PAP-721

Hydraulic Model Study of the Abrasion Damage to the River Outlet Stilling Basin at Ridgway Dam

by Leslie J Hanna

PURPOSE

The hydraulic model study was conducted at the request of the Grand Junction Area Office to evaluate hydraulic conditions in the outlet works stilling basin and downstream apron. The model study was used to determine the strength and extent of upstream velocities that could pull material into the stilling basin during normal operating conditions and to identify any unusual flow conditions that could contribute to entrainment of material into the basin.

INTRODUCTION

Basin Inspection

On November 15, 1994, an inspection of the Ridgway Dam outlet works was conducted by the Hydroelectric Research and Technical Services Group (D-8450) in conjunction with the UC Regional Office using an underwater remote operated vehicle (ROV) to video and inspect the basin areas. The approximate path traveled during the video survey is shown in figure 1. The inspection revealed severe abrasion damage to the basin floor which included large areas of exposed rebar. Large rocks (up to 1 ft in diameter), cobbles, and gravel size material lodged between rebar indicated that material churning in the basin during normal operations was the cause of the damage. As a result of the inspection, it was determined that the damage would require repairs and that a model study would be needed to determine the cause of material entrainment in the basin and to determine possible solutions for preventing damage from occurring in the future.

Basin History

The outlet works tunnel was used for diversion during construction of Ridgway Dam from 1982 to 1986. At that time, the stilling basin and downstream riprap basin were already completed. During the time of the dam construction, several storm events caused considerable flow and rock alluvium material to pass through the outlet works. Although this material was to have been removed from the basin in 1986, the contract specified that material be removed to the extent necessary so that final evaluation of the damage to structural concrete could be assessed and repairs made. There appears to be no documentation which describes if all of the material was actually removed; so part of the current damage may be a result of not fully cleaning the basin of this material in 1986.

In addition to this, much of the material that was cleaned out of the basin was deposited on the riprap apron immediately downstream of the basin end sill. A significant amount of gravel and cobble size material likely remained mixed amongst the riprap immediately downstream of the basin end sill following 1986. Normal outlet works operation of a hydraulic jump energy dissipation basin will cause a reverse flow eddy over the basin end sill and lower apron as shown in figure 2. This eddy is driven by a high velocity jet rising off the basin floor near the end of the basin. Riprap placed on the apron is designed to be stable under this condition. However, if significant amounts of smaller material are in the area immediately downstream of the end sill, it will be transported into the basin.

THE MODEL

Froude scaling was used to model the Ridgway Dam outlet works from station 16+23 downstream to station 19+25 (figure 3) on a 1:10.5 scale. The model was used to investigate the hydraulic conditions in the stilling basin and apron area under various operating conditions. The model included the 54-in bifurcation stub, pantleg bifurcation, transitions, and the two 42-in high pressure slide gates (figure 4) discharging into 2:1 sloping twin chutes and twin stilling basins (figure 5). Discharge through the outlet works ranged from 360 ft^3/s for 20% gate opening up to a maximum discharge of 1300 ft^3/s at 85 % gate in the prototype. The downstream riprap apron topography was modeled with moveable bed material to approximately station 19+25.

The 30" prototype bypass pipe which parallels the outlet works and exits about 23 ft upstream of the end of the basins was also included in the model. Discharge through the bypass ranged up to a maximum of 100 ft^3/s.

A pressure transducer was mounted at a position 8.5 ft upstream of the bifurcation stub at station 16+33. This transducer was used to set the head at this location (adjusted for head loss) which corresponded to the designated reservoir elevation. Velocity measurements were determined using a sontek acoustic flow meter.

TEST PLAN

Velocities were mapped along the length of the riprap apron at a depth representing between 6 in and 9 in above the apron invert. Velocity measurements were taken representing 5-ft increments downstream of the basin end sill for symmetric gate operations, with gate openings ranging from 20 percent to 85 percent (specifications recommend that the maximum gate opening be limited to 85 percent to minimize or prevent the occurrence of pulsations and vibrations).

Velocities were measured at the centerpoints of each bay to a maximum distance of 73 ft downstream of the endsill. Dye traces were used to confirm that this distance contained the transition from predominantly upstream to predominantly downstream velocities for each gate opening.

In addition to this, hydraulic conditions were investigated while operating under the following conditions:

1. Symmetric gate operations with changes in tailwater elevation.
   a. Velocities were measured at the centerpoints of each bay immediately downstream of the basin endsill. Tailwater elevations up to a maximum of 5 ft above the designated tailwater for each gate opening were investigated in order to determine velocity sensitivity to tailwater elevation.

2. Symmetric gate operations with changes in reservoir elevation.
   a. Velocities were measured at the centerpoints of each bay immediately downstream of the basin endsill. Measurements were made over a range of reservoir elevations up to the maximum elevation of 6880 ft.

3. Bypass operation only.
   a. The magnitude of upstream velocities caused during conditions of only bypass operation were determined at the centerpoints of each bay for discharges up to a maximum of 100 ft^3/s.

4. Bypass operation concurrent with symmetric gate operation.
   a. The magnitude of upstream velocities as a result of bypass operation concurrent with symmetric gate operation were determined at the centerpoints of each bay for bypass discharges up to a maximum of 100 ft^3/s.

5. Unbalanced gate operation.
   a. Velocities were determined during nonsymmetric gate operations and compared with the magnitude of velocities resulting from symmetric operation of the same total discharge.

Preliminary tests showed that the maximum reservoir elevation of 6880 ft represents the worst case for the occurrence of upstream velocities, therefore all measurements, unless otherwise stated, were taken under these conditions. A tailwater curve was not available for the Ridgway Dam outlet works, however, as a result of observations from Tri-county Water Conservancy District field personnel, a tailwater curve was generated (figure 6). Tailwater elevation was estimated based on waterline marks measured on the outside of the stilling basin walls. Water surface elevations were estimated for releases of 100 ft^3/s and 1,000 ft^3/s.

RESULTS

These are the results of the model study:

1. Flow conditions within and downstream of the stilling basin appear to be normal. No unusual flow conditions were identified as a result of the design of the outlet works stilling basin.

2. Upstream velocities occur downstream of the basin end sill throughout the range of gate openings investigated. Figure 7 shows average velocities measured 6 in to 9 in above the apron invert at 5-ft increments downstream of the basin end sill (zero position is referenced at the downstream end of the basin end sill) over the range of gate openings from 20 percent to 85 percent. Negative values indicate upstream velocities. Three standard deviations were used to predict with a 99 percent confidence level the peak upstream velocities for each of the cases investigated. These values were plotted in figure 8 and range up to a maximum upstream velocity of 5.5 ft/s for a gate opening of 85 percent.

3. Over the range of gate openings tested, velocities transitioned from predominantly upstream in direction to predominantly downstream at a maximum distance of about 60 ft downstream from the basin end sill. Dye traces were used to verify the transition point and also demonstrated that velocities upstream of the transition pull laterally from across the width of the apron towards the twin bays.

4. Upstream velocities showed little affect with increases in tailwater elevation up to a maximum of 5 ft above the designated tailwater elevation.

5. Preliminary tests showed that the maximum reservoir water surface elevation of 6880 ft resulted in worse case upstream velocities and was therefore used in all investigations.

6. Peak upstream velocities at the basin end sill did not exceed 3 ft/s for bypass operation only, up to a maximum discharge of 100 ft^3/s.

7. Table 1, which shows peak upstream velocities for the bypass operating with and without symmetric gate operation, demonstrates that bypass operation concurrent with gate operation produces higher velocities which amplify the potential for entraining material.

8. Table 2 shows peak upstream velocities (measured at the basin end sill) during symmetric and nonsymmetric gate operations which produce approximately the same total discharge. This demonstrates that higher velocities as well as a greater disparity between left and right bay velocities occur as a result of nonsymmetric gate operation and

therefore may contribute to producing an amplified eddy and the mechanism for entraining material. Gate operations which produce similar discharges are separated into sections by the bold lines in Table 2. The first row of each section represents symmetric gate operation.

Table 1. Peak upstream velocities resulting from bypass operation.

Bypass Discharge (ft^3/s)	Symmetric Gate Opening (%)	Distance Downstream from Basin Endsill (ft)	Velocity (ft/s)	
			Left Bay	Right Bay
100	0	0	-.57	-2.59
100	0	2.5	-1.62	-1.08
100	40	0	-4.29	-2.52
100	40	2.5	-2.36	-3.73
0	40	0	-3.14	-3.31

Table 2. Unbalanced Gate Operations.

Left Gate Opening (%)	Right Gate Opening (%)	Total Discharge (ft^3/s)	Symmetric Gate Operation?	Velocity (ft^3/s)	
				Left Bay	Right Bay
50	50	835	Yes	-3.36	-3.25
30	70	835	No	-3.9	-4.5
40	40	686	Yes	-3.14	-3.31
70	0	677	No	-4.08	1.48
0	70	677	No	-1.67	-4.79
30	50	686	No	-3.13	-3.63
20	20	362	Yes	-3.05	-2.83
40	0	363	No	-3.36	1.81

RECOMMENDATIONS

The following recommendations are based on criteria stated in Reclamation Engineering Monograph No. 25 and *Design of Small Dams*.

1. All material in the basin must be removed and deposited well away from the stilling basin and downstream riprap apron.

2. Riprap and bedding should be removed for a distance of 60 ft downstream of the basin end sill and across the width of the apron.

3. Riprap should be replaced to original specifications with the following exceptions:
   - a. D_0 stone size should be no less than 9 inches. Engineering Monograph No. 25 predicts that a stone of this size will not move until a flow velocity of about 7 ft/s is reached.
   - b. Riprap should begin at a depth of 6 to 12 inches below the elevation of the endsill.

4. We recommend that the bedding material be replaced as follows:

   a. The bottom liner should be a geofabric membrane which meets specifications as stated in Table 3, as well as meeting the following criteria:
      1) Seams should be overlapped by 3 feet.
      2) No tears or punctures shall be allowed.
      3) No staples shall be allowed at the seams or in the field.

   b. Bedding material should be 12 inches to 15 inches thick and should meet original specifications with the exception of size specifications which should meet the following gradation criteria:

      1) 1 inch $\leq D_0$
      2) 2 inches $< D_{15} <$ 2.5 inches
      3) 3 inches $< D_{50} <$ 4 inches
      4) 6 inches $< D_{85} <$ 8 inches
      5) $D_{100} \leq$ 9 inches

   The above-mentioned gradation criteria are taken from *Earth and Rock Dams*, by J. L. Sherard, J. W. Richard, F. G. Stanley, and A. C. William.

Table 3. - Bedding liner specifications.

Property	Unit	Test method	Minimum average roll value
Weight	oz/yd^2	ASTM D-3776-84	10.0
Thickness	mils	ASTM D-1777-64	120
Grab tensile strength	lbs	ASTM D-4632-86	225
Grab tensile elongation	%	ASTM D-4632-86	50
Trapezoidal tear strength	lbs	ASTM D-4533-85	90
Mullen burst strength	lb/in^2	ASTM D-3786-87	500
Puncture strength	lbs	ASTM D-4833-88	140
Apparent opening size	U.S. Std. Sieve	ASTM D-4751-87	100+
Permitivity	sec^1	ASTM D-4491-85	1.0
Flow rate	gal/min/ft^2	ASTM D-4491-85	75
UV resistance after 500 hours	% strength retained	ASTM D-4355-84	70

5. Bypass operation concurrent with gate operation may produce higher upstream velocities which could contribute to the entrainment of material in the basin and therefore is not recommended.

6. Nonsymmetric gate operation may produce an amplified eddy which could enhance the mechanism for entraining material into the basin. Therefore nonsymmetric gate operation is not recommended.

7. The basin should be inspected and cleaned of material a) after initial operation to clear the basin of any materials that may be entrained in the basin as a result of construction activity and b) every two to three years thereafter, since there is always the potential for small rock or debris to enter the basin or apron area by means such as being thrown in or washed over a wall.

If you have any questions or comments, please contact Leslie Hanna in the Water Resources Research Laboratory, D-8560, at (303) 236-2000, extension 468.

* - OBSERVATIONS
* - APPROXIMATE ROUTE TAKEN

FIELD EXAMINATION - NOVEMBER 15, 1994.

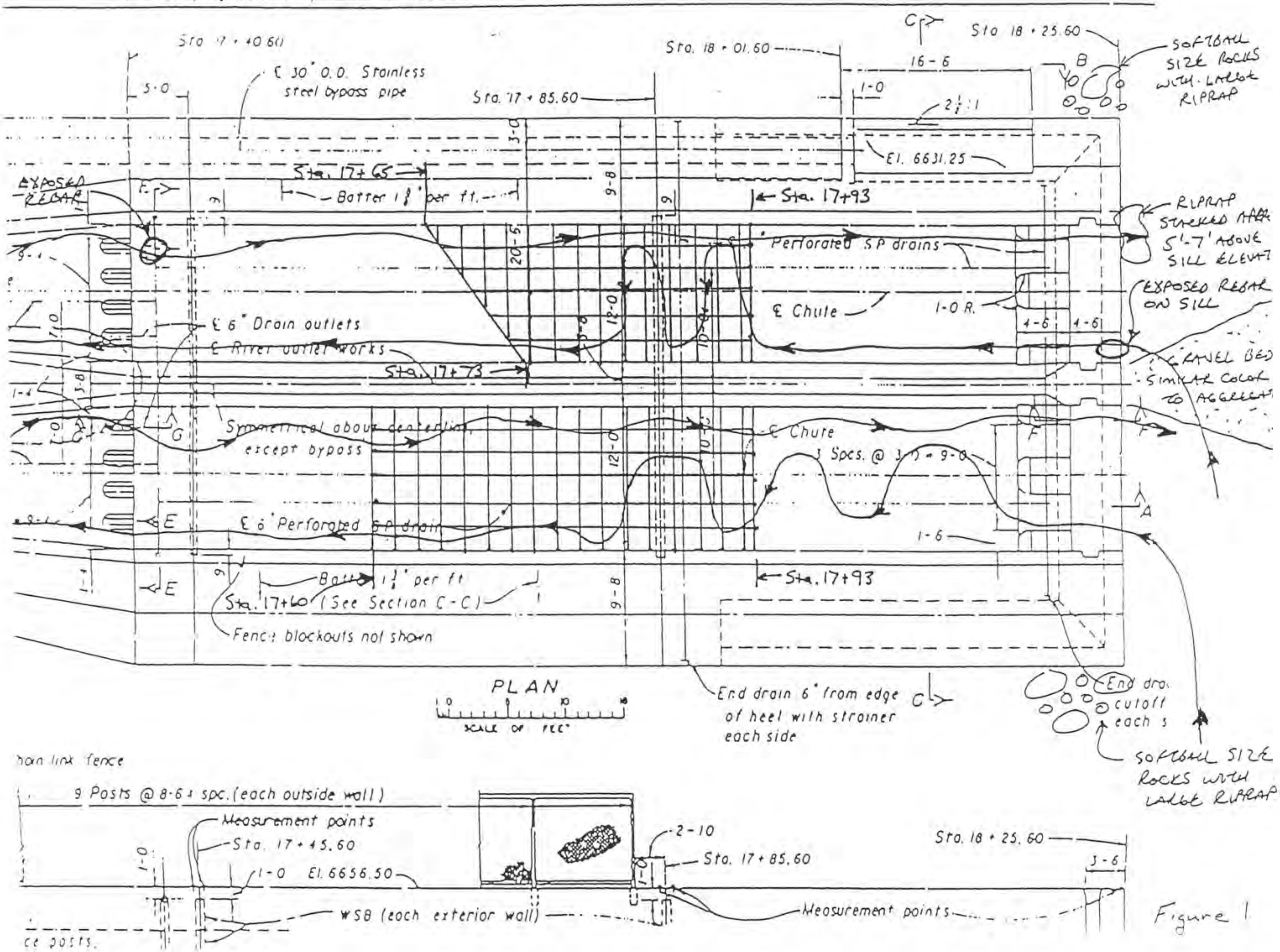


Figure 1

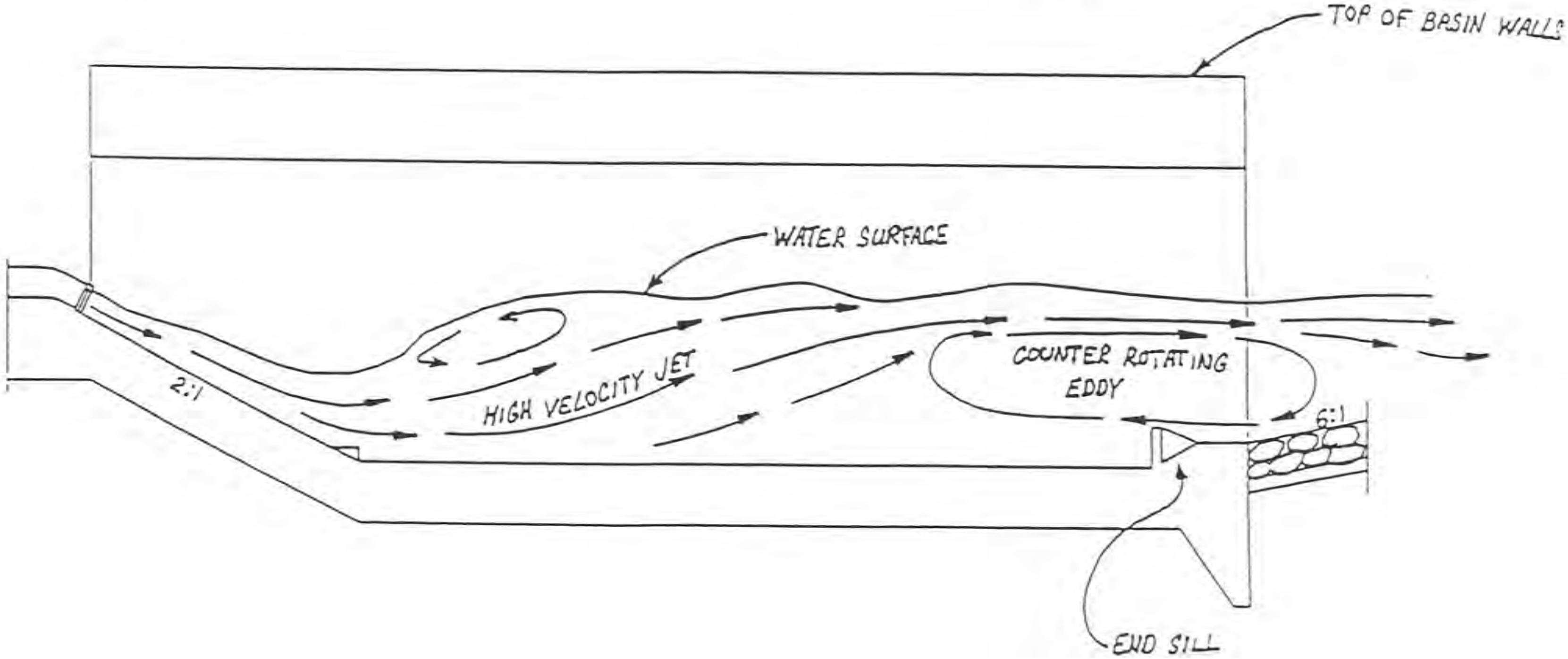
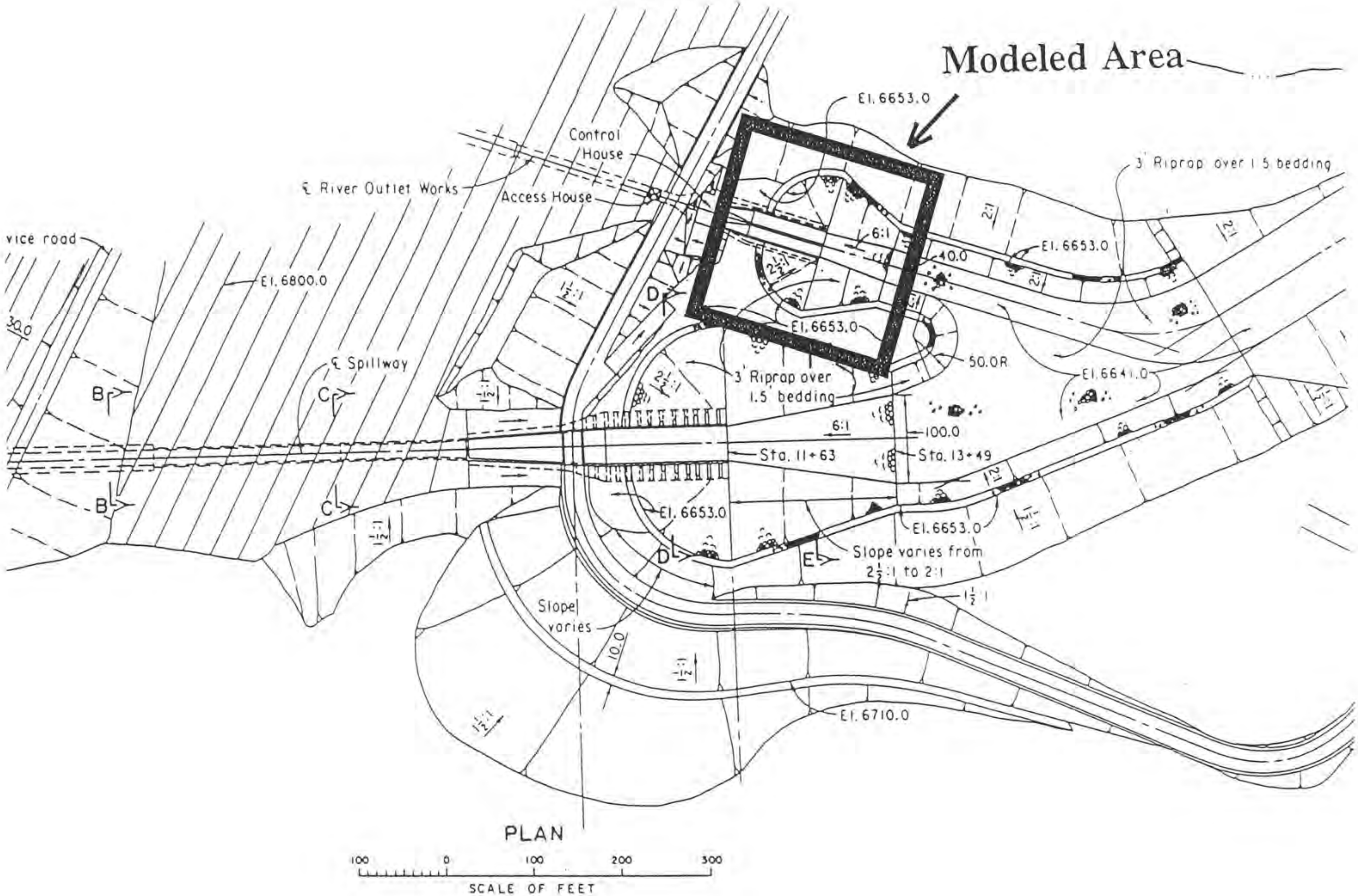
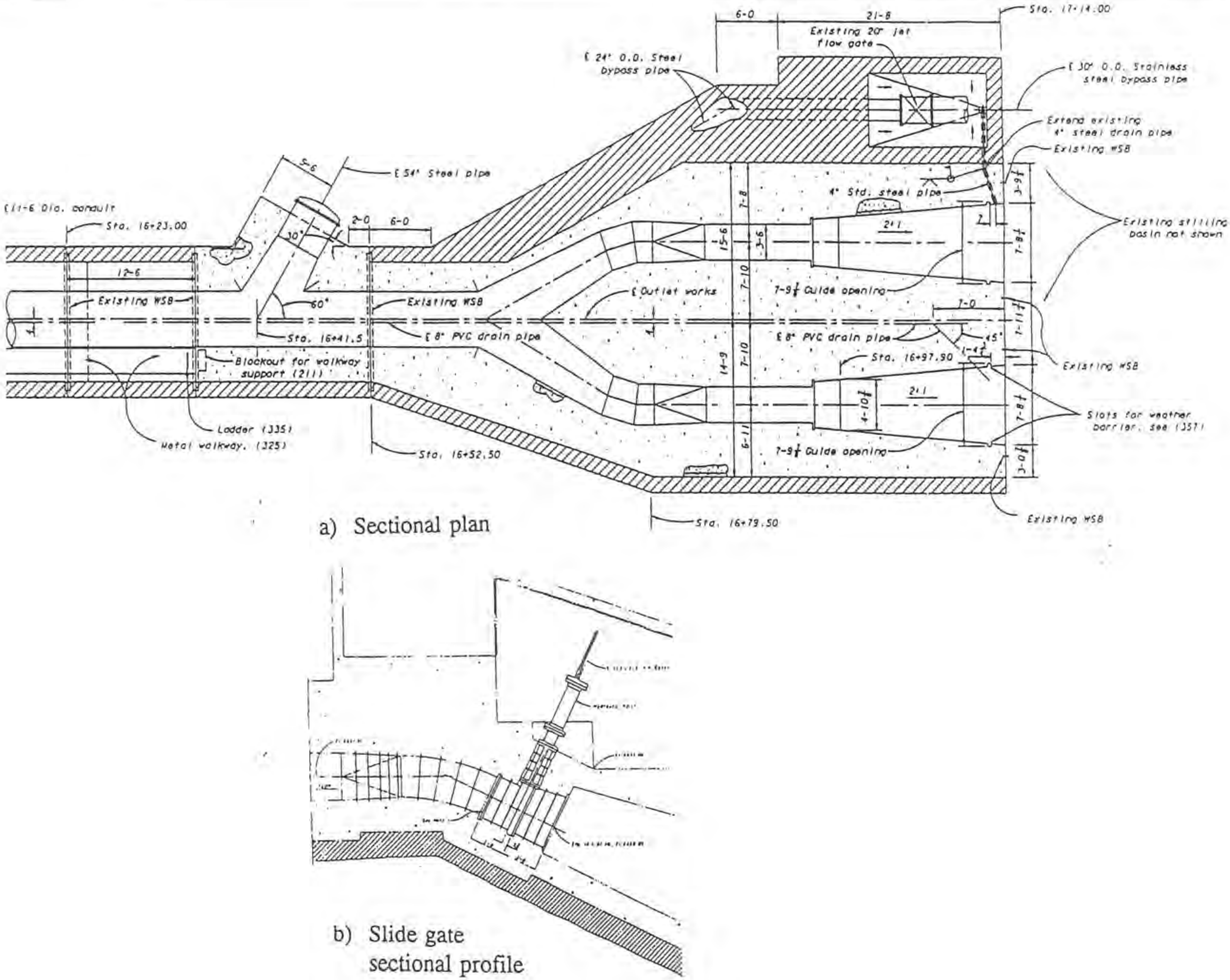

TOP OF BASIN WALLS
WATER SURFACE
HIGH VELOCITY JET
COUNTER ROTATING EDDY
2:1
6:1
END SILL

Figure 2. [illegible]



Modeled Area
El. 6653.0
3' Riprap over 1.5 bedding
Control House
℄ River Outlet Works
Access House
vice road
El. 6800.0
6:1
40.0
El. 6653.0
El. 6653.0
50.0R
℄ Spillway
3' Riprap over 1.5' bedding
El. 6641.0
6:1
100.0
Sta. 11+63
Sta. 13+49
El. 6653.0
El. 6653.0
Slope varies from 2½:1 to 2:1
Slope varies
10.0
El. 6710.0
PLAN
100 0 100 200 300
SCALE OF FEET



a) Sectional plan

b) Slide gate sectional profile

Figure 4. Ridgway Dam outlet works a) sectional plan from station 16+23 to

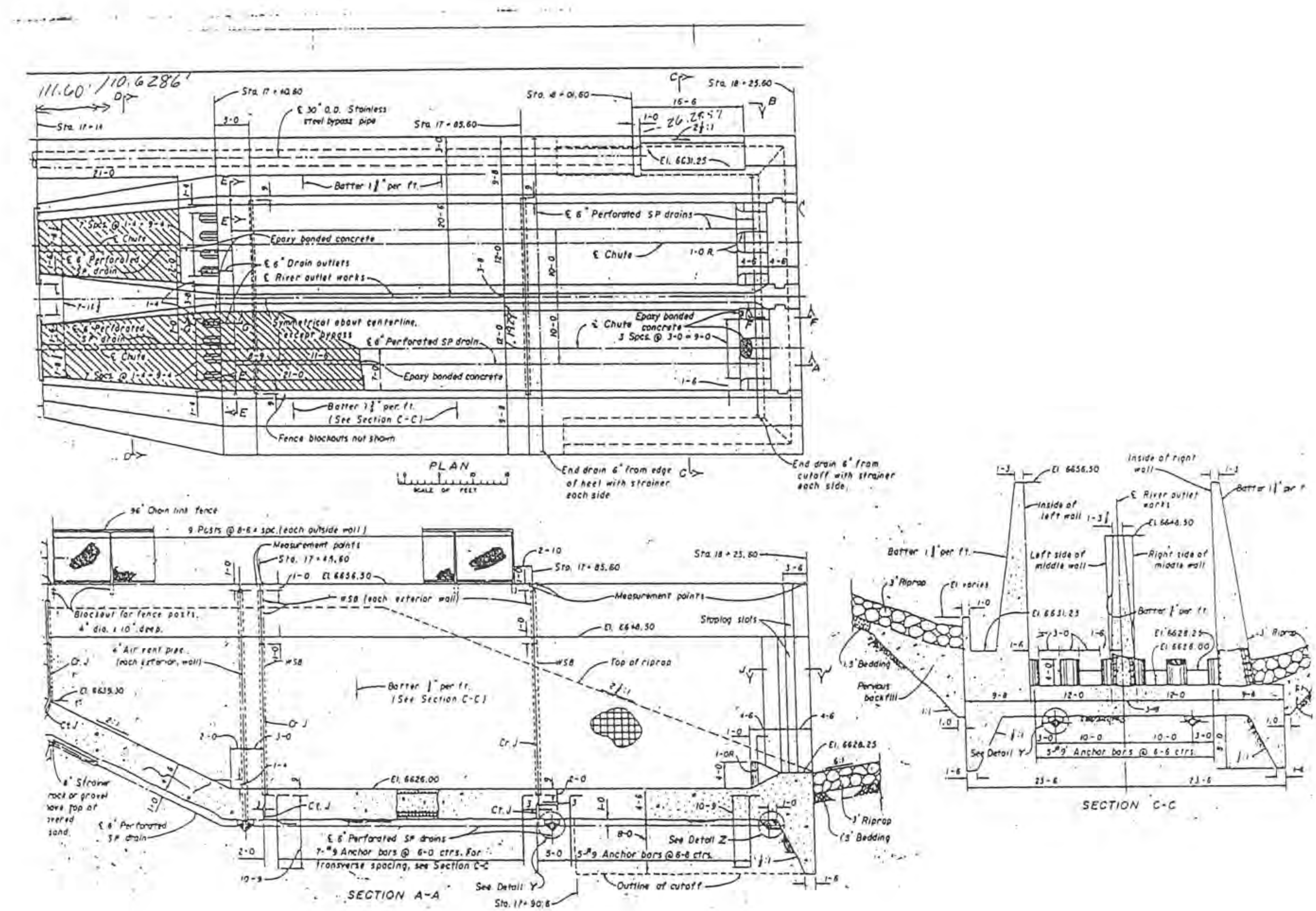


Figure 5. Outlet works stilling basin twin sloping chutes and twin bays.

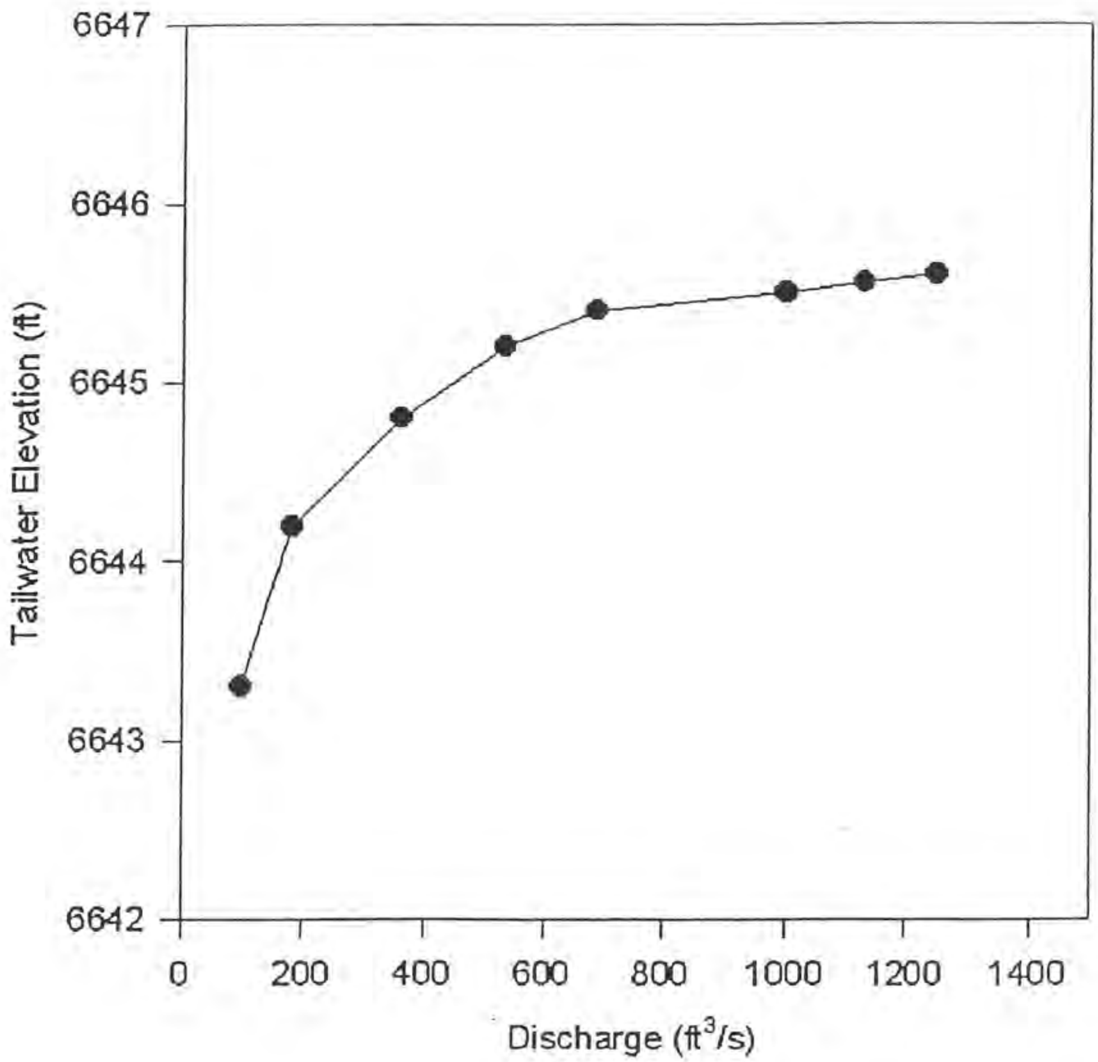


Figure 6. Tailwater curve generated for the Ridgway Dam outlet works.

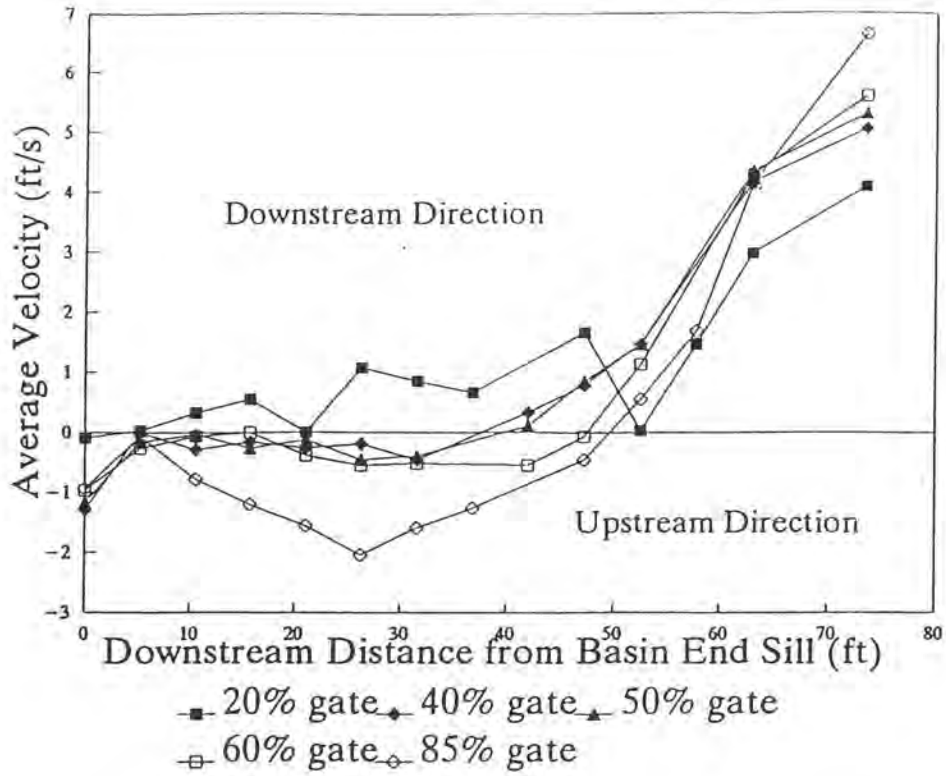


Figure 7. Average velocities measured at 5 ft increments downstream of the stilling basin end sill.

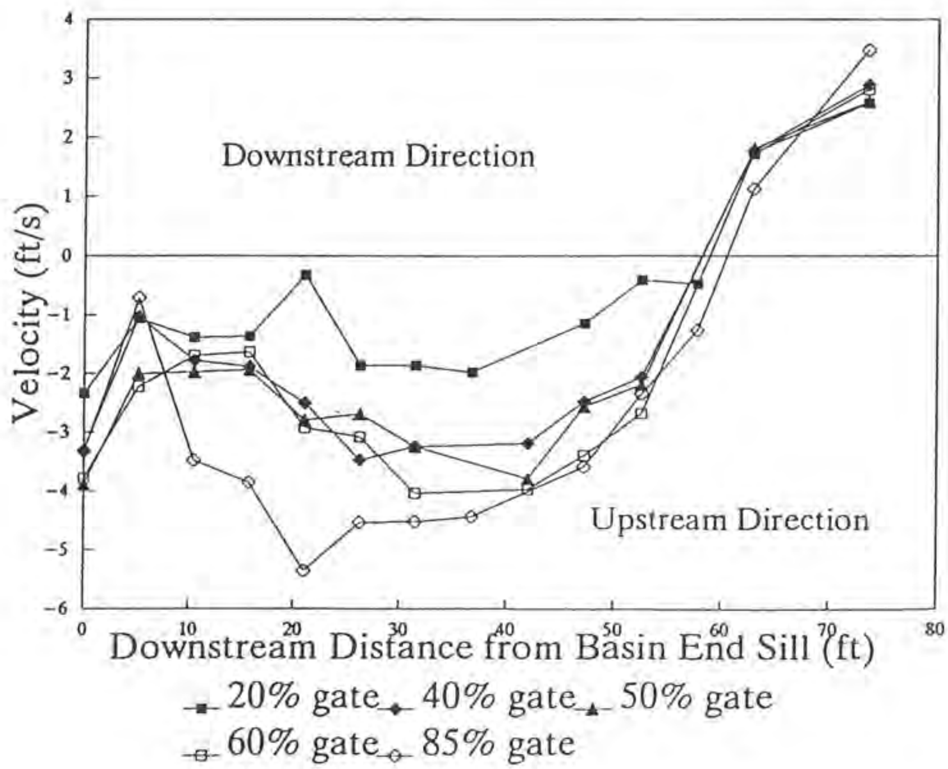


Figure 8. Maximum upstream velocities within 3 standard deviations at 5 ft increments downstream of the basin end sill.