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HYDRAULIC MODEL STUDY OF THE SPRING CREEK DEBRIS DAM SELECTIVE WITHDRAWAL SYSTEM

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U.S. DEPARTMENT OF THE INTERIOR
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As a client service to the Environmental Protection Agency, the Bureau of Reclamation is designing a selective withdrawal outlet works structure as part of the modifications to Spring Creek Debris Dam. The selective withdrawal structure will be used to discharge varying concentrations of pollutants from the reservoir and to decrease the frequency of releases from the existing spillway. The hydraulic model study was used to determine the losses through the system and operational limits on the submergence of the skimming weir and slide gates in order to maintain control with the downstream gates and to suppress vortex formation. Additional items that were investigated were flow conditions in the conduit with more than one slide gate discharging, pressures acting across the weir gate under large submergences, and conditions under which blowback of entrained air might occur.

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by

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U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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PURPOSE

The Bureau of Reclamation conducted a model study to provide hydraulic information, and to establish operating criteria and restrictions for the Spring Creek Debris Dam selective withdrawal structure. This structure is the new proposed outlet works to be installed at the dam.

INTRODUCTION

The Environmental Protection Agency has requested modification of Spring Creek Debris Dam as part of the cleanup for the Iron Mountain Superfund site. The Spring Creek drainage enters the Sacramento River between Shasta Dam and Keswick Dam. The location of the existing damsite on Spring Creek and the heavy metal pollutants being retained by the dam require that releases be closely monitored because of concern over endangered salmon species in the Sacramento River.

The modifications include raising the existing dam and installing a proposed selective withdrawal outlet works. The selective withdrawal system (fig. 1), located on the dam abutment, will be used to discharge varying concentrations of pollutants from the reservoir and to decrease the frequency of releases from the existing spillway. When discharges are high in the Sacramento River, more of the pollutants may be released from Spring Creek Debris Dam without exceeding acceptable levels. Normal discharges through the selective withdrawal system will range from 30 to 75 ft^3/s; maximum discharge will be about 1,375 ft^3/s.

The selective withdrawal system consists of five slide gates, covering openings in a rectangular conduit, that will be used to allow discharge from various elevations in the reservoir. The three uppermost slide gate openings each measure 7 ft by 8 ft, and the lower slide gate openings measure 5 ft by 8 ft. Each slide gate will be covered individually with a trashrack. The operation of the skimming weir gate makes this selective withdrawal system unique (fig. 1, section A-A). The weir gate, 68.5 ft in length, will follow the reservoir level and traverse the entire length of the selective withdrawal conduit. Flow through the selective withdrawal outlet will be controlled by regulating gates at the downstream end of the outlet works.

A physical model study was conducted because of the complex hydraulic design and the consequence of releasing pollutants into the Sacramento River as a result of unexpected operational difficulties with the withdrawal system. The model study was used to determine the head losses through the system and operational limits on the submergence of the weir gate and slide gates. This information is required to maintain control with the downstream regulating gates because this control is critical for acceptable operation. Vortex formation was investigated because the structure geometry and the cut slopes surrounding the withdrawal system could lead to air entrainment. Conditions under which blowback of entrained air might occur must also be prevented. Additional items that were investigated were flow conditions in the conduit with more than one slide gate discharging, procedures for changing operations from one slide gate to another, and pressures acting across the weir gate under large submergences.

RECOMMENDATIONS AND CONCLUSIONS

The following results from the hydraulic model study should be incorporated into the design analysis and operating criteria for the selective withdrawal structure.

1. The selective withdrawal structure conduit must remain pressurized during all weir gate and slide gate operations to prevent damage to the gates and structure. This pressurization is accomplished by maintaining control with the outlet works regulating gates at all times. Using submergence guidelines recommended in this report in the section titled "Weir and Slide Gate Operating Criteria" will ensure control with the outlet works regulating gates and will prevent air entraining vortices from occurring at the structure inlets.

2. Two fins should be installed on the downstream face of each control sill (fig. 2). The fins will break up vortices that occur during high discharges because of water recirculating off of the top sloping surface of the control sill.

3. Figure 3 shows that head loss through the slide gate opening increases with increasing discharge. The majority of the head loss occurs through the sharp turns of the slide gate opening. Losses do not depend upon weir gate location until the weir gate is dropped below the control sill. This weir gate arrangement results in lower head losses because losses caused strictly by the weir gate are eliminated.

4. The slide gate discharge coefficients are shown on figures 4 and 5. Discharge coefficients range from 0.3 to 0.6 for discharges ranging from 200 to 1,375 ft^3/s and for submergence values ranging from 2 to 21 ft. Discharge coefficients are highest when the weir gate is not being used, again because losses caused by the weir gate have been eliminated.

5. The differential pressure acting across the weir gate was determined for a range of weir gate locations, discharges, and submergence levels up to a maximum submergence of 80 ft. The maximum differential pressure across the weir gate was predominantly a function of discharge and reached a maximum of 21.5 ft at 1375 ft^3/s.

6. Field instrumentation should be used to determine the exact location of the weir gate relative to the reservoir water surface to prevent unacceptable flow conditions. Therefore, if the weir gate cable length is being used to determine position, then slack in the cable must be detected.

7. Maximum velocities measured through the trashrack, discharging into the 5- by 8-ft slide gate, are shown on figure 6. Velocities range from 4 to 14 ft/s for discharges ranging from 200 ft^3/s to 1375 ft^3/s.

8. Surface velocities of flows approaching the weir gate are low, always below 1.5 ft/s over the range of flows from 200 to 1,375 ft^3/s (fig. 7). At 200 ft^3/s, zero velocity is reached 15 ft down the slope of the structure from the top of the weir gate, indicating that the weir gate is skimming properly. For flows in the normal operating range (less than 200 ft^3/s), velocities up the slope of the structure would be almost negligible.

9. A passageway should be constructed between the main conduit and the offset area beneath each slide gate to ensure air is flushed from this area (see detail 2 of fig. 1).

10. Installation of an air vent is recommended on the 7-ft-diameter tunnel crown immediately downstream from the selective withdrawal structure (station 2+06.68) to allow accumulated air to escape and to ensure prevention of blowback conditions. The air vent should consist of a 4-ft-diameter accumulator extending 1 ft above the crown of the tunnel. A 2-in pipeline should extend out of the accumulator and be routed to an elevation equal to or greater than the maximum reservoir elevation.

11. Prior to the operation or reopening of the slide gates, the conduit should either be fully pressurized or a slide gate which meets submergence criteria should be opened slowly to a minimal opening so that the conduit is filled at a very slow rate. Slow filling will prevent air within the structure from blowing back and possibly damaging the gates and inlet structure.

12. Investigations with multiple slide gates operating determined that submergence criteria should be based on total discharge through all operating slide gates and should always be applied to the control sill corresponding to the uppermost operating slide gate, or to the weir gate if it is used with the uppermost operating slide gate.

WEIR AND SLIDE GATE OPERATING CRITERIA

Weir gate and slide gate operations are complicated because of the complex hydraulic design of the selective withdrawal structure. The slide gates are designed to operate in fully opened or closed positions only, and neither the weir gate nor the slide gates are designed to control flow. The downstream regulating gates control the flow, keeping the selective withdrawal conduit pressurized so that no additional structural loading is applied to the slide gates or weir gate. Maintaining minimum submergence requirements on the weir gate or control sill is essential for maintaining control with the downstream regulating gates and for preventing or minimizing air entrainment which could lead to structural damage. The order of gate operations is important to ensure that minimum submergence levels are not exceeded. The following criteria were developed to ensure correct operations, including smooth transitions from one slide gate opening to the next.

1. Minimum submergence criteria are given in table 1 and are always applied to either the weir gate or the control sill.

Table 1. - Discharge versus minimum weir gate or control sill submergence.

Discharge Q (ft^3/s)	Intake gate size (ft)	Minimum submergence (ft)
$0 < Q < 175$	7 by 8	5
$175 \leq Q < 1,000$	7 by 8	11
$Q \geq 1,000$	7 by 8	20
$0 < Q < 175$	5 by 8	6
$175 \leq Q < 1,000$	5 by 8	13
$Q \geq 1,000$	5 by 8	21

The submergence criteria are applied to the weir gate any time the weir gate is in a position or traveling through a position such that flow is discharging over the weir gate and through the uppermost open slide gate. Weir gate location or weir elevation will always be referenced at the edge of highest elevation.

The submergence criteria are applied to the control sill of the uppermost open slide gate when the weir gate is not being used in conjunction with the uppermost open slide gate. The control sill location is always referenced at the edge of highest elevation.

Submergence criteria apply whether one or multiple slide gates are discharging and whether the reservoir is rising or falling.

2. The following restriction must be placed on weir gate position:

During discharge operations, the inlet area between the weir gate and any control sill must remain large enough to ensure that vortices (caused by higher velocities through the opening) or a change in control do not occur. To meet these criteria, a minimum vertical distance between the upper edge of any control sill (upper edge refers to the edge of highest elevation) and the nearest edge of the weir gate must be maintained (table 2).

Table 2. - Weir gate and control sill clearance guidelines.

Discharge Q (ft^3/s)	Minimum vertical distance from control sill to weir gate (ft)
$Q < 900$	6
$Q \geq 900$	8

3. Criteria for opening or closing slide gates during reservoir water surface fluctuations are as follows:

a. For operations without the weir gate:

(1) For a decreasing reservoir water surface: a lower slide gate should be opened before the reservoir water surface elevation encroaches on minimum submergence guidelines (table 1) for the uppermost open slide gate control sill. After the lower gate is fully opened, the upper slide gate should be closed before submergence guidelines are exceeded.

(2) For an increasing reservoir water surface: The next higher slide gate can be opened once the submergence criteria established in table 1 are met. After this gate is fully opened, the lower gate can be closed.

b. For weir gate operations (i.e., the weir gate is following the reservoir water surface elevation within the guidelines set in table 1):

(1) For a decreasing reservoir water surface, the following procedure should be followed:

The weir gate will follow the reservoir water surface according to the guidelines set in table 1. Before the reservoir water surface encroaches on minimum submergence guidelines for the uppermost open slide gate and prior to opening the lower slide gate, the weir gate must be dropped to an elevation that meets the criteria stated in table 2. After the lower slide gate has been opened, the uppermost open slide gate should be closed before submergence criteria are exceeded.

(2) For an increasing reservoir water surface, the following procedure should be followed:

The weir gate will follow the reservoir water surface according to the guidelines set in table 1. When the weir gate reaches the minimum vertical distance from a control sill as established in table 2, weir gate movement must be stopped. When minimum submergence criteria are achieved for the next higher control sill, the upper slide gate can be opened. After the upper slide gate is fully open, the lower slide gate should be closed in order to continue skimming operations. Once these steps are completed, the weir gate may begin following the reservoir water surface again.

THE MODEL

The model was placed in the hydraulic laboratory's permanent 4-ft-wide flume facility (fig. 8). The selective withdrawal conduit was placed in the center and at the downstream end of the flume, upstream from an existing 8-ft-high bulkhead. The 1.75:1 sloping rectangular conduit was constructed with Plexiglas on one side for viewing flow conditions. Flow through the sloping conduit was also viewed through the top by constructing the skimming weir gate of Plexiglas.

The model scale and resulting number of gates modeled were limited by a number of factors:

- The height and width of the laboratory facility in comparison to the prototype structure
- The ability to evaluate the relatively small discharges and resulting velocities
- The appropriate modeling of the head loss coefficient and possible air entraining vortices

The model scale was chosen based on Froude scaling with consideration of Reynolds number scale effects. A geometric scale of 1:18 allowed modeling of the two upper gates in the selective withdrawal system. The lower portion of the system was not modeled, and was replaced by a return pipe that exited through the bulkhead with a remotely controlled valve at the downstream end. Once testing was complete on the 7- by 8-ft slide gates, the lower of the two gates was modified to represent the 5- by 8-ft slide gates on the prototype. Eighteen feet of the 1:1 cut slopes and all of the 1/2:1 slopes on each side of the withdrawal system were modeled to represent the topographic influences on the flow conditions.

The model scale of 1:18 was the minimum scale that would accommodate two gates of the prototype within the flume. The accuracy of modeling the vorticity and the head loss was based upon this scale. Most recent literature cites appropriate scaling of vorticity if the ratio of the Reynolds to Froude numbers is greater than 5×10^4 (Knauss, 1987). At a geometric scale of 1:18, this ratio in the model is high enough to accurately model vortex formation for flows ranging from 175 to 1,375 ft^3/s. Results from the model study pertaining to vortex formation will provide accurate design information.

To accurately model head loss, a Reynolds number of about 10^6 or greater is needed (U.S. Department of the Interior, 1980). The prototype Reynolds number for the maximum discharge is predicted to be about 1.4×10^7 through the gate and in the rectangular conduit. To obtain a model Reynolds number of 10^6 would require a Froude scale of about 1:2, which could not reasonably be used in the laboratory. Therefore, the 1:18 scale model was constructed and model head loss data were analyzed.

INVESTIGATIONS

Submergence Criteria

To ensure satisfactory operations, control must be maintained with the downstream regulating gates of the outlet works. Also, flow separations and air entraining vortices must be prevented from forming to optimize operating efficiency and to eliminate excessive structural loading. Minimum submergence criteria were based on the minimum head above the weir gate or control sill required to maintain downstream control and also eliminate vortex formation. A conservative approach was taken in the testing by further extending the submergence criteria to include elimination of any entrainment of air.

Tests were conducted using three different weir gate elevations and the control sill only, for each size slide gate, and discharges ranging from 175 to 1375 ft^3/s. Discharges were set using the laboratory venturi metering system. The reservoir elevation was allowed to rise by adjusting the downstream valve until the flow condition changed from free flow to downstream control, and all sources of entrained air, including vortices, were eliminated. This procedure was used to develop the minimum required submergence as a function of discharge for the weir gate and control sill elevations shown on figure 9. The submergence curves do not depend on weir gate elevation until a flow of about 1,000 ft^3/s is reached. At this flow, the submergence criteria for the lowest weir gate elevation and control sill elevation (elevations 845 ft and 836 ft for the 7- by 8-ft slide gate; elevations 743 ft and 734 ft for the 5- by 8-ft slide gate) increase significantly, indicating that flow conditions change as the weir gate approaches the control sill elevation. These sets of curves were used to determine specific submergence criteria shown in table 1.

Using the same procedure stated above, investigations were conducted with two slide gates discharging. A submergence curve was developed (fig. 9) based on total discharge through both operating slide gates and referenced to the control sill or weir gate elevation of the uppermost operating slide gate. This curve follows the other curves closely; therefore, the submergence criteria stated in table 1 may also be applied to multiple discharging gates.

Additionally, minimum clearances between the weir gate and control sill were determined (table 2) to provide an inlet area greater than the area of the conduit. This greater area will prevent a change in control caused by the restricted inlet area between the weir gate and control sill.

Head Loss

Head loss was determined from pressures measured at the three piezometer ring locations shown on figure 10 and referenced to the centerline of the conduit. Head loss changes are negligible from piezometer ring 1 to piezometer ring 3, indicating that the majority of the head loss occurs through and upstream from the slide gate opening because of the change in flow directions. Figure 3 shows that head loss through the slide gate opening increases with increasing discharge and does not depend upon weir gate location. However, head loss values are less when the weir gate is dropped below the control sill where it no longer influences flow, indicating a definite loss associated with the weir gate. The head loss values given on figure 3 are based on the total discharge through one open slide gate; therefore, if multiple gates are discharging, the discharge through individual gates must be known for the head loss values to apply.

Head loss coefficients were calculated from the model head loss data to determine if model head loss values could be accurately scaled to the prototype. Head loss coefficients were determined from (Pugh, 1982):

$$K = \frac{\Delta H}{\frac{V^2}{2g}}$$

where:

K = head loss coefficient
ΔH = head loss (ft)
V = velocity through conduit (ft/s)
g = gravity (ft/s^2)

The coefficients were plotted versus model Reynolds numbers on figure 11. Figure 11 shows that the coefficient is constant for model Reynolds numbers above 79,000. This Reynolds number corresponds to 0.291 ft^3/s in the model, which scales to 400 ft^3/s in the prototype. This result indicates that Reynolds number effects are negligible in scaling head loss from the model to prototype and model head loss values will accurately scale to the prototype for prototype discharges above 400 ft^3/s (fig 3). For prototype discharges less than 400 ft^3/s, scaled values of predicted head loss may be too high. However, head loss values are very low over this range, so the error should be small when compared to the overall head loss throughout the system.

Discharge Coefficients

The discharge coefficients for the structure were determined from:

$$C = \frac{Q}{A\sqrt{2g\Delta H}}$$

where:

C = discharge coefficient
ΔH = head loss (ft)
Q = discharge through the conduit (ft^3/s)
A = conduit cross-sectional area (ft^2)
g = gravity (ft/s^2)

Discharge coefficients versus discharge and submergence levels are shown on figures 4 and 5, respectively. Discharge coefficients range from 0.3 to 0.6 for discharges ranging from 200 to 1,375 ft^3/s and for values of head over the weir gate ranging from 2 to 21 ft. As with the head loss coefficients, the discharge coefficients do not depend on weir gate location until the weir gate is dropped below the control sill. This weir gate arrangement results in higher discharge coefficients because losses caused strictly by the weir gate are eliminated. For multiple gates discharging, the discharge coefficients given on figures 4 and 5 can be applied to individual gates only if the discharge through each slide gate is known.

Vortex Formation

The formation of air entraining vortices was observed at the structure inlets throughout the range of flows (175 to 1,375 ft^3/s) and for all weir elevations when minimum submergence was not maintained. The strongest vortices occurred as the weir gate approached the next higher control sill because of the restriction in the flow area. The submergence criteria in table 1 were developed to provide sufficient head above the weir gate or control sill to eliminate these vortices. Additionally, following the criteria set in table 2, which states minimum clearances between the weir gate and control sill, will prevent vortex formation as a result of higher inlet velocities through the restricted inlet area.

However, during additional testing, vortices were observed when the weir gate was in a position 11 to 13 ft below the control sill elevation, even though recommended submergence criteria were followed. These weir elevations caused the water surface elevation to be located on the top sloping surface of the control sill. This water surface elevation caused water recirculating off of the top sloping surface of the sill to produce new vortices in the two corners adjacent to where the control sill meets the conduit walls. Under these flow conditions, an additional 2 to 3 ft of weir gate submergence was required to eliminate these vortices. Various structural additions to the structure were investigated to avoid making an exception to the established submergence criteria or increasing the overall submergence criteria. Tests determined that attaching two fins to the downstream face of the control sill would be effective in breaking up these vortices so that additional submergence would not be required (fig. 2).

Therefore, with fins installed, following the recommended submergence criteria and weir gate restrictions given in tables 1 and 2 should eliminate any vortex formation at the inlets of the structure.

Weir Gate Differential Pressure

Differential pressures acting across the weir gate were determined for a range of weir gate locations, submergence levels, and discharges. The differential pressures will be used to ensure structural stability of the weir gate.

Seven piezometer taps were located along the length of the weir gate to measure the pressure on the underside of the weir gate (note x-axis of fig. 12). Three flow rates through the 7- by 8-ft slide gate opening (located adjacent to control sill elevation 802 ft) were investigated, and for each flow rate, three different weir elevations were tested. Weir elevations 830 ft and 828 ft correspond to 6 ft and 8 ft below the upper control sill, respectively. Weir elevation 807 ft corresponds to a position 29 ft below the upper control sill. For each case, at least three different water surface elevations were used, up to a maximum of 60 ft of weir gate submergence for the two higher weir elevations, and up to a maximum of 80 ft of weir gate submergence for the lower weir elevation. The differential pressure across the weir gate was determined at the seven piezometer tap locations for each condition.

The magnitude of the pressure beneath the weir gate always remains above atmospheric. The largest pressure drop across the weir gate always occurred at the piezometer tap location closest to the lower control sill and was caused by flow separation due to circulating turbulent flows adjacent to the slide gate opening. This pressure drop corresponded to piezometer tap 7 for weir elevations 830 ft and 828 ft and piezometer tap 3 for weir elevation 807 ft. However, as the weir gate elevation is changed, the maximum pressure drop will occur at the section of the gate located closest to the control sill. The maximum differential pressure along the slope of the weir gate (referenced from the upstream edge of the weir gate) for each flow rate is shown on figure 12 for weir elevation 830 ft. Changes in the magnitude of the differential pressure were insignificant for changes in water surface elevation or weir gate location and therefore were independent of these two conditions. In many cases, the maximum differential pressure occurred at a water surface elevation less than the maximum that was tested. Therefore, the maximum differential pressure across the weir gate is predominantly a function of discharge and increases to a maximum at the discharge of 1375 ft^3/s. The maximum differential pressure for each discharge is given in table 3 and should be used for weir gate loading design calculations.

Table 3. - Maximum differential pressure across the weir gate for each discharge tested.

Discharge (ft^3/s)	Maximum Differential Pressure (ft)
200	2.5
1000	11.5
1375	21.5

Blowback

Blowback may occur when a large air pocket accumulates somewhere in the system and travels upstream and back through the inlet. This explosive phenomena can damage the structure and should be prevented. Blowback may be prevented by eliminating air in the system, either by preventing it or venting it.

Exactly when (i.e., under what discharges and flow conditions) blowback is a concern is difficult to determine. Model observations were made to determine what direction different size bubbles moved for various discharges, thereby determining which discharges might set up conditions for accumulation of air and potential blowback. Observations determined that a flow of 800 ft^3/s or greater cleared all sizes of bubbles from the sloping conduit. At this flow rate, clearing velocities in the downstream outlet tunnel will be exceeded and bubbles will be transported out of the system and will not contribute to blowback (Falvey, 1980). At flows less than 600 ft^3/s, medium to large size air bubbles collected at the crown of the sloping conduit, coalesced, and moved up the slope, but not through the slide gate opening. However, smaller bubbles at flows less than 600 ft^3/s were transported down the slope.

Because these smaller bubbles may coalesce downstream from the structure to form air pockets which could blow back, installation of an air vent is recommended downstream from the sloping structure at station 2+06.68. The air vent will consist of a 4-ft-diameter accumulator extending 1 ft above the crown of the horizontal tunnel. A 2-in pipeline will extend out of the accumulator and be routed to an elevation equal to or greater than the maximum reservoir elevation. This vent pipe will allow most of the air that accumulates downstream from the structure to be vented rather than contribute to blowback. Maintaining proper submergence so that less air is entrained in the flow will lessen conditions that may contribute to blowback.

An additional concern during model testing was that large air pockets were observed collecting at the crown of the offset area of the closed slide gate. To prevent the formation of air pockets at this location, installation of a passageway (dimensions to be determined by the structure designers) should be installed between the main conduit and the offset area to ensure air is flushed from this area (detail 2 of fig. 1).

Velocity Measurements

To provide designers with more information for determining trashrack structural loading, maximum velocities were measured at the trashrack entrance on the 5- by 8-ft slide gate. The maximum velocities measured did not depend on weir gate elevation, but did increase with increasing discharge to a maximum of 14 ft/s at 1375 ft^3/s as shown on figure 6.

Additionally, to determine if flow was being drawn from lower portions of the reservoir during weir gate skimming operations, velocity measurements were taken at various distances down the slope of the weir gate as referenced from the edge of highest elevation on the weir gate. The weir gate was set to an elevation of 845 ft and velocities were measured in a direction parallel to the sloping conduit. Velocities decreased with increasing distances down the slope of the conduit as shown on figure 7. At a discharge of 200 ft^3/s, velocities drop to zero at a distance of 15 ft down the slope of the weir gate. This velocity indicates that for normal discharges (less than 200 ft^3/s), the weir gate should be skimming properly.

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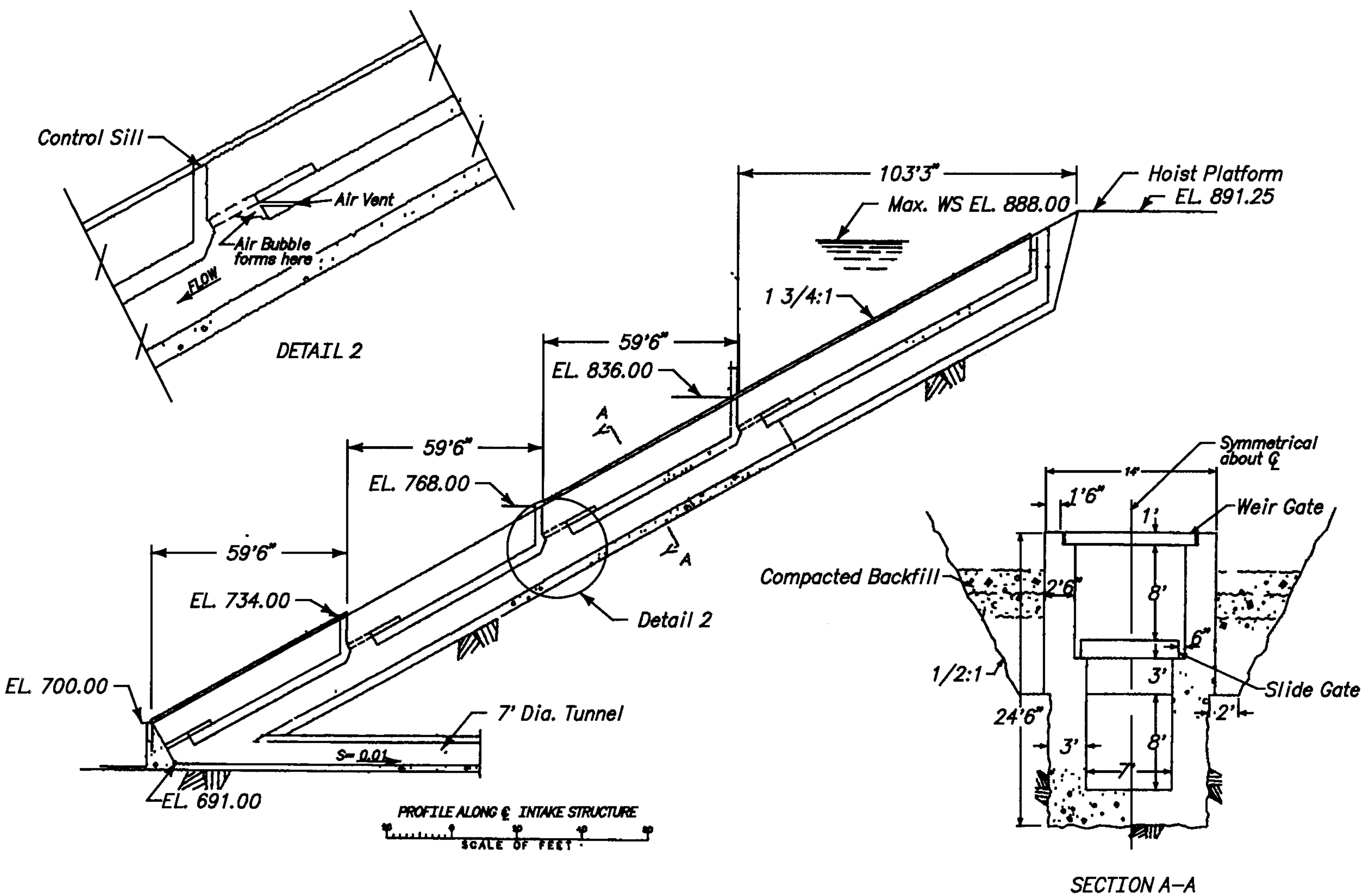
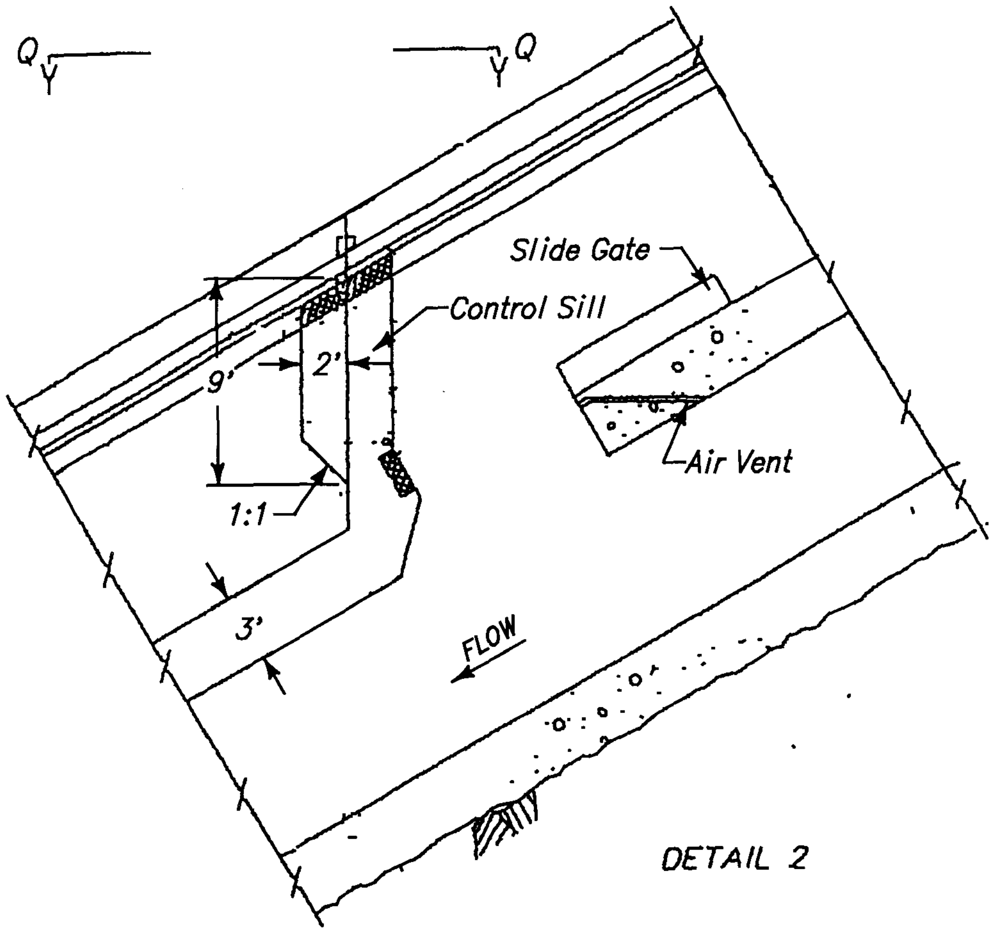


Figure 1. - General elevation and section of the proposed selective withdrawal system.



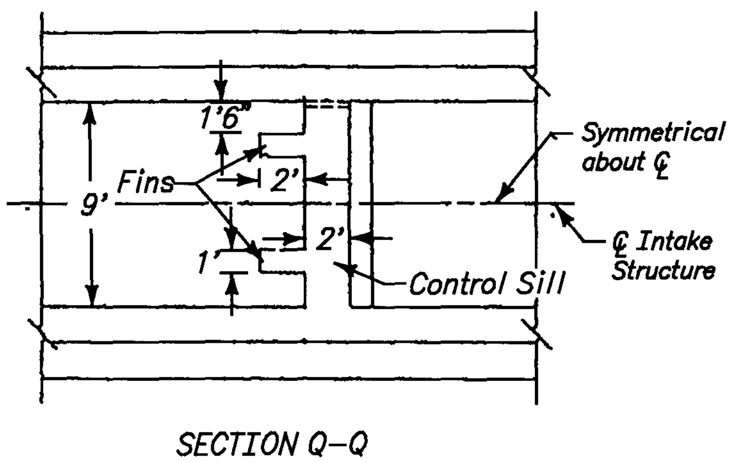
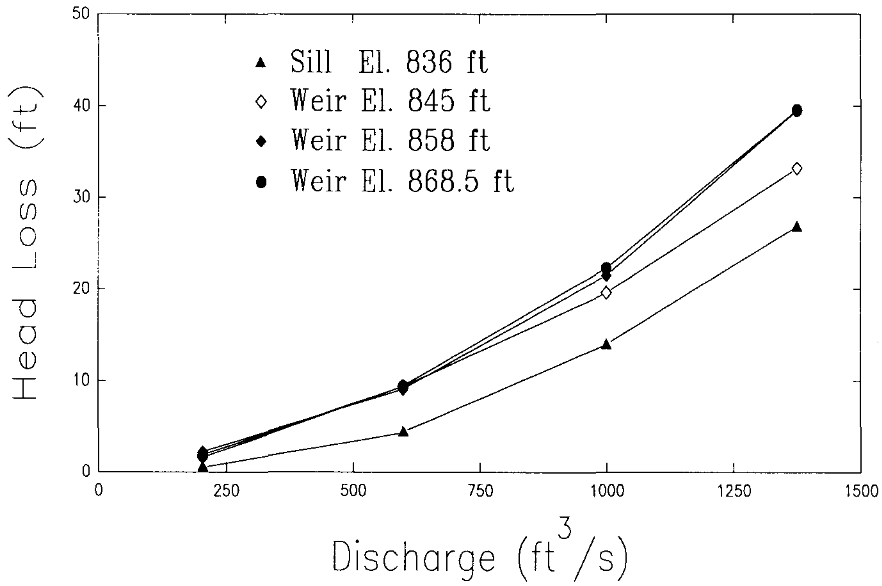


Figure 2. - Detail 2 of figure 1 with fins installed.



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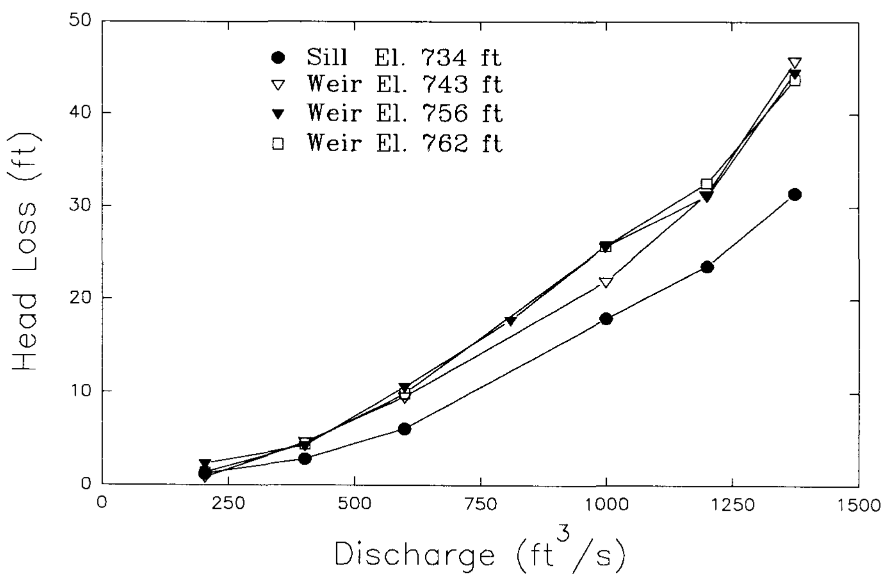

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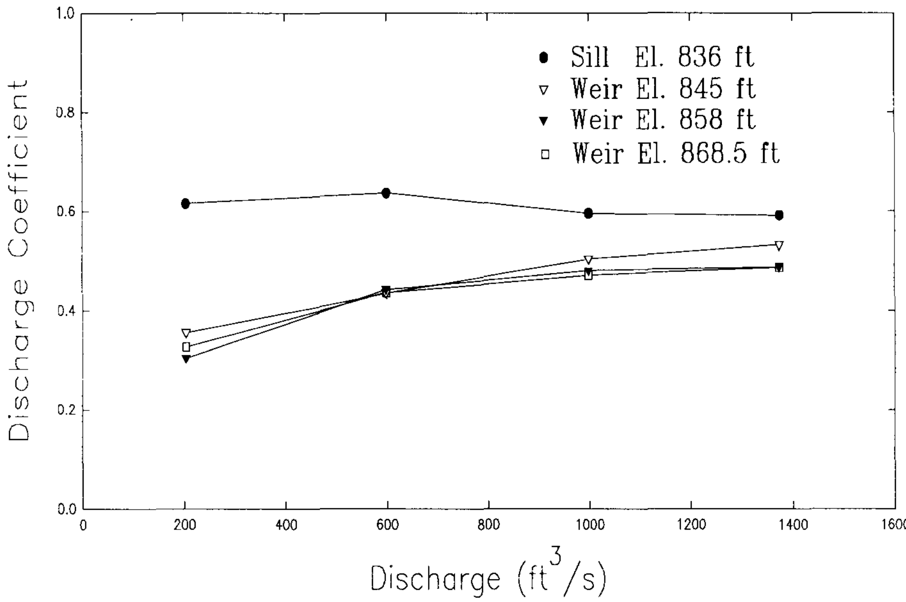
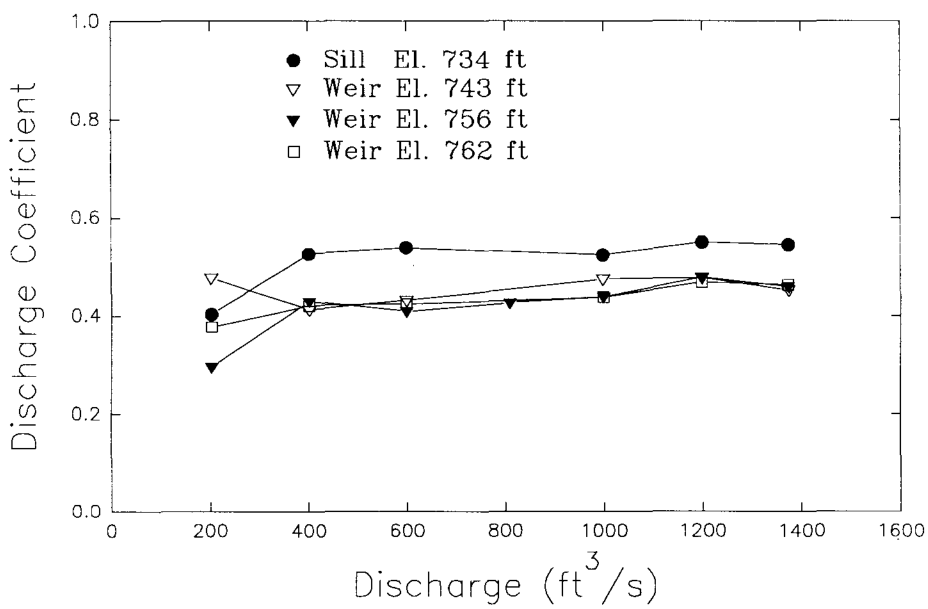
Figure 3. - Head loss versus discharge (a) 7- by 8-ft slide gate and (b) 5- by 8-ft slide gate.

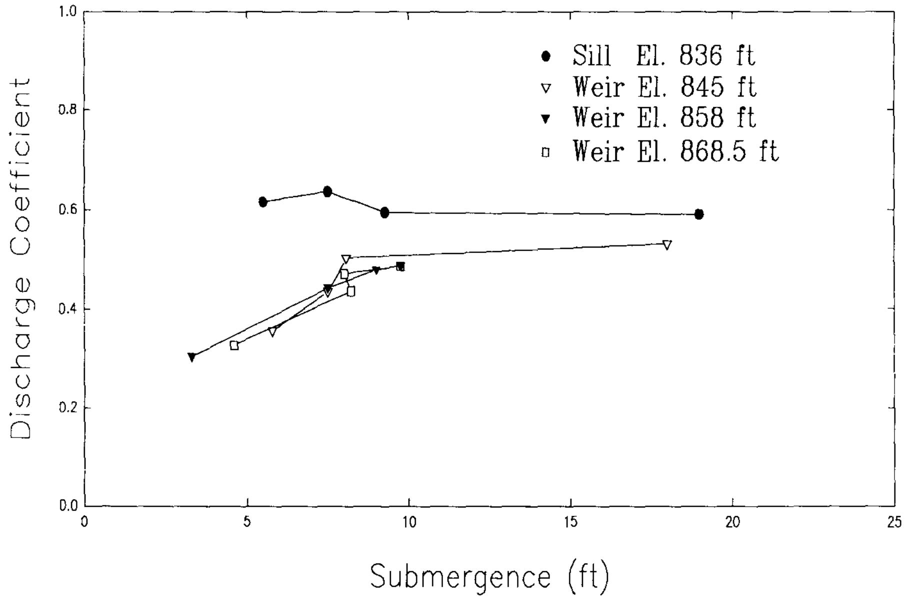


(a)

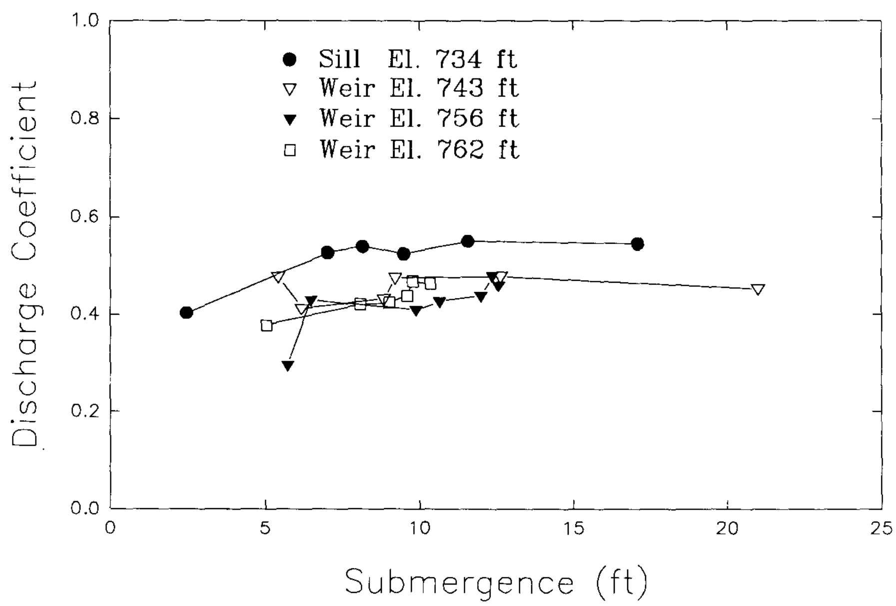


(b)

Figure 4. - Discharge coefficients versus discharge (a) 7- by 8-ft slide gate and (b) 5- by 8-ft slide gate.



(a)



(b)

Figure 5. - Discharge coefficients versus submergence (a) 7- by 8-ft slide gate and (b) 5- by 8-ft slide gate.

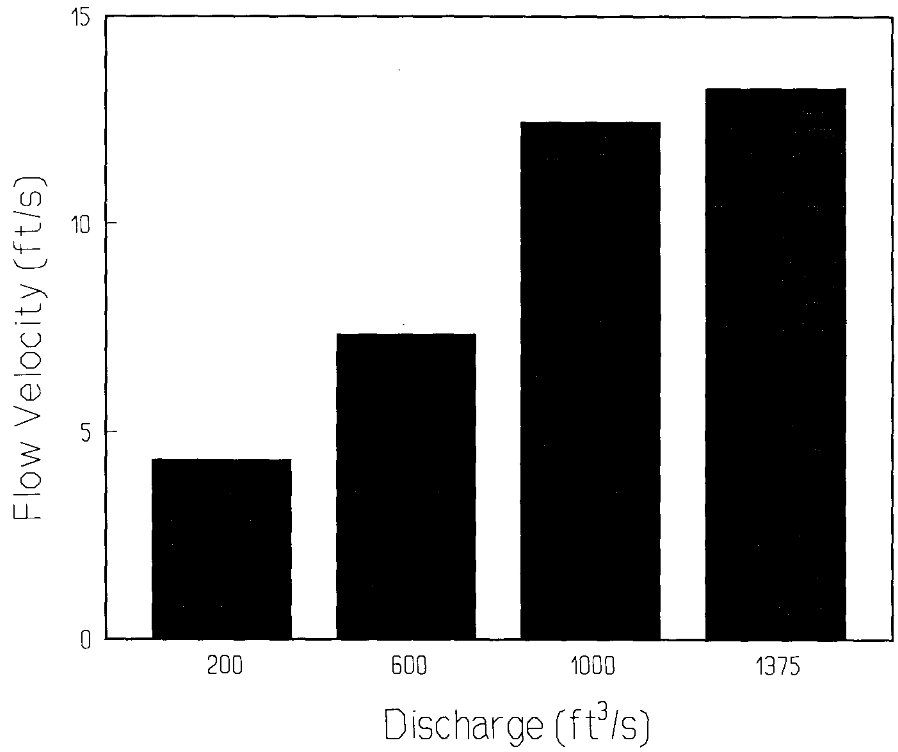
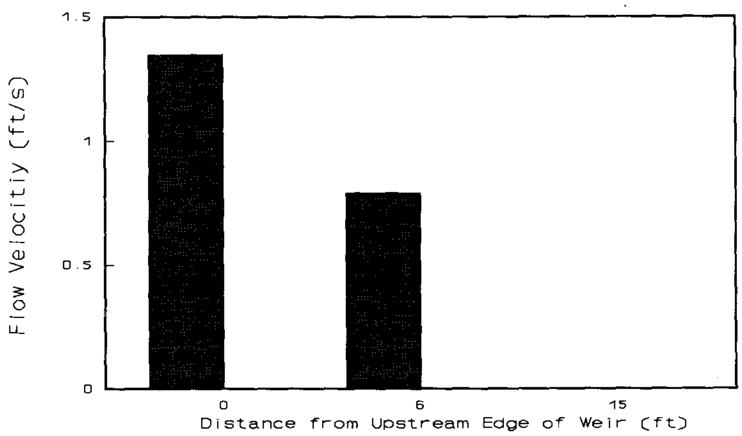
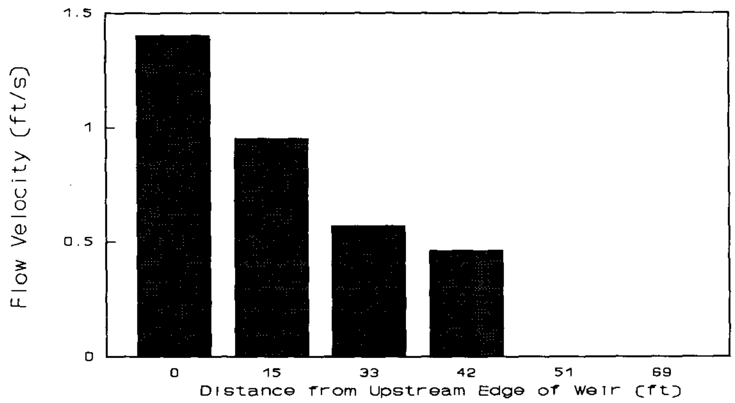


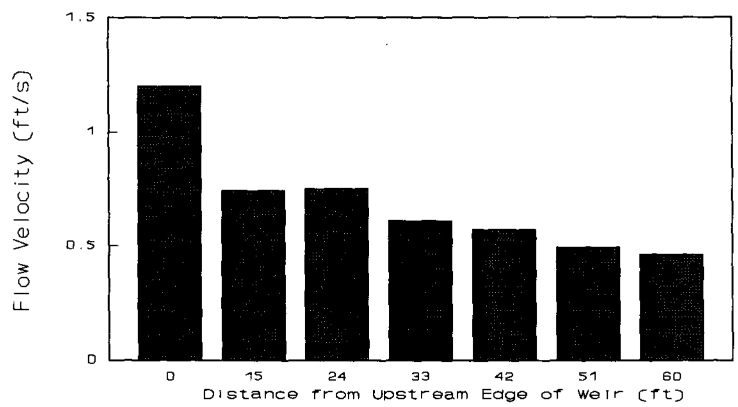
Figure 6. - Maximum velocities measured through trashrack.



(a) 200 ft³/s discharge



(b) 690 ft³/s discharge



(c) 1375 ft³/s discharge

Figure 7. - Velocities measured along the slope of the weir, referenced from the upstream edge of the weir; weir elevation 845 ft.

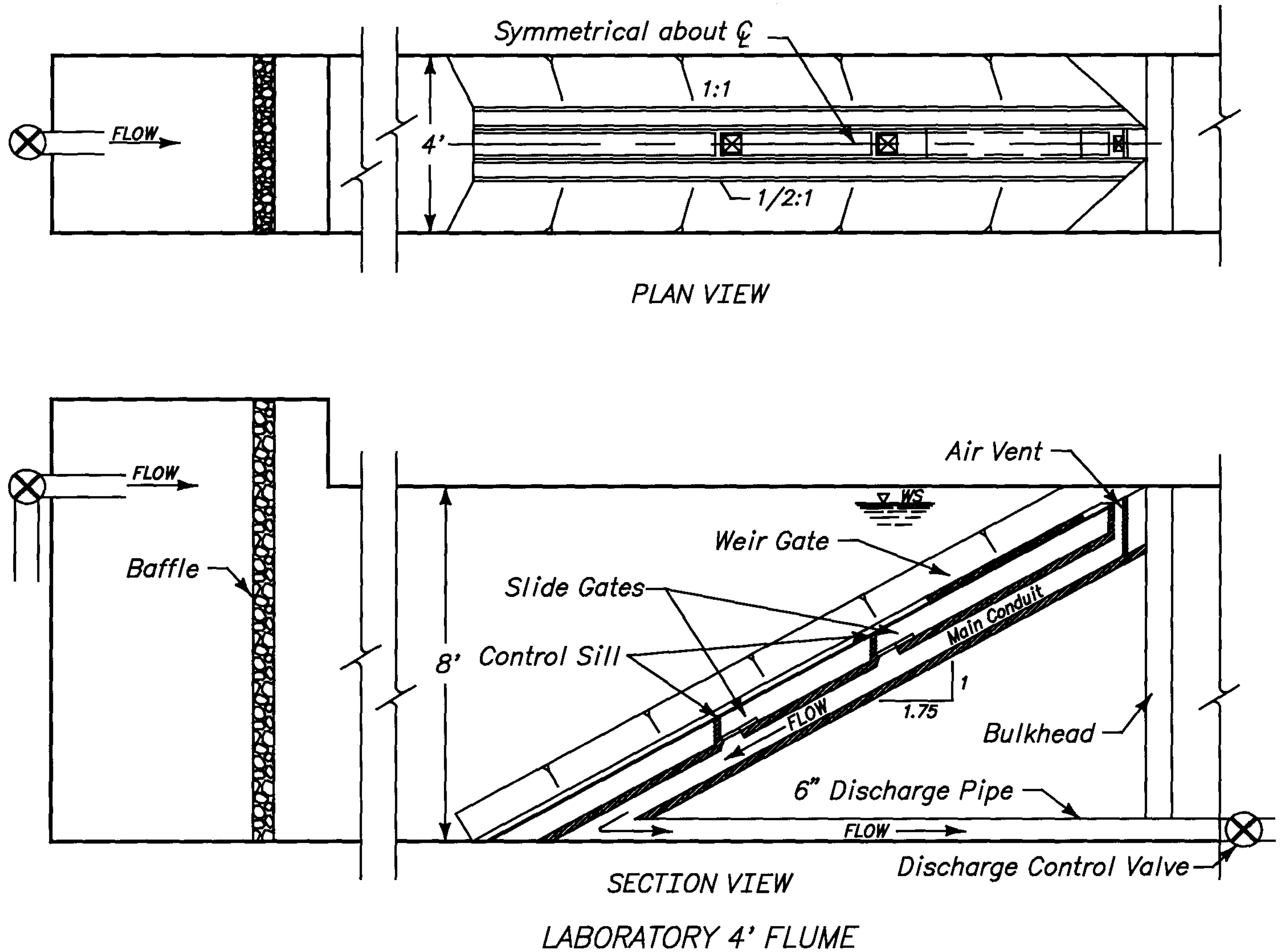


Figure 8. - Spring Creek selective withdrawal system as modeled at a 1:18 scale in the laboratory flume.

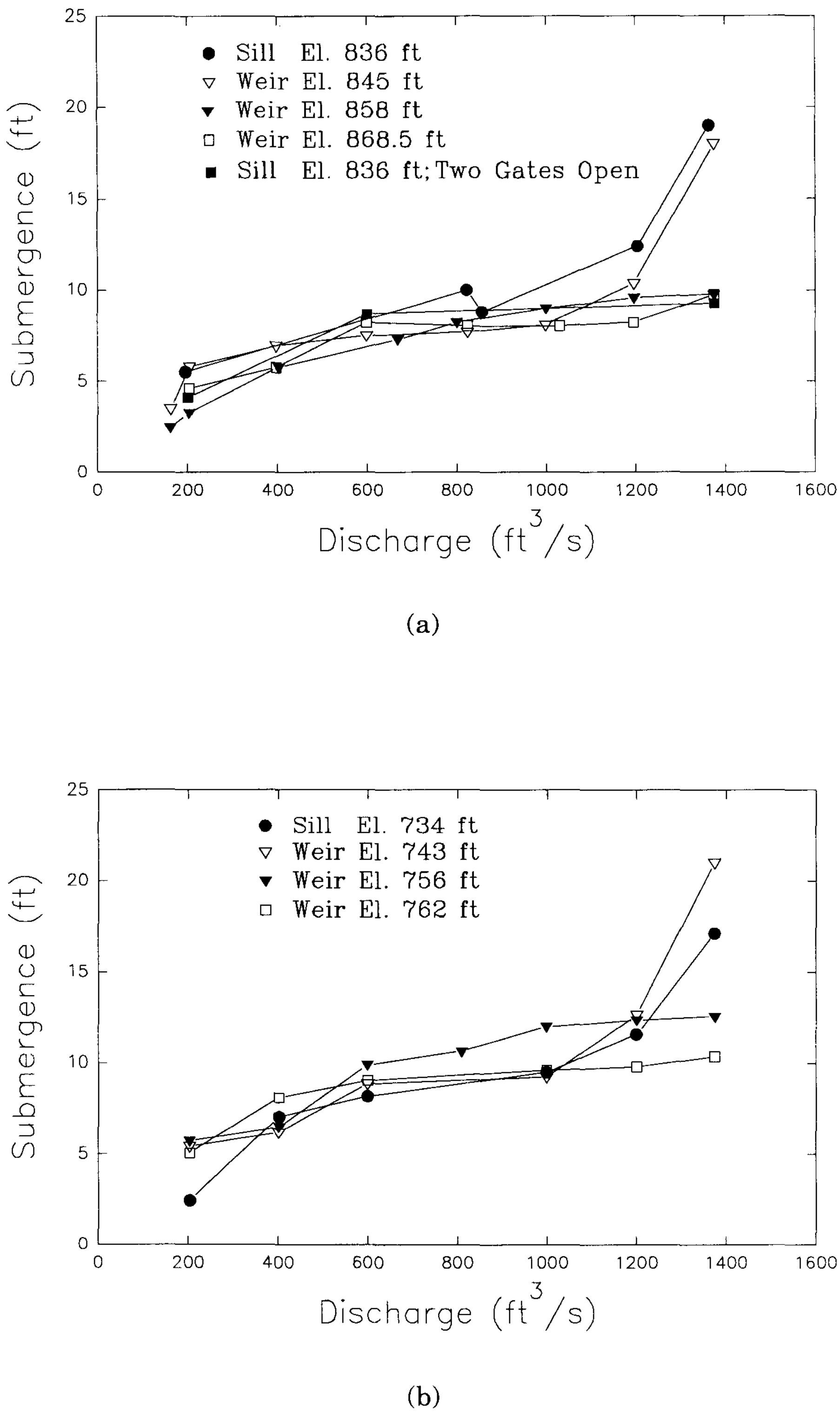


Figure 9. - Minimum submergence versus discharge (a) 7- by 8-ft slide gate and (b) 5- by 8-ft slide gate.

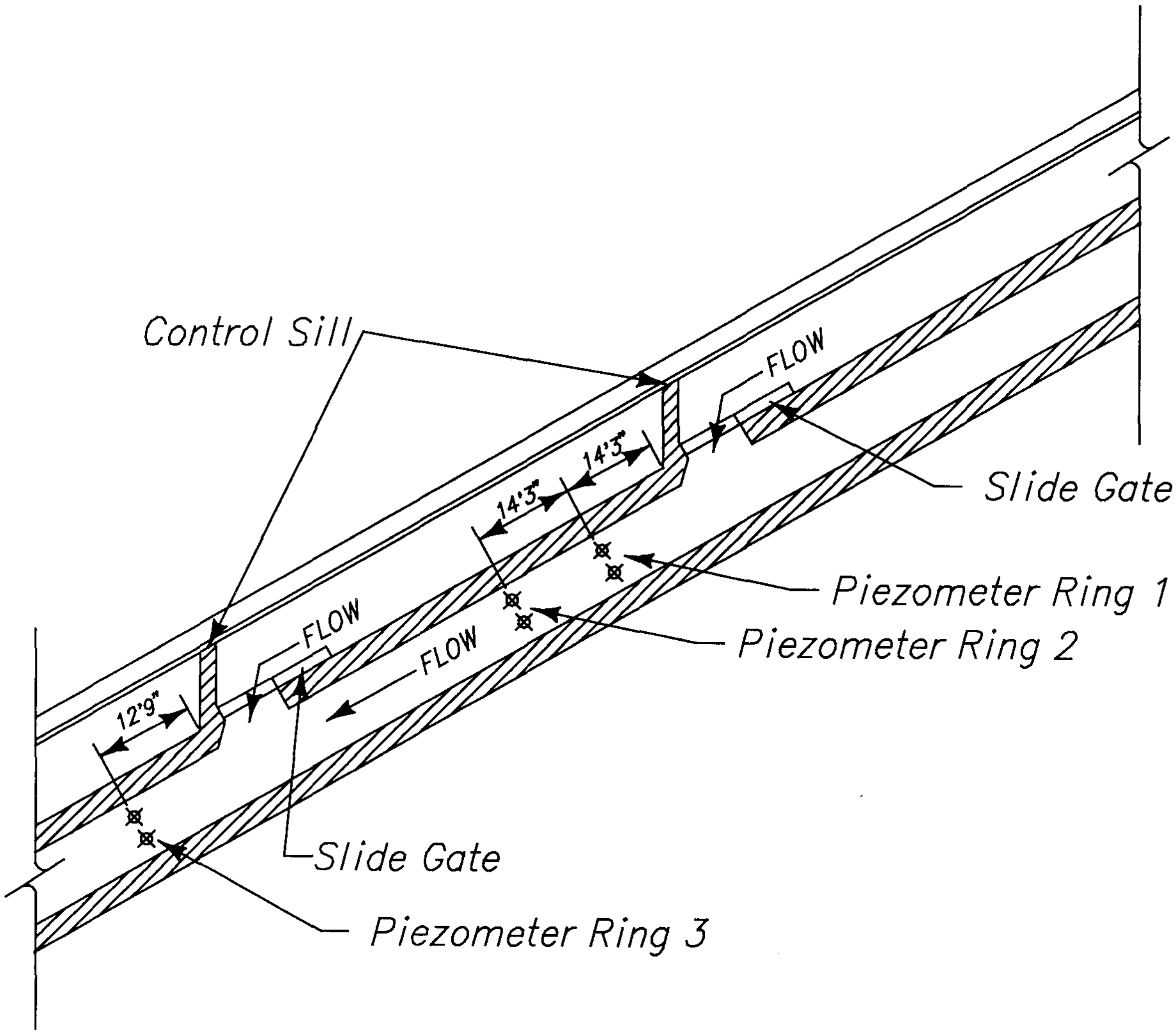
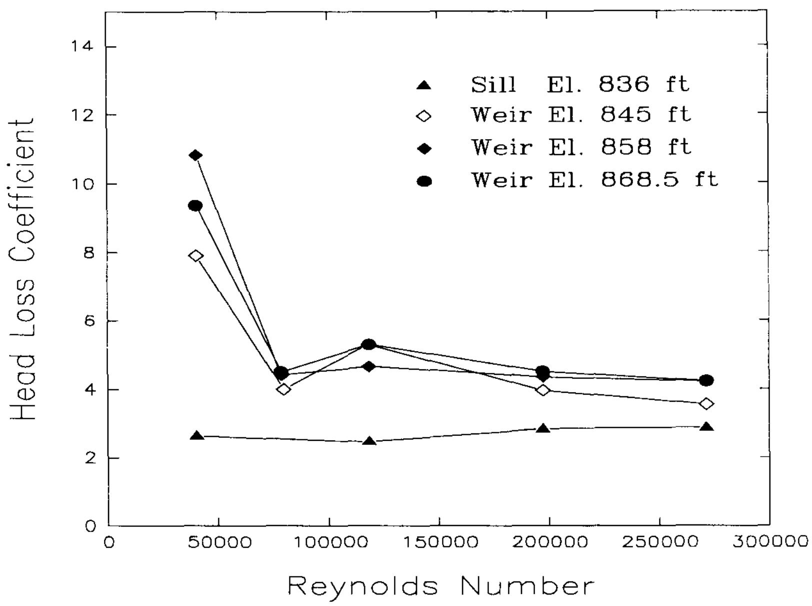
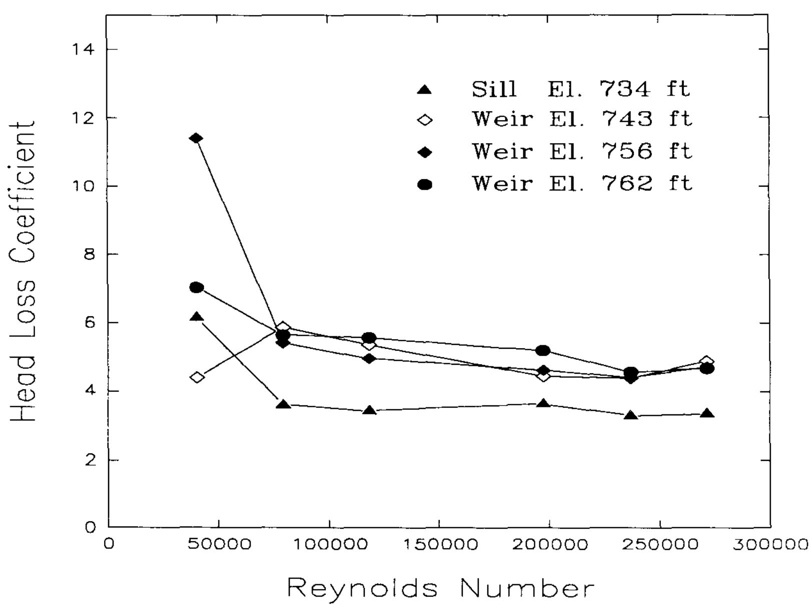


Figure 10. - Conduit piezometer ring locations.



(a)



(b)

Figure 11. - Head loss coefficients versus model Reynolds numbers (a) 7- by 8-ft slide gate and (b) 5- by 8-ft slide gate.

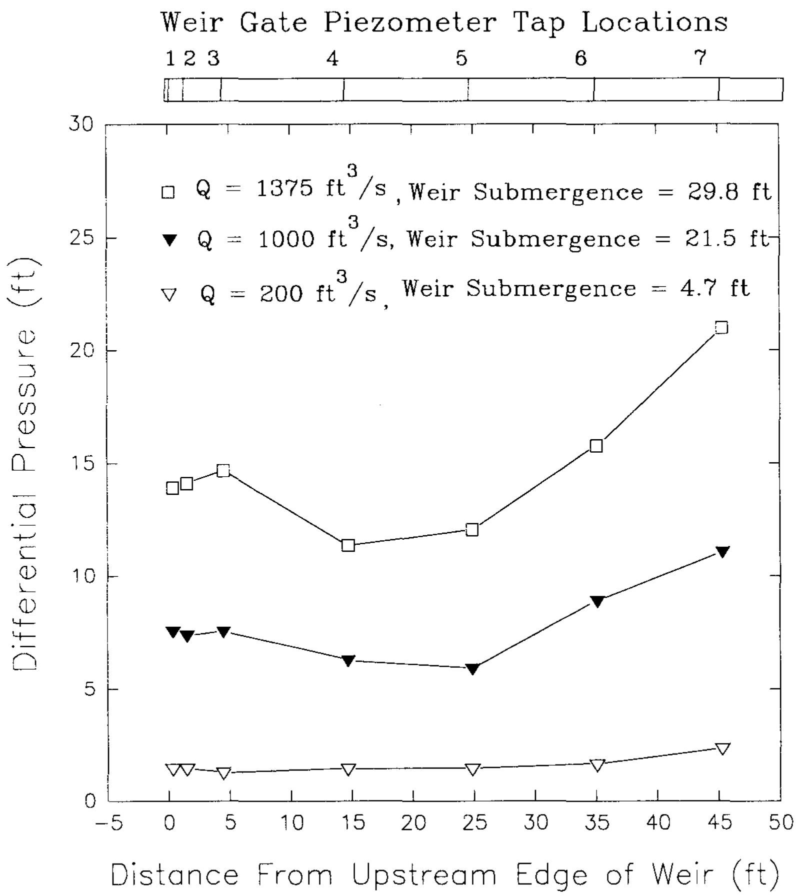


Figure 12. - Differential pressure profile measured down the slope of the weir gate from the upstream edge of the weir for weir elevation 830 ft.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.