AUTOMATED OUTLET STRUCTURE DESIGN FOR WINDSOR LAKE TO IMPROVE IRRIGATION OPERATIONS AND ATTENUATE FLOOD FLOWS

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ABSTRACT

Windsor Lake (Kern Reservoir) serves as a storage facility, an equalizer reservoir for the Greeley No. 2 Canal, and a regional detention pond for the Windsor Basin. The affect of rapid urbanization surrounding the Town of Windsor created the need of a regional detention pond for a portion of the nearby Law Basin. Windsor Lake is capable of serving this purpose, though several feet of reservoir storage will need to be surrendered. The New Cache La Poudre Irrigating Company, (owners of the Greeley No. 2 Canal), and Kern Reservoir and Ditch Company (owners of Windsor Lake) have agreed to give up the reservoir storage with the stipulation that the outlet structure is replaced with an automated structure to improve reservoir and canal operations for shareholders.

Requirements for the new outlet structure are to control and measure irrigation releases up to the decreed flow rate of 600 cfs, and serve as the primary spillway for two different 100-year flood scenarios. The first scenario models the existing conditions in the basins and the second models the future condition in which both basins are assumed to be fully urbanized. In addition, the Dam Safety Branch of the State Engineer's Office requires the structure to pass a flood event equating to 17% of the Probable Maximum Flood (PMF). Furthermore, the structure is required to be capable of functioning during the winter months to measure and control small releases for augmentation purposes. Two alternative designs were evaluated during a feasibility study. Rubicon Flume Gates^{tm}, a type of overshot gate, are utilized in the final design to meet the outlet structure requirements. The new structure gives The New Cache La Poudre Irrigating Company (NCLPIC) efficient control over the discharges in their system and reduces the flood potential for downtown Windsor.

INTRODUCTION

In the past Windsor Lake has served as an equalizer reservoir for the Greeley No. 2 Canal and provided water storage for the Kern Reservoir and Ditch Company. Windsor Lake is a Class 1 (High Hazard) Intermediate Dam under jurisdiction of

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the State Engineer's Office (SEO). Water is diverted from the Cache La Poudre River into the canal for delivery to shareholders for irrigation purposes. The canal is routed through the reservoir to help attenuate fluctuations in the canal discharge resulting from the rise and fall of the river throughout the day. The existing outlet consists of radial gates and a rated concrete section for flow measurement.

The canal also intercepts flood flows from the Windsor Basin and either transports them to Windsor Lake, or overtops, in which case the water eventually makes its way to the lake (see Figure 1). In this manner, Windsor Lake has served as a detention facility for the Windsor Basin. The nearby Law Basin has historically entered the Bypass Canal and joined the Greeley No. 2 Canal downstream of the Windsor Lake Outlet structure. This has resulted in flood flows from the Law Basin continuing down the Greeley No. 2 Canal unabated.

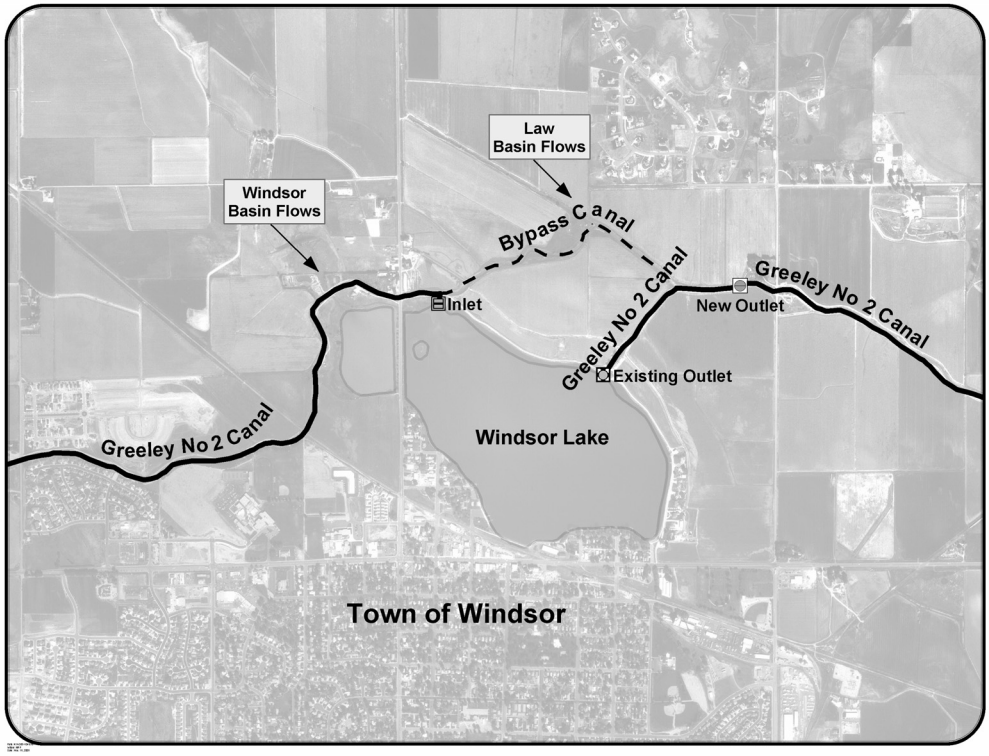

Figure 1. Vicinity Map

The master drainage plan for the Town of Windsor, prepared by Anderson Consulting Engineers, Inc[1], identified the need for a regional detention pond for the Windsor Basin and a portion of the Law Basin. Relocating the Windsor Lake Outlet further downstream on the Greeley No. 2 Canal allows flood flows from the Law Basin to be routed through Windsor Lake. The master drainage plan estimated that the maximum normal water surface elevation needs to be decreased by approximately two feet to provide the required flood storage. In addition, normal irrigation flows will pass down the bypass canal and then either enter Windsor Lake or exit through the outlet structure and continue down the canal.

The canal between Windsor Lake and the new outlet will be capable of flowing in two directions. When the canal discharge from the river exceeds the desired discharge, the excess water will flow from the canal into Windsor Lake. When the canal discharge is short of the desired discharge, water will flow from the lake and supplement the canal discharge.

The Kern Reservoir and Ditch Company and NCLPIC agreed to surrender the required storage volume if the existing outlet and flow measurement structures are replaced with an automated structure capable of both controlling and measuring discharge. Tetra Tech RMC used the hydrographs from the master drainage plan to perform unsteady hydraulic modeling of the system involving the Greeley No. 2 Canal, the two drainage basins, and Windsor Lake. This modeling was performed in conjunction with the drainage plan for the Greenspire Subdivision bordering the canal and Windsor Lake on the north and east. [(2) (3) (4)]

Three separate storm scenarios were analyzed. The first represented the existing basin conditions during a 100-yr precipitation event and the second modeled a future 100-yr precipitation event which assumed the basins are fully developed. The future scenario assumes that new development within the basin would be required to detain the 100-yr flood event and release it at the historic 10-yr peak flowrate. Therefore, the first scenario has the highest peak flows and a short duration while the second has lower peak flows but a much longer duration.

The new outlet structure is required to control both 100-yr flood events in such a manner as to not allow Windsor Lake to rise above the crest of the emergency spillway at an elevation of 4,797.10 ft. (NAVD 88). Rules and regulations set forth by the SEO also require the structure to safely pass the Probable Maximum Flood (PMF) unless a smaller flood can be justified through an incremental damage analysis (IDA). Tetra Tech RMC performed an IDA to reduce the Inflow Design Flood (IDF) to 17% of the full PMF. The new outlet structure design must satisfactorily pass these three flood scenarios assuming that the canal is carrying 600 cfs. of irrigation water.

Tetra Tech RMC's analysis models the outlet structure as a 12 ft wide overshot gate which would function as the primary spillway at an elevation of 4,793.50 ft during a flood event. A 114-ft long concrete weir at an elevation of 4,798.00 ft is also required to meet design requirements for the existing 100-yr and 17% PMF flood events. However, this structure does not include a measuring structure, and the overshot gate specified cannot measure flowrate within the $^{+}$/- 2% accuracy desired by NCLPIC under submerged conditions.

FEASIBILITY STUDY

Design Criteria

New Cache La Poudre Irrigating Co. requested Applegate Group, Inc. to perform the new outlet and measuring structure design. Two design alternatives were examined in detail during the feasibility study. The first used simple overshot gates to control releases from Windsor Lake, and a separate structure to measure discharges. The second alternative combines the two structures into one by using Rubicon Flumegates[tm] to control and measure discharges.

Accurate discharge measurement is a necessity for NCLPIC. The canal has two typical operating regimes. Canal discharges during the irrigation season range from 100-600 cfs. During the fall and winter months the canal releases smaller discharges of approximately 2-100 cfs to replace evaporative losses from the surface of the canal during the summer months, as required by the SEO. Therefore, the outlet structure must be capable of measuring discharges ranging from 2 to 600 cfs with an accuracy of +/- 2%. The new outlet structure must also be capable of releasing water at reservoir elevations ranging from 4,785.00 ft to 4,793.50 ft. Finally, the structure needs to be capable of controlling storm flows for the three flood scenarios described earlier.

Alternative 1

For the first alternative Obermeyer Gates are used to control releases from the reservoir. Obermeyer gates consist of a gate leaf placed atop an air bladder which is raised and lowered by adjusting the air pressure in the bladder. A separate structure is required to attain the desired flow measurement accuracy of +/- 2% under submerged conditions. A Supervisory Control And Data Acquisition (SCADA) network will tie the two structures together and allow the NCLPIC to automate and remotely operate the structure. A long-throated flume is the preferred flow measurement device for a couple reasons. First, typical flumes require a significant change in water surface elevation to obtain accurate flow measurement which will decrease the available operating range of lake elevations for a given discharge. Long throated flumes can typically obtain the required flow accuracy with a 2.00 inch change in water surface elevation which will maximize the operating range of the lake. Second, a long-throated flume is capable of measuring a wide range of discharges with the desired accuracy.

Alternative 2

The second alternative utilizes Rubicon Flumegates[tm] to control and measure discharge through the structure. Rubicon Flumegates[tm] are a type of overshot gate manufactured in Australia. The gate includes four piezometers to measure water levels upstream and downstream of the structure and a digital shaft encoder that measures the position of the gate leaf. Using this information, the gate software

calculates an instantaneous discharge with a measurement accuracy of +/- 2% with as little as a 2 inch change in water surface elevation across the gate. This measurement accuracy has been verified through independent testing performed by Hydro Environmental[5] on the Goulburn-Murray Water system in Australia. Nearly 2,000 of these gates are have been installed throughout Australia and they are rapidly gaining popularity in the United States with approximately 100 gates in service at the time of publication. The user can set the Flumegate[tm] to maintain a specified upstream or downstream water surface elevation, or maintain a desired flowrate, and the gates can be tied into NCLPIC's existing SCADA system to facilitate remote operation of the gates.

Figure 2. Rubicon Gates in Operation at Windsor Outlet

The feasibility study concluded that it would be more economical to build a single structure with Rubicon Flumegates[tm] than building two separate structures. Therefore, the second alternative is selected for final design.

FINAL DESIGN

Irrigation Modeling

The first step in the final design is to determine the gate size necessary to discharge irrigation flows up to 600 cfs. Rubicon Systems recommends that the gates be manufactured to the maximum dimensions of their standard shipping crate to prevent damage during shipping. This results in a gate that is approximately 7.50 ft wide and 7.25 ft long. A gate this size is capable of discharging a maximum of 351 cfs, assuming that there is no backwater on the gate and Windsor Lake is at a maximum operating water surface elevation of 4,793.50 ft. However, backwater from the Greeley No. 2 Canal decreases this

maximum discharge to approximately 233 cfs, thereby requiring three gates to obtain the design discharge of 600 cfs. Using three gates in this structure will increase the maximum irrigation discharge to 700 cfs with backwater conditions and allow NCLPIC a little flexibility in the operating range available for the design flowrate of 600 cfs. The only problem with this gate size is that it can only release water down to an elevation of 4,787.75 ft, which will further restrict the operating range of the lake. To address this issue the gates will be built on removable stoplogs which allows the gate to be moved to a lower position to release water down to the design elevation of 4,785.00 ft. It is anticipated that this will only be required during periods of extreme drought and is therefore an acceptable solution to NCLPIC. Figure 3 displays the operating range attainable for the new outlet structure and data points from previous years. The total width of the gate section is 27 feet and it is located in the center of the outlet structure.

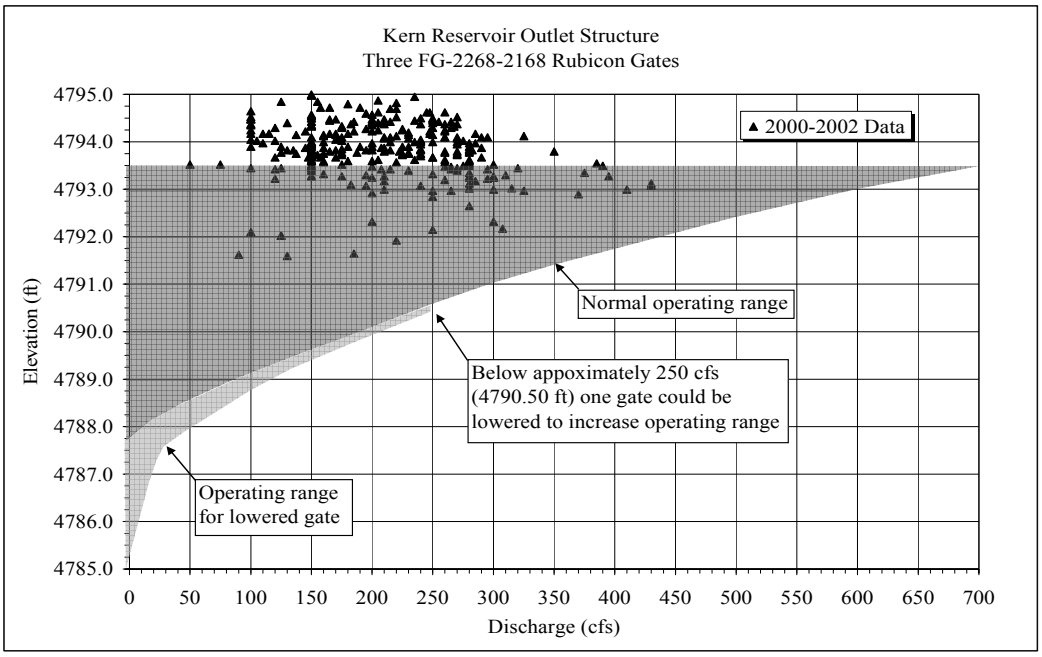

Figure 3. Operating Range of Windsor Lake Outlet

Flood Modeling

As mentioned earlier, the structure must pass two different 100-yr flood events without allowing water to rise above the elevation of the existing emergency spillway on Windsor Lake. All flood water in these two scenarios will exit the reservoir through the Greeley No. 2 Canal. Tetra Tech RMC determined that the peak discharge through the structure for the existing and future conditions is 1,029 cfs and 865 cfs, respectively.

It is believed that allowing these flood flows to pass freely over the Flumegate[tm] will damage the gate controls located in the pedestal above the gate. To reduce the potential for damage, a concrete wall placed in front of the gates will direct water to the primary concrete spillway located to the side of the gate section at an elevation of 4,793.5 ft. This wall extends up to an elevation of 4,798.0 ft and will begin to function as a spillway at that elevation. During the existing 100-yr flood event and the 17% PMF, water will pass over this wall and flow around the gate pedestal and over the gate leaf. It is anticipated that the gate controls will not sustain damage during either of the 100-yr flood scenarios (see Figure 4).

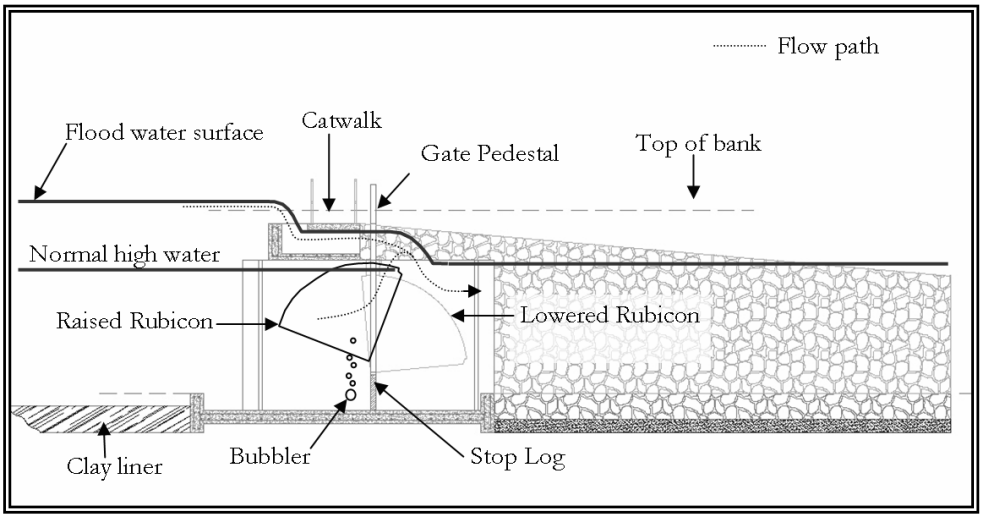

Figure 4. Outlet Gate Profile

Modeling the structure with Flumegates[tm] during a flood event in which the reservoir elevation exceeds 4,793.50 ft is somewhat complicated. When the gates are fully raised the gate leaf is at an elevation of 4,793.50 ft. Magnets embedded in the gate panels and frame do not let the gate rise any higher and the gate does not seal the remaining opening between the gate leaf and frame. This results in a horizontal opening of 6.48 ft by 2.04 ft. When the lake level rises above 4,793.50 ft water passes through this opening and then flows over the gate leaf. A submerged rectangular orifice equation and a free flowing weir equation are used to model this opening.

$$Q_{gate-orifice} = C_d A\sqrt{2g}(h_1 - h_2)^{0.5} \quad (1)$$

$$Q_{gate-weir} = CL(h_2)^{1.5} \quad (2)$$

Where: Q = discharge (cfs)
C_d = orifice coefficient (0.60)
A = orifice area (ft^2)
g = gravity constant (32.2 ft/s^2)
h_1 = upstream water depth above gate leaf (ft)

h_2 = downstream water depth above gate leaf (ft)
C = weir coefficient (3.3)

An iterative process which equates the weir discharge to the orifice discharge is used to calculate h_2 for a given value of h_1. Then equation (2) is used to calculate the discharge. Repeating this process for different values of h_1 results in a stage-discharge curve for the gate orifice assuming that the gate is in the fully closed position and h_1 is between 4,793.50 and 4,798.00 ft. Above an elevation of 4,798.00 ft water will flow over the upper weir and combine with the flow passing through the gate orifice before flowing over the gate leaf. The discharge passing over the weir is calculated using Equation 2. The total discharge equation is written as Equation 3.

$$Q_{gate-weir} = Q_{gate-orifice} + Q_{concrete-weir} \quad (3)$$

After modeling the gate section of the structure as described above, the spillway widths on either side of the gate section are adjusted to best match the discharge curve for the structure designed by Tetra Tech RMC. This avoids significantly impacting the unsteady hydraulic modeling of the reservoir and ditch system upstream of the gate. Decreasing the primary spillway width at an elevation of 4,793.50 to 4 ft. sufficiently accounts for water passing through the gate orifice. The upper spillway width at 4,798.0 ft must be increased to 140 ft to best match the curve from Tetra Tech RMC. A comparison of the Flumgate[tm] design to Tetra Tech RMC's preliminary design is shown in Figure 5.

SUMMARY

The new automated outlet structure for Windsor Lake is able to meet the needs and requirements of several entities, including the Kern Reservoir and Ditch Company, New Cache La Poudre Irrigating Company, the Town of Windsor, and the State Engineer's Office.

The use of Flumegates[tm] in the structure allows the ditch company to remotely operate the gate and provide more accurate water deliveries to shareholders. The new outlet represents a significant improvement to the flood control system for the Town of Windsor. Construction began in November 2005 and was completed by April 2006 in time for the irrigation season.

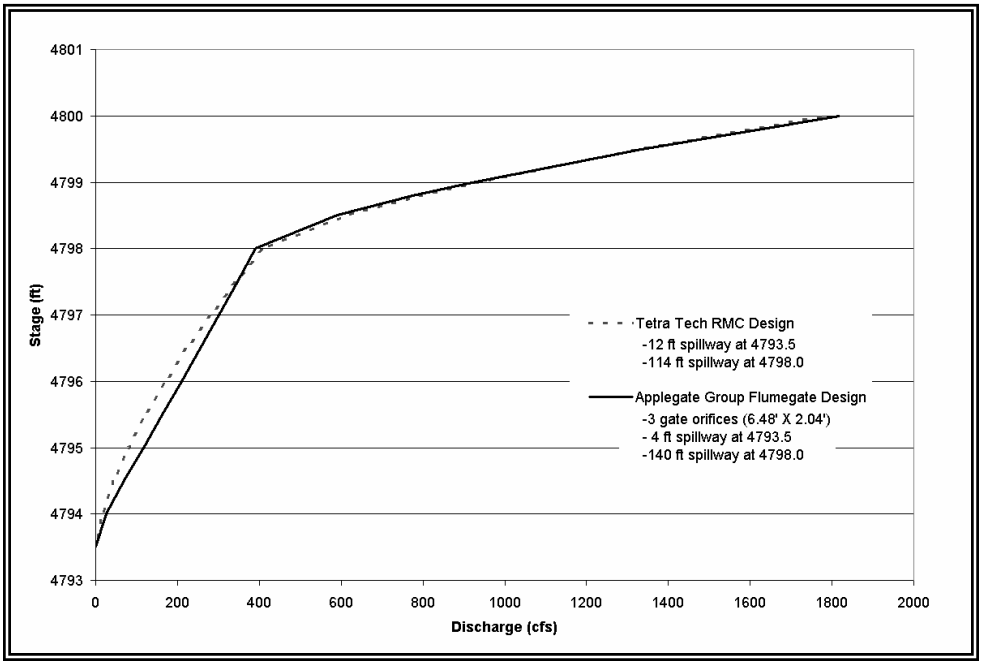

Figure 5. Outlet Structure Rating Curve Comparison

REFERENCES

(1) Anderson Consulting Engineers, Inc., (October 2003), "Town of Windsor Master Drainage Plan Weld County, Colorado."

(2) Tetra Tech RMC, (Sept 2004), "Windsor Lake Emergency Spillway – Evaluation of Hydraulic Adequacy."

(3) Tetra Tech RMC, (Sept 2004), "Windsor Lake Emergency Spillway – Evaluation of Hydraulic Adequacy Technical Addendums."

(4) Tetra Tech RMC, (Oct 2004), "Final Drainage Report for Greenspire Subdivision."

(5) Hydro Environmental, (Jan 2004), "Flumegate^{tm} Metering Accuracy Review Project."