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Guernsey Dam South Spillway Hydraulic Model Study



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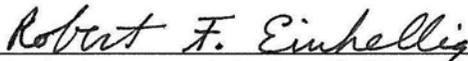
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Guernsey Dam South Spillway Hydraulic Model Study



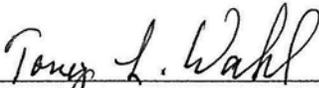
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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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LIST OF SYMBOLS AND ACRONYMS

DTM	Digital terrain model
ft	feet
ft/s	Feet per second
ft ³ /s	Cubic feet per second
in	Inches
Reclamation	Bureau of Reclamation
WSEL	Water-surface elevation

Executive Summary

This physical hydraulic model study evaluated proposed modifications to the south spillway for Guernsey Dam, located on the North Platte River in eastern Wyoming. The two drum gates on the south spillway have not been utilized for many years and have fallen into disrepair, thus limiting spillway releases to just the north spillway. Current work to add spillway capacity at Glendo Dam, just upstream, has created the need to rehabilitate the south spillway at Guernsey Dam. Other modifications are also planned for Guernsey Dam, including raising the height of the parapet wall that will allow for an increase in the maximum water surface. To reduce future maintenance costs associated with the south spillway, only one drum gate will be rehabilitated. The other gate will be removed and replaced with a fixed-height concrete weir at elevation 4420 ft (the top of conservation storage). Both drum gates cannot be replaced with weirs because the full capacity of one open gate is needed to pass the required spillway design flow.

A 1:47-scale physical hydraulic model of Guernsey Dam including both spillways, 545 ft of the south spillway's horseshoe tunnel, and approximately 1,000 ft of the reservoir immediately upstream from the dam was constructed in Reclamation's hydraulics laboratory in Denver, Colorado in 2012. The purpose of the model study was to investigate which drum gate should be replaced, analyze the hydraulic conditions associated with the new configuration, and develop a new stage vs. discharge relationship for the south spillway.

The study found that the maximum discharge for a one-gate/one-weir configuration will be obtained with the drum gate in the right hand bay (the west bay, furthest from the dam) and the weir in the left hand bay. This condition provided 1% to 5% more discharge capacity at a given reservoir level than the opposite configuration. The study also evaluated alternative positions for the weir wall (adjusting its position within the gate bay). Placement of the weir crest in a forward position (toward the reservoir) or back (closer to the drop inlet) had little effect on discharge efficiency and there were minimal negative flow effects associated with either configuration. Thus, there are no compelling hydraulic reasons for preferring one position over another.

The new, unsymmetrical gate and weir configuration produced swirling flow conditions in the drop inlet area. Velocities along the back wall of the south spillway were measured as high as 34 ft/s. The highest velocities occurred at lower discharges. The discharge through the south spillway became unstable between 38,000 ft³/s and 40,000 ft³/s, exhibiting unpredictable shifting of control between the crest, the throat, and the tunnel.

The study evaluated flow conditions along the upstream face of the dam approaching the north spillway to address the concern that higher north spillway flow rates associated with the increased reservoir elevation could cause erosion of

the dam face. Velocities along the face of the embankment at the entrance to the north spillway were as high as 19 ft/s.

These findings have been used by the design team during the development of the designs and specifications for the dam modifications. The stage vs. discharge relationships given in this report are for the current preferred design with the drum gate in the right hand (west) bay and the weir in the left hand (east) bay, in the middle position.

Introduction

Project Background

Guernsey Dam is located on the North Platte River near the town of Guernsey, Wyoming. The dam was built by the Bureau of Reclamation and completed in 1927. It is 25 miles below Glendo Dam and is part of the North Platte Project (Figure 1). It is a 135-ft-high embankment dam (92 ft hydraulic height) with 2 spillways and a powerplant. The top of the embankment is at elevation 4430 ft with an existing 3 ft parapet wall up to elevation 4433 ft.



Figure 1. Location map showing Guernsey Dam.

Guernsey Dam was originally equipped with two spillways. The north spillway is controlled by a 50 ft by 50 ft Stoney gate (vertical sluice gate) (Figure 2). The invert of the north spillway was originally built at elevation 4370 ft, but in 1983 an 8 in. concrete overlay raised the invert to its current elevation of 4370.67 ft. The south spillway (Figure 3) is controlled by two 64 ft by 14.5 ft drum gates. Downstream from the gates, a warped concrete structure referred to as “the bathtub” transitions into a 31-ft-diameter vertical shaft leading to an elbow and then a horizontal, horseshoe-shaped tunnel that is approximately 30 ft in diameter and 723 ft long with a constant invert elevation of 4319 ft. The south spillway

crest elevation is 4405.5 ft when the drum gates are in the open (lowered) position. The south spillway crest elevation is 4420 ft when the drum gates are in the closed (raised) position.

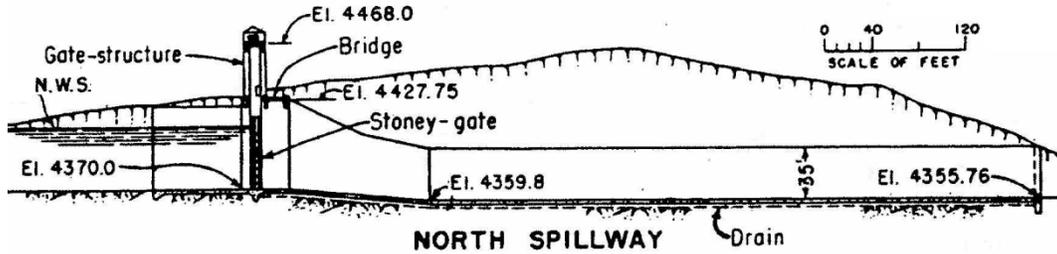


Figure 2. North Spillway. Note this drawing does not indicate the 8 in. concrete overlay that was placed on the spillway invert in 1983.

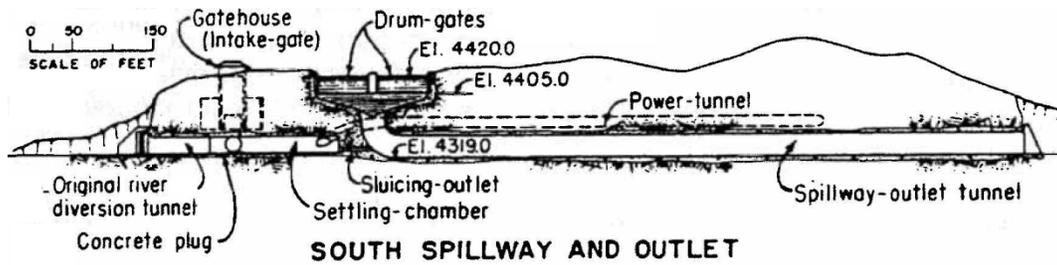


Figure 3. South Spillway and Outlet.



Figure 4. Guernsey Dam south spillway. The left photo is taken from the dam crest looking at the entrance to the left and right spill bays. The right photo is taken from the right wall of the spillway, looking into the transition section and the vertical shaft.

Glendo Dam was constructed with flood control space and a limited discharge capacity, and since Guernsey Dam has a larger spillway capacity than Glendo Dam, Guernsey has been protected by the upstream Glendo Dam since its construction in 1958. The drum gates on the Guernsey south spillway have not been used for many years, and use of the spillway has not been required due to the limited spill capacity at Glendo Dam. However, a new uncontrolled emergency

spillway at Glendo Dam is nearing completion; therefore the larger flood related discharge from Glendo Dam will require larger releases at Guernsey Dam to mitigate hydrologic overtopping risk (Schneider 2010). To provide the additional release capacity, the south spillway must be restored again to good operational condition. The two drum gates in the Guernsey Dam south spillway will require significant rehabilitation to meet current operational standards.

As a cost saving measure and to reduce future maintenance costs, the proposed alternative is to only rehabilitate one drum gate and remove the other gate, replacing it with a fixed-height concrete weir at an elevation of 4420 ft. Both drum gates are not being replaced with weirs because the flow capacity of one fully open gate is needed to successfully route the design flood. Current operational procedures require that the reservoir be able to store water up to an elevation of 4420 ft. Therefore, for this model study it is assumed that the crest of the weir(s) must be at an elevation of 4420 ft. In addition, the maximum flood water-surface elevation (WSEL) will be raised to 4433 ft, requiring the parapet wall to be raised to maintain sufficient freeboard.

Model Objectives

South Spillway:

- Determine which drum gate should be replaced with a fixed weir to achieve the maximum discharge capacity.
- Determine the location of the weir within the gate bay, relative to the reservoir and drop shaft.
- Analyze and mitigate any adverse hydraulic conditions associated with the new configuration.
- Determine a stage vs. discharge rating for the new configuration.

North Spillway:

- Determine a stage vs. discharge rating of the existing structure.
- Measure flow velocity along the embankment face approaching the north spillway entrance.

Model Description

Model Scale

A physical hydraulic model of Guernsey Dam including both spillways, 545 ft of the south spillway's horseshoe tunnel, and approximately 1000 ft of the reservoir

immediately upstream from the dam was constructed in Reclamation’s hydraulics laboratory in Denver, Colorado in 2012. In order to include all desired model features in the floor space available, the physical hydraulic model was built at a 1:47 geometric scale. At this scale an 8 in. PVC pipe accurately represented the cross-sectional area of the horseshoe tunnel and an 8 in. steel elbow (previously constructed for a model study of another dam) accurately represented the diameter of the drop shaft and the elbow curve radius in the south spillway.

Similitude between the model and the prototype is achieved when the ratios of the major forces controlling the physical processes are kept equal in the model and prototype. Since gravitational and inertial forces dominate open channel flow, Froude-scale similitude was used to establish a relationship between the model and the prototype parameters. The Froude number is

$$Fr = \frac{v}{\sqrt{gd}}$$

where v = velocity, g = gravitational acceleration, and d = flow depth. When Froude-scale modeling is used, the following relationships exist between the model and prototype where the r subscript indicates the ratio of the model to the prototype:

Length ratio: $L_r = 1:47$

Velocity ratio: $V_r = L_r^{1/2} = (47)^{1/2} = 6.86$

Time ratio: $T_r = L_r^{1/2} = (47)^{1/2} = 6.86$

Discharge ratio: $Q_r = L_r^{5/2} = (47)^{5/2} = 15,144.14$

Model Setup

Figure 5 shows a plan view of Guernsey Dam, the two spillways, and the reservoir immediately upstream from the dam. The outline of the area included in the physical model is also shown. Flow approaching the dam and spillways must negotiate a sharp left-hand curve; a significant part of this curved approach is included in the modeled area. The river bed just upstream from the dam was originally at elevation 4330 ft, but the reservoir experienced a lot of sediment accumulation before Glendo Dam was completed in 1958. A photograph taken at low WSEL in September 2010 shows a large sediment deposit at an elevation of approximately 4380 ft (Figure 6). On a regular basis the north spillway is used to sluice the reservoir to carry fine sediments downstream with the intent to line the irrigation canals and maintain reservoir storage. Due to the expedited nature of this project there was not time to obtain current bathymetry. Therefore, topography was constructed from the original dam construction drawings from the

1920's, USGS 1:24,000 topography maps, and information inferred from available photographs, such as Figure 6.

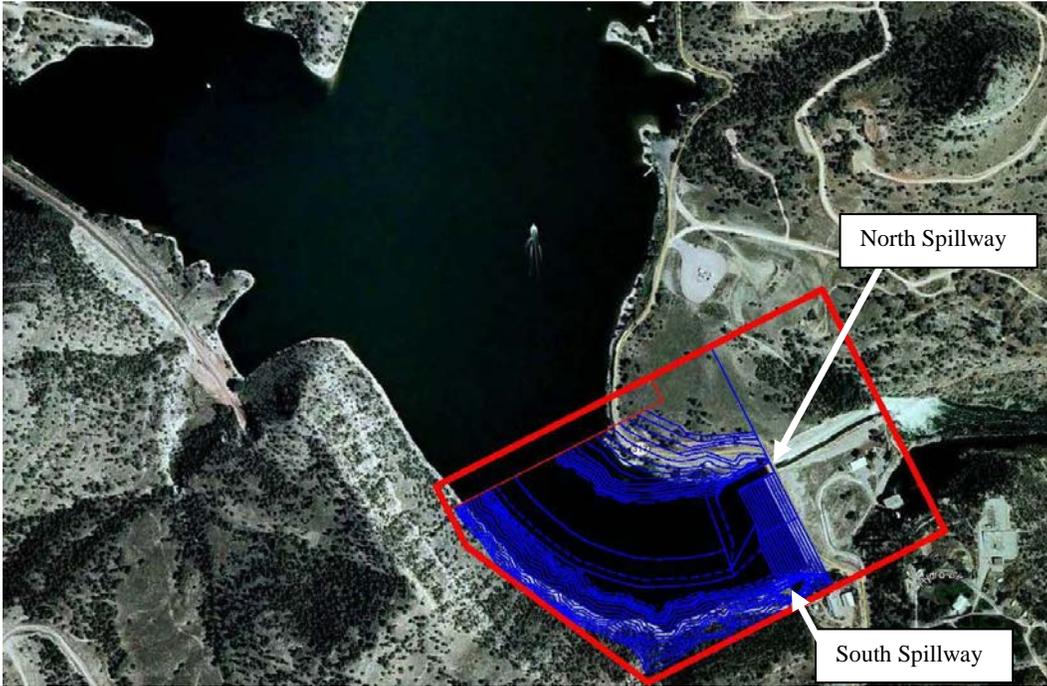


Figure 5. Aerial photo of Guernsey Dam and part of Guernsey reservoir. The physical model boundaries are outlined in red.



Figure 6. A collage of photos showing Guernsey Dam, the north and south spillways (far left and middle, respectively), and the accumulated sediment berm. The photos were taken on September 18, 2010. The reservoir WSEL was 4379.3 ft while discharging 5066 ft³/s. The powerplant intake is visible to the right of the south spillway.

The size and location of the reservoir sediment deposits were estimated and incorporated into the physical model. Based on observations by personnel familiar with the project, the sediment deposit seen in Figure 6 extends far up into the reservoir. At low flow there is a channel on the river right side that leads to the powerhouse penstock intake and then cuts across the face of the dam to the

north spillway (Breuer 2012). In the model this channel was estimated to be at the elevation of the invert of the penstock intake, 4360 ft. As the channel traverses across the face of the dam it transitions to the invert of the north spillway, 4370.67 ft.



Figure 7. Guernsey Dam hydraulic model showing the modeled reservoir, north spillway (left) and south spillway (right). The picture shows how the model represents the sediment deposits on the river left side of the reservoir (see Figure 6). Water flows down the river right side of the reservoir, across the face of the dam, and through the north spillway.

The north spillway approach and Stoney gate are included in the model, but the north spillway channel downstream from the dam centerline was represented with a simple rectangular channel, rather than the trapezoidal channel that exists in the prototype. This part of the north spillway was not of interest, but was only included to set the correct discharge and flow conditions to be maintained through the Stoney gate.

The south spillway consisted of the two 64-ft-wide spillway bays, piers, warped concrete transition section (bathtub), vertical curve, and 544 ft (75%) of the horseshoe tunnel. The primary focus of the model study was on flow conditions around the entrance to the south spillway. For economy the horseshoe tunnel was

modeled using a circular 8 in. PVC pipe. The effective flow area of the horseshoe tunnel very closely matched the modeled PVC pipe.

The entire length (723 ft) of the south spillway horseshoe tunnel invert is at a constant elevation of 4319 ft and the normal tailwater is around 4328 ft; therefore, the tunnel is backwatered at all times. At most discharges, the flow through the spillway is controlled by the entrance conditions. At high discharges the control will likely shift to the throat of the vertical shaft, and at very high discharges control will shift to the tunnel. When flow through the spillway is restricted by the tunnel the tailwater will also be extremely high and will have an impact on the flow through the tunnel.

To accurately determine the discharge capacity during pipe control, the downstream flow conditions need to be modeled. Due to time and budget constraints analytical methods were used to determine when the shift to pipe control occurred. Conservative calculations suggest that the spillway may shift to pipe control at a discharge as low as 40,000 ft³/s, depending on the reservoir and tailwater elevations. In the model, some testing was conducted with the end of the tunnel artificially backwatered to represent the shift to pipe control in accordance with the calculations. The primary purpose of these tests was investigation of flow conditions in the drop shaft intake area under tunnel control. These tests were not meant to allow for accurate determination of a stage-discharge relationship under tunnel control, since the tailwater stage is unknown. Generalized flow conditions approaching the spillway and in the bathtub transition are representative of what the prototype will experience during pipe control.

All simulations involving drum gates modeled the gate in the fully open (lowered) position. The model was built to allow interchangeable pieces representing the drum gate and the weir to be moved in and out of place for different model configurations. The weir was built to allow the placement of the weir to be “forward” (closer to the reservoir), “back” (farther from the reservoir and closer to the drop shaft), or at any intermediate position (Figure 10). In the “middle” position the front of the weir is 13.5 ft from the front edge of the structure. The weir is 3 ft thick with a radius on the upstream edge of 2.3 ft (Figure 8).

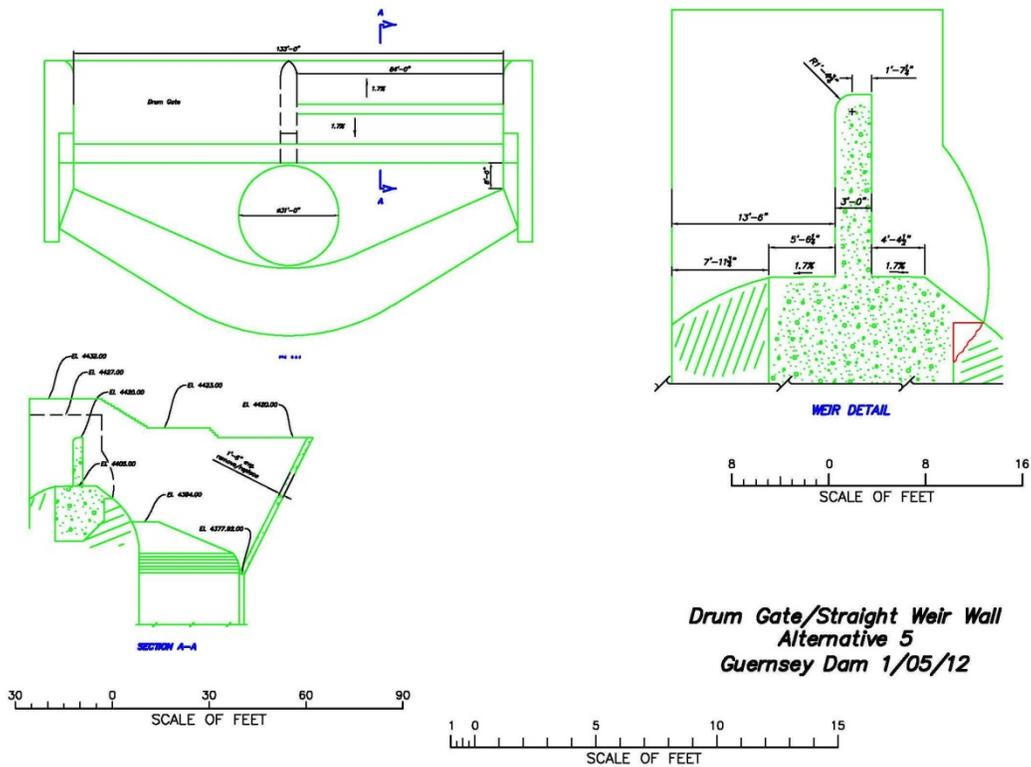


Figure 8. Drawing details of weir for Guernsey Dam south spillway.

Construction of the bathtub area of the spillway was accomplished using a digital terrain model (DTM) of this part of the structure. The DTM was created from photos taken in the field, using CalibCam and 3D Analyst photogrammetric analysis software from ADAM Technology Software. The original purpose for creating the DTM was to evaluate the condition of the concrete, but it also proved very useful for physical model construction. The DTM of the spillway was scaled down to the model size, and topography lines at intervals of the thickness of marine grade plywood were created using AutoCAD Civil 3D. The topography lines were then transferred to the plywood and the spillway shape was cut and formed (Figure 9). An auto body repair filler material was used to “fill in” the steps between the contours (Figure 10). The spillway piers and crest were machined from high-density polyurethane foam.



Figure 9. Guernsey Dam model, south spillway, topography lines from the DTM were transferred to plywood and then cut out to shape the spillway basin.

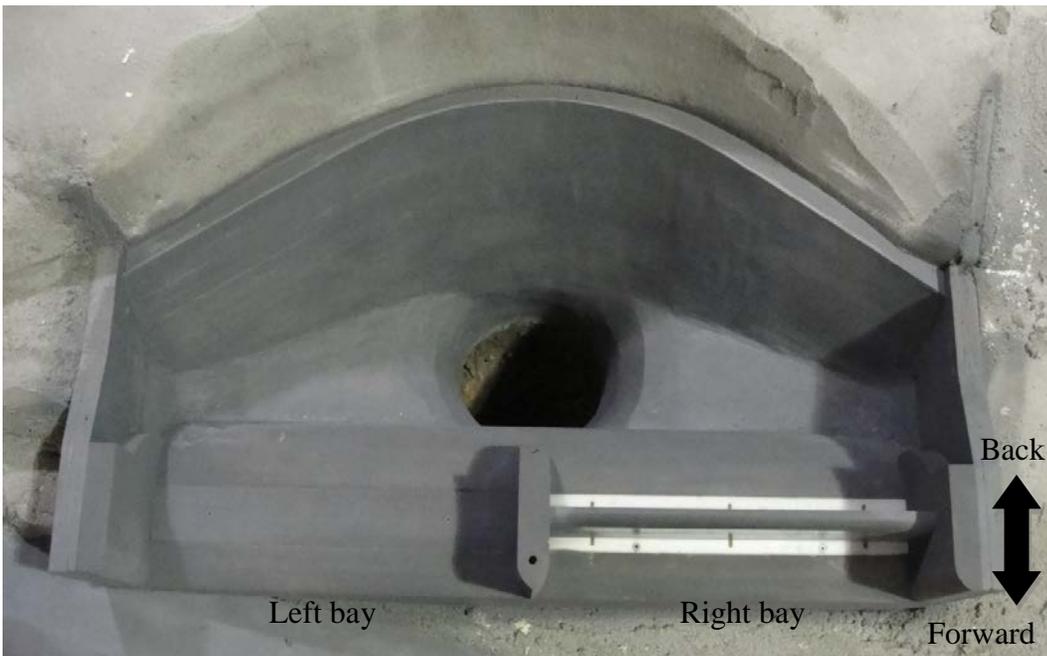


Figure 10. Guernsey Dam model, south spillway. An auto body repair material was used to create a smooth surface from the plywood templates. The left bay is modeling the drum gate in the open or lowered position. In the right bay the drum gate has been removed and the concrete weir is being modeled. In this picture the weir is placed in a mid-position (forward vs. back).

The structural design team was concerned about the loading associated with flow of water entering the spillway basin over the side walls, (Figure 11). This flow condition occurs when the reservoir level exceeds 4423 ft. To provide additional strength, the designers proposed thickening both sidewalls as shown in Figure 12. The thickened walls were included in most of the model testing to ensure that they would not introduce undesirable hydraulic conditions.



Figure 11. South Spillway, reservoir WSEL at 4426 ft with water flowing over the side of the spillway basin. The reinforcing concrete walls are not being modeled in this photo. Compare with Figure 12.

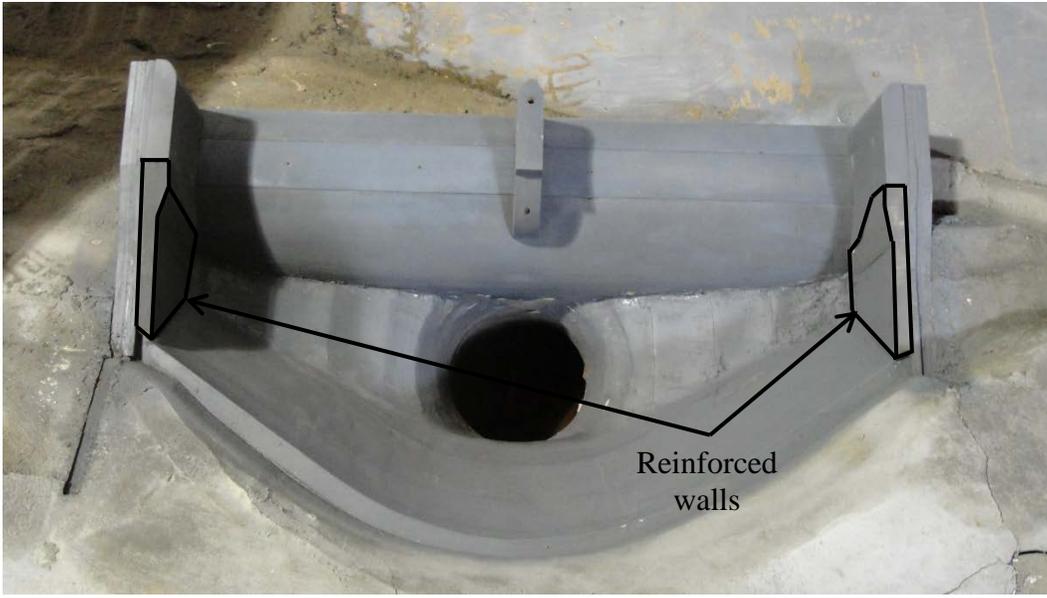


Figure 12. South Spillway basin with the reinforced walls (outlined in black) added to the sides of the spillway.

Data Collection

Measurements of discharge, reservoir WSEL, point velocities, photo and video records were all used to document the study of Guernsey Dam. Flow entering the model was measured using the laboratory's venturi meter measurement system. Most testing of the south spillway took place while there was also flow through the north spillway. Thus, it was necessary to independently measure the flow through the south spillway. This was accomplished by directing the south spillway flow into a trapezoidal exit channel leading to a calibrated ramp flume designed specifically for the study. Flow through the north spillway was then calculated as the difference between the incoming flow and the south spillway flow rate.

Reservoir WSEL was measured using a Massa M-5000 ultrasonic transducer in a stilling well. The stilling well was tapped into the reservoir approximately 425 ft (prototype) upstream from the dam. The transducer instrument has an accuracy of ± 0.0083 ft. Another ultrasonic transducer was located very near the dam crest. There was not a significant amount of drawdown observed between the two measurement locations over the range of flows tested.

Velocity measurements were made with a Swoffer 3000 hand-held current meter. This meter has a 50 mm diameter horizontal axis propeller and an accuracy of $\pm 1\%$ of the measured velocity. When the south spillway was configured with one drum gate and a weir wall in the other bay, flow in the bathtub area was unsymmetrical with strong circulation, and water traveled along the back wall of the spillway with significant velocity. The location and orientation of the

measured velocity are shown in Figure 13. In this figure the drum gate is in the right bay so the direction of velocity along the back wall of the spillway is from right to left looking into the intake. In configurations where the drum gate was in the left bay the velocity along the back wall was in the opposite direction. Velocity measurements were always taken in the center of the spillway in the direction of water travel. The meter was placed into the current deep enough that the propeller was submerged and did not impact the back wall. The maximum WSEL on the back wall of the spillway was also measured by marking the maximum level and measuring to reference elevations in the structure.

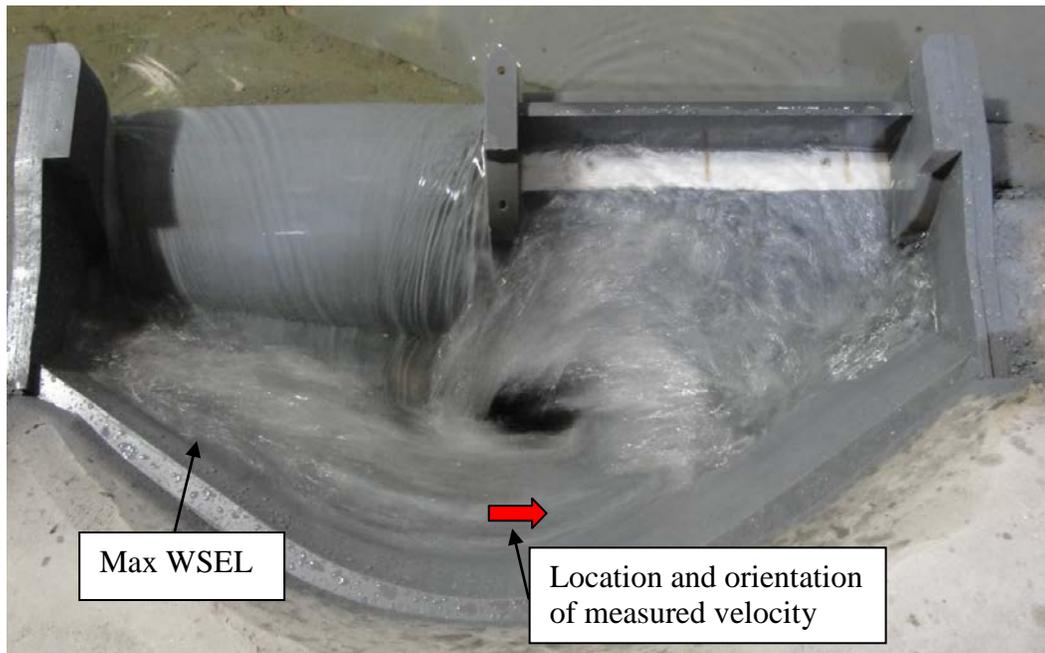


Figure 13. Guernsey south spillway showing the location and orientation of measured velocities and the maximum WSEL. Often the maximum WSEL was not in the center of the spillway, as shown in this photo.

There have been reports that riprap on the face of the dam near the north spillway has been washed away in past flow events. Velocity measurements in this area were also collected with the meter's propeller submerged and without impacting the face of the dam as shown in Figure 14.

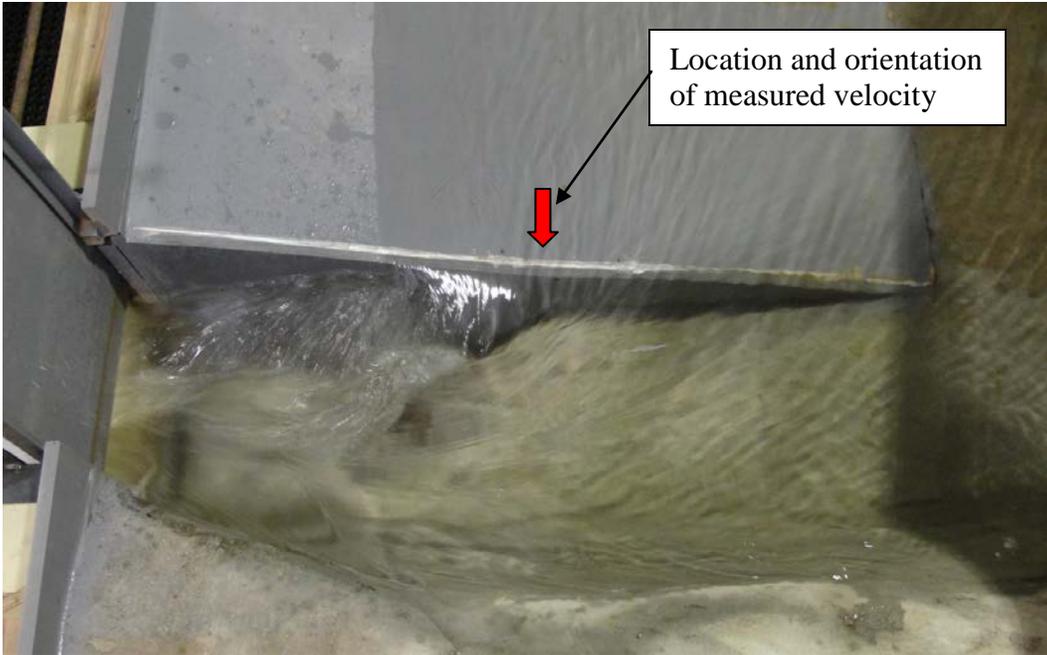


Figure 14. Guernsey Dam north spillway, showing the location and orientation of velocity measurements. The gray area at the top of the photo is the upstream dam face. The open Stoney gate is at the left.

Results

South Spillway

Six drum gate/weir configurations were analyzed in the model under differing flow conditions. Variations of the weir/drum gate location (left bay or right bay) and positions within the bay are described below. Spillway bays are identified as right hand or left hand, referenced to a viewpoint that looks downstream into the spillway structure. The left hand bay is closest to the dam face and is on the east end of the spillway intake structure. The placement of the weir within the bay is described as forward or back, with back indicating closer to the back wall of the bathtub area and drop shaft. Figure 10 helps to illustrate this terminology.

- 1) Left bay = Weir (forward), Right bay = Drum Gate
- 2) Left bay = Weir (middle), Right bay = Drum Gate
- 3) Left bay = Weir (back), Right bay = Drum Gate
- 4) Left bay = Drum Gate, Right bay = Drum Gate
- 5) Left bay = Drum Gate, Right bay = Weir (forward)
- 6) Left bay = Weir (middle), Right Bay = Weir (middle)

Stage vs. discharge plots were developed and compared to determine the efficiency of each configuration (Figure 15). Hydraulic conditions in the bathtub transition area were also analyzed.

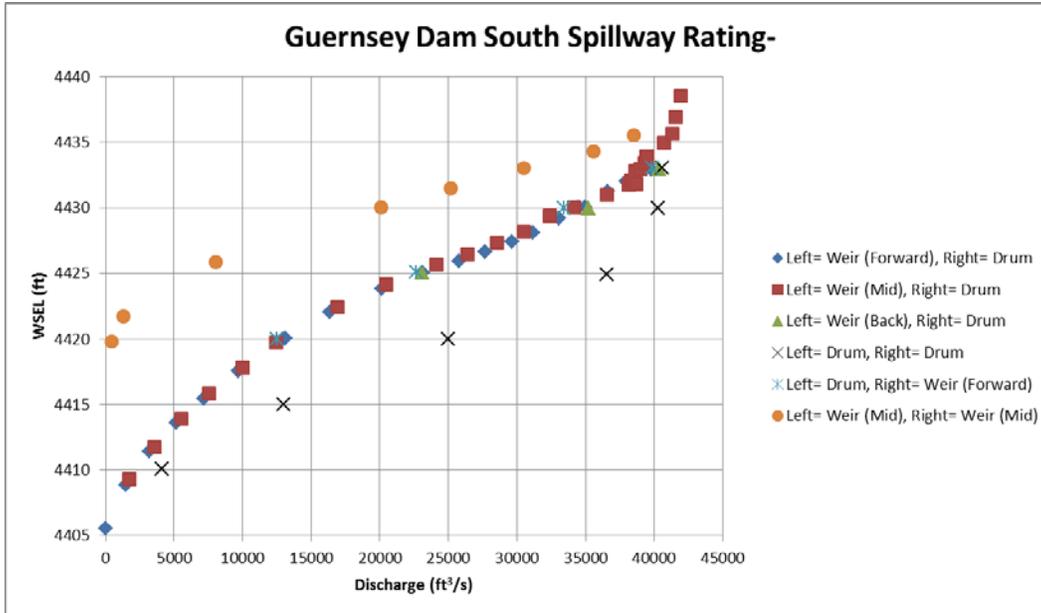


Figure 15. Stage vs. discharge ratings for each configuration tested in the south spillway.

Efficiency

Overall, the placement of the weir forward or back had little impact on the spillway efficiency. When the weir was in the forward or middle position and was not submerged, as in Figure 16, the nappe was not continuously aerated and tended to be pulled down toward the back side of the weir. When the weir was in the back position the nappe was sometimes disrupted by water coming around the upstream side of the middle pier. This caused the nappe to oscillate between aerated and not aerated. This oscillation may produce vibrations when the weir is in the back position. If there is a compelling reason to place the weir in the back position, this oscillation should be investigated further. No other large differences in flow conditions were observed. Due to the lack of hydraulic benefits or negative effects, these minor hydraulic differences should not be the primary influence of the placement of the concrete weir in either the forward or back position.



Figure 16. South spillway discharge of 23,200 ft³/s at a reservoir WSEL of 4425 ft. The weir is in the left hand bay in the forward position.

The spillway was slightly more efficient (higher flow capacity for a given reservoir level) with the weir in the left hand bay. Water from the reservoir has a straighter approach to the right hand bay than the left, so the control structure with the greatest capacity (the drum gate) should be in the right bay. The difference in spillway capacity was only about 1% to 5% over the range of discharges tested.

Configurations with two weirs and two drum gates were also modeled. As expected, the configuration with two drum gates has the highest capacity, while 2 weirs at an elevation of 4420 ft has the lowest capacity (Figure 15). However, these configurations either do not satisfy the economic goals of the modification (two drum gates) or do not meet the discharge capacity requirements (two weirs). They were modeled for the purpose of comparing flow conditions and spillway discharge limits.

Figure 17 shows the stage vs. discharge relationship for configuration 2, the weir in the left bay in the middle position and the drum gate in the right hand bay. The plot also indicates shifts from entrance to throat to pipe control. As discussed in the model setup section, only 75% of the tunnel was modeled. In the model, the tunnel was backpressured to simulate analytical estimates of stage vs. discharge at the tunnel exit during pipe control.

Figure 17 also shows the analytical estimates of the discharge curve. However, the analytical solution shows that pipe control is more limiting than throat control and therefore control jumps directly from entrance control to pipe control as the discharge increases. Model data collected at flow rates between the zones of entrance control and pipe control suggest that the spillway is either shifting to throat control, or at this flow condition the vortex that forms in the drop shaft inlet (e.g., see Figure 13) is decreasing the spillway efficiency (Humphreys 1970). In this range, discharge through the spillway was unstable. Discharge would randomly increase or decrease over time (Figure 17).

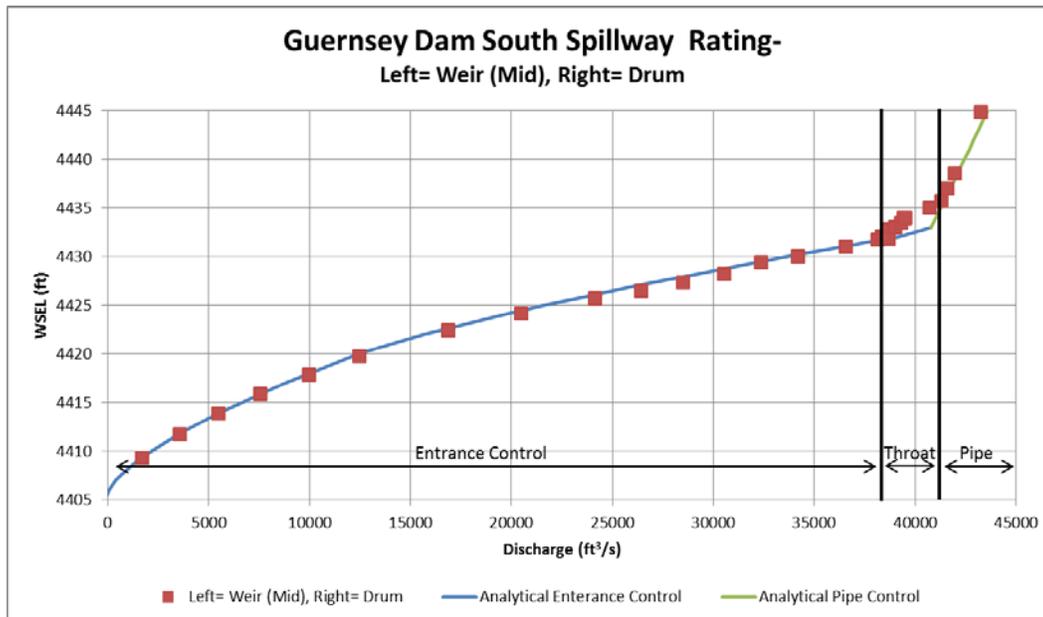


Figure 17. Stage vs. discharge rating in the south spillway with the weir in the middle position of the left bay and the drum gate fully open in the right bay. The physical model is compared with the analytical discharge estimates.

Spillway Transition Hydraulics

In the south spillway structure the bays and transition area are symmetric and exhibit better hydraulic conditions when flow entering the spillway is symmetric, i.e. both drum gates open the same amount. In this case, water passes through the bays and circles around to the center of the bathtub, impacts on itself, and goes down into the tunnel (Figure 18). The replacement of just one drum gate with a weir having a much higher crest elevation leads to extremely unsymmetrical flow conditions. Thus, in the configurations where flow through one bay was much greater than the other, a large vortex formed as water raced around the back of the spillway bathtub (Figure 19).



Figure 18. South spillway discharge of 25,000 ft³/s at a reservoir WSEL of 4420 ft, modeling two drum gates. Note the symmetric flow conditions in the spillway.



Figure 19. South spillway discharge of 13,100 ft³/s at a reservoir WSEL of 4420 ft. The configuration here is the fixed weir at the forward position in the left bay (looking downstream into spillway) and the drum gate in the right bay, Notice the large vortex in the center of the spillway.

For the various configurations that led to unsymmetrical flow, the velocity on the back wall of the spillway ranged from 11.8 ft/s to 34.3 ft/s over the range of discharges tested. The highest velocities were observed at low discharges. As the discharge increased, the gradual shift toward throat and eventually tunnel control caused the water level in the bathtub area to increase, thus reducing velocities along the back wall.

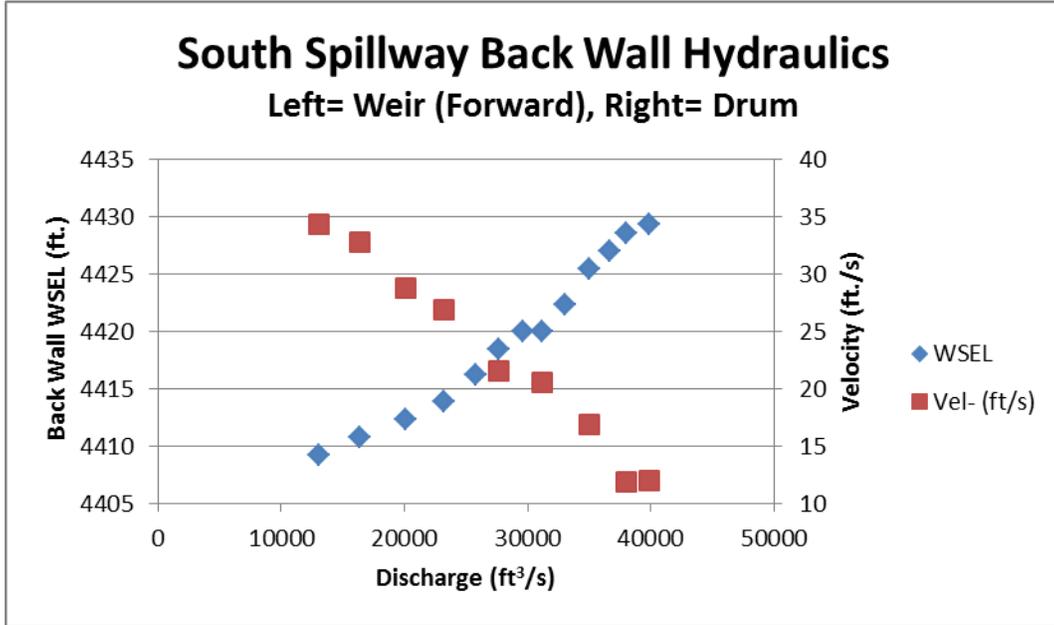


Figure 20 shows the discharge vs. back wall velocity and discharge vs. the back wall maximum WSEL with a drum gate in the right hand bay and a weir in the left hand bay. See Figure 13 for the location and direction of the velocity measurements. The general trends shown in Figure 20 are typical of each flow configuration.

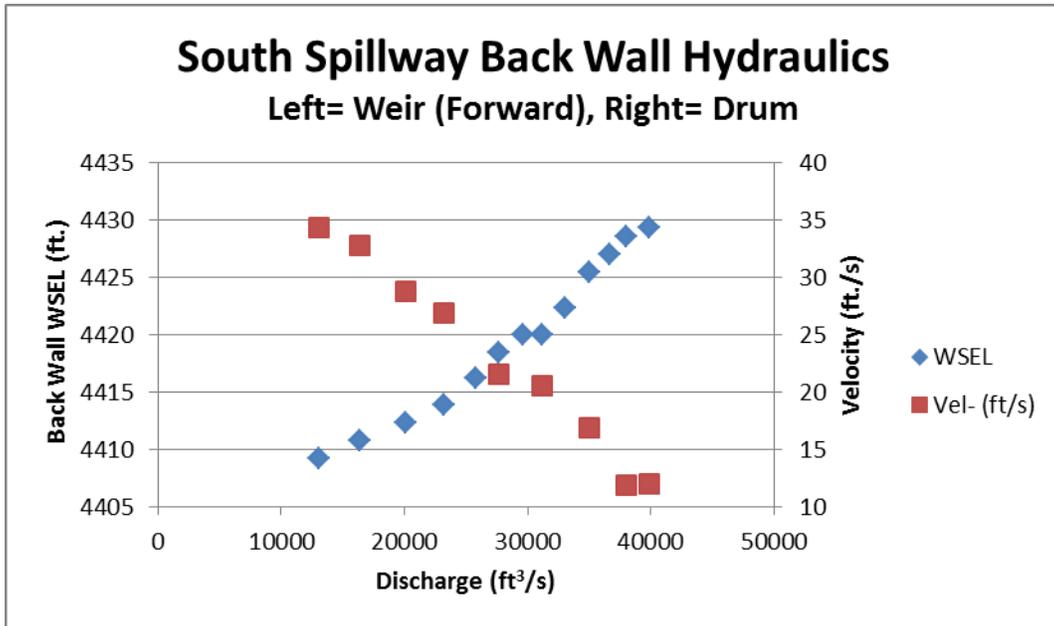


Figure 20. South spillway back wall hydraulic conditions, left bay = weir (forward), right bay = drum gate.

North Spillway

Gate Opening

The current limit switch settings and standard operating procedures for the north spillway limit the Stoney gate to an opening of 38 ft as shown by the gate position indicator (Koenig 2010), which is not adjusted to account for the effects of the 8 inch crest overlay. Drawing 20-D-476 indicated the maximum gate opening is 42 ft above elevation 4370.0 ft which is 4412.0 ft. The spillway crest elevation with the new overlay is now 4370.67 ft, for an opening of 41.33 ft. In the physical model study, the north spillway gate was set to both 38 ft and 42 ft openings as would be read on the gate position indicator. The actual openings are 37.33 ft and 41.33 ft, respectively. Figure 21 compares the discharge curve for a 38-ft and 42-ft opening.

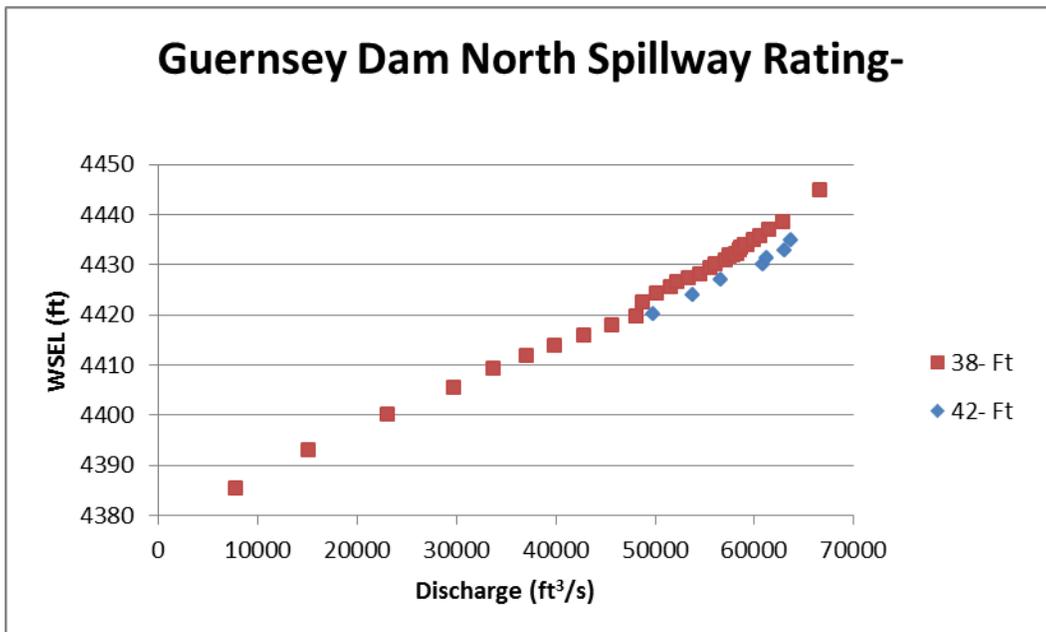


Figure 21. North Spillway discharge vs. elevation rating curve with the Stoney gate open 38 ft and 42 ft, according to the gate indicator (37.33 ft and 41.33 ft actual)

When the north spillway is discharging, some water travels along the face of the embankment and then pours over the concrete wall into the spillway entrance. It has been reported that some riprap on the embankment has been washed away. In the model, velocities along the face of the embankment were measured over the range of discharges tested. See Figure 14 for the location and orientation of the velocity measurements. Figure 22 shows the velocity along the embankment vs. discharge through the spillway. In general, the larger discharges exhibited larger

velocities. For discharges between 40,000 ft³/s and 60,000 ft³/s velocity measurements ranged from 17 ft/s to 19 ft/s. Figure 22 also shows the depth of water against the Stoney gate. The depth was measured from the bottom of the gate to the maximum water surface against the gate.

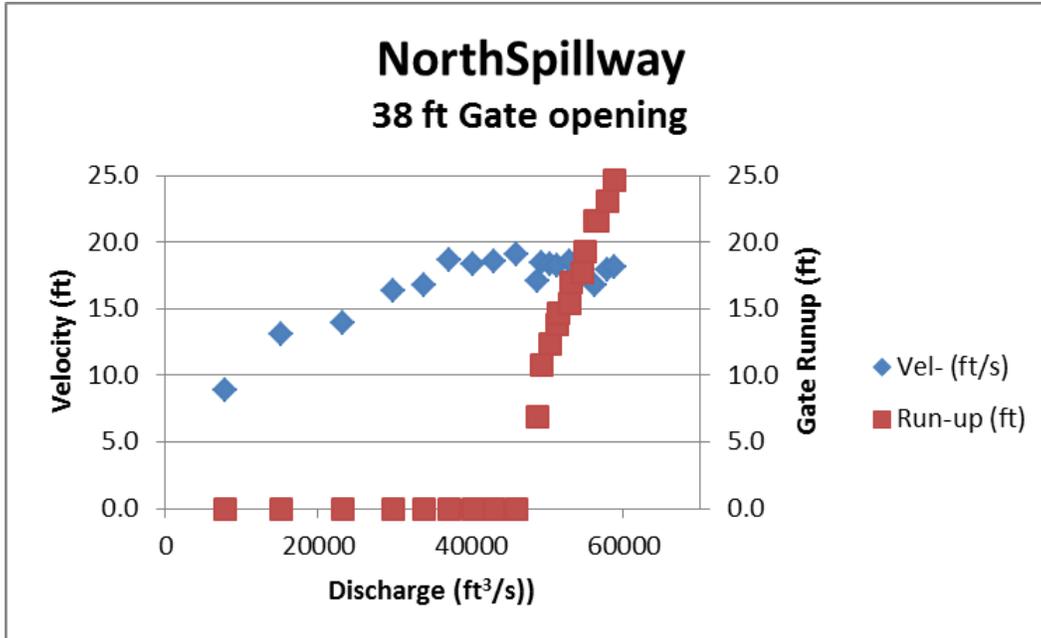


Figure 22. Velocity along the embankment face near the north spillway entrance and the depth of water above the lower lip of the Stoney gate (elev. 4408.0).

Conclusions

- Several alternative configurations of the south spillway were studied that utilize one rehabilitated drum gate and one fixed weir at elevation 4420 ft. The maximum discharge with this combination of spillway controls is obtained with the drum gate in the right hand bay and the weir in the left hand bay. This configuration provides 1% to 5% more discharge than the opposite configuration.
- Placement of the fixed weir at the forward or back positions in either spillway bay has little effect on discharge efficiency and no significant negative flow effects.
- Due to unsymmetrical flow conditions, velocities along the back wall of the south spillway can be as high as 34 ft/s. The highest velocities occurred at low discharges around 13,000 ft³/s.
- Flows into the south spillway exhibit unstable shifts of control between the crest, the throat, and the tunnel between 38,000 ft³/s and 40,000 ft³/s.
- Velocities along the face of the embankment approaching the north spillway inlet can be as high as 19 ft/s for large discharges through the north spillway (near 60,000 ft³/s).
- These findings have been used by the design team during the development of the design and specifications for the dam modifications. The spillway ratings for the preferred alternative, with the weir in the left bay in the middle position, and the drum gate in the right hand bay are given in Figure 23 through Figure 25 and Table 1.

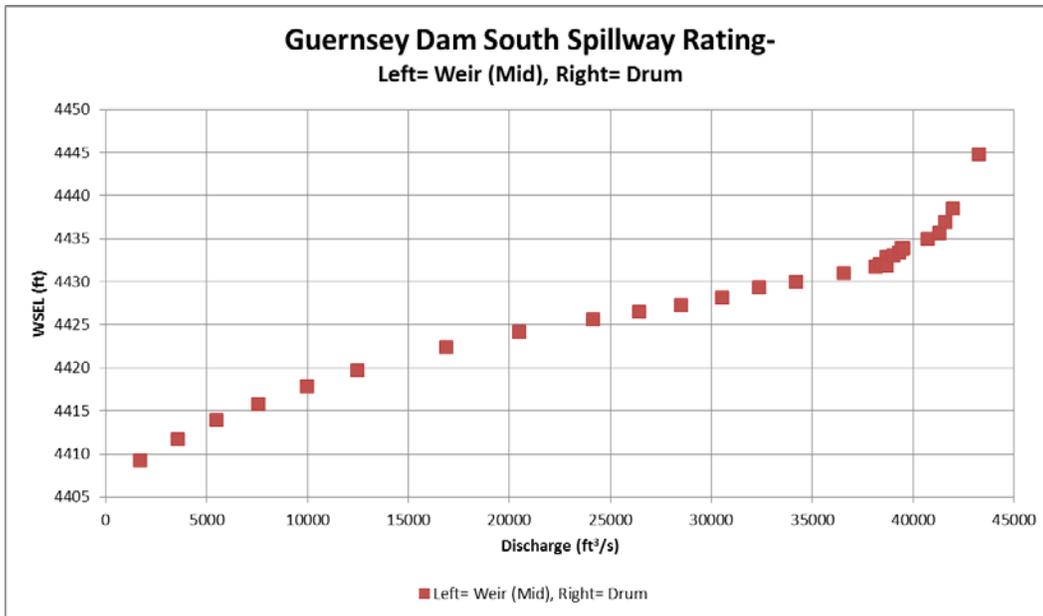


Figure 23. Guernsey Dam south spillway rating curve for the configuration with the weir in the left hand bay in the middle position, and the drum gate in the right hand bay.

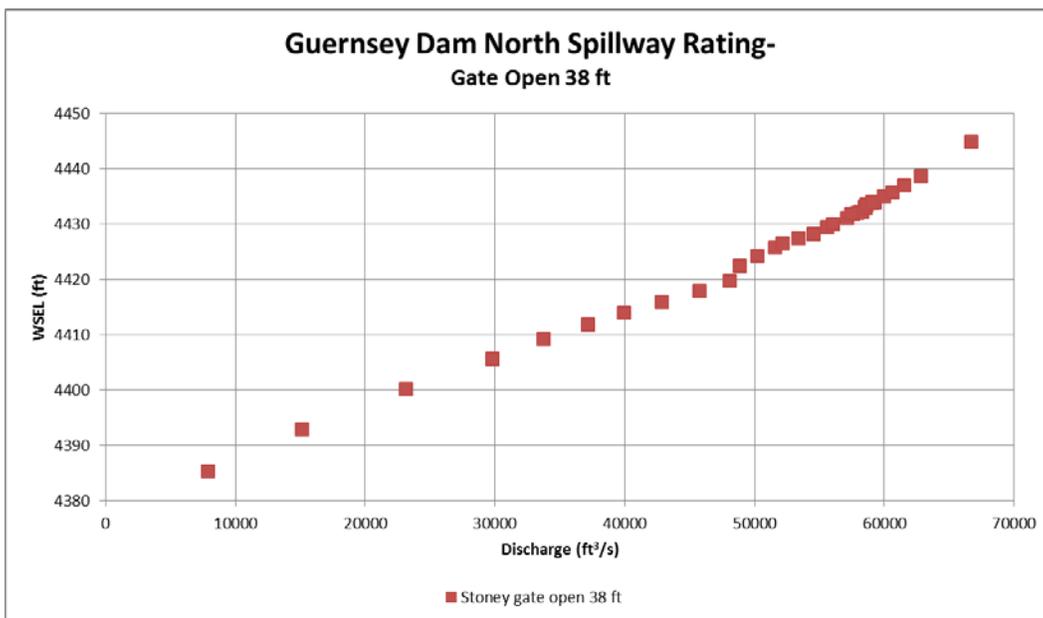


Figure 24. Guernsey Dam north spillway rating curve with the Stoney gate open 38 ft.

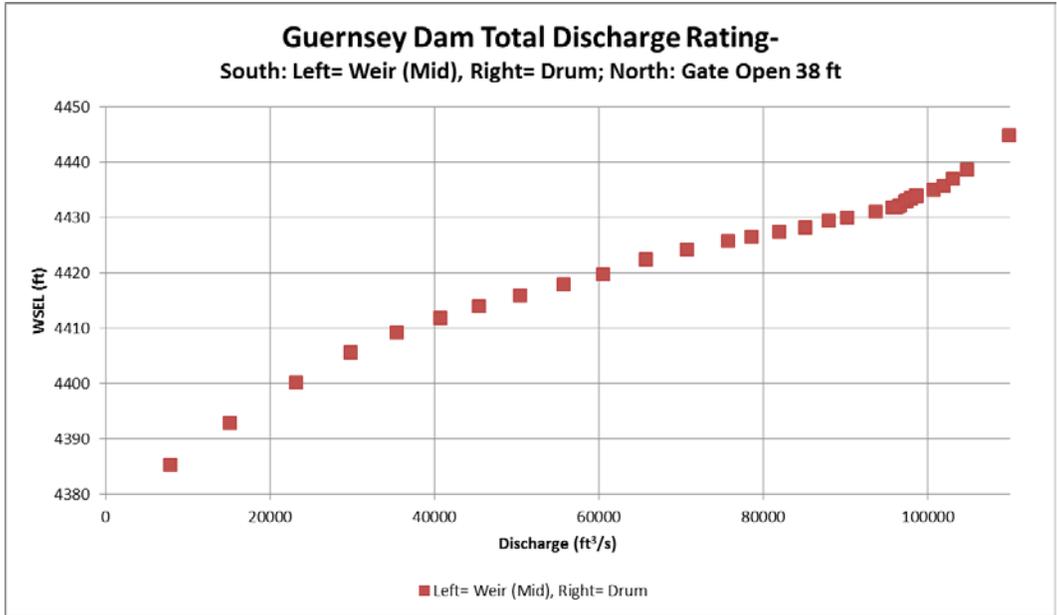


Figure 25. Guernsey Dam total discharge rating curve for the south spillway configuration with the weir in the left hand bay in the middle position, and the drum gate in the right hand bay, and the Stoney gate open 38 ft.

Table 1. Guernsey Dam Discharge vs. Stage relationship

Guernsey Dam Discharge vs. Stage			
South Spillway: Left bay = Weir (Mid), Right bay = Drum Gate			
North Spillway: Stoney Gate Open 38 ft			
Total Q (ft ³ /s)	South Spillway (ft ³ /s)	North Spillway (ft ³ /s)	Res-WSEL (ft)
7,875	0	7,875	4385.27
15,144	0	15,144	4392.93
23,171	0	23,171	4400.11
29,834	0	29,834	4405.54
35,437	1,721	33,716	4409.29
40,738	3,571	37,167	4411.75
45,432	5,509	39,923	4413.91
50,430	7,549	42,881	4415.82
55,730	9,975	45,755	4417.81
60,577	12,470	48,107	4419.71
65,726	16,884	48,842	4422.40
70,723	20,472	50,251	4424.14
75,721	24,130	51,591	4425.66
78,598	26,417	52,181	4426.48
81,930	28,521	53,409	4427.32
85,110	30,526	54,584	4428.20

Guernsey Dam Discharge vs. Stage			
87,987	32,389	55,598	4429.37
90,259	34,202	56,057	4430.01
93,742	36,582	57,160	4431.00
95,711	38,146	57,565	4431.75
96,468	38,582	57,886	4432.01
96,620	38,339	58,281	4432.08
96,620	38,481	58,139	4432.09
97,225	38,668	58,557	4432.79
96,165	38,702	57,463	4431.83
97,528	39,022	58,506	4432.99
97,983	39,325	58,658	4433.41
98,588	39,492	59,096	4433.83
98,739	39,452	59,287	4433.93
98,588	39,512	59,076	4433.93
100,709	40,714	59,995	4434.96
101,920	41,308	60,612	4435.67
103,132	41,605	61,527	4436.97
104,797	41,964	62,833	4438.53
109,946	43,270	66,676	4444.84

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