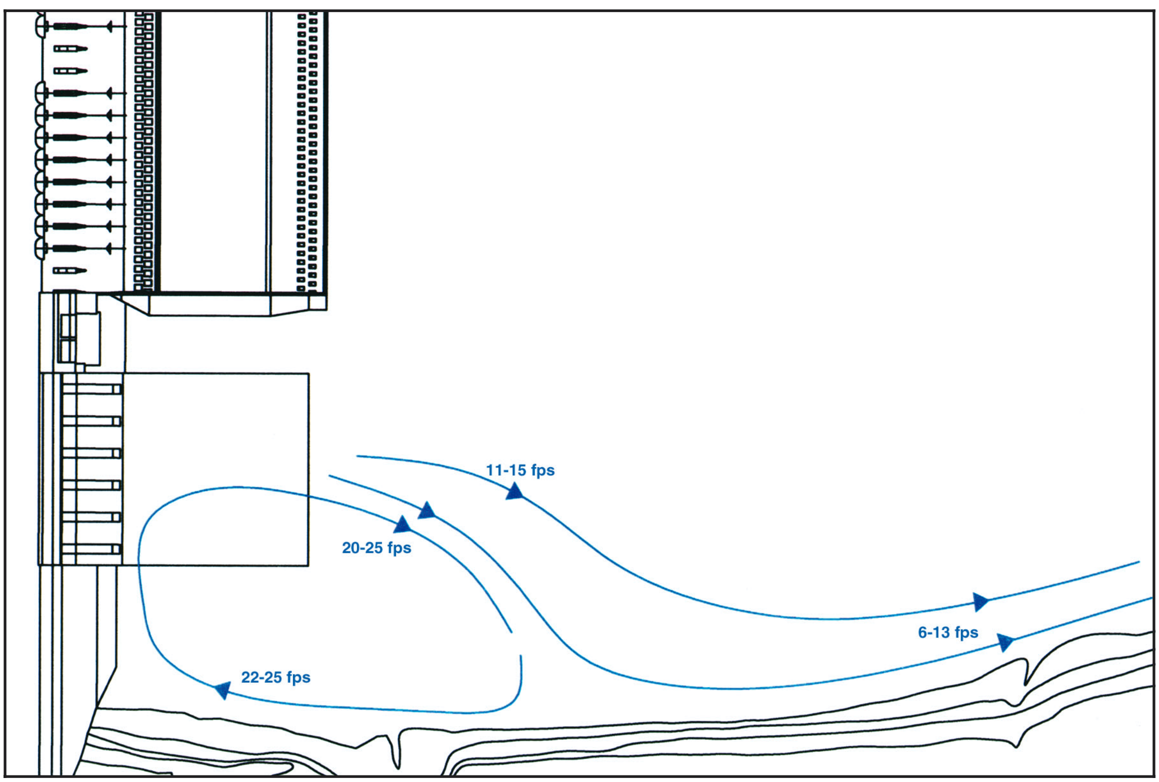


Figure 29. Size and intensity of eddy downstream of penstocks during PMF with 30 deg of deflection toward channel

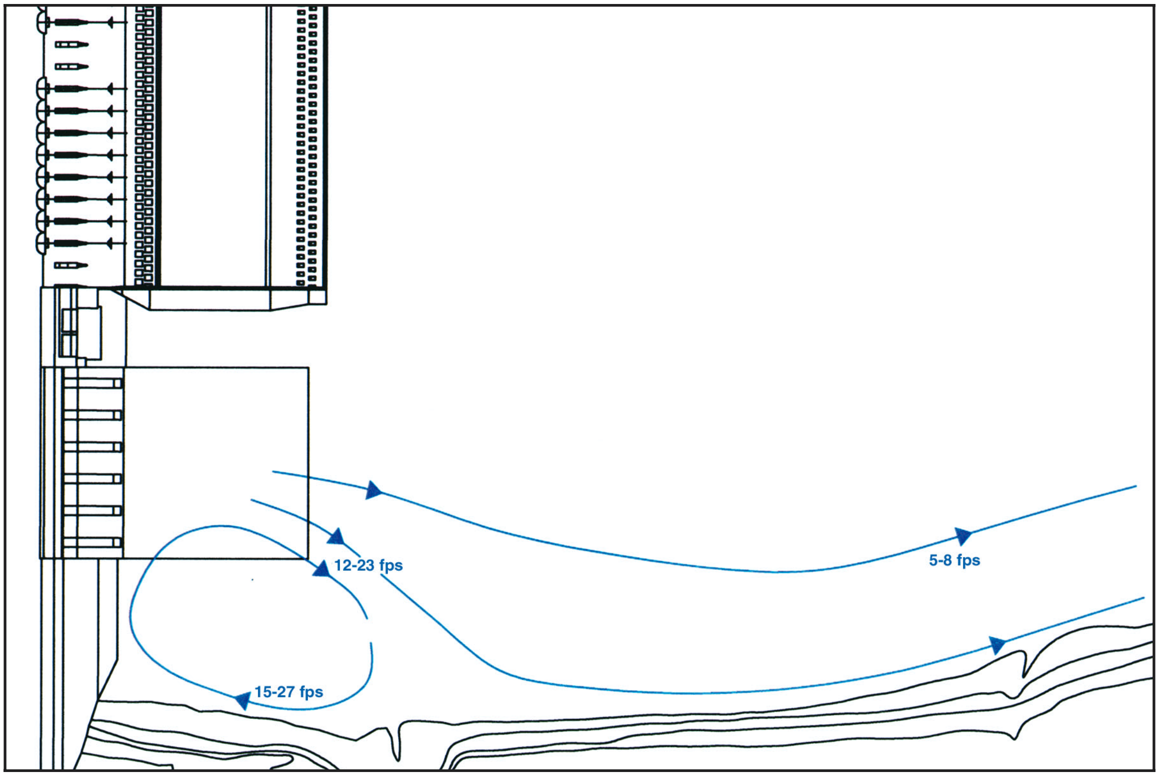


Figure 30. Size and intensity of eddy downstream of penstocks during PMF with 15 deg of upward deflection

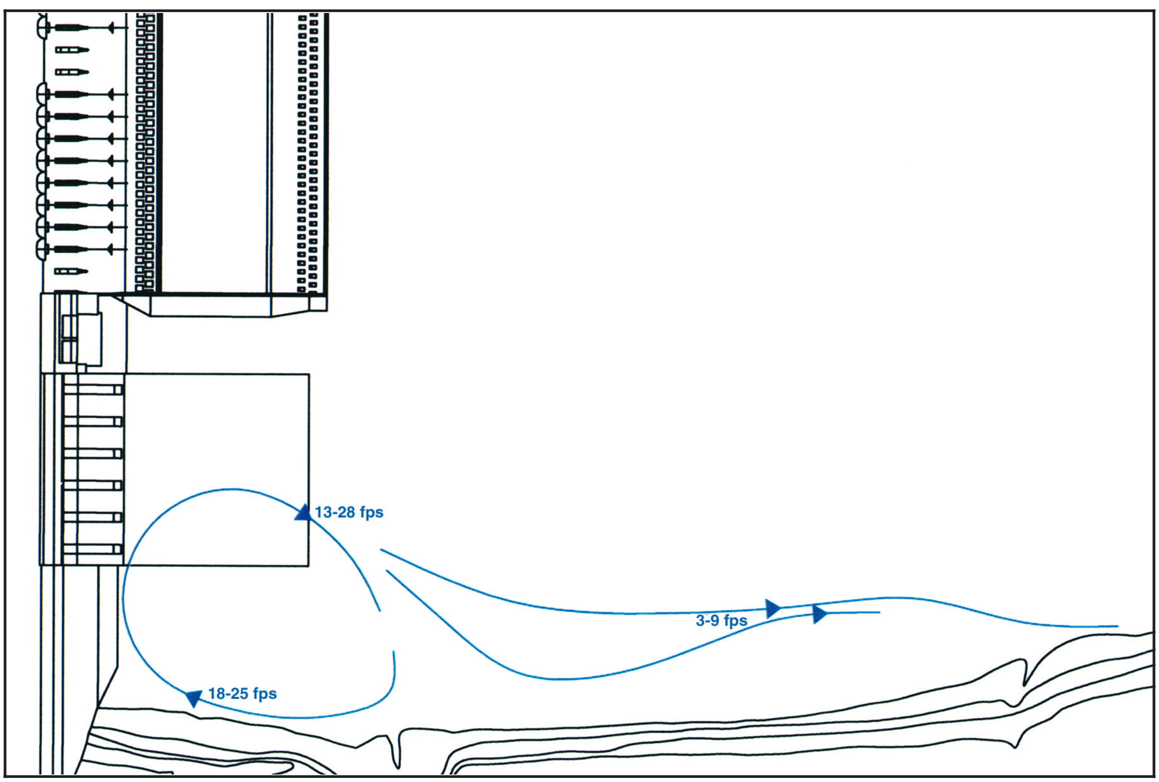


Figure 31. Size and intensity of eddy downstream of penstocks during PMF with 30 deg of upward deflection

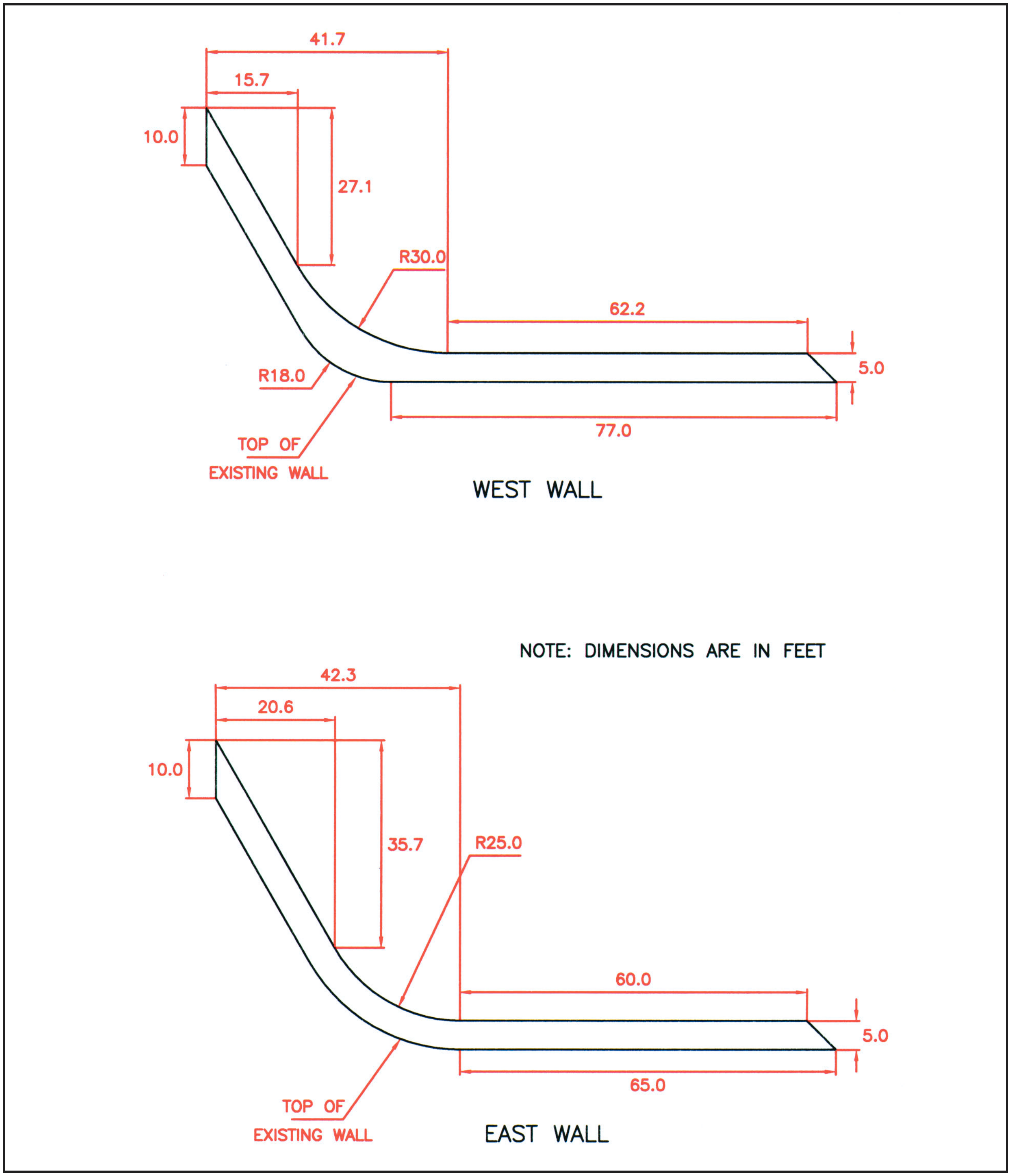


Figure 32. Final training wall designs

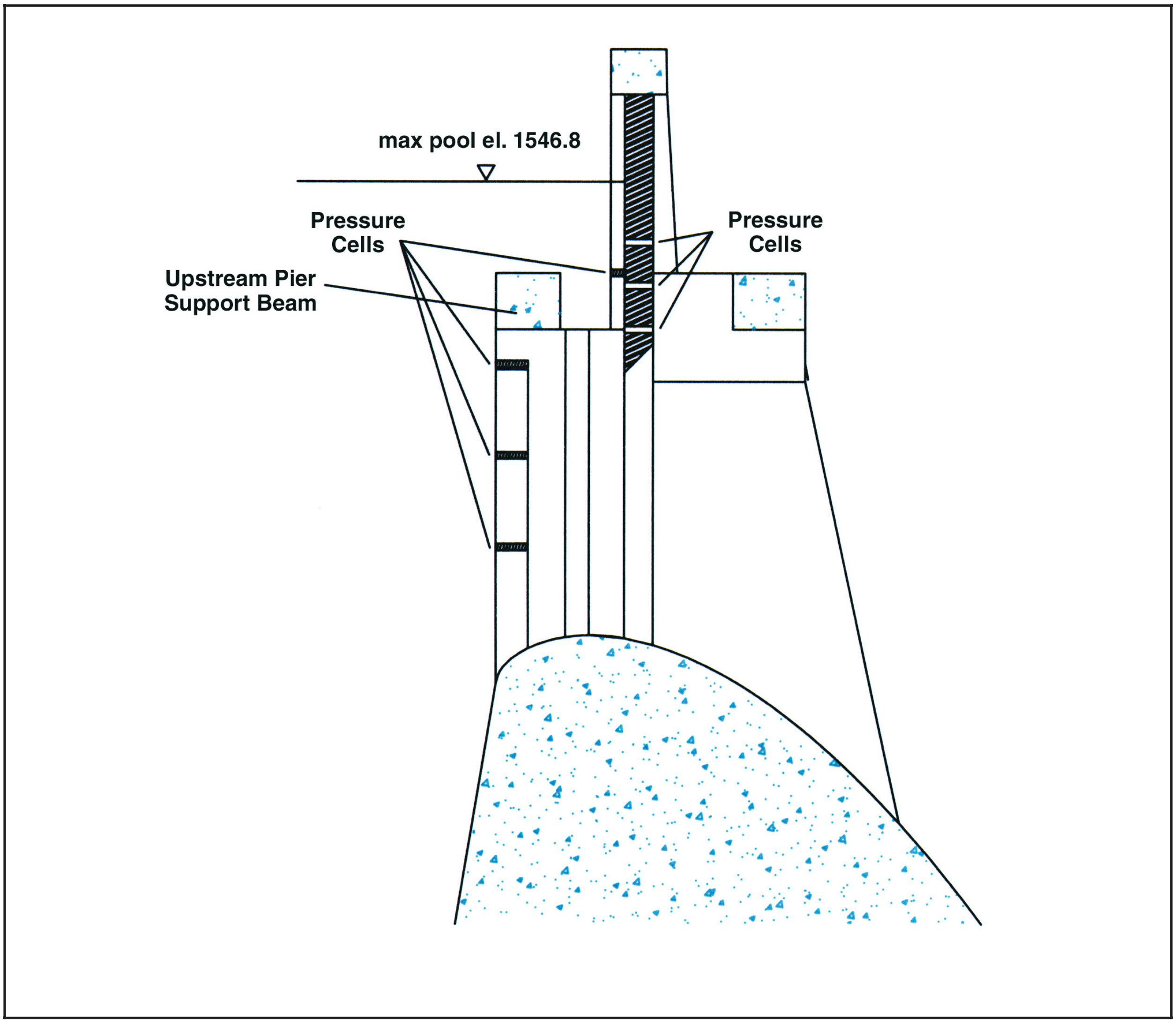


Figure 33. Cross section of spillway showing spill gate, pressure cell locations, and support beam

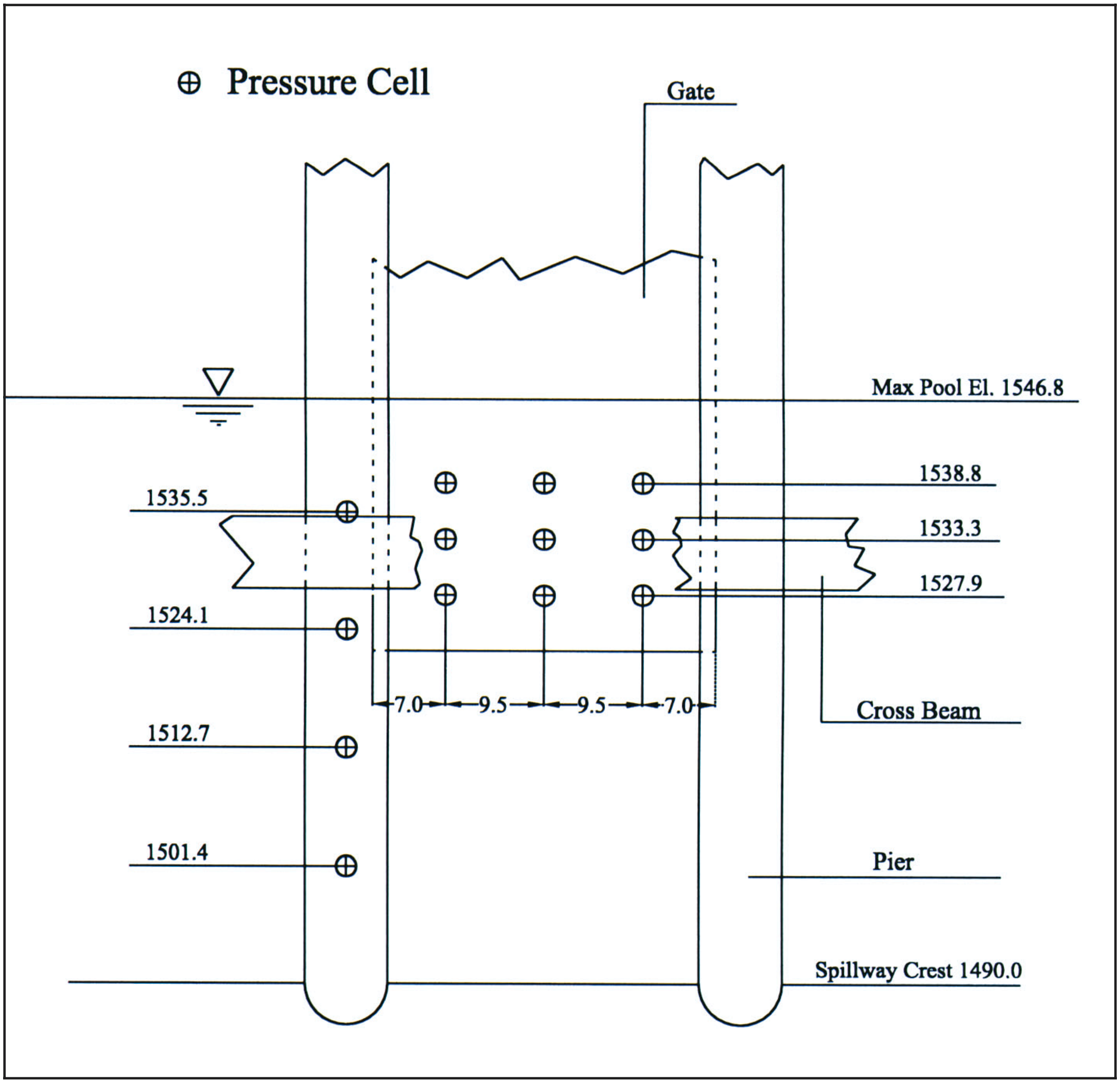


Figure 34. Spill gate and pier pressure cell locations, looking downstream

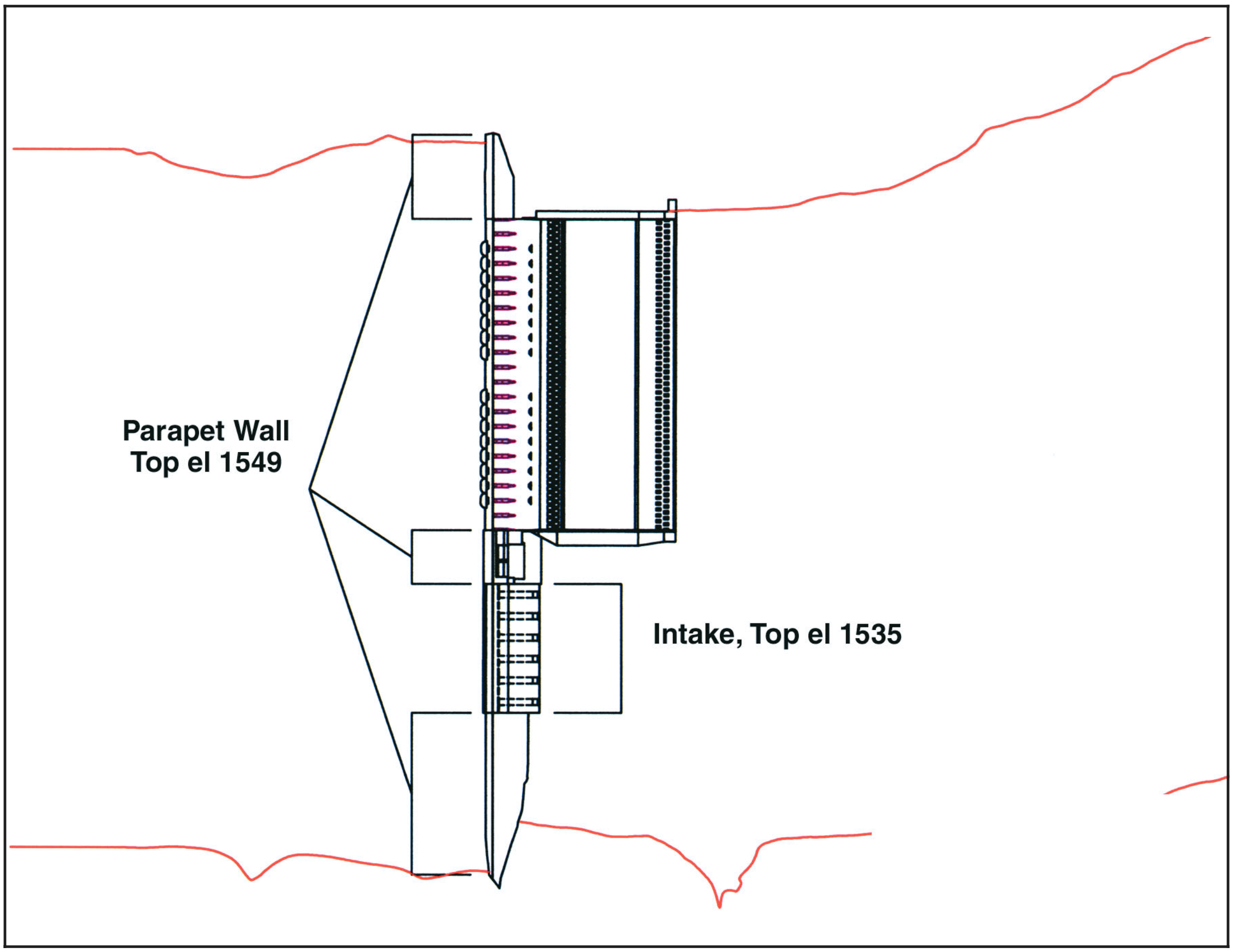


Figure 35. Layout of structures indicating overtopped (intake) section

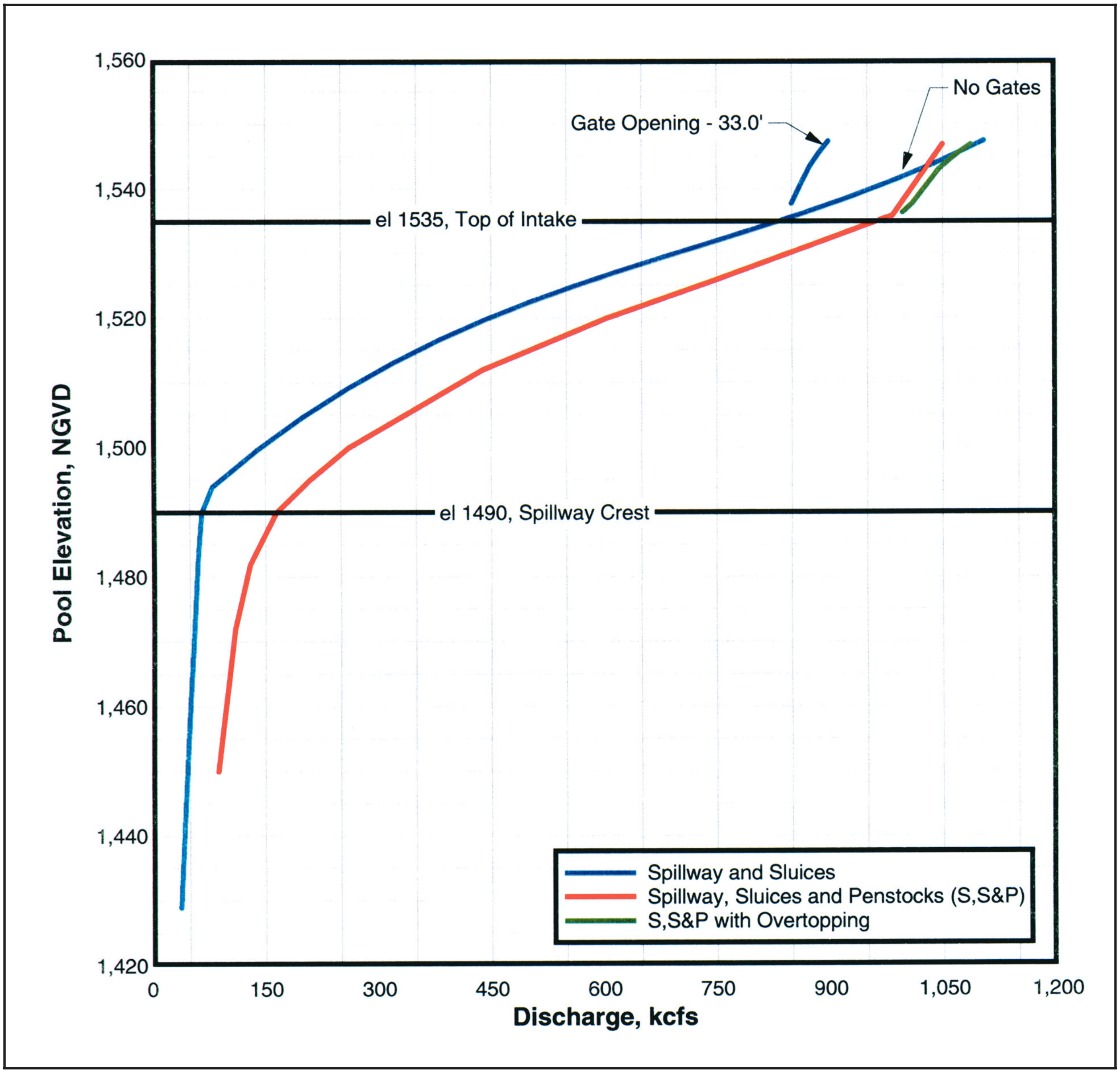


Figure 36. Extended rating curve, spillway, sluice, penstock, and overtopping discharge

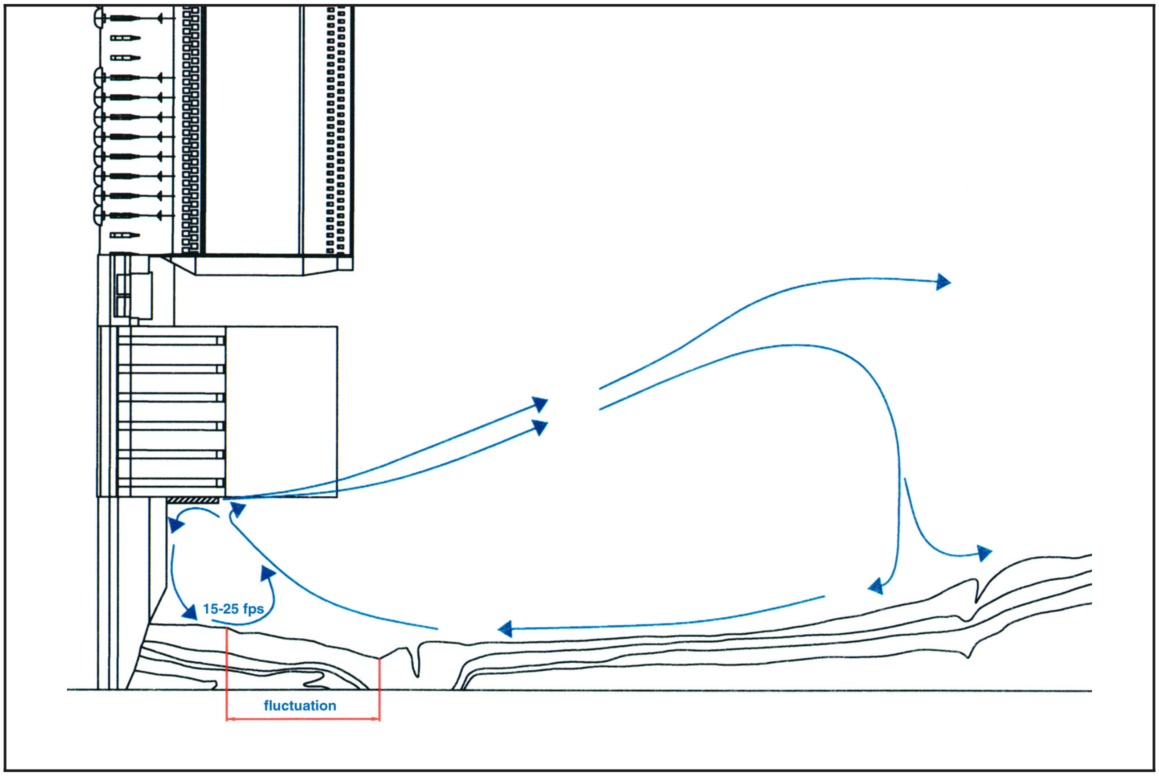


Figure 37. Eddy size and intensity with 100-ft-long training wall

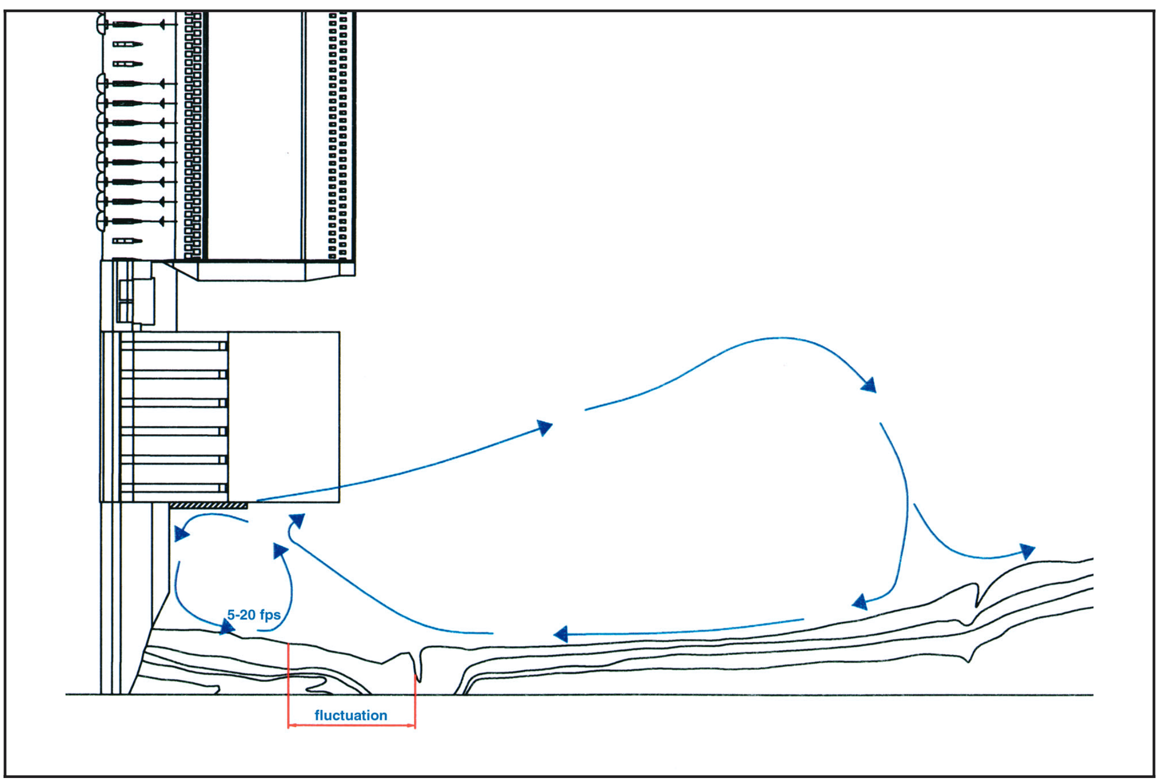


Figure 38. Eddy size and intensity with 150-ft-long training wall

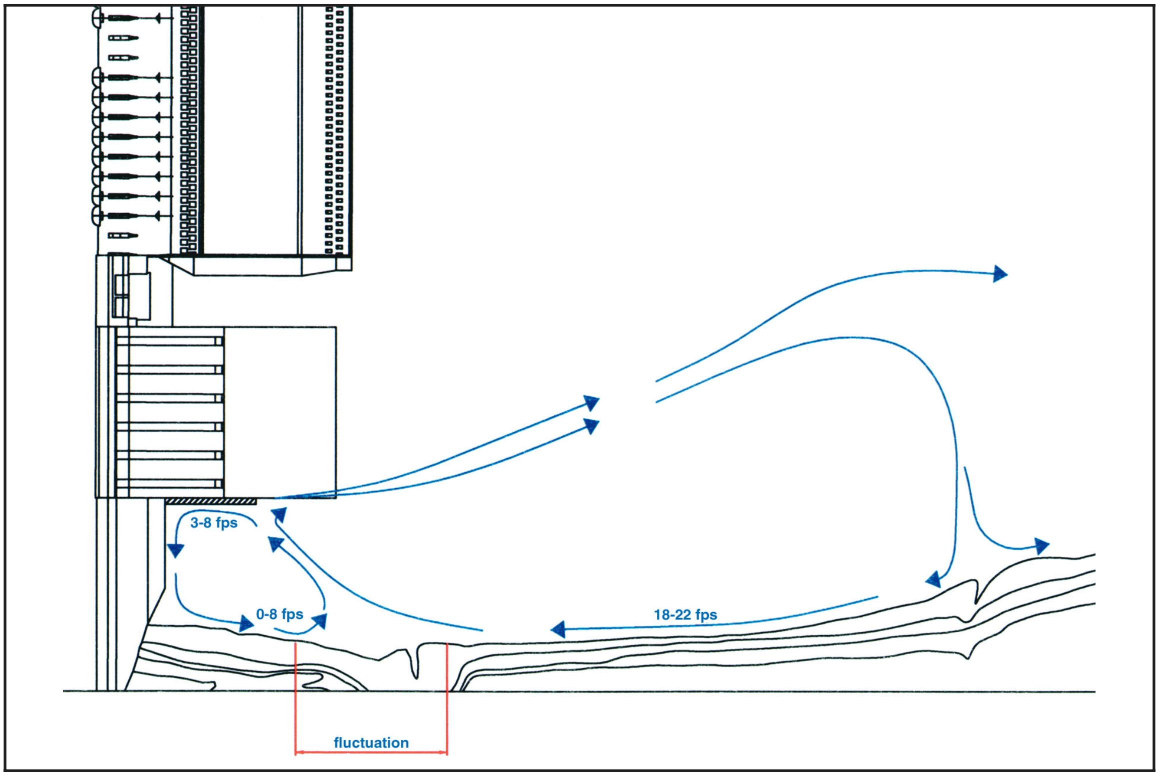


Figure 39. Eddy size and intensity with 175-ft-long training wall

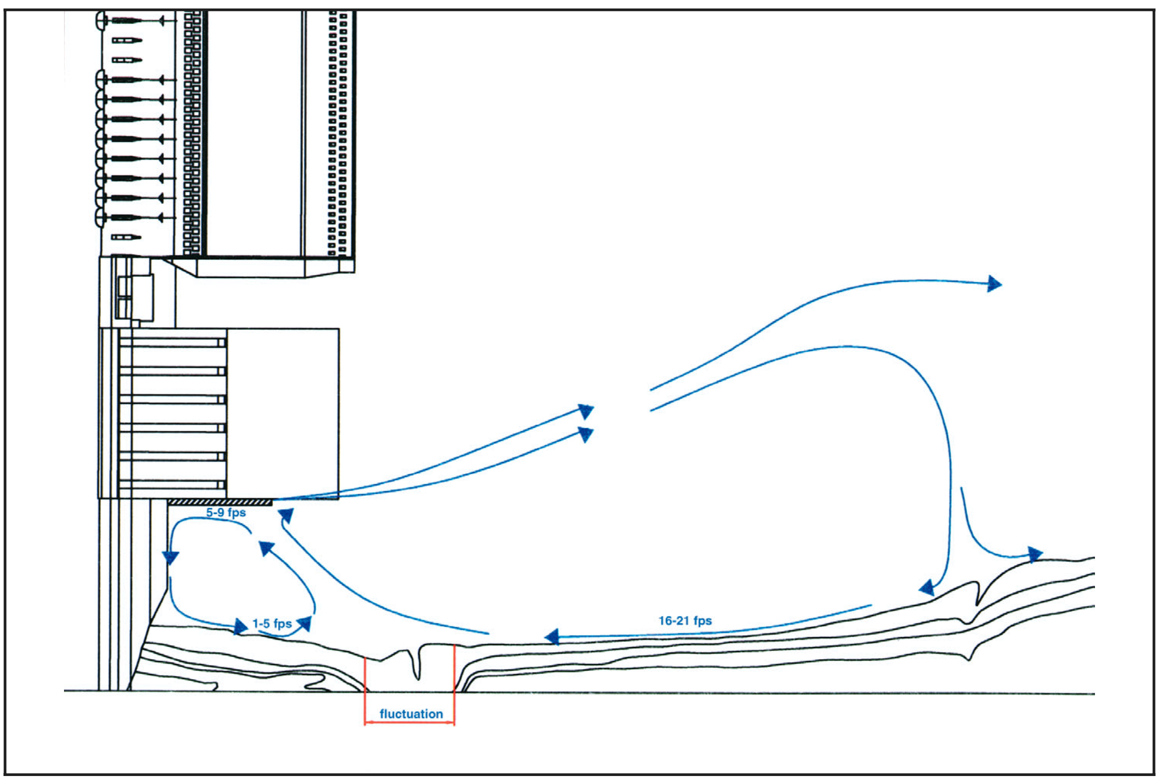


Figure 40. Eddy size and intensity with 200-ft-long training wall

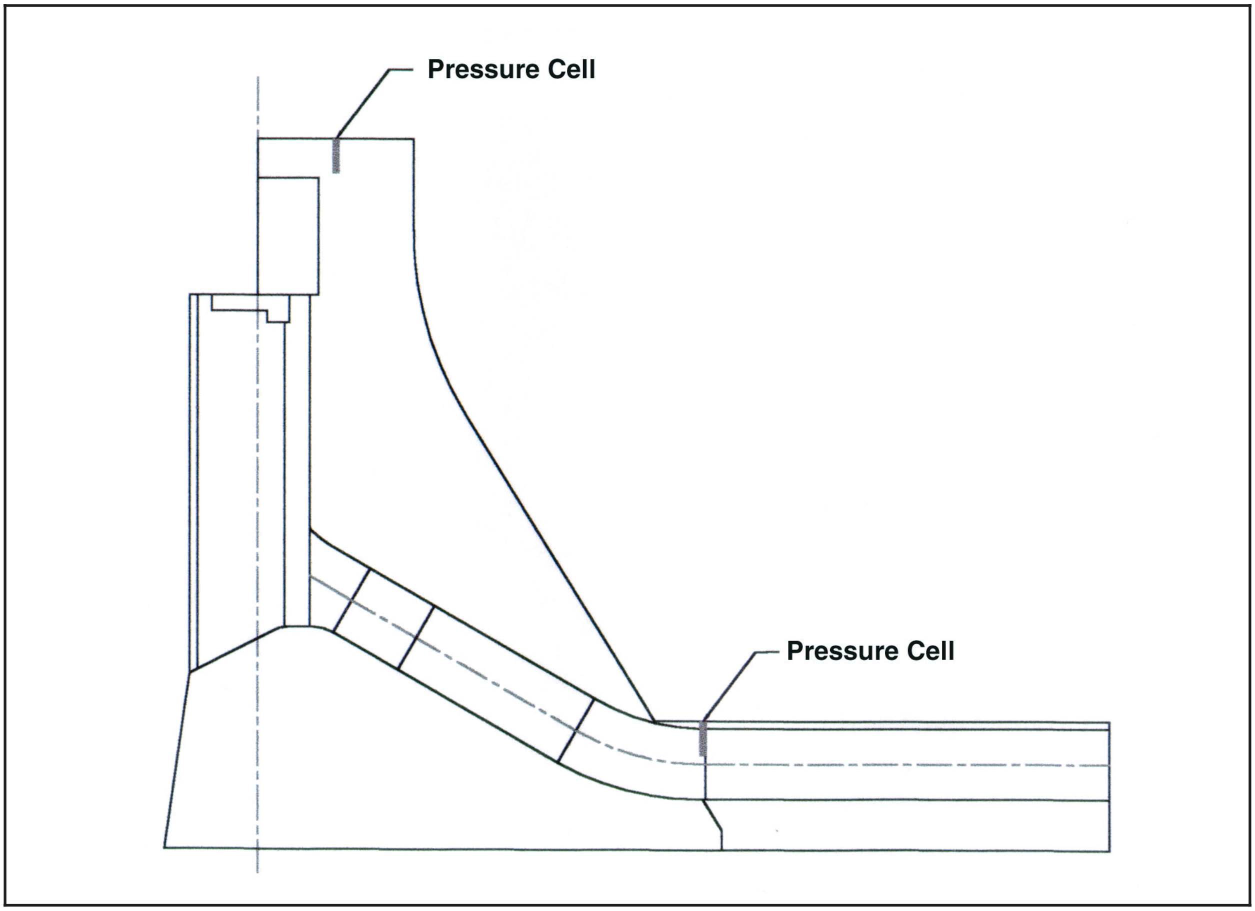


Figure 41. Overtopping study pressure cell locations

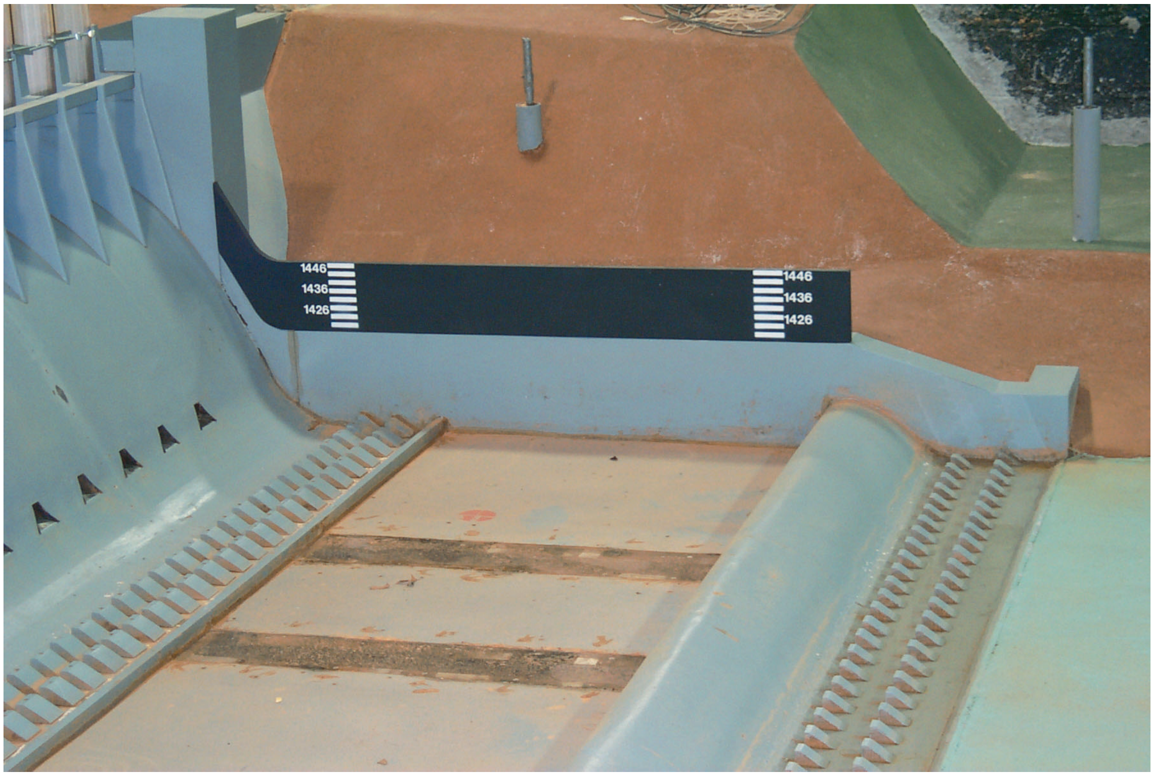


Photo 1. West training wall extension. Heights are shown in NGVD

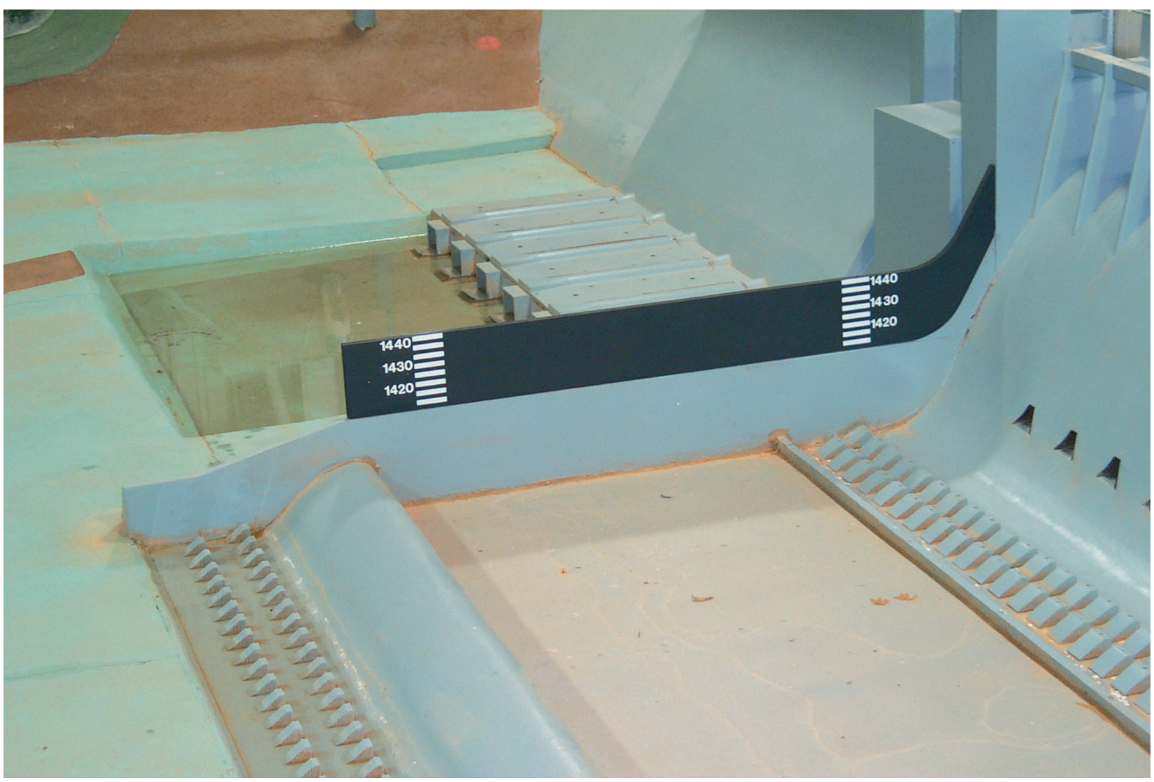


Photo 2. East training wall extension. Heights are shown in NGVD

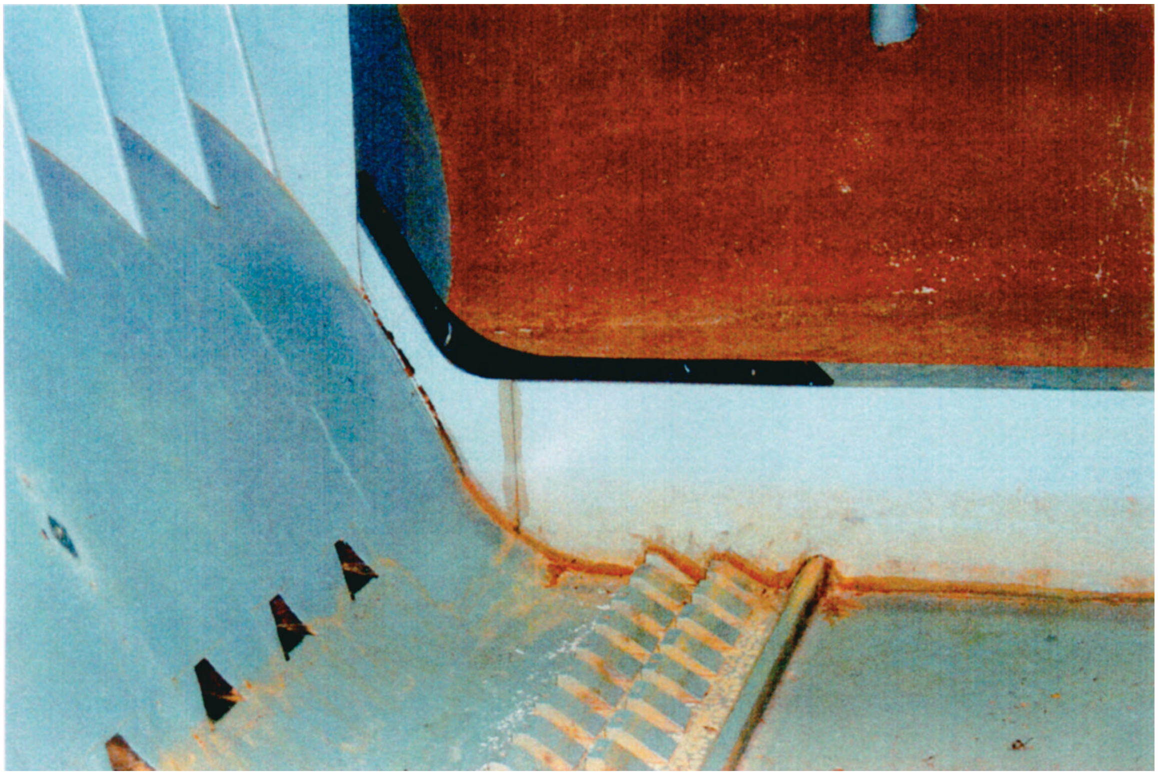
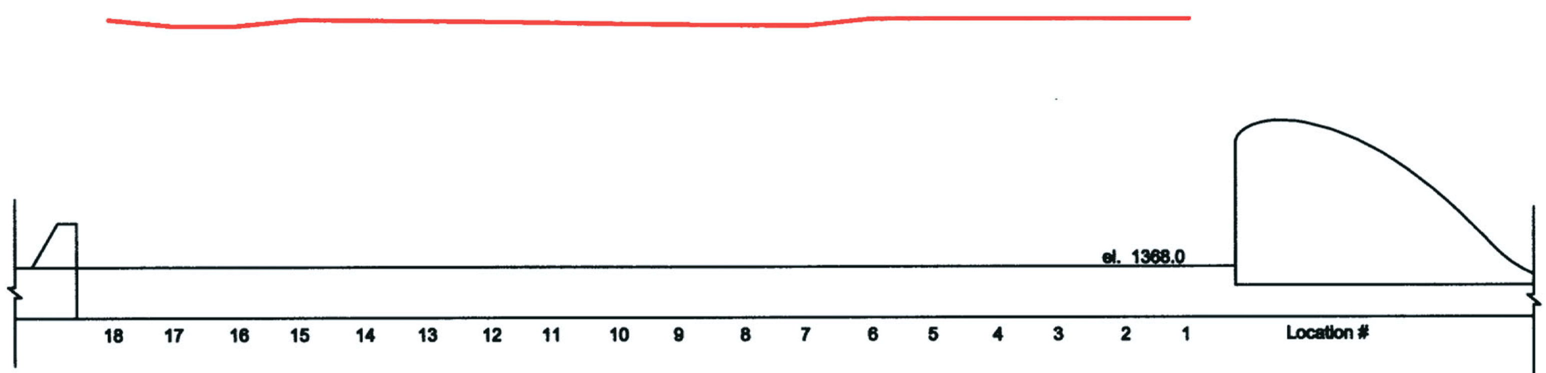


Photo 3. Final west training wall extension

Photo 4. Final east training wall extension

Appendix A
Piezometric Pressure Data, Stilling Basin



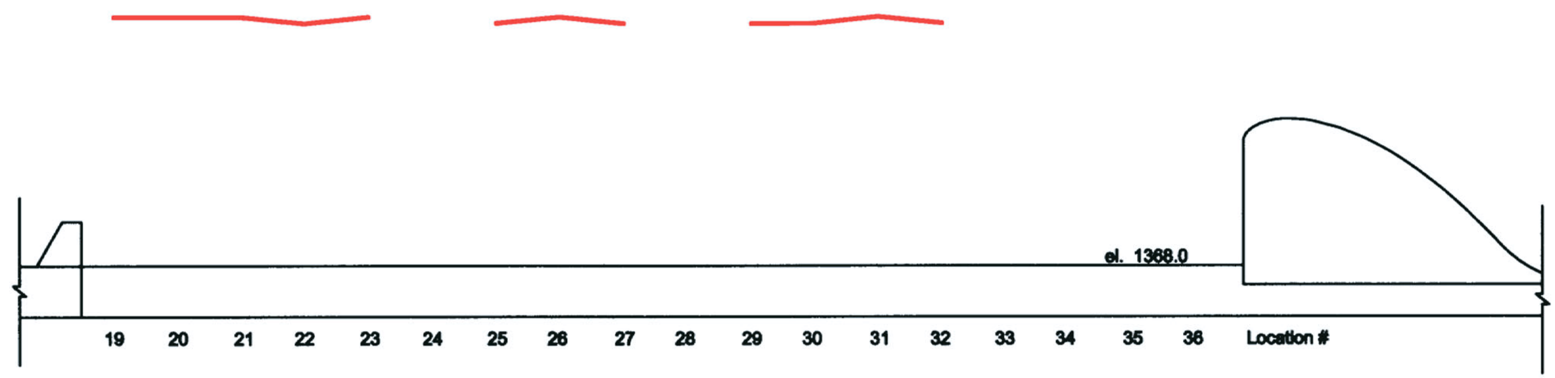
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1407
17	185	1406
16	195	1406
15	205	1407
14	215	1406
13	225	1406
12	235	1406
11	245	1406
10	255	1406

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1406
8	275	1406
7	285	1406
6	295	1407
5	305	1407
4	315	1407
3	325	1407
2	335	1407
1	345	1407

Bluestone General Model

Condition Number 4

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5



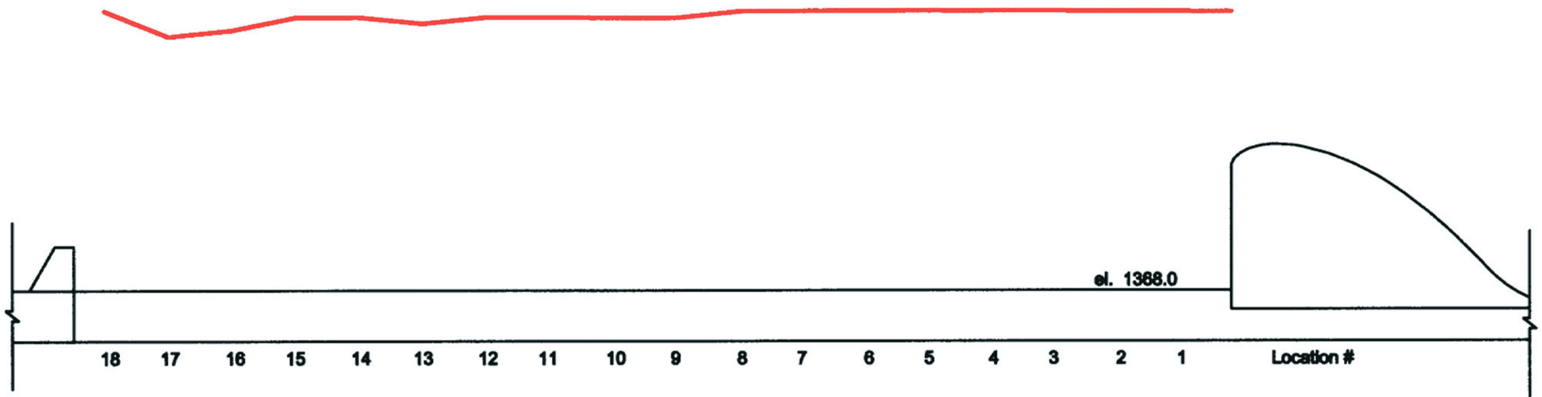
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1407
20	185	1407
21	195	1407
22	205	1406
23	215	1407
24	225	
25	235	1406
26	245	1407
27	255	1406

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
28	265	
29	275	1406
30	285	1406
31	295	1407
32	305	1406
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 4

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



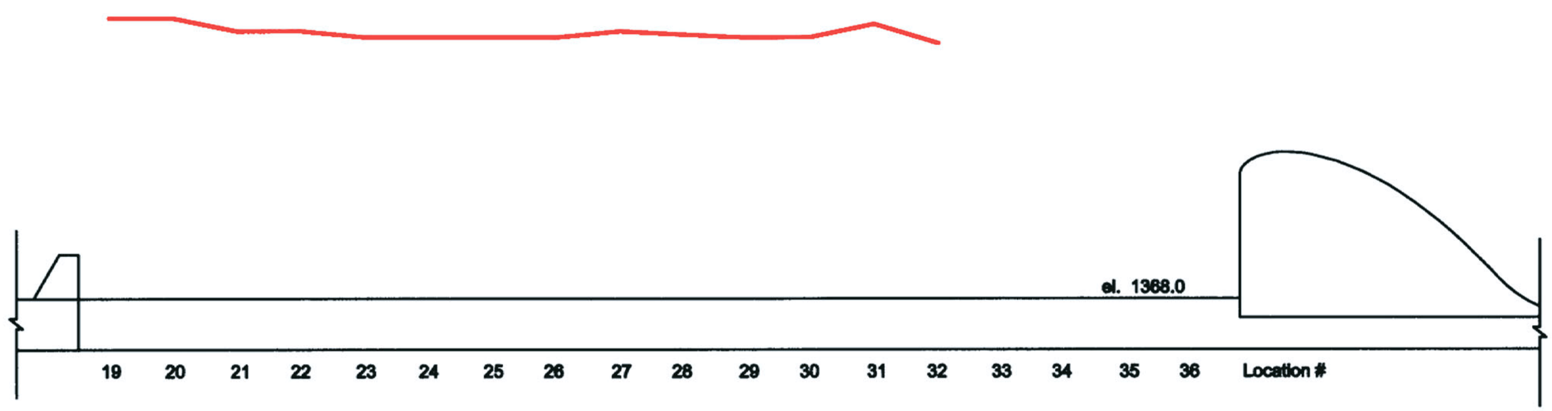
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1412
17	185	1408
16	195	1409
15	205	1411
14	215	1410
13	225	1410
12	235	1411
11	245	1411
10	255	1411

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1411
8	275	1412
7	285	1412
6	295	1412
5	305	1412
4	315	1412
3	325	1412
2	335	1412
1	345	1412

Bluestone General Model

Condition Number 5

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5



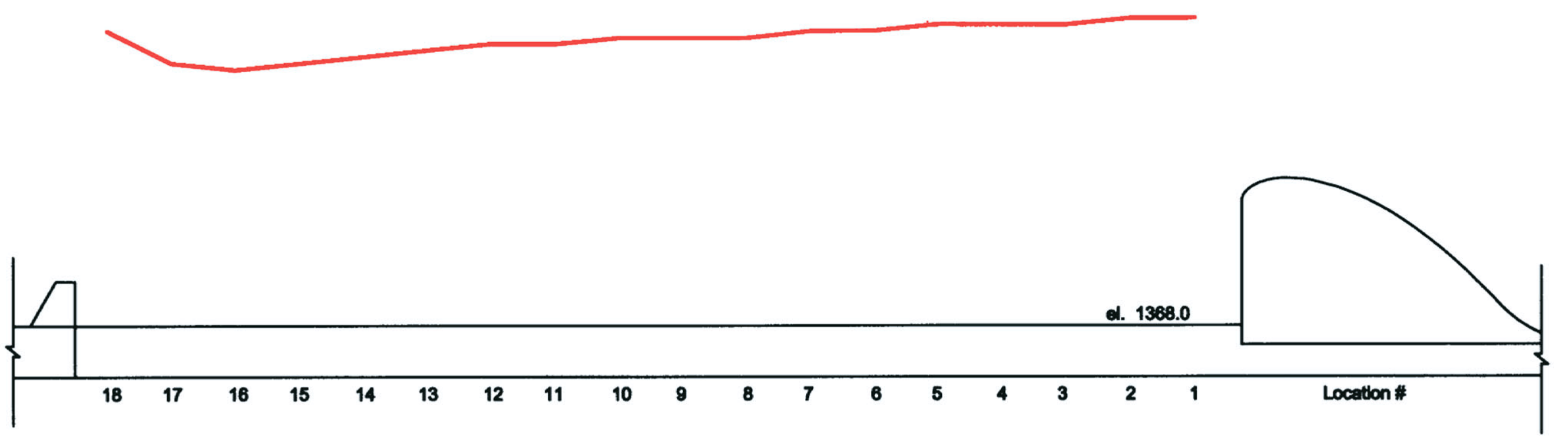
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1412
20	185	1412
21	195	1410
22	205	1410
23	215	1411
24	225	1411
25	235	1411
26	245	1411
27	255	1410

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
28	265	1410
29	275	1409
30	285	1409
31	295	1410
32	305	1408
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 5

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



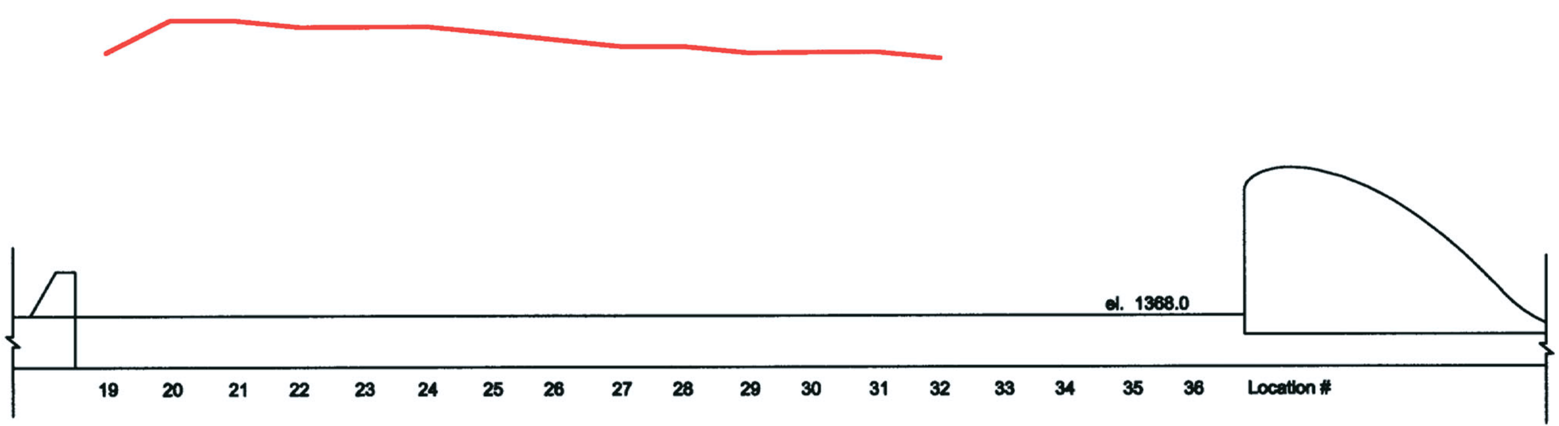
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1414
17	185	1409
16	195	1408
15	205	1409
14	215	1410
13	225	1411
12	235	1412
11	245	1412
10	255	1413

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1413
8	275	1413
7	285	1414
6	295	1414
5	305	1415
4	315	1415
3	325	1415
2	335	1416
1	345	1416

Bluestone General Model

Condition Number 6

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5

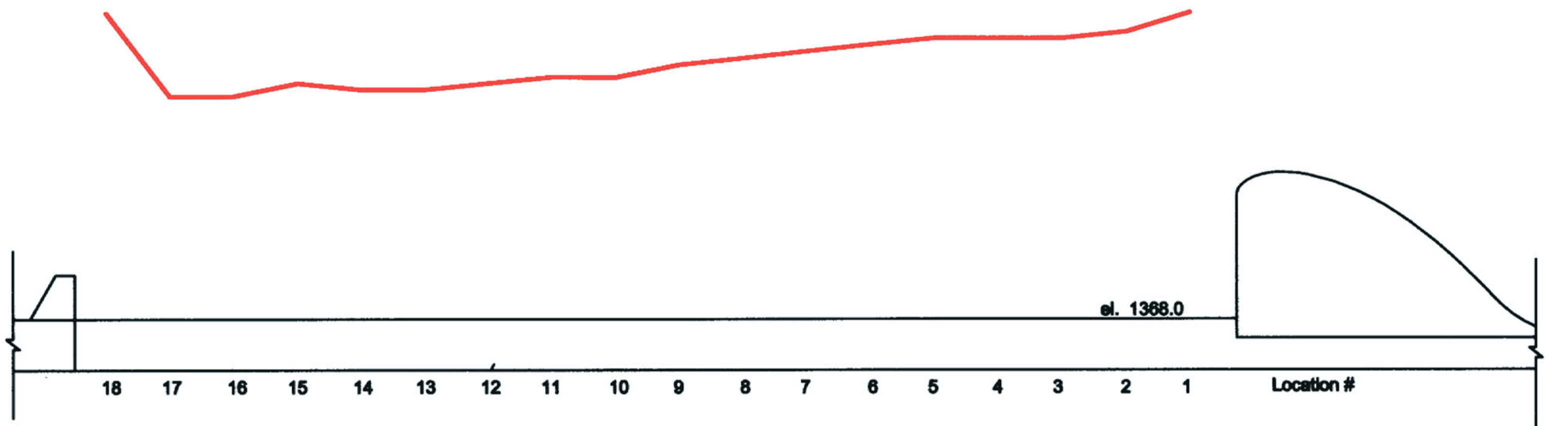


Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1409
20	185	1414
21	195	1414
22	205	1413
23	215	1413
24	225	1413
25	235	1412
26	245	1411
27	255	1410
28	265	1410
29	275	1409
30	285	1406
31	295	1409
32	305	1408
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 6

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



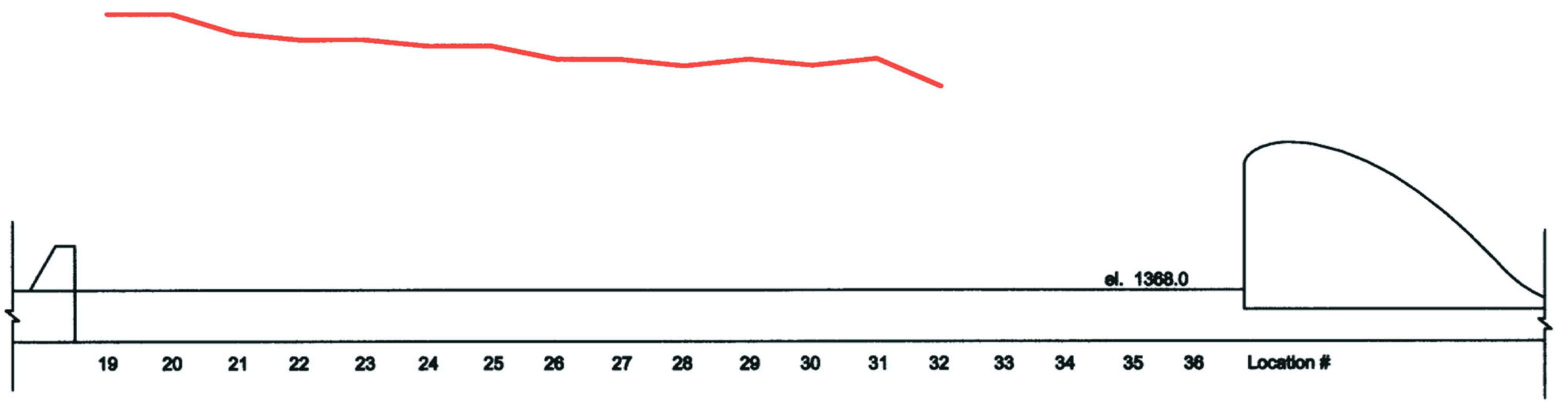
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1417
17	185	1403
16	195	1403
15	205	1405
14	215	1404
13	225	1404
12	235	1405
11	245	1406
10	255	1406

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1408
8	275	1409
7	285	1410
6	295	1411
5	305	1412
4	315	1412
3	325	1412
2	335	1413
1	345	1416

Bluestone General Model

Condition Number 7

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5

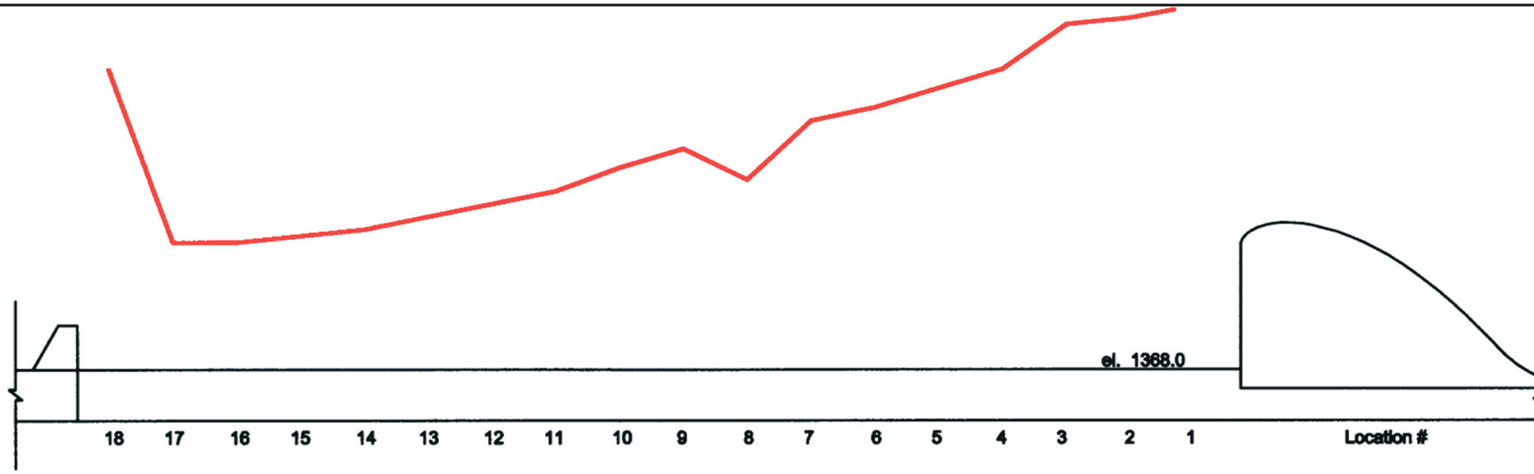


Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1411
20	185	1411
21	195	1408
22	205	1407
23	215	1407
24	225	1406
25	235	1406
26	245	1404
27	255	1404
28	265	1403
29	275	1404
30	285	1403
31	295	1404
32	305	1401
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 7

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



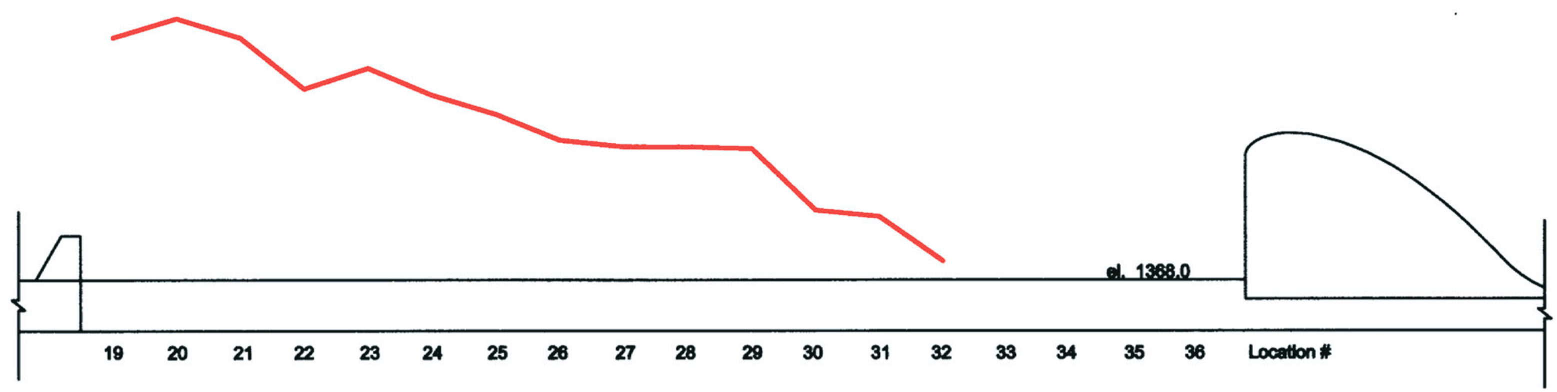
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1415
17	185	1388
16	195	1388
15	205	1389
14	215	1390
13	225	1392
12	235	1394
11	245	1396
10	255	1401

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1404
8	275	1400
7	285	1407
6	295	1409
5	305	1412
4	315	1415
3	325	1418
2	335	1416
1	345	1420

Bluestone General Model

Condition Number 8

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5



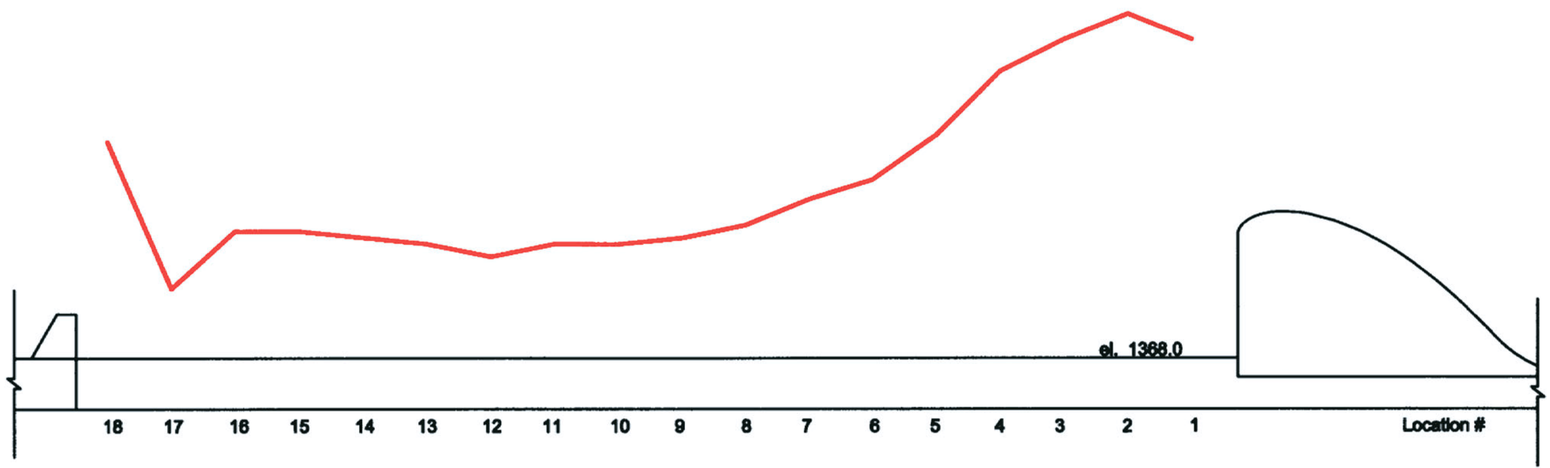
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1406
20	185	1409
21	195	1406
22	205	1398
23	215	1400
24	225	1397
25	235	1394
26	245	1390
27	255	1389

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
28	265	1389
29	275	1388
30	285	1379
31	295	1378
32	305	1371
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 8

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



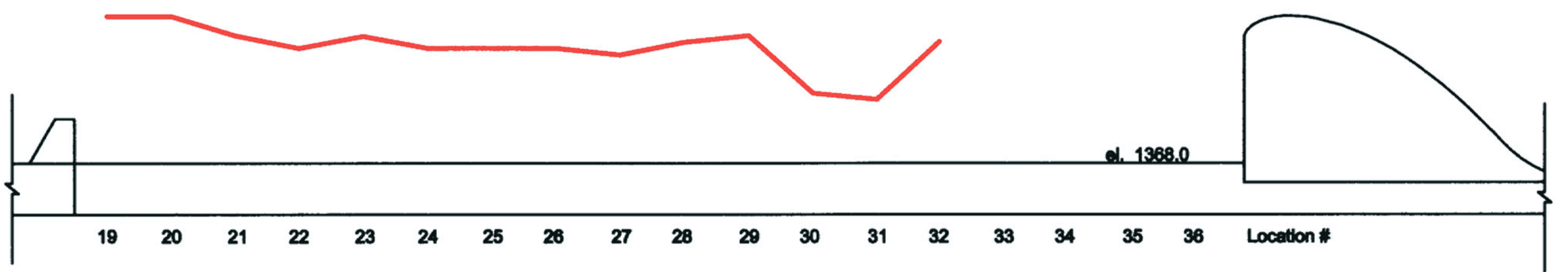
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1402
17	185	1379
16	195	1388
15	205	1388
14	215	1387
13	225	1386
12	235	1384
11	245	1386
10	255	1386

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1387
8	275	1389
7	285	1393
6	295	1396
5	305	1403
4	315	1413
3	325	1418
2	335	1422
1	345	1418

Bluestone General Model

Condition Number 9

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5



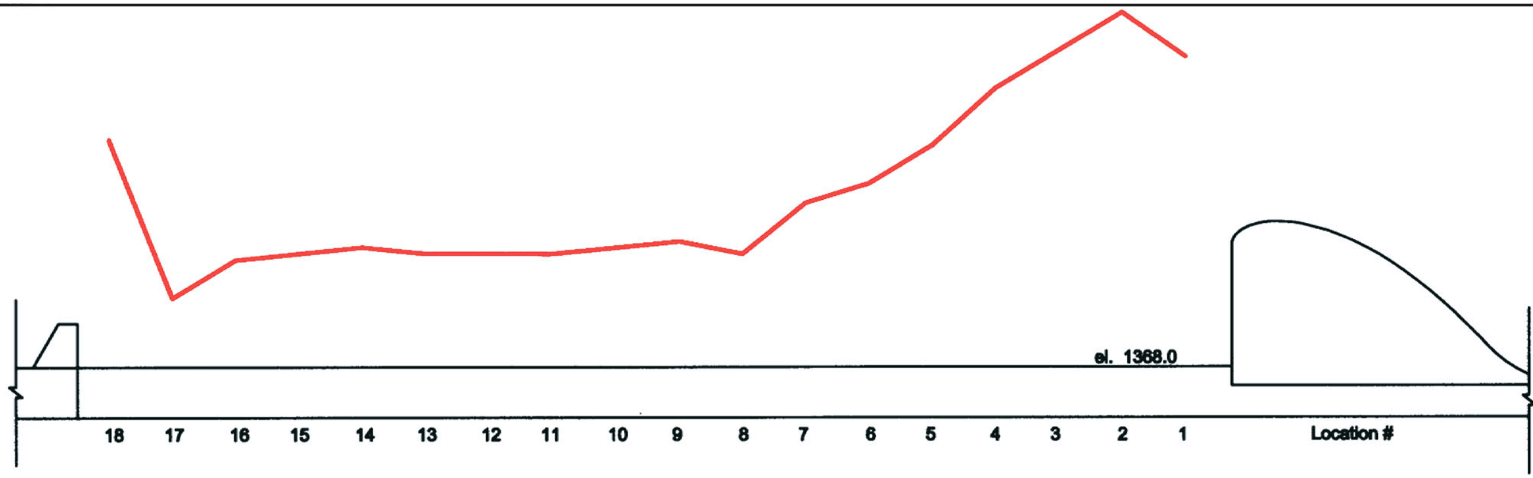
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1391
20	185	1391
21	195	1388
22	205	1386
23	215	1387
24	225	1386
25	235	1386
26	245	1386
27	255	1385

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
28	265	1387
29	275	1388
30	285	1379
31	295	1378
32	305	1387
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 9

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8



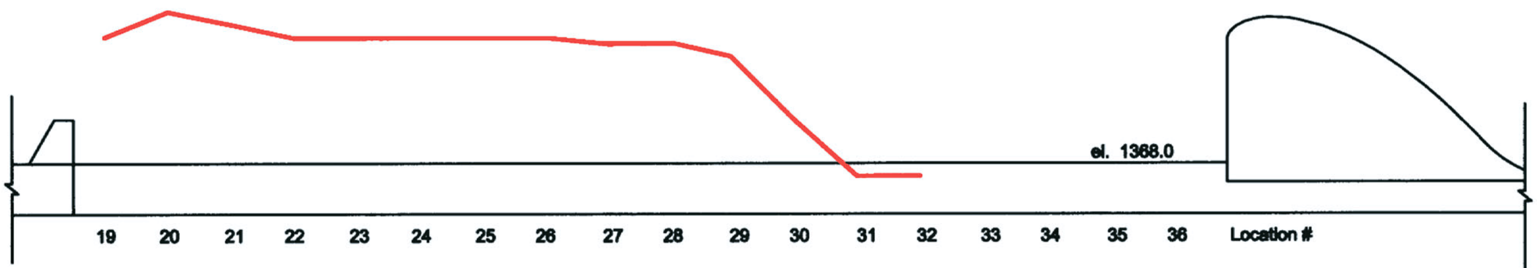
Location Number	Distance from CL of Dam, ft	Pressure, ft of water
18	175	1402
17	185	1379
16	195	1385
15	205	1386
14	215	1387
13	225	1386
12	235	1386
11	245	1386
10	255	1387

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
9	265	1388
8	275	1386
7	285	1394
6	295	1397
5	305	1403
4	315	1412
3	325	1418
2	335	1424
1	345	1417

Bluestone General Model

Condition Number 10

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 5



Location Number	Distance from CL of Dam, ft	Pressure, ft of water
19	175	1388
20	185	1392
21	195	1390
22	205	1387
23	215	1387
24	225	1387
25	235	1387
26	245	1387
27	255	1386

Location Number	Distance from CL of Dam, ft	Pressure, ft of water
28	265	1386
29	275	1385
30	285	1375
31	295	1366
32	305	1366
33	315	
34	325	
35	335	
36	345	

Bluestone General Model

Condition Number 10

Stilling Basin Pressures
Piezometer Measurements
Downstream of Spillbay 8