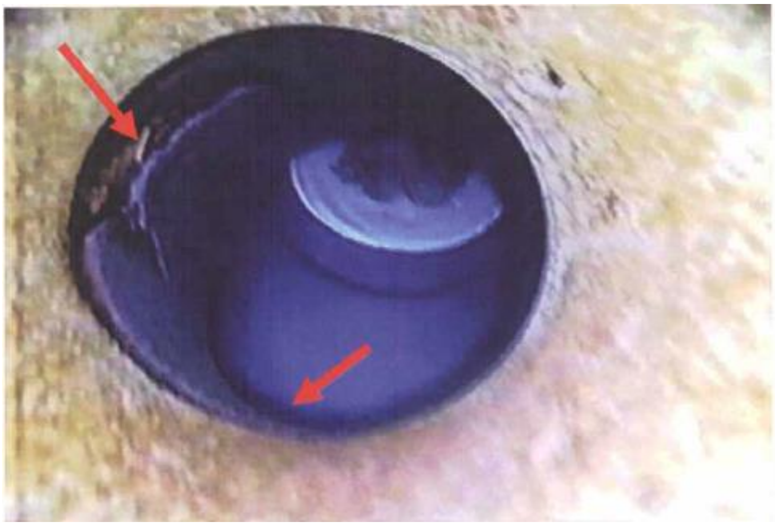
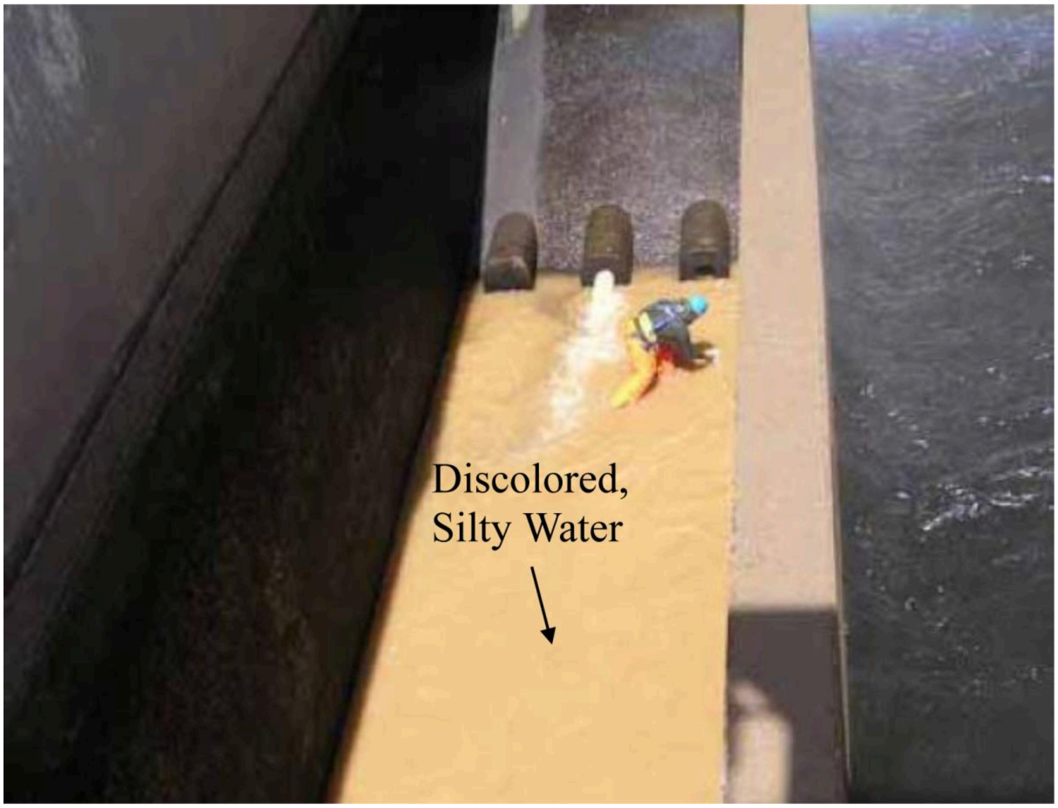
No. 4 and No. 5 were completely filled with sand and gravel. Outfall No. 6 contained a large cobble, which halted the video inspection.



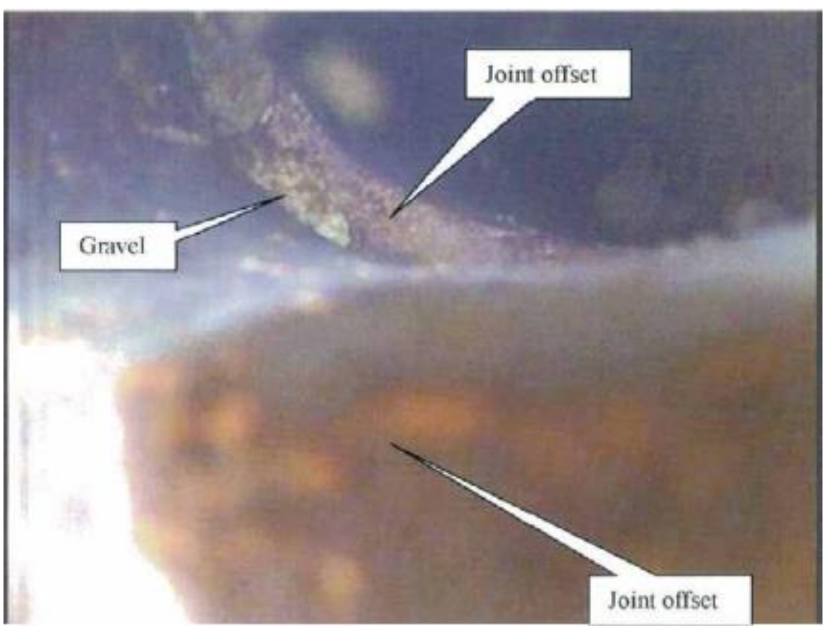
PHOTOGRAPH 1. Rupture in the Drain Pipe in Underdrain No. 2 at the Second Bend. (Hawkins, 2009)

PHOTOGRAPH 2. Crushed Elbow at the Left End of the Spillway Stilling Basin Underdrain System. Arrow points to gravel observed outside the pipe. (Hawkins, 2010)

The dive team performing the camera inspection also inspected the concrete of the stilling basin for damage. The concrete directly downstream of the chute blocks was found to be eroded approximately 2 inches from the original concrete surface. Further downstream from chute blocks at about the middle of the basin, the concrete was found to be eroded in an undulating pattern with an amplitude from ½ to 1 inch deep. The wave-like pattern was postulated to be due to smaller erosive media such as coarse sand and gravel moving through the basin. The inspection concluded that these materials could be moving through the structure's drains.



PHOTOGRAPH 3. Silty Water Entering the Right Side Outlet Works Basin at Sugar Loaf Dam Following the Removal of Temporary Drain Plugs. Also note the significant amount of flow from the drain under the chute. (Pytlik, 2005)



PHOTOGRAPH 4. View of Offset Joints in the Transverse Drain in the Sugar Loaf Outlet Works Drain System at Drain Outfall No. 4. (Hawkins, 2010)

Discussion of the 2008 camera inspection resulted in performing a follow-up camera inspection at the outlet works drains in 2009. Only outfall Nos. 1, 2, and 3 were able to be inspected at the outlet works for this exam. Outfall No. 1 was still clear at this exam. Outfall No. 2, where the rupture was observed in 2008, was now found to be filled with sand and gravel. Outfall No. 3, which had gravel deposits in 2008, was found to be mostly open. However, a new rupture was observed at one of the pipe bend fittings, exposing gravel. The dive team also noted a lack of algae on the concrete immediately downstream of the drain outfalls. This lack of algae indicates flow from the drain outfalls.

The spillway drains were also inspected during the 2009 exam. The spillway only has 4 drain outfalls, numbered 1 to 4 starting at the right wall (looking downstream). Outfall No. 1 was filled with fine sand soon after camera entry. A ½- to 1-inch-diameter hole in the pipe was observed just upstream of the filled pipe. This hole likely occurred during construction from equipment striking the pipe. Outfall Nos. 2, 3, and 4 were mostly clear with only localized sand and gravel observed in the pipe. In each of these pipes, the camera was able to enter the first cross-drain pipe. A vertical pipe at the end of this cross-drain pipe was found to have been forced through the elbow connection, shattering the pipe and exposing gravel outside the pipe as shown on Photograph 2.

Based on the results of both exams, the dive team installed temporary plugs in the drain outfalls for both structures to halt particle movement at the end of the 2009 exam. During installation of the plugs at the spillway, new sand boils were observed immediately to the left of the stilling basin just upstream of the end of the walls. Detailed inspection of the sand boils indicated they were mounding approximately 3 to 4 inches of material. The drain plugs were removed to lower the groundwater in the drain system. When the drain plugs were removed, sand and gravel material accumulated behind the plug was discharged into the stilling basin. These exams and evidence were used to justify repair construction at Twin Lakes Dam.

Sugar Loaf Dam

The first signs of distress at Sugar Loaf Dam were observed during an outlet works concrete examination in 2005. For this 2005 exam, the concrete in the chute and stilling basin was inspected following dewatering of the basin. Temporary plugs were installed in the structure drain outfalls to allow the basin dewatering. The concrete in the stilling basin was found to be eroded up to 2 inches deep, downstream from the chute blocks to approximately the midpoint of the stilling basin. A minor amount of undulation of the concrete erosion was observed. Following removal of the temporary plugs at the drains, silty water discharged from the drain system as shown on Photograph 3.

The outlet works and spillway drain systems at Sugar Loaf Dam were inspected with the CCTV in 2010. At the outlet works, there are four drain outfalls in the chute blocks numbered 1 to 4 from the right stilling basin wall (looking downstream). Outfalls No. 1 and No. 4 are connected to the drain systems below the chute and outfalls No. 2 and No. 3 are connected to the drain systems beneath the stilling basin. At outfall No. 1, silty sand was observed in the pipe near the exit. This material became coarser, incorporating gravel, the further the camera traveled. After several feet of inspection, the camera encountered an offset joint in the pipe. The joint offset was significant enough to allow the entry of gravel-sized material into the pipe. The pipe at outfalls No. 2 and No. 3 were both completely filled with sand and gravel within a couple of feet of the exit. At outfall No. 4, the camera was advanced nearly the same distance as outfall No. 1 before encountering an offset joint. The offset joint appeared to allow gravel to enter the pipe as shown on Photograph 4 and the camera could not be advanced past the joint. The source of the joint offsets is unknown but is likely related to settlement of the drain pipe and the outlet works conduit. Survey results from the outlet works conduit indicate conduit settlements up to 0.3 foot.

The spillway stilling basin drain system has the same number of drain outfalls as the outlet works and they were numbered the same. The camera was advanced about 4 feet into the first outfall to the first cross-drain. This cross-drain was half filled with sediment. Organic material at this cross-drain became suspended in the water and prevented visual inspection of any of the other outfalls. At each outfall, the camera was able to be inserted to a distance of 9 to 10 feet before it could not be advanced any further. The camera inspections indicate it is likely that material is entering the drains and flushing out downstream. The investigations at Sugar Loaf Dam are on-going and future corrective actions are being evaluated.

CONTRIBUTING FACTORS

There are many factors which could contribute to the potential for internal erosion at these drains. The most significant factor is flaws in the drain pipes, which open the pipe interior to the abutting materials. Flaws in the drain pipes can be caused by:

- Settlement of the structures separates joints in the pipe
- Some older clay tile pipe was placed with open joints (Sugar Loaf and Twin Lakes Dams do not have these features)
- Construction defects such as crushed or damaged pipe

However, even with flaws in the drain pipe opening the pipe to materials, internal erosion also requires seepage flow with enough velocity to move particles. There are several mechanisms which may contribute to or exacerbate this flow.

One mechanism is related to operational flows for drain outfalls below the water surface. Observations of the flows in concrete stilling basins indicate that the hydraulic nature of the water in the stilling basin fluctuates. This results in water pressures at the drain outfalls changing between positive and negative pressures, or water flushing into and out of the drain outfalls. This is termed "surging" in Reclamation's dive reports. Thus, materials could fall into the drain pipes due to gravity or minor seepage flows during periods when the outlet works or spillway is not discharging. Then these materials are washed into the stilling basin and downstream during releases. This allows additional material to fall into the drain pipes and sets up a cycle of material removal.

Alternately, the seepage at the structures can be subject to much higher gradients than seepage through the embankment. Seepage along conduits is a known concern, particularly at older structures (Federal Emergency Management Agency, 2005). For Twin Lakes and Sugar Loaf Dams, the seepage gradient through the embankments typically ranges from 0.18 to 0.19. It is probable that this seepage is forced under the chute structures of the outlet facilities. The chute structures at these dams range from 23 to 51 feet in height. The seepage gradient under the much shorter horizontal distance of the chute increases to 0.33 to 0.36 for Twin Lakes and Sugar Loaf Dams, nearly double the anticipated gradient through the embankments. This general relationship is shown on Figure 5.

The gradient at the structures is also impacted by unwatering the basins for inspection. Typically, structures are unwatered very quickly to reduce the downtime associated with the examination. This can result in the equivalent of rapid drawdown with the fill beneath the basin retaining water while the basin is unwatered. This mechanism also exacerbates the gradient in the drain system and can result in the flushing of materials through the drain outlets.

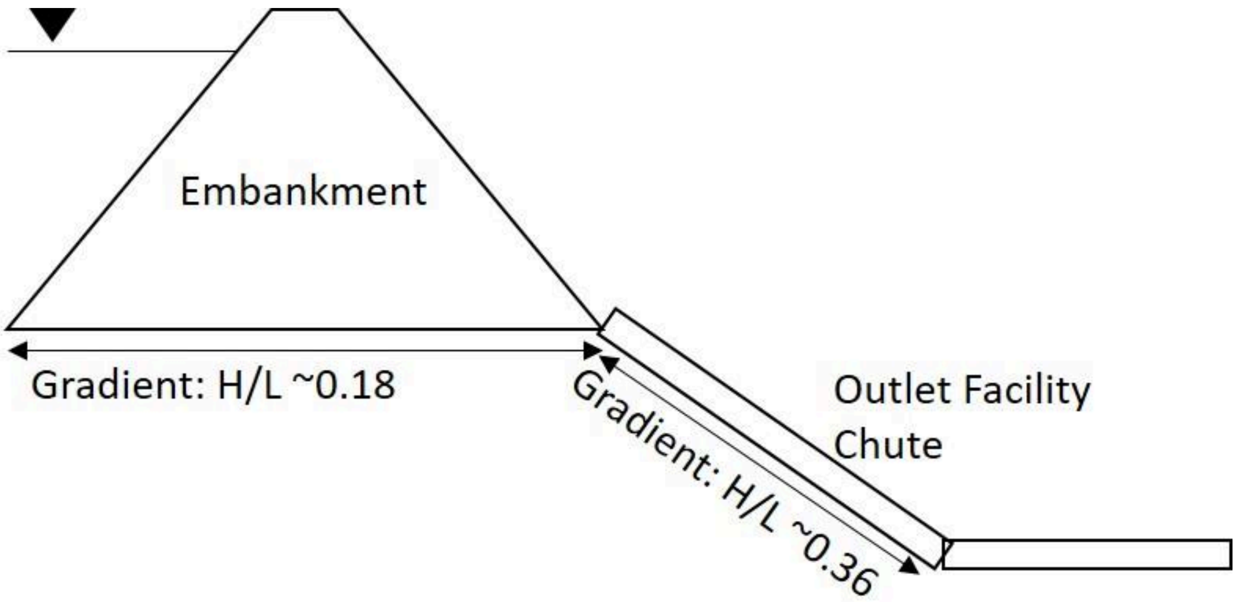


FIGURE 5. General Relationship of Typical Gradient Values Through the Embankment Compared to Gradient Values at Outlet Facility Chutes With Elevation Drop.

TWIN LAKES DAM MODIFICATION

Following the CCTV exams at Twin Lakes Dam, the decision was made to grout the structure underdrains (Maier and Heyder, 2015). Based on the observations of the material movement, it was assumed that voids had developed under the structure, with the voids connected to the drain pipes. Grouting was determined to be the most comprehensive repair method.

Prior to the grouting repair, the stability of the outlet works and spillway concrete structures was analyzed. These concrete basins could be subject to uplift during unwatered loading or high groundwater conditions. The drain systems were designed to relieve the uplift pressures which could float the basins. Both structures were found to be stable when unwatered considering increased groundwater conditions, resulting from the drain grouting, surrounding the structures.

The probability of redirecting seepage below the structures to new outlets adjacent to the structures was also considered. Twin Lakes Dam has an extensive sand blanket to filter seepage emerging at the toe of the embankment. Thus, any seepage routed from beneath the structure into the adjacent areas is now filtered and the potential for the movement of particles is reduced.

Grouting the drain systems was performed by Reclamation drilling and grouting staff directed by a civil engineer experienced in grouting dam foundations and drain systems. The grouting was accomplished through several steps to maximize the grout take and void filling, including:

- Drilling grout holes through structure concrete
- Pressure testing to evaluate back pressure
- Dye testing to evaluate water flow and boring locations
- Grouting

The outlet works was repaired first. Eight borings were drilled through the right bay concrete and six borings were drilled through the left bay concrete as shown on Figure 6. Packers were installed in each boring following the drilling. At each boring, the crew used the presence of foam and PVC pipe in the drill bit to determine if they had intercepted the drain pipe. Out of the borings drilled, only R-5 missed the drain pipe while borings R-2, L-5, and R-7 were not located to intercept the drain pipes.

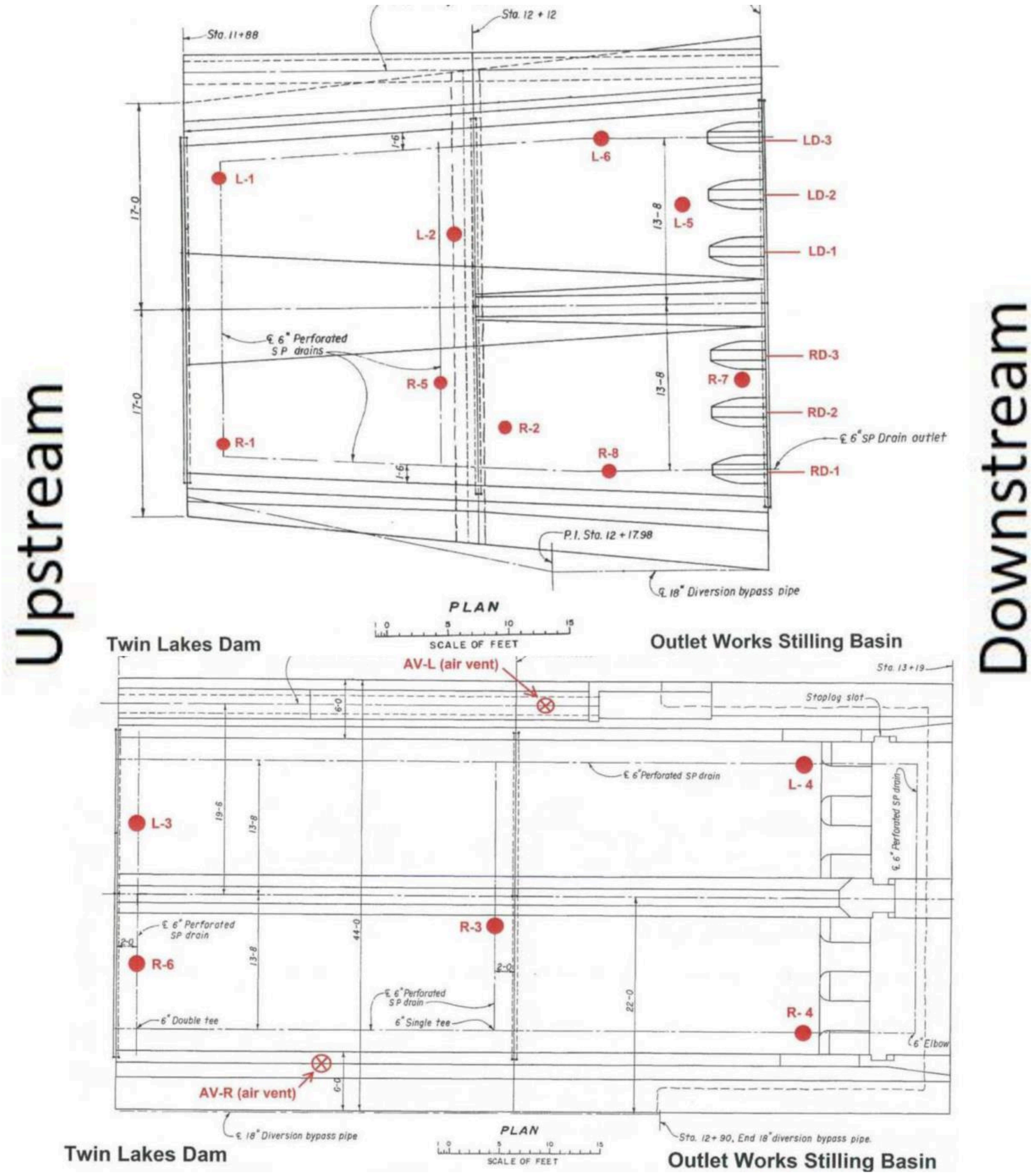


FIGURE 6. Boring Locations for Grouting Twin Lakes Dam Outlet Works.

Water under pressure was encountered at all the borings in the bottom of the stilling basin and at the borings lower on the chute. This was a changed condition from the assumed conditions and increased the difficulty of installing the packers in each boring. Additionally, flows from borings L-2, R-2, and R-5 were cloudy and moved small amounts of sand and gravel, further evidence that material was exiting through the drain system. Voids of 0.55 foot and 1 foot were observed in borings R-7 and L-5, respectively.

Once the borings were drilled and the packers were in place, the borings were pressure tested to evaluate the back pressure. The back-pressure readings were used to determine the net pressure of grouting (the gage pressure minus the back-pressure). Back-pressure readings ranged from 0 to 6.8 psi.

The dye testing was performed to evaluate the water flow directions under the structure. For optimal grouting, it is best if the grout is traveling upstream against the water flow and to displace air. The dye testing showed the downstream direction of the flow.

Blue dye was injected at boring R-1 (assumed to be the furthest upstream). Dye was observed at most of the borings within 23 minutes. Dye was not observed exiting three of the drain outfalls including the one which appears directly attached to boring R-1. The dye was first observed at boring R-6, far downstream of R-1, which was assumed to indicate an interconnected void beneath the slab connecting the upstream drains to the downstream drains. The dye was observed at boring R-5 last, indicating that while it is likely this boring did not intercept the drain pipe, it was connected to the network of voids.

The grout used had a water to cement ratio ranging from 0.6 to 0.7 by volume. Grouting was performed starting at the lowest boring, R-4, and proceeding upstream. At first, grout was pumped with all valves open. Typically, grey water was observed at the valves prior to observing grout. Open valves were closed once heavy grout was observed from any boring. This progression was used to grout from the downstream end of the stilling basin to the uppermost borings on the chute, R-1 and L-1. The grout takes at both of the uppermost borings were relatively low under higher grout pressures indicating that most, if not all, of the seepage paths beneath the structure from this point had been filled and grouting was completed at the outlet works structure.

For the outlet works, the total grout pumped through the system was 14 cy. The total estimated volume of the drain system pipes was 6 cy. Thus, approximately 8 cy of void volume was filled under the structure.

Following the grouting at the outlet works, the construction shifted to the spillway structure. Ten borings were completed through the spillway chute and stilling basin concrete as shown on Figure 7. Packers were installed in each boring following the drilling. At each boring, the crew used the presence of foam and PVC pipe in the drill bit to determine if they had intercepted the drain pipe. Each of the borings planned to intercept the drain pipes was successful. Boring S-9 was completed to evaluate the presence of voids beneath the structure but no discernible void was found. Boring S-8 was located at the downstream end of the structure for initial grouting to slow any water flow through potential voids under the structure and to increase the probability that the remaining borings could be successfully grouted without washing out.

Once the borings were drilled and the packers were in place, the borings were pressure tested to evaluate the back pressure. The back-pressure readings were used to determine the net pressure of grouting (the gage pressure minus the back-pressure). Back-pressure readings ranged from 0 to 6.4 psi.

The dye testing was performed to evaluate the water flow directions under the structure. Blue dye was injected at boring S-1 (assumed to be the furthest upstream). Dye was observed at all the boring locations within 1 hour and 25 minutes. A small sand boil was located adjacent to the left spillway wall in the spillway stilling basin. Dye was observed at this sand boil 20 minutes after injection at boring S-1 as shown on Photograph 5. It was concluded that this is indication of a large void beneath the structure which was allowing water flow to pass directly from the upstream end of the chute to outside the stilling basin structure.

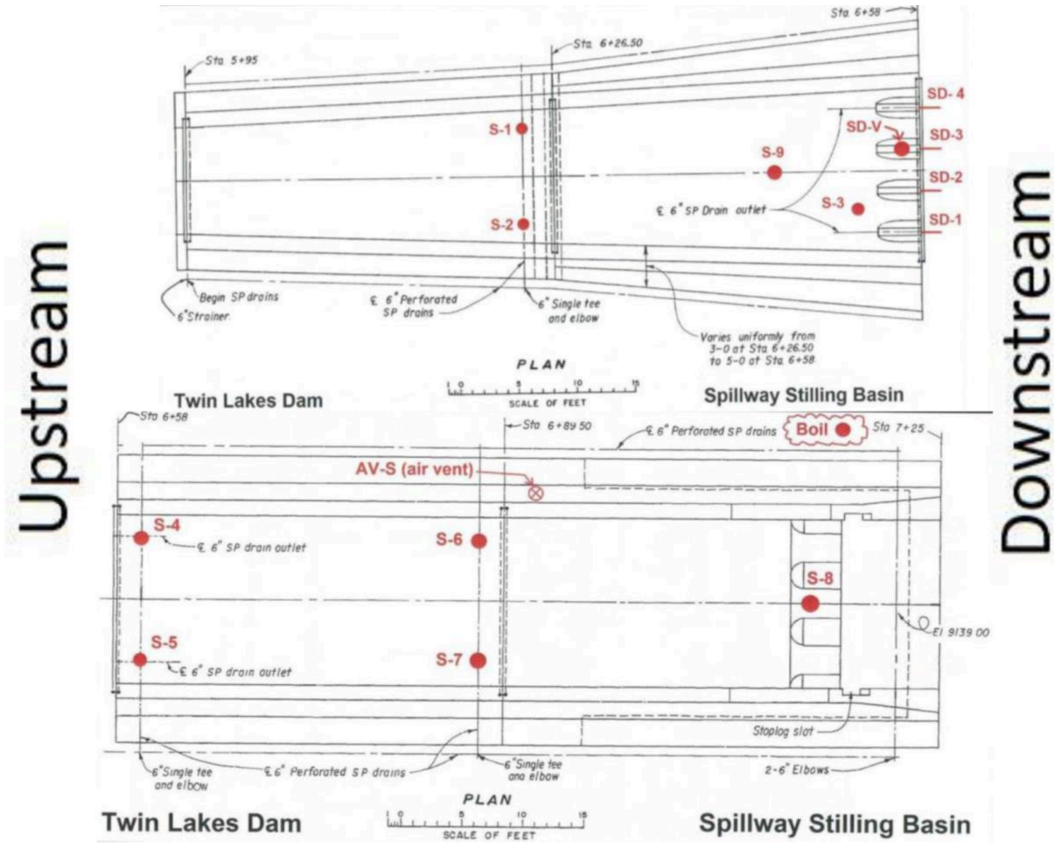
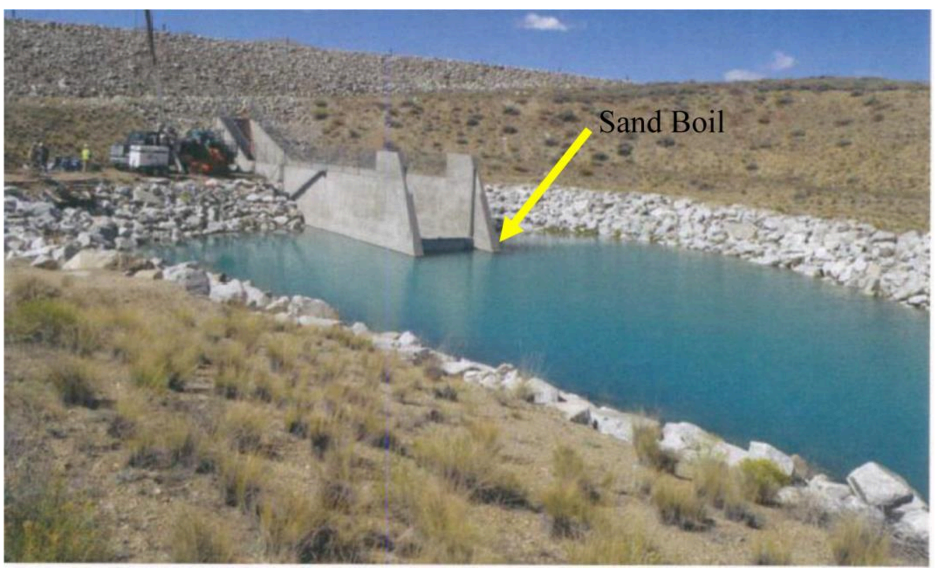


FIGURE 7. Boring Locations for Grouting Twin Lakes Dam Spillway.



PHOTOGRAPH 5. Water in the Spillway Pool Dyed Blue Through Seepage at a Boil Adjacent to the Spillway.

The grout used had a water to cement ratio ranging from 0.6 to 0.7 by volume. Grouting was performed starting at boring S-7 and proceeding upstream with the option to switch to S-8 if needed to slow water flow. At first, grout was pumped with all valves open except S-6 (due to proximity) and SD-3. Within 5 minutes of pumping grout, cloudy water was observed at the sand boil adjacent to the left wall of the spillway stilling basin. Ten minutes later, grout was observed at the sand boil. From that point, grouting was moved to further upstream borings and followed the same protocol as grouting at the outlet works. The last boring grouted was boring S-8 at the downstream end of the stilling basin. Higher grout pressures and low take at this boring indicated grouting was complete.

For the spillway, the total grout pumped through the system was 13 cy. The total estimated volume of the drain system pipes was 6 cy. A dive inspection at the adjacent sand boil was performed and the estimated volume of grout ejected at the sand boil was 2 to 3 cy. Thus, approximately 4.5 cy of void volume was filled under the structure.

Following the grouting, each boring was dry packed with concrete. The drain outfalls were also filled with concrete using a plywood hopper. The sand boil adjacent to the spillway was inspected following the grouting and the seepage at this location had stopped. However, some increased seepage was observed at other areas around the spillway, indicating seepage had found new paths near the structure. The frequency of visual inspection and instrumentation monitoring at the dam has been increased to twice weekly when the water is below the spillway crest and daily when the reservoir is spilling to monitor for any additional changes in the seepage at the facility.

CONCLUSIONS AND RECOMMENDATIONS FOR PRACTICE

Problems were found in the outlet works and spillway drain systems at Twin Lakes and Sugar Loaf Dams. The drain systems at Twin Lakes Dam were compromised by construction defects and structure settlements. The drain systems at Sugar Loaf Dam were likely compromised by structure settlements, which are up to 0.3 foot at the outlet works conduit based on survey results.

Signs of the defects in the drain systems at both dams included offset joints and pipe breaks, pipes filled with sediments, concrete abrasion damage, and discharge of sediments from the drain pipes. Drain systems at both dams were installed with dual stage filters, consisting of gravel and sand envelopes surrounding the pipe. However, the problems with the drain pipes have been large enough to pass particles up to the gravel size used for the filters, rendering the filters ineffective.

The particle movement and probability of internal erosion at Twin Lakes Dam provided the justification for repairs. The repairs consisted of grouting the drain system. The grouting program at Twin Lakes Dam revealed the probable existence of voids beneath the outlet works and spillway structures up to 8 cy, which were filled during the grouting program.

It should be noted that all of the grouting was performed under the direction of a civil engineer with grouting experience. Any grouting project at a dam needs to proceed with extreme caution and safeguards in place. The injection of pressurized grout into a dam foundation or the foundation of a dam structure can have unintended consequences. Reclamation requires the onsite presence of an experienced engineer for any foundation or backfill grouting project.

The drain system issues found at Twin Lakes Dam and Sugar Loaf Dam have been observed at other Reclamation facilities and issues have been noted at other facilities as well. Several steps can be used to detect issues with these outlet and spillway facility drainage systems, including:

- CCTV examination of the drain systems
- Examination of the concrete condition at the drain outfalls and in drain stilling basins

There are no known failures directly related to internal erosion through these drain systems at this time. However, internal erosion through these drain systems can lead to the formation of voids, sinkholes, and can undermine chute structures. These symptoms can lead to larger issues if not detected and repaired. It is recommended that special site examinations of chute and stilling basin facilities include considerations for drain systems. Camera inspections should be performed if possible. Observations of the concrete condition can also be used for early detection of drain system problems. Unwatering of stilling basin facilities should be performed sparingly and consider the impact on the drain systems. Unwatering should avoid rapid drawdown conditions which could potentially flush materials out through the drain system and damage the surrounding filter(s).

ACKNOWLEDGMENTS

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