Canyon Lake Flood Emergency Operations During the Summer of 2002

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Abstract

An approved reservoir regulation plan, when combined with the consequences of engineering and real estate decisions made 45 years ago, contributed to unintended, severe limitations on outlet works operation during a flood emergency in the summer of 2002 at Canyon Lake Dam near New Braunfels, Texas. From 29 June to 10 July 2002, a 0.4 percent annual chance of exceedance (250-year) hydrologic event occurred over the Guadalupe River Basin upstream from Canyon Lake Dam. The basin wide average rainfall was 22 inches, with weather radar indicating up to 50 inches at some locations. The emergency spillway was overtopped for the first time in the dam's 38-year history, resulting in significant spillway channel erosion and subsequent sediment deposition in the Guadalupe River. Outlet works releases, coupled with high tailwater from the spillway, led to riprap failure and damage to the outlet works stilling basin. There were concerns that the riprap trapped in the stilling basin would cause additional damage during future releases to lower the flood control pool below the spillway crest. These flood control releases might also cause additional residential flooding, a result of lost channel capacity due to sediment deposition in the river reach between the outlet works and the spillway discharge channels. In a highly coordinated team effort between the Fort Worth District, Comal County officials, debris removal contractors, and local property owners, the debris, rock and sediment were removed. The flood control pool was then lowered, thus returning Canyon Lake to safe operation.

Introduction

Canyon Lake and Dam is one of 25 reservoir projects built by the U.S. Army Corps of Engineers and operated by the Fort Worth District. For its first 38 years of operation, the pool had been close to the spillway crest only three times. Then in the summer of 2002, with basin-wide rainfall averaging 22 inches over a 2-week period, it exceeded the spillway crest by 7.3 feet. Although the uncontrolled broadcrested weir spillway performed satisfactorily, an estimated 850,000 cubic yards of rock, soil, and trees from the spillway discharge channel found its way to the Guadalupe River downstream from the dam. The following discussion looks at how that material, along with spillway flows, impacted outlet works operation and downstream flooding, and what was done over the next 3 months to return the dam to normal operations.

Location. Canyon Dam is located at river mile 303.0 on the Guadalupe River. It is about 40 miles northeast of San Antonio in the Texas Hill Country. The dam is

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located on the southeastern edge of the Edwards Plateau along the Balcones Escarpment. The area around the lake is in rugged topography with elongated hilltops averaging about 250 feet in height. The primary geologic strata exposed at the damsite are part of the Glen Rose Formation, which consists of extensive, Upper Cretaceous limestones with a few thin shale seams. There are several faults in the vicinity of the lake, one of which runs just south of the main embankment and intersects the spillway discharge channel. The watershed above the lake is approximately 1,400 square miles. The Guadalupe River, upstream and downstream from the lake, is one of the most popular tubing and canoeing rivers in the state.

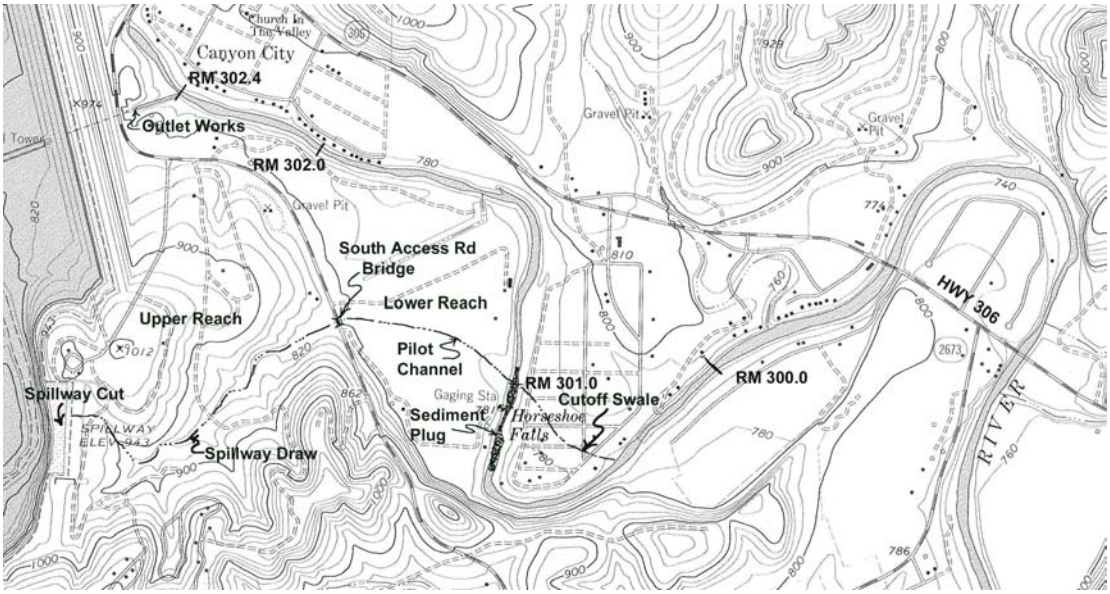

Figure 1. Guadalupe River Downstream from Canyon Dam

Embankment. Canyon Dam is an earth fill embankment 4,620 feet long (including a 210-foot long dike) and 224 feet high at its highest point above the valley floor. Construction began in 1959, and deliberate impoundment began on 16 January 1964.

Outlet Works. The outlet works consists of a 9.33-foot diameter, 994-foot long, steel-lined concrete conduit with two 5.67-ft x 10-ft slide gates at the upstream end and one 10-ft x 10-ft gate at the downstream end. The original conduit diameter was 10.0 feet. A steel liner and downstream gate were installed when hydropower was added to the project in 1985. As part of the work, the transition section between the conduit portal and the rectangular stilling basin chute was removed to make room for the downstream gate. A rectangular section of conduit with a very short transition section was added. The hydropower diversion pipe is located in the roof of the rectangular section. Hydropower releases can be made only when the 10-ft x 10-ft gate is closed and the conduit is under pressure. All flood control releases are made with the downstream gate fully open. The downstream gate is never used to regulate flow. Most low flow releases are made through the powerhouse. A 39-foot wide, 84-foot long stilling basin with two rows of baffle blocks and a 5-foot high vertical endsill is at the end of the conduit. The stilling basin is in a 1V:2H rock cut with

riprap protection on the sideslopes. The downstream discharge channel is 200 feet long and discharges into the Guadalupe River at river mile 302.4.

When the lake pool elevation is at the spillway crest (top of flood control pool), the maximum release through the outlet works with both gates fully open is 5,100 cfs. The original capacity was about 5,800 cfs before the 9.33-foot diameter steel-liner was added. The stable gated release was originally about 4,000 cfs with both gates opened to 5 feet. Higher gate settings produced surging until the flow increased enough to sustain fully pressurized flow in the conduit. The stable gate operating range for the Canyon Dam outlet works has always been limited due to the 994-foot long conduit that provides the necessary length for the gated discharge to reach pressure flow before exiting the conduit. With the 9.33-ft diameter liner, the transition from open channel to pressure flow now occurs at gate openings between 4 and 5 feet and at a discharge slightly greater than 3,900 cfs.

Spillway and Spillway Discharge Channel. The spillway is a 1,260-foot long broadcrested weir located in a topographic saddle 1,600 feet southwest of the right dam abutment. The crest, which is a 2-foot wide concrete sill at elevation 943.0 feet National Geodetic Vertical Datum (NGVD), is 200 feet vertically above, and about a mile from, the Guadalupe River. The spillway discharge channel is 6,500 feet long. The South Access Road divides it into two distinct reaches.

The upper reach of the discharge channel includes the spillway cut and the spillway draw, which is about 4,200 feet of natural channel. Flooding in this reach was not a problem during the spillway event. A HEC-RAS model of the spillway discharge channel and Guadalupe River, developed from pre-flood topography, indicates that the 500-year discharge is easily contained in the original valley section for the upper reach of the spillway discharge channel. Flood capacity is now even higher – a result of massive erosion during the July 2002 spillway event. The reach is steep, with an average slope of 3.5 percent, and flow regimes alternate between subcritical and supercritical. Originally the overburden material varied from 5 feet thick near the spillway to 30 feet at the South Access Road. Hydraulic jumps, high velocities, loose soil, and weathered rock offered a high probability that substantial erosion would occur. This was observed during the 2002 spillway event. Although the Hydrology and Hydraulics chapter in Design Memorandum No. 7 on Canyon Reservoir Spillway, dated July 1958, states that supercritical flow will occur in the upper reach, potential erosion problems were not addressed. The Geology chapter discusses erosion in the immediate vicinity of the spillway, but not in the downstream draw and pilot channel where the problems occurred during the flood.

The lower reach of the discharge channel is a 2,300-foot long excavated channel in alluvial material 15 to 30 feet thick. The channel, which is referred to as a pilot channel, was originally 300 feet wide at the bottom, had 1 vertical to 6 horizontal sideslopes, and a bottom slope ranging from 1.08 percent to 2.0 percent. It was about 10 feet deep. At its confluence with the river, there was a drop from the bottom of the pilot channel to the bottom of the river of about 20 feet. For the lower discharges, the

tailwater in the river would have been significantly lower than the flow elevation in the pilot channel, and the water surface would have been supercritical for the first 300 feet upstream from the river. The water surface in the river would not have controlled the water surface in the pilot channel until the discharge was above 90,000 cfs. Consequently, the potential for headcutting during the initial stages of a spillway event would have been high. It is likely that the downstream end of the reach would be the source of the first material to deposit in the river during a spillway event. (The average velocity in the river is low compared to the pilot channel.) Although the lower end of the reach had a channel capacity of about 50,000 cfs, the capacity decreased significantly about 400 feet downstream from the South Access Road. At this location, the pre-flood HEC-RAS model shows that flows above 9,000 cfs will break out on the left side of the pilot channel and go north through a pecan orchard and then down to the river. This is consistent with field observations during the July 2002 spillway event.

Guadalupe River Channel. The spillway discharge channel outfalls into the Guadalupe River at RM 301.0, opposite the Horseshoe Falls Estates subdivision. This subdivision is on the inside of a 1,000-foot long meander loop. The spillway channel is located at 80 degrees to the river channel and lines up with a high flow cutoff swale that cuts across the meander about one-fourth of the distance from the bottom of the loop. The overflow swale is a natural feature and is visible on Canyon Lake pre-construction topography maps. A HEC-RAS analysis, based on pre-flood topography, indicates that flows greater than 40,000 cfs on the Guadalupe River use the swale. This occurs regardless if the flow comes from the direction of the spillway discharge channel or if it comes from the upstream river channel. The overflow swale is not discussed in either the Spillway DM or the Real Estate DM. These Design Memoranda were published in 1958 and 1959 respectively. At that time, the area directly below the dam was largely agricultural except for some recreational cabins along the river upstream from the meander in the vicinity of the outlet works discharge channel outfall. The land in the meander loop was vacant. Most of this land, including the overflow swale, was removed from the 100-year flood plain when the dam was built. Consequently, in the time since dam construction, the land has developed with little consideration for potential flooding.

It may seem obvious for hydraulic reasons that the swale should have been considered a logical extension of the spillway discharge channel and would be needed for safe spillway operation. However, under the real estate rules in effect at the time the dam was designed and built, the Corps of Engineers was not required to purchase right-of-way or obtain flowage easements through this low lying area. The area floods much less frequently than it did before the dam was built. A revised Outlet Works Design Memorandum plate, published the same month as the Spillway DM, shows the spillway pilot channel to be extended across the Horseshow Falls bend to the opposite side of the meander. Even though it is labeled as a borrow ditch, and for unknown reasons never made it into the Spillway and Real Estate DM's, its alignment does suggest that someone may have considered spillway outfall hydraulics.

The Flood of 2002

The rainfall and resulting runoff that flowed into Canyon Lake in July of 2002 was estimated at a 0.4 percent chance of occurrence (250-year recurrence interval) for the maximum pool elevation of 950.3. Table 1 shows how this compares to other events.

Table 1. Canyon Lake Frequency Discharges and Elevations

Frequency	Recurrence Interval	Elevation Feet NGVD	Discharge CFS
1.5%	67-year	943.0 (crest)	0
1.0%	100-year	946.0	14,000
0.4%	250-year	950.3	66,800
0.2%	500-year	954.0	130,000

When the rainfall began on 30 June, the pool was at elevation 908. 6. This is 34.4 feet below the spillway crest and 0.4 feet below the top of conservation pool. By 3 July, the pool was at elevation 932.4. Low flow releases were switched from the powerhouse to the flood control gates. When the pool reached elevation 941.0 on 4 July, the 11-hour procedure to fully open the gates was initiated. The gates remained fully open until the morning of 5 July. Spillway flow began on 4 July, peaked once on 5 July, and again on 6 July. The maximum inflow was 110,000 cfs. Maximum outflow was 66,800 cfs. For a detailed discussion of the rain and runoff refer to the paper entitled "The Flood Event of June 30 – July 18, 2002 in the Texas Hill Country" by John Rael, P.E., Hydraulic Engineer, Fort Worth District Reservoir Control Branch.

What Happened at the Spillway. During the flood, the spillway operated as intended. The concrete sill, rock floor, and abutments suffered little or no damage. Significant erosion did not occur until the first topographic dropoff, about 330 feet downstream from the sill near the top of the spillway draw. Most of the damage occurred in the early hours of 5 July as spillway flows cut a wider and deeper channel on the way down to the river. Between the crest and the South Access Road an estimated 600,000 cubic yards of rock, soil, and trees were removed, leaving a limestone canyon 100 to 300 feet wide and as much as 40 feet deep in some places. The natural channel cross-section in this reach was only about 10 feet deep and 25 feet wide. The eroded material and debris were deposited in the river or strewn across a wide area on the north side of the channel downstream from the South Access Road. By 1000 hrs on 5 July, the newly formed canyon was close to its ultimate size. The Corps of Engineers property is 400 feet wide at its narrowest point in this reach. All of the erosion was within Corps of Engineers property.

Although not quite as dramatic, extensive erosion in the lower reach dropped the pilot channel bottom 20 feet, but left the top width about the same as pre-flood conditions. An estimated 250,000 cubic yards of alluvial material were eroded away. This material contributed to the estimated 300,000 cubic yards that were ultimately excavated from the river.

Figure 2. Guadalupe River Sediment Plug (Photo Source: Comal County Engineering Website)

Sediment from the spillway discharge channel was deposited in the Guadalupe River on the upstream side of the Horseshoe Falls Estates meander. The debris and sediment plugged the river channel for a distance of about 1,200 feet. The river was completely plugged upstream from the spillway channel outfall. An island had formed in the river downstream from the outfall. This can be seen in Figure 2. Water went through both the overflow swale in Horseshoe Falls Estates and the channel downstream from the plug. Even without the downstream plug, part of the 66,800 cfs from the spillway would have gone through the overflow swale.

What Happened at the Outlet Works.

At 0800 hrs on 3 July the lake pool elevation was 927.9, which is 15.1 feet below the spillway crest. Using available rainfall data from the previous day and stream gage data, the Reservoir Control Branch forecast that the lake would rise about 15 feet over the next 4 days. At 1530 hrs the forecast was revised after additional rain had fallen and the USGS repaired a stuck stream gage at Spring Branch, just upstream from the lake. The new forecast predicted that the lake pool would overtop the spillway crest by a few tenths of a foot on 6 July. Although the outlet works was switched to flood control gate operation late on 3 July, the release from the outlet works was limited to 115 cfs. The flow at the Gonzales gage, one of the five downstream control points, had already exceeded the downstream control point discharge of 12,000 cfs.

Heavy rainfall continued through the evening. Projected inflows indicated that the lake pool would peak faster and higher than previously expected. Rainfall reports available the next morning would show a 24-hour total of 8.75 inches of precipitation near Kerrville, which is about 55 miles upstream from the dam. At 0130 hrs on 4 July a Fort Worth District recommendation was made to Comal County officials to evacuate the residential areas immediately downstream from the dam. Evacuations started at about 0300 hrs. When the spillway was overtopped at 1530 hrs on 4 July, most everyone had been moved out.

At 1000 hrs on 4 July the District declared a major hydrologic event. In accordance with the approved Canyon Lake Reservoir Regulation Plan, project personnel started raising the flood control gates at 1000 hrs. They completed the procedure at 2100 hrs when the pool was 1.65 feet above the spillway crest and the spillway discharge was 5,740 cfs. The total lake outflow was about 10,900 cfs.

The Regulation Plan stipulates when to open the gates, but does not address under what circumstances to close the gates during a major hydrologic event. With a rising pool that is forecast to exceed 943.0, the plan specifies making gated releases up to a combined outlet works and spillway discharge of 5,000 cfs to maintain a flow of 12,000 cfs on the Guadalupe River at the downstream control points. By the time the spillway discharge reaches 5,000 cfs, the gates are to be closed. If the inflow forecasts indicate that a flood of near spillway design magnitude is in progress (a major hydrologic event), the outlet works gates are to be reopened fully. Although reopening the gates makes sense from a lake operations perspective, there could be unintended consequences that would affect the ability to make future gate releases, as was demonstrated during the July 2002 spillway event.

Normally, with the flood control gates fully open and no flow over the spillway, the stilling basin tailwater is at the top of the training walls. The channel sideslopes above the walls are steep (1 vertical to 2 horizontal) and are protected with 24-inch rock riprap above elevation 764.0, and with 6,000-pound derrick stone below 764.0. The top of the stilling basin training walls is at 764.0. As the discharge over the spillway increased, the tailwater at the outlet works also increased. By midnight of 4 July, the pool elevation was at 945.8 with a spillway discharge of 14,600 cfs. With no flow from the outlet works, the theoretical tailwater elevation at the stilling basin would have been 756.3 for 14,600 cfs. An additional 5,100 cfs from the outlet works would have increased the tailwater to 762.4, still at least theoretically, safely below the top of training walls. This assumes no problems with debris and sediment deposition in the river that would have increased the tailwater elevation at the outlet works. When lake rangers made a routine check of the outlet works stilling basin at 0200 hrs on 5 July, they discovered large surge waves rolling through the stilling basin and sideslope riprap sliding into the basin. By then the spillway discharge was 22,000 cfs, and high tailwater was evidently becoming a significant problem. This information was reported; however, it was not relayed to Reservoir Control Branch. Consequently, the gates remained open until the next morning.

At 0800 hrs on 5 July the flow over the spillway was 46,300 cfs, flow through the outlet works was 5,100 cfs, and there were still large surge waves rolling through the stilling basin. The downstream powerhouse was flooded at least 9 to 10 feet deep. Even without including the effects of downstream sediment and debris, the HEC-RAS model indicates that the tailwater at the outlet works would have been at least 771.3, which is more than 7 feet above the top of the training walls and 1 foot above the top of the conduit. The actual height above the training walls may have been as much as 15 feet. When additional District personnel arrived on site at 0930 hrs, the decision was made immediately to close the gates. Emergency shutdown took about 2 hours. With the gates closed, the tailwater was still several feet higher than the training walls.

The Aftermath

Spillway flow peaked at 66,800 cfs on 6 July. By this time, the sediment plugs in the Guadalupe River had fully developed. Water was still flowing through the Horseshoe Falls overflow swale. Six houses built in the swale were completely destroyed, leaving only the slabs, and another six were damaged beyond repair. At least 20 more houses in Horseshoe Falls Estates and another 29 houses between there and the outlet works were damaged. Although outlet works releases were zero, the water was still backed up to the outlet works. Many houses along the river between the outlet works and spillway discharge channels were still flooded. By 8 July spillway flow had stopped going through the Horseshoe Falls Estates overflow swale. However, there was only marginal relief for the upstream homeowners between the spillway channel outfall and the outlet works. The decreasing flows revealed a sediment plug just upstream from the mouth of the spillway discharge channel and a partial plug downstream from the mouth. The upstream plug ponded water all the way to the stilling basin to a height just 4 inches below the top of the training walls.

With the lake elevation now decreasing, attention turned to how to restore outlet works operation in order to draw down the pool below the spillway crest without causing more damage to the stilling basin or additional downstream flooding. It was not known how much riprap and debris were in the stilling basin, and what damage, if any, had been done to the baffle blocks and floor by the grinding action of the "loose" riprap. Volunteer professional divers from nearby San Marcos examined and videotaped the submerged basin on 11 July. They found that a significant amount of riprap was still in the bottom of the basin, and that several of the baffle blocks were partially broken. There was also exposed rebar. Since the stilling basin floor and baffle blocks had been repaired in 1998, this was apparently recent damage. There was also a large pile of submerged riprap just downstream from the endsill. Before the outlet works could be returned to operation, the stilling basin would have to be dewatered, cleaned out, and temporarily repaired, if necessary, to prevent more damage.

The two sediment plugs near the spillway also posed a problem for outlet works operation. The upstream plug had dammed-up the river channel upstream from the

spillway channel outfall. The plug would have to be removed before the stilling basin could be economically dewatered. The removal of the second plug, which was more of an island, would be necessary to restore channel capacity for outlet works releases.

Two separate contracts were used for river channel sediment removal and stilling basin dewatering and cleanout work. The channel contract was awarded to Phillips and Jordan, Inc. on 15 July, and work started on 17 July. The initial contract was for $98,900 and would be paid out based on equipment hours. It was estimated that at least 30,000 cubic yards of material could be removed for the contracted price. The contract was subsequently modified as more funds became available. The stilling basin work was done under an existing local contract with Waco Paving, Inc. and cost $59,147.92. The work was for dewatering and debris removal only.

Stilling Basin Contract. Waco Paving, Inc. started work on 29 July. They built a cofferdam, dewatered the stilling basin, and removed the failed riprap with heavy equipment. They finished on 9 August after removing about 700 cubic yards of rock. An inspection of the cleaned-out stilling basin showed that damage to the baffle blocks and floor was not excessive and that the outlet works could be operated safely to lower the pool below the spillway crest. All of the large riprap downstream from the basin endsill was still intact. The only constraint would be to keep the tailwater below the top of the training walls to prevent additional riprap failure.

Sediment Removal Contract. Phillips and Jordan, Inc. breached and removed most of the upstream plug first. This dropped the tailwater at the stilling basin several feet so that the stilling basin contractor could build a cofferdam. It was evident that removal of the upstream plug would not be enough to allow resumption of full outlet works operation when spillway flows ceased. The downstream island plug would also have to be excavated. The work was difficult and dangerous because flow from the spillway was still greater than 3,000 cfs. Using track hoes with extra long arms, all excavation work was done from the bank. Phillips and Jordan worked until 26 July, and then stopped because the equipment could no longer reach the sediment in the river. Spillway flows were still too high to drive across the channel to the island. The contractor returned on 8 August when the spillway flow had dropped to 1,350 cfs and work could safely start on reducing the size of the island plug. They worked 8 August thru 9 August. Outlet works operation was scheduled to resume on 10 August after the stilling basin work was complete.

In less than a month, over 50,000 cubic yards of sediment had been removed from the river. However, most of the downstream plug still remained in the river. Whether or not there would be enough channel capacity to make 5,100 cfs outlet works releases was not known.

Resuming Outlet Works Operations. Outlet works operation resumed at 0700 hrs on 10 August. The pool was at 943.7 with about 1,350 cfs going over the spillway. Canyon Lake project personnel were stationed along the river to monitor channel capacity between the outlet works and spillway discharge channel. Initially the plan

was to slowly open the gates over a two-day period until the water reached the top of the training walls or was starting to flood downstream habitable structures. If either of these conditions were met, the gate settings would remain at that level until the lake dropped 10 to 15 feet below the spillway crest (elevation 943.0). The outlet works would then be shut down, and more sediment removed from the river. With additional channel capacity, releases would resume and continue until the pool dropped to 909.0, the top of conservation pool. If the gates were fully opened on 11 August with no overtopping the training walls and no flooding of habitable structures, then the gates would remain open until the pool reached 909.0. Under the second scenario it would take about 6 weeks to lower the pool.

The gates were raised in 1/2-foot increments every 30 minutes. First one gate was raised 1/2 foot; then, the other gate was raised 1/2 foot 30 minutes later. This is the normal procedure. At gate openings of 4.0 feet, tailwater in the stilling basin was still below the top of the training walls and no downstream structures had been flooded. The flow in the basin was also stable. However, at 4.5 feet, slug flow in the conduit developed. Waves, 10 to 15 feet high, surged through the stilling basin. This was disappointing. The gates were less than half open, and the total flow was only 3,900 cfs. The gates were immediately lowered to 3.75 feet. Although slug flow was expected as the conduit discharge changed from open channel to pressure flow, it was not expected at this small of a gate opening. That evening it was discovered that the bottom of the 10-ft x10-ft downstream gate may have been below the roof of the conduit, and could have initiated the slug flow at a lower than expected discharge. The gate was hand cranked to a higher position. On 11 August the flood gates were slowly raised to 5.0 feet of opening with no problems. The flow appeared to be on the verge of, or had just gone to, pressure flow. At this point the tailwater was near the top of the training walls, and the two lowest downstream structures were 1 to 2 feet above the water.

The final gate changes to fully open were scheduled for 15 August. In the interim, the lowest house along the downstream reach was to be sandbagged. Additional freeboard would also be gained if the discharge from the outlet works dislodged more sediment in the downstream reach, thus lowering the water surface. It was also determined that 1 to 2 feet of training wall overtopping would not cause additional damage to the sideslopes above the stilling basin. Based on how high the water came up during previous gate changes, it was thought that going to 5,100 cfs would raise the water by about 2 feet, and not cause any problems. By 15 August the pool had dropped to 941.7. There was no flow going over the spillway. When the gate changes were made and the downstream tailwater had stabilized, the conditions were much better than expected. The water surface came up only to the toe of the sandbags protecting the lowest downstream house. The average tailwater at the stilling basin was at the top of the training walls with waves overtopping the walls by a few inches. This was well within acceptable limits.

On 23 September the pool reached 909.0 and discharges were reduced to low flow releases. During the pool drawdown period the average water surface in the reach

between the outlet works and spillway discharge channel was several feet higher than the maximum outlet works release profile under pre-flood conditions. A contract modification was negotiated with Phillips and Jordan, Inc. to remove the mid-channel sediment plug. The final cost of the contract was $235,982. The work was completed by 15 October. Additional dredging is still needed to restore pre-flood channel capacity. A release of 3,500 cfs in November was still about 2 feet higher than pre-flood conditions. The work will be done whenever funding becomes readily available.

Lesson Learned

From a lake operations perspective, the main lesson learned from the Flood of 2002 at Canyon Lake was to decrease or eliminate outlet works releases during uncontrolled spillway operation. Whereas spillway erosion and sediment deposition in the Guadalupe River were not controllable during the flood, damage to the stilling basin and its riprap protection was easily preventable. As a result of this experience, the Fort Worth District will review the approved outlet works operation procedures for all district lakes to ensure that clear and appropriate guidelines are given for making the transition from outlet works to spillway operation.

References

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