FINAL REPORT

HYDRAULIC MODEL STUDY
PARACHUTE CREEK DAM AND RESERVOIR
FLIP BUCKET AND PLUNGE POOL STILLING BASIN

For

CHEVRON SHALE OIL COMPANY
AND
UNION OIL COMPANY OF CALIFORNIA

By

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General Description of the Project

The Parachute Creek Dam and Reservoir proposed for construction is a major feature of a system to provide water to develop the oil shale resources of western Colorado. The dam and reservoir will store water originating in the headwaters of the Parachute Creek Basin and also water pumped from the Colorado River. The dam is to be located on Parachute Creek in Garfield county in western Colorado. A plan of the dam and appurtenant works is shown in Figure 1. The dam consists of an earth embankment across Parachute Creek. The embankment will rise to a maximum height of 193 ft. The crest of the dam will have a length of about 2463 ft. The reservoir will have an ultimate storage capacity of approximately 33,773 acre-ft.

The spillway for the dam is located near the right (west) abutment. It consists of a vertical free fall morning glory spillway, emptying into a horizontal conduit. There are six streamline guide vanes located on the crest of the morning glory spillway which extend radially across the spillway crest. These guide vanes prevent vortex action from drawing too much air into the spillway shaft. The shaft empties into a ninety degree elbow and circular conduit which have been designed to flow partially full over the entire length of the conduit. Near the downstream end of the conduit the lower half of the circular tunnel is changed to a rectangular shape through a transition. The resulting horseshoe shaped conduit extends for approximately 175 ft to the portal. A flip bucket is located downstream from the portal of the tunnel. A flip bucket is constructed with a sixty foot vertical curve starting at the portal and terminating 5.6 ft above the invert elevation of the portal. The angle at the lip of the flip bucket was initially set at twenty five degrees above horizontal. The flip bucket discharges into a plunge pool which utilizes an overflow side weir arrangement to discharge into the outlet channel shown in Figure 1.

The spillway for Parachute Creek Dam has been designed to pass the design flood resulting from a probable maximum precipitation occurrence. The design criteria corresponds to a Category One level of protection. This criteria assures that the inflow hydrograph due to the probable maximum precipitation occurrence does not overtop the dam but is passed through the spillway to the channel downstream. The design inflow flood hydrograph and spillway outflow hydrograph are shown in Figure 2. The inflow design hydrograph has a peak discharge of 35,000 cfs and a total volume of water of 17,000 acre-ft. The outflow design hydrograph results from routing the inflow design hydrograph through the reservoir with the proposed spillway. The outflow hydrograph has a peak discharge of 22,000 cfs which is the required design capacity of the spillway, conduit, flip bucket and plunge pool.

The design discharge will reach the spillway conduit exit portal under a velocity head of more than 100 ft. This results in a velocity of about 85 fps at the flip bucket. The energy in the flowing water must be substantially dissipated before being allowed into the outlet channel. The outlet channel conveys the water from the plunge pool basin to the Parachute Creek streambed. The outlet connecting the stilling basin to Parachute Creek has been located well downstream from the toe of the dam as shown on Figure 1. The outlet channel has a 100 ft bottom width which is necessary to accommodate the design discharge of 22,000 cfs. The channel bottom and side slope will be protected by riprap to a depth of 4 ft corresponding to the water level resulting from a flood with a recurrence interval exceeding 100 years. The calculated Parachute Creek tailwater depth at a discharge of 22,000 cfs is approximately 14 ft in the valley downstream of the point of return to Parachute Creek. The water surface elevation at this point will be approximately 5617. The maximum tailwater surface at the entrance to the outlet channel is expected to be greater than 5623. Therefore, the valley tailwater will not interfere with the operation of the stilling basin and outlet channel.

The plunge pool combined with the flip bucket is expected to substantially dissipate the energy in the spillway outflow before it enters the discharge channel. Since this plunge pool discharges through a side overflow weir arrangement and is specifically tailored to fit the specific location, it is not certain that a preliminary engineering layout of the plunge pool will perform satisfactorily. For this reason a hydraulic model testing program was conducted to establish a recommended design and configuration of the flip

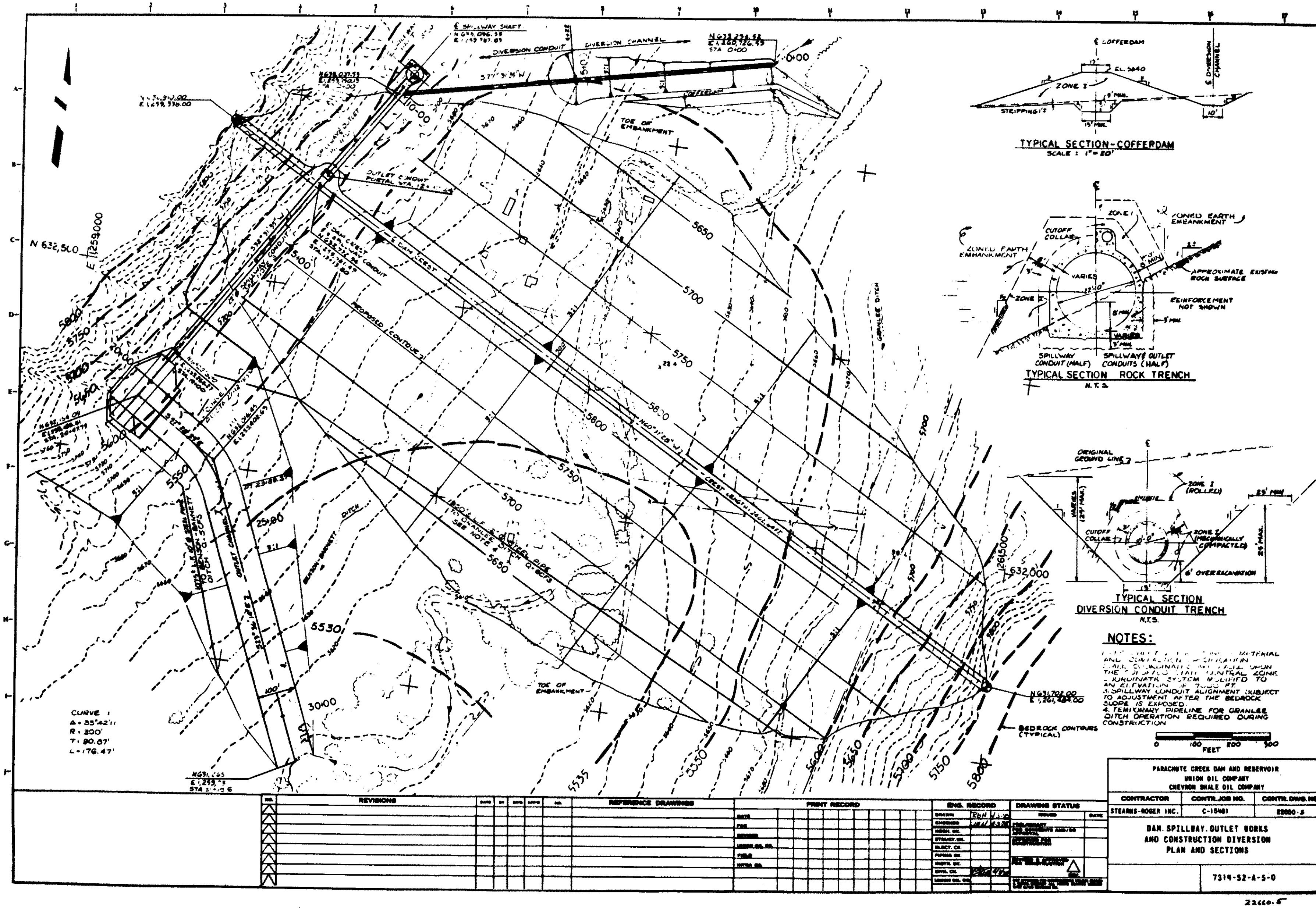


Figure 1 - Plan of Parachute Creek Dam

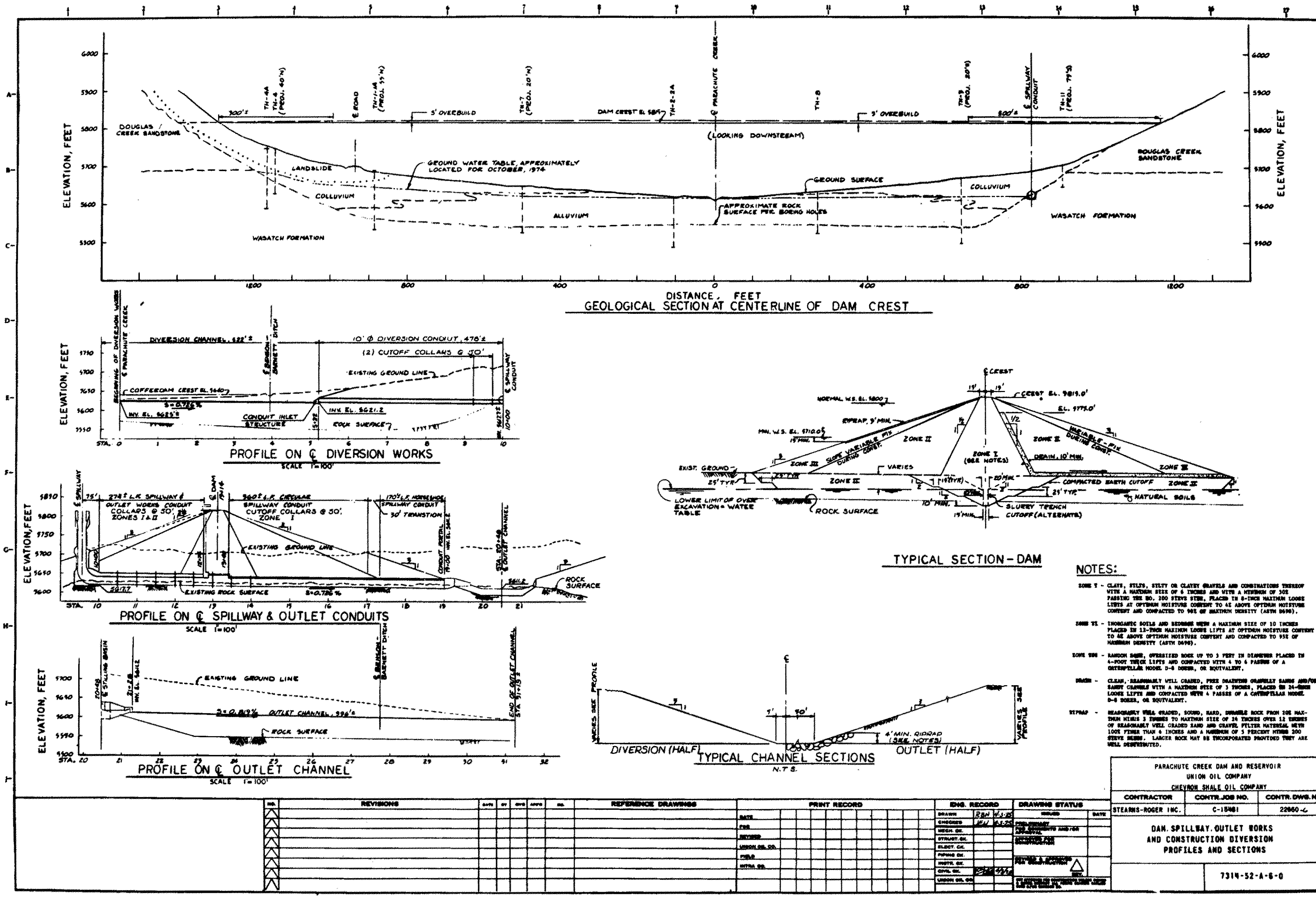


Figure 1 continued - Plan of Parachute Creek Dam

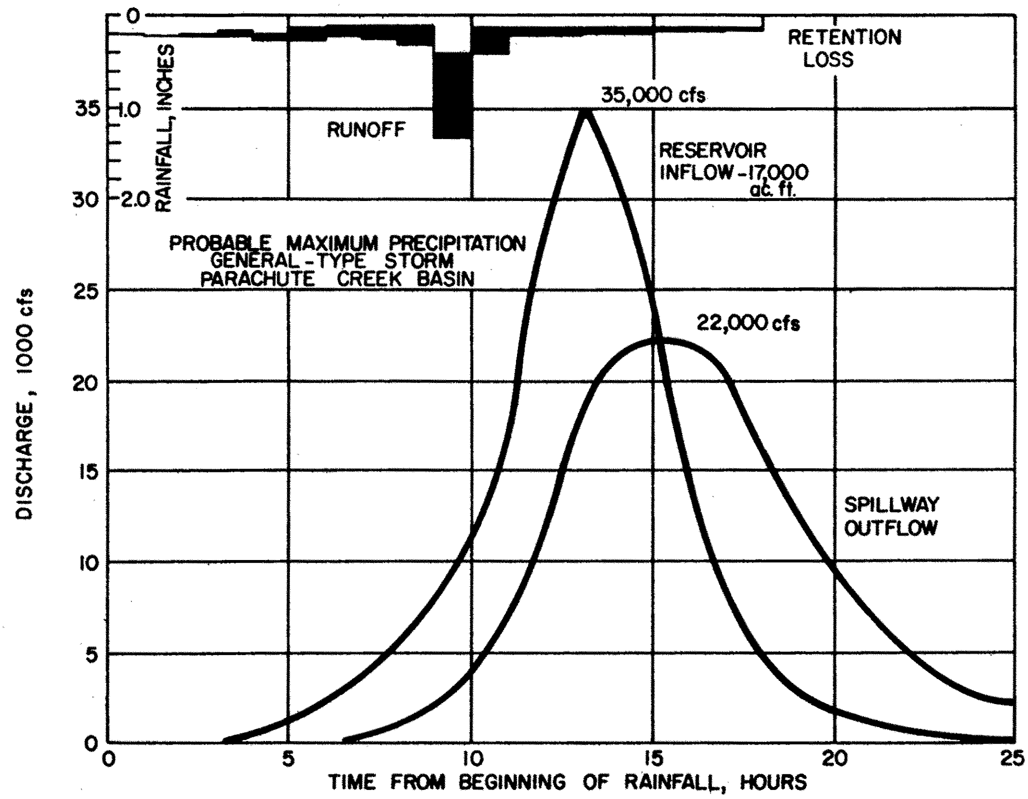


Figure 2 - Design Inflow Flood Hydrograph and Spillway Outflow Hydrograph

bucket and plunge pool. The study was initiated using a plunge pool based upon United States Bureau of Reclamation design criteria.

Scope of the Model Study

The purpose of this study was to evaluate hydraulic characteristics of flow in the plunge pool stilling basin. The specific objectives of the model study are:

1) to insure that energy is satisfactorily dissipated within the plunge pool;
2) to observe flow patterns in the plunge pool stilling basin;
3) to observe the flow in the flip bucket;
4) to modify the basin geometry, flip bucket geometry, and channel geometry, if needed, to provide satisfactory energy dissipation and flow conditions for the final design of the stilling basin.

Model Criteria

The purpose of the model study is to predict prototype behavior. The principles of similitude are applied to determine in so far as possible an indication of full scale phenomena based upon model tests. The Froude number $V/\sqrt{gD}$ is the significant parameter for this model study. The Froude number represents the ratio of the inertial forces to the gravitational force. The plunge pool is used to reduce the kinetic energy of the flowing water entering the pool through dissipation of the energy and through conversion to potential energy before it leaves the pool. Therefore, the Froude criterion was selected to determine the geometric scale of the model. A geometric scale ratio of 1:19.75 (model-prototype) was selected based upon a model size that would give an accurate representation of the flow conditions. Since it was anticipated that there would be some modifications to the plunge pool basin the scale ratio was determined primarily based upon the ease of construction, construction tolerances, available space and facilities, and economy. A list of some characteristic model-prototype ratios based upon the selected scale is given in Table I.

TABLE 1. Model-Prototype Scale Ratios, Scale Ratio - 1:19.75

Parameters	Scale Ratio: Function of Length Ratio	Scale Ratio: Numerical Ratio	Absolute Magnitude: Prototype	Absolute Magnitude: Model
Length	L_r	1:19.75	19.75 ft	1 ft
Area	L_r^2	1:390	390 ft^2	1 ft^2
Velocity	$L_r^{\frac{1}{2}}$	1:4.4	4.4 fps	1 cfs
Discharge	$L_r^{5/2}$	1:1733	1733 cfs	1 cfs
Time	$L_r^{\frac{1}{2}}$	1:4.4	4.4 min.	1 min.

THE MODEL

Model Construction

The model consisted of a portion of the 22 ft diameter conduit, a horseshoe shaped conduit near the outlet, the flip bucket, the plunge pool and about 150 ft of the downstream channel. A schematic representation of the basin is shown in Figure 3 and a photograph of the completed model is shown in Figure 4. The 22 ft diameter conduit is represented by a 13.34-inch diameter pipe. The flip bucket floor and walls were constructed from plexiglass. The plunge pool and downstream channel were fabricated from lumber and plywood. Water was supplied to the model from an 18-inch turbine pump. The discharge measurements were made with an orifice in the 18-inch supply line. The discharge was regulated by a bypass valve at the pump and by a valve located upstream from the 22 ft diameter conduit model. The second valve also regulated the depth of flow in the conduit. Provisions were made to adjust the tailwater depths in the channel with stop logs. Piezometers were used to measure pressures along the centerline of the flip bucket and the downstream wall on which the jet entering the pool impacted. The locations of the piezometers are shown in Figure 5.

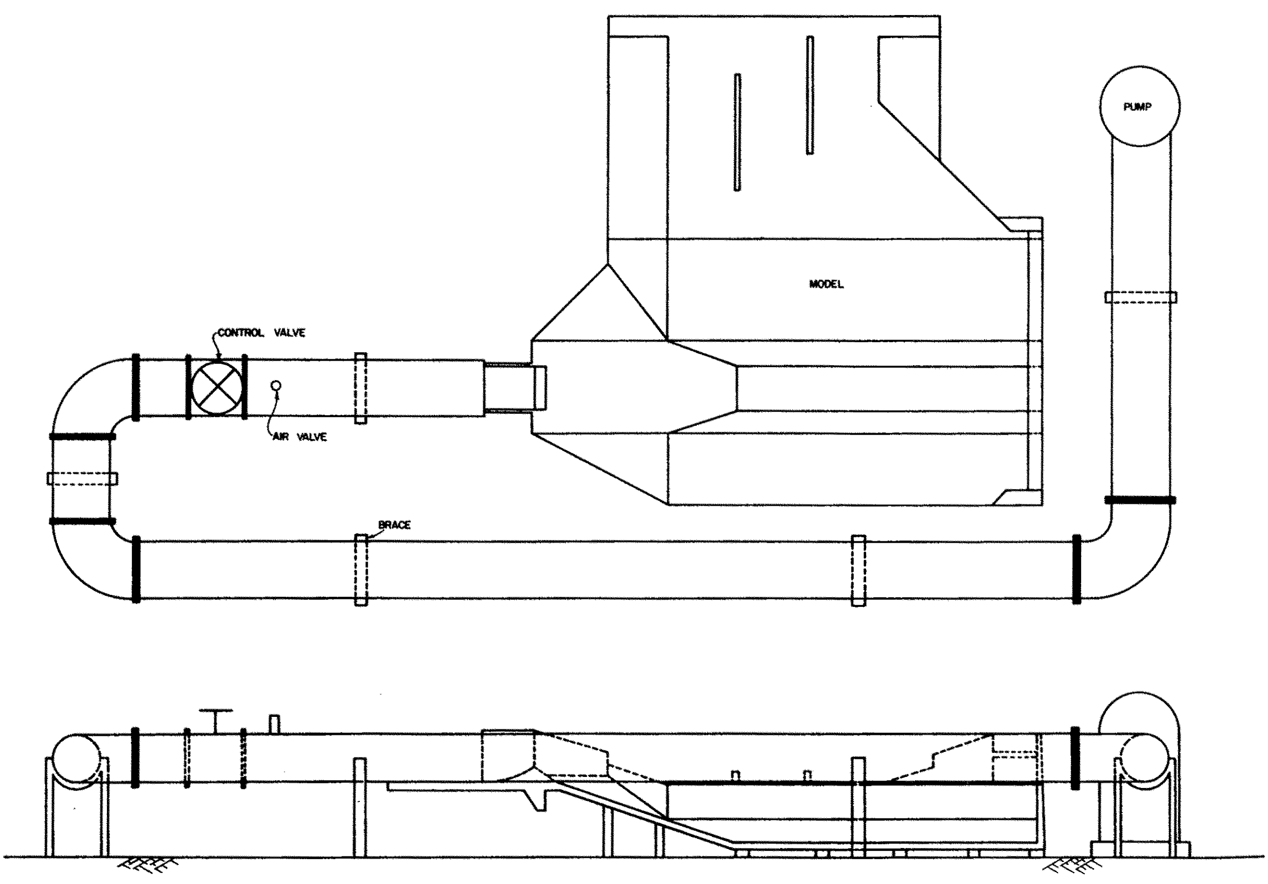


Figure 3 - Schematic Drawing of Model

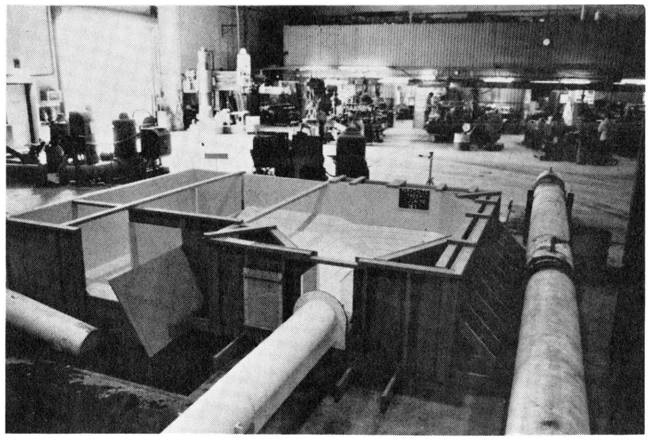


Figure 4 - Photograph of Model

Piezometer No.	Elevation in Feet
1	5614.4
2	5615.1
3	5616.3
4	5616.5
5	5615.3
6	5614.2
7	5613.3
8	5612.5
9	5611.9
10	5611.4
11	5611.2

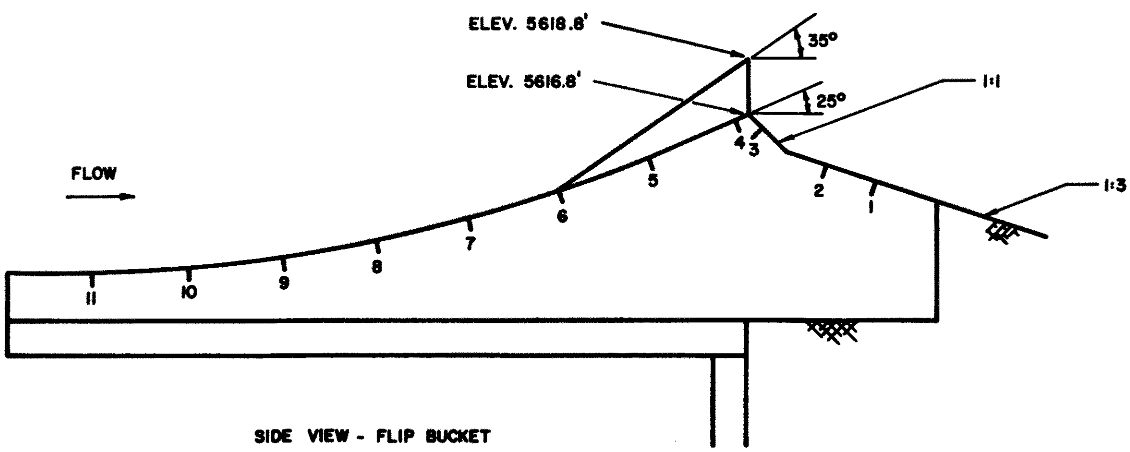


Figure 5 - Piezometer Locations in Flip Bucket

Chapter III

MODEL TESTS AND RESULTS

Model Test Program

The model test program was designed to provide sufficient information to predict prototype behavior for a wide range of discharges. The model was operated at 6 simulated discharges; 4,000, 8,000, 12,000, 15,000, 18,000 and 22,000 cfs. All the discharges represented a condition when the flow water was flipped from the bucket into the plunge pool. The point where this sweeping out of the flow and flipping from the bucket occurs is at a discharge estimated somewhere between 2,000 and 4,000 cfs. At discharges less than this a jump will form in the conduit and the water will flow over the lip and spill onto the sloping apron of the plunge pool. No problems are anticipated for these flow conditions and therefore the model did not attempt to evaluate flow under these conditions.

Each test consisted of the following sequence of events. The discharge and depth of flow at the portal of the conduit were adjusted by manipulation of the bypass valve at the pump and the valve located upstream from the conduit. Flow patterns in the flip bucket and the stilling basin were observed visually and recorded photographically. The tailwater depth was adjusted to correspond to tailwater depths determined from backwater calculations in the conduit. (see Appendix B for calculations). Piezometers readings were taken in the flip bucket for the initial sequence of runs with the twenty five degree flip bucket lip. Piezometer readings in the downstream wall were taken only when the final dimensions of the plunge pool were established. Peizometer readings on the flip bucket were not taken when the modifications installed in the flip bucket did not provide satisfactory performance of the flip bucket plunge pool structures. Piezometer readings for the twenty five degree flip bucket without modifications are presented in Appendix A Table A-1.

Flip Bucket-Plunge Pool

Tests were performed starting with a plunge pool basin 209.5 ft long by 117 ft wide. The floor was set at an elevation of 17.4 ft below the invert at the conduit portal or 22 ft below the lip of the flip bucket.

At a flow of 4,000 cfs, the jet trajectory caused the water to impact upon the back wall of the basin. Some spray and splash occasionally exceeded the proposed elevation of the top of the wall at elevation 5637.2. At all discharges of 8,000 cfs or greater there was considerable turbulence near the back wall of the plunge pool with little energy dissipation being accomplished within the plunge pool itself. The jet exiting from the flip bucket impacted on the back wall and was deflected upward beyond the top of the proposed wall of the basin. In most cases this elevation extended approximately 15 to 20 ft above the proposed wall. However, it would occasionally splash and spray to elevations as great as 30 to 40 ft above the wall as can be seen at a discharge of 15,000 cfs in Figure 6. The water falling back into the basin caused waves along the right wall of the basin that surged back to the flip bucket lip and partially submerged the jet. The impact of the waves and the jet caused the jet trajectory to be deflected upward several degrees resulting in almost an oscillating condition. These flow conditions were not satisfactory. Figure 6 shows the adverse flow conditions within the basin and demonstrates the need for some modification to the basin.

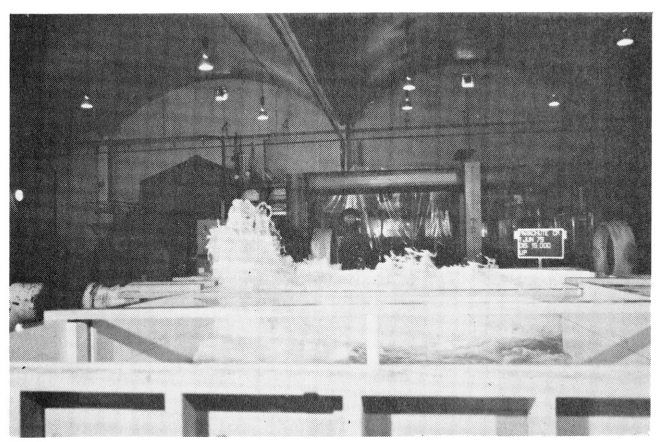


Figure 6 - Profile View of Orginal Basin During Operation at 15,000 cfs.

Numerous modifications were installed and tested. A description of the modifications to the basin, flip bucket and downstream channel are presented in Table II. From the initial tests it appeared that the plunge pool would have to be lengthened and the depth of the pool increased. This was done in stages as indicated by the change described in Table II. The proposed length and depth were suggested by observations of the model and calculations based on ideal conditions.

TABLE II. Modifications to Plunge Pool Basin, Flip Bucket and Channel

Modification No.	Description
1	Removed the 2:1 section of impact wall
2	Increased basin length to 232.5 ft measured from flip bucket lip to intersection of back wall and floor
3	232.5 ft basin - inserted 35 degree flip bucket
4	232.5 ft basin - 35 degree flip bucket - lowered basin floor 11.5 ft
5	232.5 ft basin - 25 degree flip bucket - lowered basin floor
6	Extended basin to 255 ft - 35 degree flip bucket with lowered floor
7	255 ft basin - 25 degree flip bucket with lowered floor at elevation 5582.3
8	255 ft basin - 35 degree flip bucket - lowered floor with seawall and 5.75 ft high vane in outflow channel
9	Extended basin 275 ft - 35 degree flip bucket with lowered floor with seawall at elevation 5637.2, 5.75 ft high vane in outflow channel
10	Dispersion flip bucket extended 23 ft beyond original flip bucket with 275 ft basin
11	Conical lip section - 10 ft elevation with 275 ft basin
12	Conical lip section - 6.5 ft elevation with 275 ft basin
13	Conical lip section - 3.3 ft elevation with 275 ft basin
14	Extended 35 degree bucket outside original flip bucket structure - 275 ft basin
15	35 degree bucket, 255 ft basin, angled channel corner - double seawall - 9 ft high vane in outflow channel
16	Lower seawall on impact wall with extended 255 ft basin - 35 degree bucket - angle channel corner - 9 ft vane in outflow channel
17	Vertical wall - angle corner - lower single seawall on impact wall - 35 degree bucket, 255 ft basin - 9 ft vane in outflow
18	Angle corner - 35 degree bucket - 255 ft basin vertical wall - double seawall (upper seawall 2.5 x 2.5 ft; lower seawall extended horizontally 5.75 ft, vertically 2.5 ft; vane in outflow)
19	9 ft high vane in outflow - 35 degree bucket - vertical wall - double seawall - angle corner - 255 ft basin
20	Two 5.75 ft high vanes in outflow channel- vertical back wall - 35 degree bucket - 255 ft basin - double seawall

In addition to the changes in the basin, it was felt that the trajectory of the jet could be improved by increasing the angle of the flip bucket from 25 degrees to 35 degrees. At 25 degrees the jet did not appear to penetrate the water surface satisfactorily and was deflected almost horizontally along the water surface or impacted on the wall and was deflected upward without sufficient energy dissipation to keep the water within the basin. With a 35 degree deflector, the jet entered the water at a greater angle and was able to penetrate to the floor of the basin and impact where expected. This plunging jet provided greater energy dissipation within the pool and on the flow and walls of the basin rather than surging upward beyond the top of the walls.

The distance to the back wall of the plunge pool extended by stages to determine the best location. Three modified basin lengths were tested: 232.5 ft, 255 ft, and 275 ft. The length of the basin is measured from the flip bucket lip to the intersection of the basin floor and back wall. The depth of the pool was increased by 11.5 ft which placed the floor at elevation 5582.3 after the 232.5 ft basin was tested.

Flow conditions in the 232.5 ft long basin were similar to those for the original basin. A portion of the jet still impacted high on the back wall. Lowering the basin floor by 11.5 ft, showed some improvement but conditions were still not satisfactory.

The basin was extended to 255 ft in length with the floor elevation remaining at 5582.3. Flow conditions were substantially improved with these basin dimensions. Flow conditions were further improved by installing the 35 degree flip bucket lip. Some spray and splash over the back wall were still evident. Therefore, the basin wall was extended to 275 ft.

Flow conditions in the 275 ft basin were less satisfactory than those in the 255 ft basin. This was due to the energy of the jet not being dissipated by impact with the back wall. The jet entered the pool and was deflected horizontally with little energy dissipation. When the jet encountered the back wall it was again deflected upward with little energy dissipation. The flow emerged from the pool and the water was carried above the height of the proposed top of the wall. The addition of a seawall assisted in containing the water within the basin for the flows less than about 18,000 cfs. Overall energy dissipation and flow conditions were not as satisfactory as the flow conditions in the 255 ft plunge pool basin. Before reinstalling the 255 ft basin, modifications to the flip bucket were attempted.

Several different types of deflectors were installed in the flip bucket and were tested in addition to the 35 degree lip. The dispersion flip bucket (Modification 10) was the only additional deflector that performed satisfactorily other than the 35 degree lip. The photograph of the dispersion flip bucket as it was installed is shown in Figure 7. The dispersion bucket extended approximately 23 ft beyond the proposed bucket and the elevation of the lip was raised approximately 8 ft above the proposed elevation of the lip.

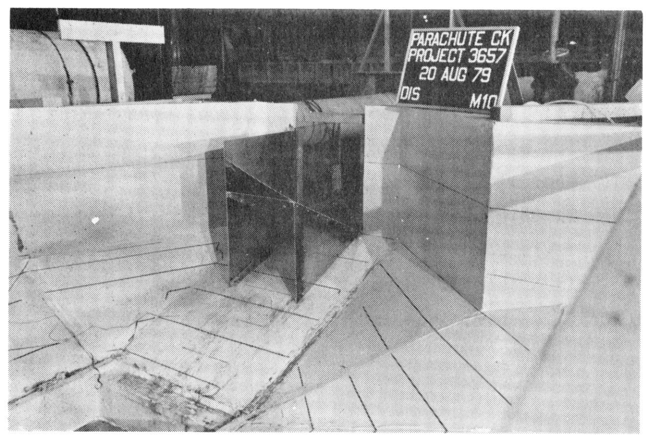


Figure 7 - Dispersion Flip Bucket
(Modification No. 10)

The improvement of the performance with this lip resuled from the jet not being influenced by the tailwater and from the spreading of the jet to force more flow into the right side of the outlet channel. The improvement did not warrant final consideration because of the massiveness of the structure that would be required in the prototype and because of later results achieved in the testing program.

The 255 ft plunge pool basin was reinstalled in an effort to optimize the flow conditions within the basin. A back wall was installed at a slope of 1:2 horizontal to vertical. Seawalls were tested at different elevations and in combinations in an effort to reduce the occasional splash and spray from overtopping the back wall. The most improvement was noted with a seawall located about 14 ft from the proposed top of the wall.

The back wall of the plunge pool basin was rotated to the vertical position and tested. This wall performed satisfactorily with the seawalls installed on it.

The tailwater to the right of the flip bucket in the plunge pool was about elevation 5632 at 22,000 cfs. This tailwater depth still influenced the trajectory of the jet and resulted in considerable cross flow at the entrance to the outlet channel. Some improvement of the flow conditions in the outlet channel resulted from the installation of a guide vane in the center of the channel. Improvement in the basin flow conditions and the outlet channel flow conditions was accomplished by removing the corner between the stilling basin and the right side of the channel. This increased the flow cross section and allowed the flow to enter the channel with less restriction. This modification also reduced the tailwater depth about 1 ft.

Some of the turbulence and waves generated within the plunge pool were carried into the outlet channel. Guide vanes were installed in the entrance to the outlet channel in an effort to direct the flow downstream and to prevent the cross flow from surging over the left wall of the outlet channel. Near the entrance to the outlet channel small standing waves were observed. The guide vanes reduced the magnitude of these standing waves and reduced the surges in the channel. However, the elevation of the channel walls should be increased by approximately 3 ft to elevation 5627 to contain the flow entirely within the channel.

Two different guide vane arrangements were tested in the outlet channel. The configuration of the vanes are shown in Figure 8. One consisted of a 9 ft high wall extending from the beginning of the channel downstream approximately 107 ft. This guide vane was located along the centerline of the outlet channel.

The second guide vane arrangement consisted of two guide vanes located along lines approximately 18 ft from the centerline of the channel. These guide vanes were 5.75 ft high and approximately 59 ft long. The end of the left guide vane was placed 29.58 ft upstream from the outlet channel. The end of the right guide vane was located 9.83 ft from the channel outlet. Both guide vane configurations performed satisfactorily.

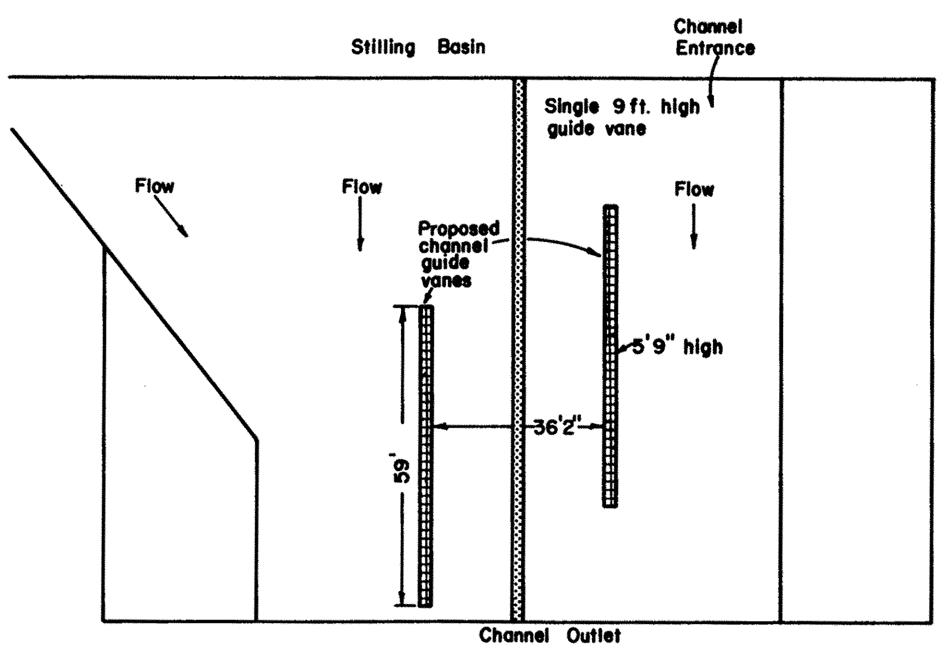


Figure 8 - Plan View of Outflow Channel with Recommended Guide Vanes

CONCLUSIONS AND RECOMMENDATIONS

The recommended design for the flip bucket plunge pool stilling basin and outlet channel entrance based upon the hydraulic model study test results is shown in Figure 9. These designs provide satisfactory energy dissipation and flow conditions with the expectation that some maintenance may be necessary in the channel and plunge pool basin when the extremely rare flow events greater than about 12,000 cfs pass through this structure.

The model was tested with vertical walls in the lower portion of the basin between elevation 5582.3 and 5593.8. This was required because of an unanticipated structural change made in the model. Performance of the basin will be similar if the walls of the basin parallel to the centerline of the conduit sloped at 1:1 (horizontal to vertical) and the upstream side is extended at the present slope of 3:1 to the basin floor. The downstream or impact wall should remain vertical. These recommended changes should alleviate ice problems and improve construction techniques in the prototype basin. These improvements have been reflected in Figure 9.

Figure 10 gives a pictorial representation of the flow conditions for the discharges tested. Flow conditions at 4,000 cfs are excellent within the basin. A small hydraulic jump forms near the right guide vane but is not detrimental to flow in the channel. At 8,000 cfs the tailwater in the plunge pool basin is high enough that it just touches the lower edge of the jet, causing some dispersion of the lower portion of the jet. Flow conditions are satisfactory within the basin with energy being dissipated by the turbulence and impact of the jet. Flow conditions within the outlet channel are satisfactory. At 12,000 cfs there is slightly more dispersion of the jet due to the effect of the tailwater. However, the flow conditions within the basin are still satisfactory. There is some acceleration of the flow along the right wall and near the entrance to the outlet channel. This acceleration results in a drawdown of the water surface as can be seen in the views of Figure 10 which show the right wall. The guide vanes installed in the outlet channel perform well by directing the flow downstream. At 22,000 cfs there are standing waves observed at the transition to the entrance of the outlet channel. There are some waves on the surface of the water in the outlet channel as shown in Figure 11 but these should be contained within the channel with the walls extended to the recommended elevation of 5627 near the entrance. At 18,000 cfs flow conditions in the basin are still satisfactory, there is an occasional splash over the back wall of the basin and standing waves are noted at the entrance to the outlet channel. At 22,000 cfs there is some dispersion of the jet due to the high tailwater and there is an occasional splash over the back wall of the basin. There are standing waves observed near the entrance to the outlet channel along the left and right walls and an occasional wave will reach the top of the left channel wall.

The top of the back impact wall of the plunge pool should be set at elevation 5637.2 as originally established. Some splash over the top may be expected at the discharges greater than 15,000 cfs. A single seawall should be located at elevation 5623.2 and extend around to the side walls as shown in Figure 9. The seawall should extend horizontally outward from the wall a minimum distance of 5.75 ft.

Two guide vanes are recommended for installation in the outlet channel. These vanes should be a minimum of 5.75 ft high. The recommended locations of the vanes are shown in Figure 9. These vanes will assist in directing the flow into the outlet channel and provide satisfactory flow conditions in the entrance to the outlet channel.

All of the above flow conditions are considered satisfactory. Some maintenance may be required if the extreme flood flow event occur.

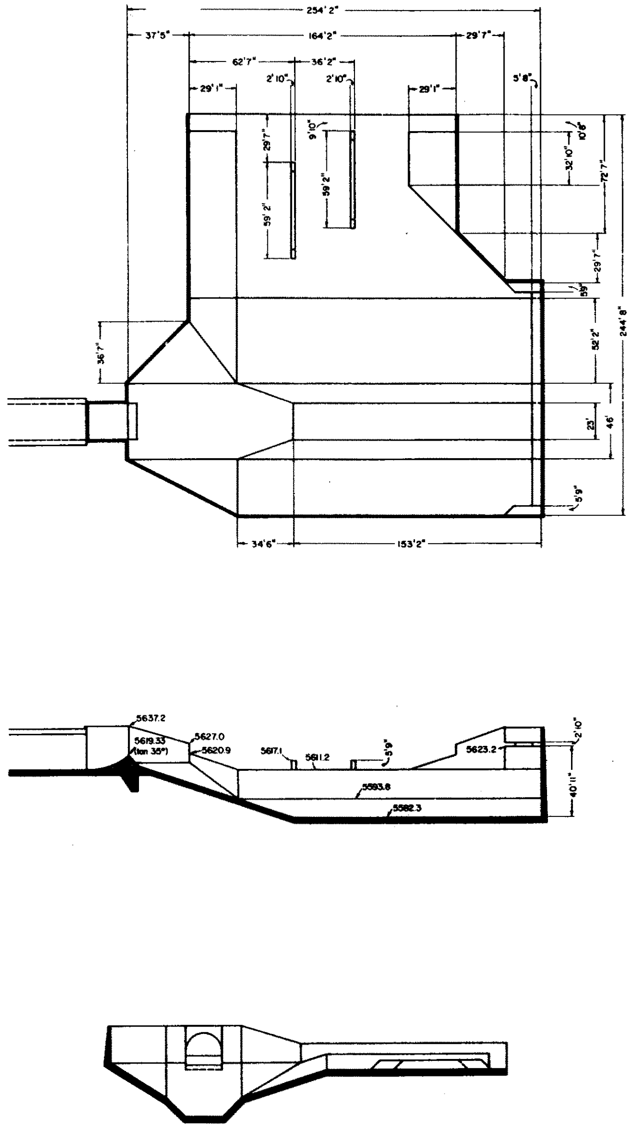


Figure 9 - Recommended Design for Flip Bucket Plunge Pool
Stilling Basin and Outlet Channel Entrance

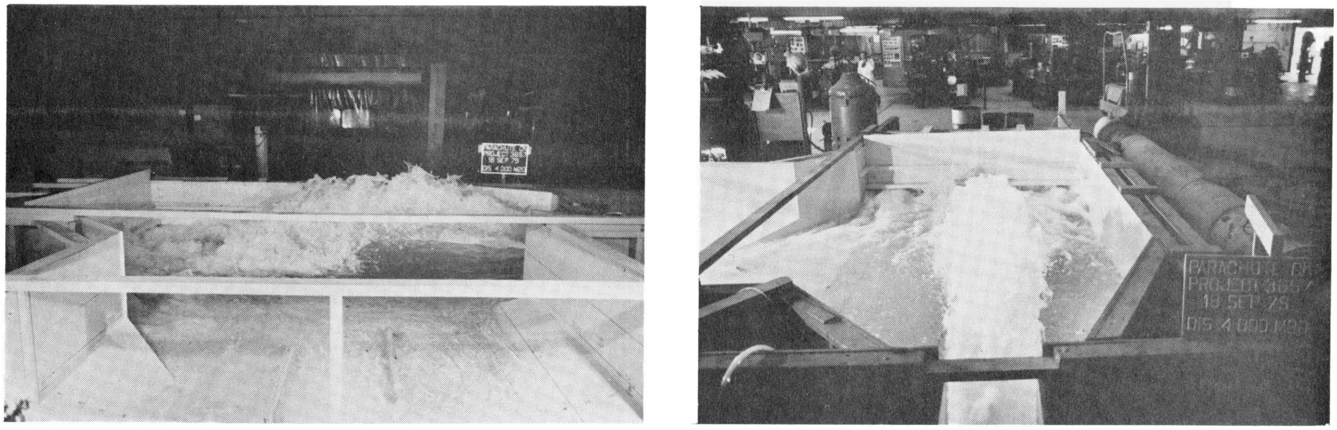


Figure 10a - Flow conditions in recommended flip bucket plunge pool
stilling basin and outlet channel entrance, 4,000 cfs

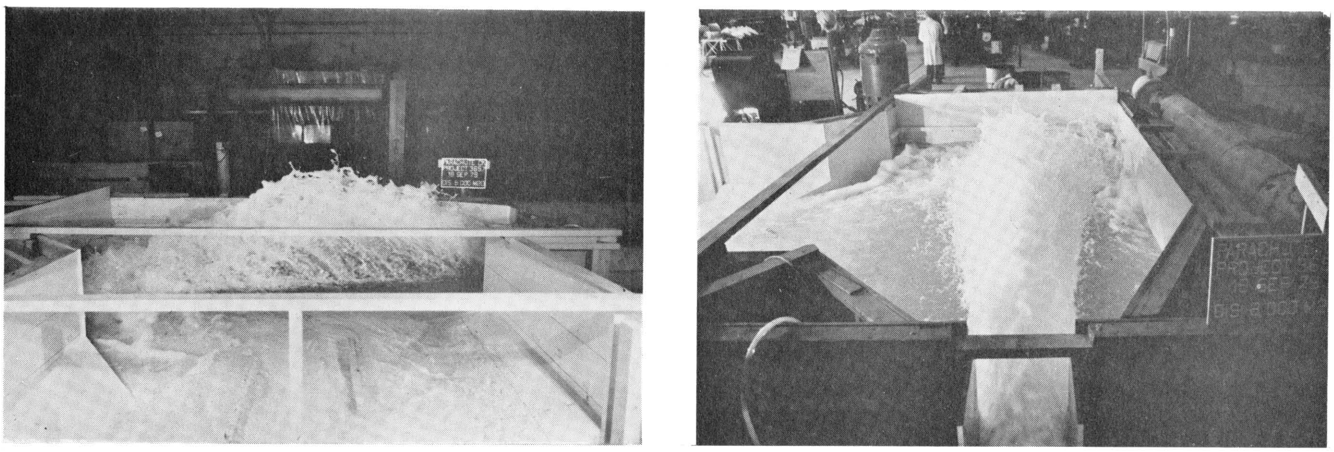


Figure 10b - Flow conditions in recommended flip bucket plunge pool
stilling basin and outlet channel entrance, 8,000 cfs

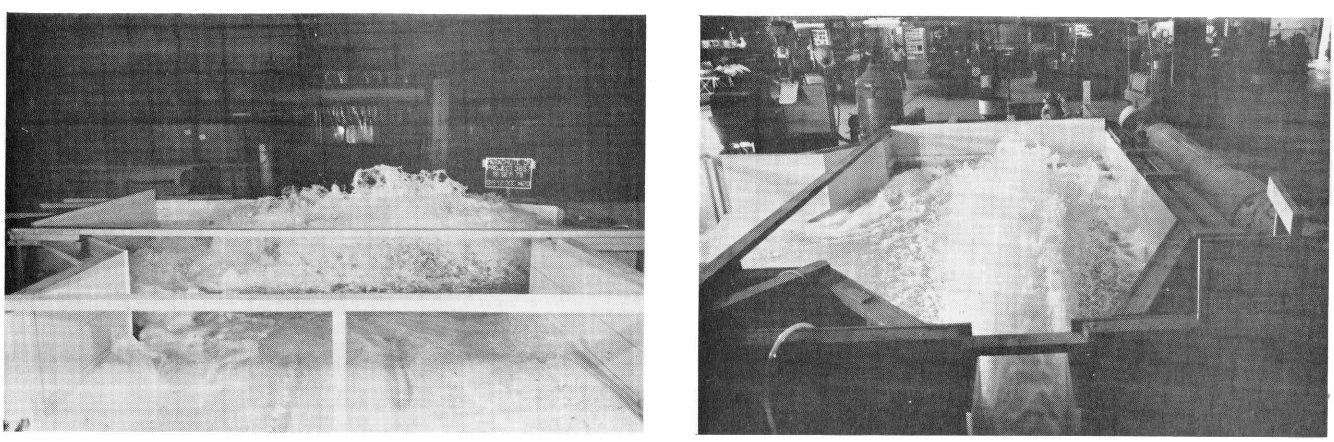


Figure 10c - Flow conditions in recommended flip bucket plunge pool
stilling basin and outlet channel entrance, 12,000 cfs

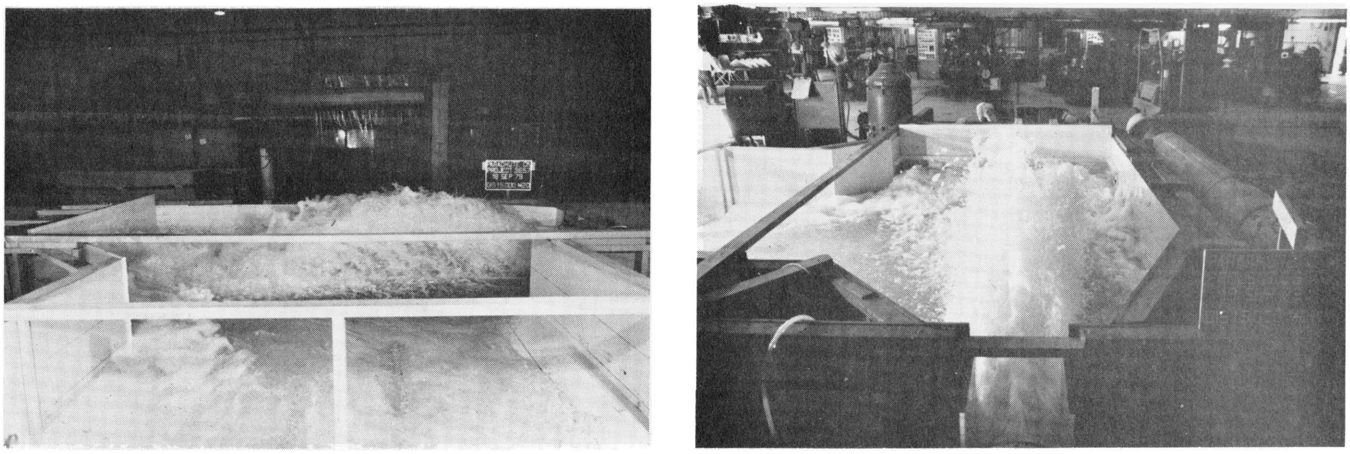


Figure 10d - Flow conditions in recommended flip bucekt plunge pool stilling basin and outlet channel entrance, 15,000 cfs

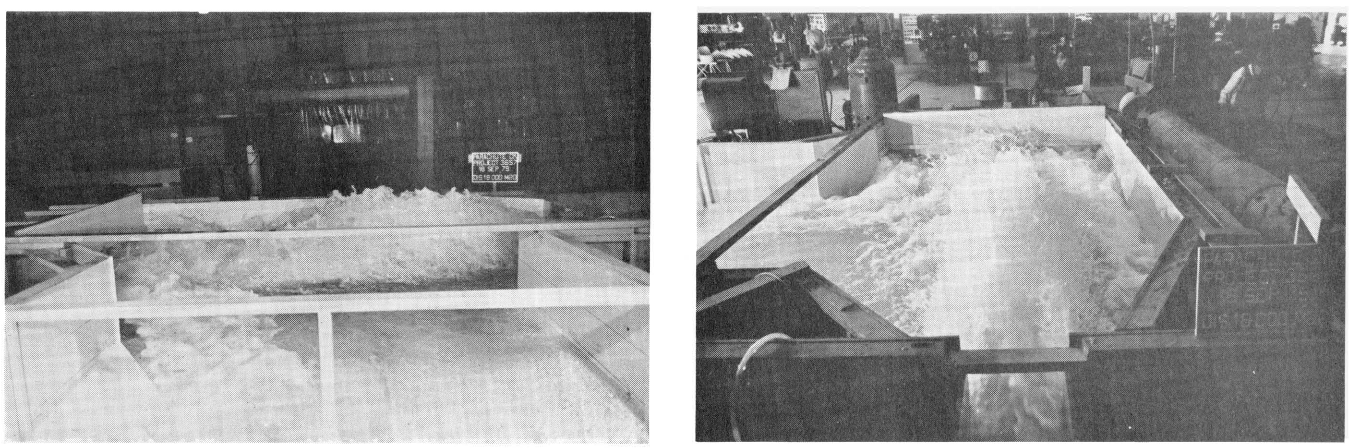


Figure 10e - Flow conditions in recommended flip bucket plunge pool stilling basin and outlet channel entrance, 18,000 cfs

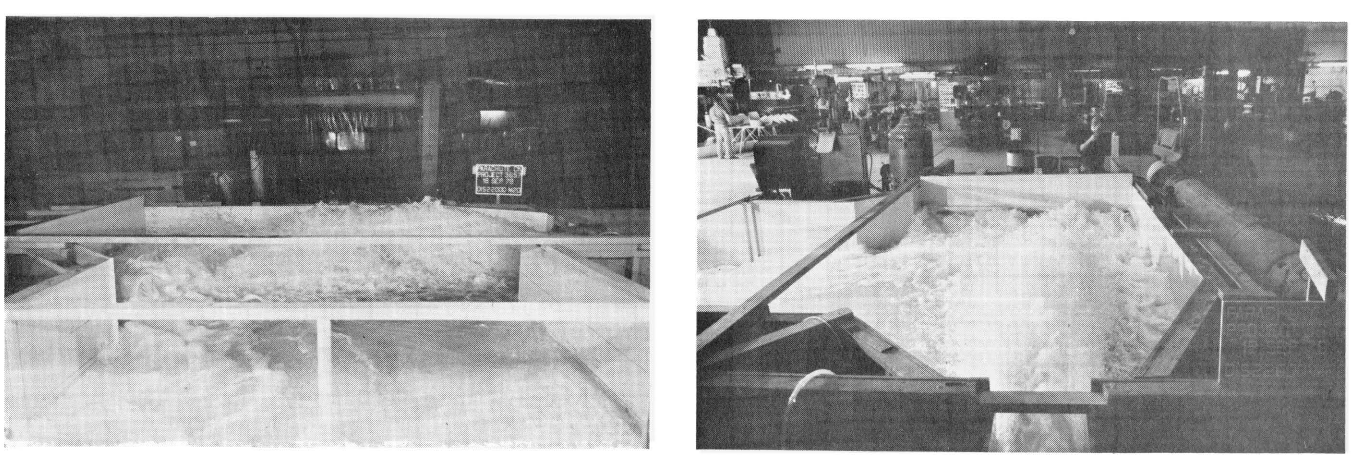


Figure 10f - Flow conditions in recommended flip bucket plunge pool stilling basin and outlet channel entrance, 22,000 cfs

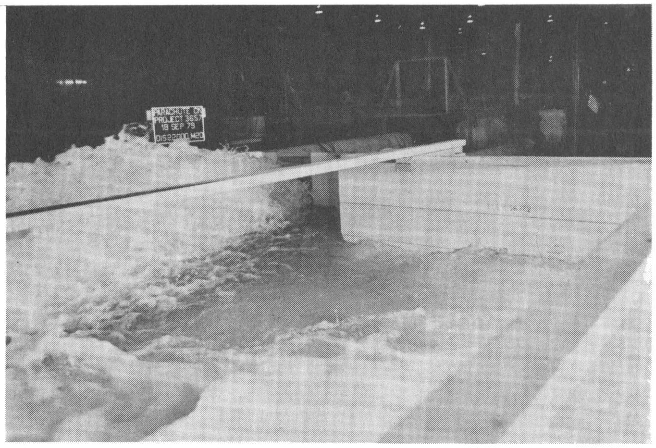


Figure 11 - Waves near outlet channel entrance
at a discharge of 22,000 cfs

APPENDIX A

Table A-1 - Piezometer Readings

Modification No. 20
35 degree lip
vertical wall

Piezometer No.	4,000 cfs	8,000 cfs	12,000 cfs	15,000 cfs	18,000 cfs	22,000 cfs
1	5617.2	5619.7	5621.2	5623.3	5624.6	5625.9
2	5617.5	5619.7	5621.3	5623.8	5624.9	5626.1
3	5617.5	5620.0	5621.6	5623.8	5624.9	5626.1
4	5617.2	5618.4	5619.7	5620.7	5618.0	5622.6
5	5618.4	5617.7	5618.4	5618.8	5620.0	5620.7
6	5668.4	5682.5	5688.3	5681.7	5693.2	5696.7
7	5635.8	5650.4	5660.3	5661.1	5671.0	5676.0
8	5627.9	5641.4	5649.6	5653.7	5662.0	5666.9
9	5626.7	5638.1	5646.3	5652.9	5661.1	5667.7
10	-	-	-	-	-	-
11	5620.0	5627.4	5634.8	5641.4	5649.6	5657.0
TWE at lip	5618	5622	5624	5627	5629	5632

Modification No. 20
25 degree lip

Piezometer No.	4,000 cfs	8,000 cfs	12,000 cfs	15,000 cfs	18,000 cfs	22,000 cfs
1	5617.0	5618.8	5621.0	5622.3	5624.8	5627.9
2	5617.2	5619.3	5621.2	5622.6	5625.3	5628.1
3	5617.2	5620.0	5621.6	5623.3	5625.4	5629.4
4	5617.4	5620.5	5623.5	5625.4	5627.6	5630.9
5	5625.8	5632.7	5641.2	5642.1	5644.4	5648.5
6	5627.6	5636.5	5646.7	5648.3	5650.9	5655.2
7	5626.7	5636.6	5648.1	5650.8	5653.7	5658.2
8	5625.6	5635.6	5645.7	5648.1	5652.8	5655.4
9	5625.9	5636.5	5648.5	5650.9	5654.6	5659.3
10	-	-	-	-	-	-
11	5619.0	5627.4	5636.3	5640.4	5645.5	5650.0
TWE at lip	5620.0	5625.0	5627.0	5628.0	5629.0	5630.0

Modification No. 15

35 degree lip

Sloped Impact Wall

Discharge / Elevation	Piezometer #1 5602.0	Piezometer #2 5612.0	Piezometer #3 5592.0
4,000	5622.5	5620.8	5619.2
8,000	5628.2	5625.8	5620.8
12,000	5643.9	5629.1	5621.7
15,000	5645.5	5630.7	5621.7
18,000	56.50.5	5643.9	5630.7
22,000	5649.6	5649.6	5638.9

Modification No. 20

35 degree lip

Vertical wall

Discharge / Elevation	Piezometer #1 5602.0	Piezometer #2 5612.0	Piezometer #3 5592.0
4,000	5619.2	5622.5	5615.9
8,000	5626.2	5638.9	5616.3
12,000	5638.1	5634.8	5623.7
15,000	5643.0	5640.2	5627.4
18,000	5645.5	5636.5	5643.0
22,000	5651.3	5644.3	5644.7

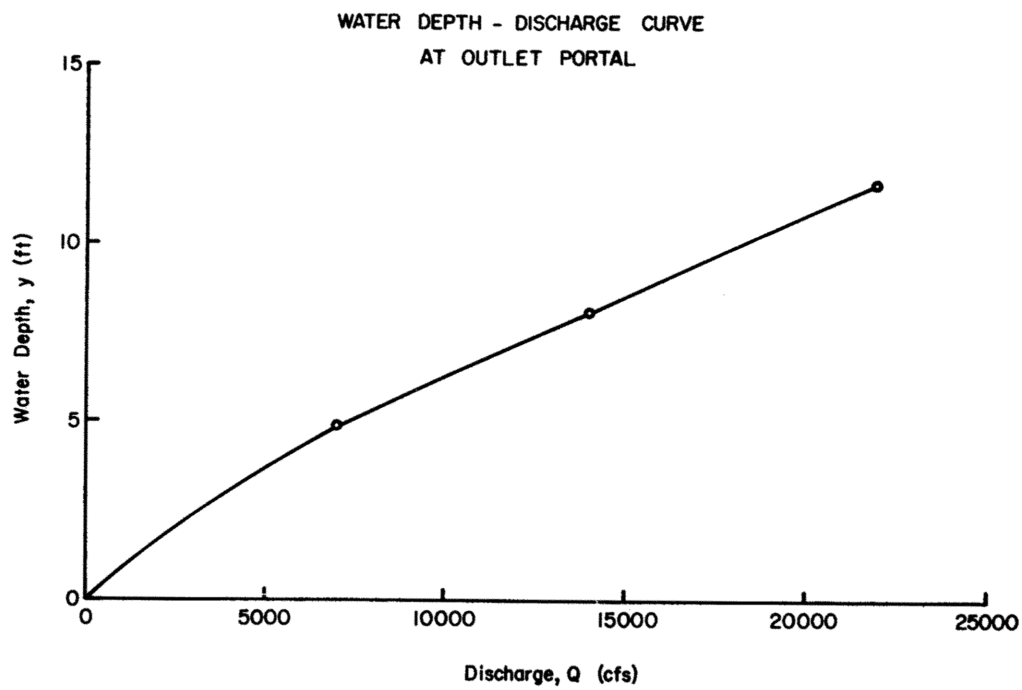
Modification No. 20

25 degree lip

Vertical Wall

Discharge / Elevation	Piezometer #1 5602.0	Piezometer #2 5612.0	Piezometer #3 5592.0
4,000	-	-	-
8,000	5623.6	5630.0	5620.3
12,000	5634.3	5643.7	5621.3
15,000	5638.8	5643.0	5625.3
18,000	5650.0	5647.7	5631.9
22,000	5652,8	5648.6	5638.6

APPENDIX B



U/S Station 17+00 = 22.0 ft I.D. Concrete Conduit

D/S Station 17+30 = 22.0 ft Concrete Horseshoe Conduit

Between stations 17+00 and 17+30 = Smooth warp transition

Ref. (1) = Design Calculations, J. E. Halcomb, 2/26/75

WATER SURFACE PROFILE COMPUTATIONS

D = 22 ft, n = 0.014, Q = 7,000 cfs

Station	ΔL ft	Trail d/D	d ft	a ft^2	v fps	hv ft	r ft	$r^{2/3}$ $ft^{2/3}$	s ft/ft	$\frac{s_1 + s_2}{2}$ ft/ft	ΔhL ft	ΣΔhL ft	$d_2 + hv_2 + \Sigma\Delta hL$ ft	Invert Elev. ft	Datum Gradient	Remarks
9 + 50	0					164.81								5640.49	5805.30	
10 + 00	78.54	0.2318	5.10	66.80	104.79	170.52	3.02	2.09	0.22313		17.52	17.52	193.14	5617.71	5810.88	Circular Conduit
		0.2341	5.15	67.73	103.35	165.85	3.05	2.10	0.21498		16.88	16.88	181.88	5617.71	5805.62	
13 + 50	350	0.2727	6.00	83.98	83.36	107.90	3.47	2.29	0.11762	0.16630	58.20	75.08	188.98	5615.20	5804.18	
		0.2736	6.02	84.36	82.97	106.91	3.48	2.30	0.11551	0.16524	57.84	74.72	187.65	5615.20	5802.85	
		0.2718	5.98	83.59	83.74	108.90	3.46	2.29	0.11869	0.16683	58.39	75.27	190.15	5615.20	5805.35	
17 + 00	350	0.3045	6.70	97.93	71.48	79.33	3.81	2.44	0.07617	0.09743	34.10	109.37	195.40	5612.66	5808.06	
		0.3073	6.76	99.18	70.58	77.35	3.83	2.45	0.07366	0.09618	33.66	108.93	193.04	5612.66	5805.70	
19 + 00	200	0.2227	4.90	107.80	64.94	65.47	3.30	2.22	0.07595	0.07481	14.96	123.89	194.26	5611.21	5805.41	Horseshoe Conduit

D = 22 ft, n = 0.014, Q = 14,000 cfs

Station	ΔL ft	Trail d/D	d ft	a ft^2	v fps	hv ft	r ft	$r^{2/3}$ $ft^{2/3}$	s ft/ft	$\frac{s_1 + s_2}{2}$ ft/ft	ΔhL ft	ΣΔhL ft	$d_2 + hv_2 + \Sigma\Delta hL$ ft	Invert Elev. ft	Datum Gradient	Remarks
9 + 50	0					168.21								5640.49	5808.70	
10 + 00	78.54	0.3773	8.30	131.30	106.63	176.54	4.51	2.73	0.13541		10.64	10.64	195.48	5617.74	5813.22	Circular Conduit
		0.3818	8.40	133.41	104.94	170.99	4.55	2.75	0.12925		10.15	10.15	189.54	5617.74	5807.28	
		0.3805	8.37	132.80	105.42	172.57	4.54	2.74	0.13139		10.32	10.32	191.26	5617.74	5809.00	
13 + 50	350	0.4182	9.20	150.72	92.89	133.98	4.87	2.87	0.09298	0.11219	39.26	49.58	192.76	5615.20	5807.96	
17 + 00	350	0.4545	10.00	168.07	83.30	107.74	5.16	2.99	0.06889	0.08094	28.33	77.91	195.65	5612.66	5808.31	
19 + 00	200	0.3659	8.05	177.10	79.05	97.04	4.62	2.77	0.07229	0.97059	14.12	92.03	197.12	5611.21	5808.33	Horseshoe Conduit

D = 22 ft, n = 0.014, Q = 22,000 cfs

Station	ΔL ft	Trail d/D	d ft	a ft^2	v fps	hv ft	r ft	$r^{2/3}$ $ft^{2/3}$	s ft/ft	$\frac{s_1 + s_2}{2}$ ft/ft	ΔhL ft	ΣΔhL ft	$d_2 + hv_2 + \Sigma\Delta hL$ ft	Invert Elev. ft	Datum Gradient	Remarks
9 + 50	0					172.01								5640.49	5812.58	
10 + 00	78.54	0.5455	12.00	212.06	103.74	167.12	5.80	3.23	0.09156		7.19	7.19	186.31	5617.74	5804.05	Circular Conduit
		0.5364	11.80	207.68	105.93	174.24	5.74	3.21	0.09666		7.59	7.59	193.63	5617.74	5811.37	
		0.5341	11.75	206.57	106.50	176.12	5.73	3.20	0.09831		7.72	7.72	195.59	5617.74	5813.33	
		0.5350	11.77	207.01	106.28	175.38	5.73	3.20	0.09791		7.69	7.69	194.84	5617.74	5812.58	
13 + 50	350	0.5818	12.80	229.46	95.88	142.75	6.01	3.31	0.07448	0.08619	30.17	37.86	193.41	5615.20	5808.61	
		0.5773	12.70	227.31	96.78	145.45	5.99	3.30	0.07634	0.08713	30.49	38.18	196.33	5615.20	5811.53	
		0.5764	12.68	226.89	96.97	146.00	5.98	3.30	0.07664	0.08728	30.77	38.24	196.92	5615.20	5812.12	
17 + 00	350	0.6227	13.70	248.83	88.41	121.38	6.32	3.42	0.05932	0.06798	23.79	62.03	197.11	5612.66	5809.77	
		0.6205	13.65	247.80	88.78	122.39	6.20	3.38	0.06124	0.06894	24.13	62.37	198.41	5612.66	5811.07	
		0.6195	13.63	247.33	88.95	122.86	6.20	3.37	0.06184	0.06924	24.23	62.47	198.96	5612.66	5811.62	
		0.6182	13.60	246.72	89.17	123.47	6.19	3.37	0.06214	0.06939	24.29	62.53	199.60	5612.66	5812.26	
19 + 00	200	0.5318	11.70	257.39	85.47	113.44	5.67	3.18	0.06412	0.06313	12.63	75.16	200.30	5611.21	5811.51	Horseshoe Conduit
		0.5305	11.67	256.76	85.68	114.00	5.66	3.17	0.06484	0.06349	12.70	75.23	200.90	5611.21	5812.11	

ΔL = Length of conduit a = Area of flow hv = Velocity head s = Friction slope

d = Depth of Flow v = Mean velocity r = Hydraulic radius n = Manning's coeficient

$$hv = \frac{v^2}{2g} \qquad s = \left(\frac{vn}{1.486\, r^{2/3}}\right)^2$$