Association of State Dam Safety Officials 2014 National Conference

Dodging a Bullet: Lily Lake Dam and the 2013 Colorado Flood

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Abstract

This paper is about identification of high risks at a dam, multiple efforts to promptly mitigate those risks, and how the 2013 Colorado Flood severely tested those mitigation efforts. Had the National Park Service (NPS) not made major efforts to improve the safety of the dam before the event, the dam could have failed by lateral spillway erosion and head cutting, threatening the lives of people in more than two dozen homes downstream.

This paper and companion presentation are to share the lessons the NPS and others learned in the areas of risk estimation/evaluation, Emergency Action Planning, environmental compliance, Early Warning System, dam repair, monitoring, event detection, incident response, and incident documentation. The paper describes the use of the Bureau of Reclamation – *Small Embankment Dam Safety Guideline* [1] approach of teamwork, expert elicitation, making conservative assumptions, building consensus, and the leadership needed to move a high risk, but small dam, project forward in a timely manner to reduce confirmed high risk exposure.

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A. Background and Risk Estimation/Evaluation

Dam Description and Setting

Lily Lake Dam (245 ft long and 15 ft high) is an embankment dam in Rocky Mountain National Park (RMNP) in the headwaters of Fish Creek above the town of Estes Park. It was constructed in 1913 and enlarges a natural lake. The reservoir has an area of 18 acres and has a maximum storage at dam crest of 92 ac-ft. The crest is from 6 to 15 feet wide at elevation 8,926 feet. The spillway invert is about 10 feet wide with a crest that is 3.5 feet below the crest of the dam. The dam is approximately 200 feet upstream from Colorado State Highway 7 which provides access into and out of the Town of Estes Park. The dam's reservoir, Lily Lake, is a highly used recreation area with a trail along the dam crest and around the lake.

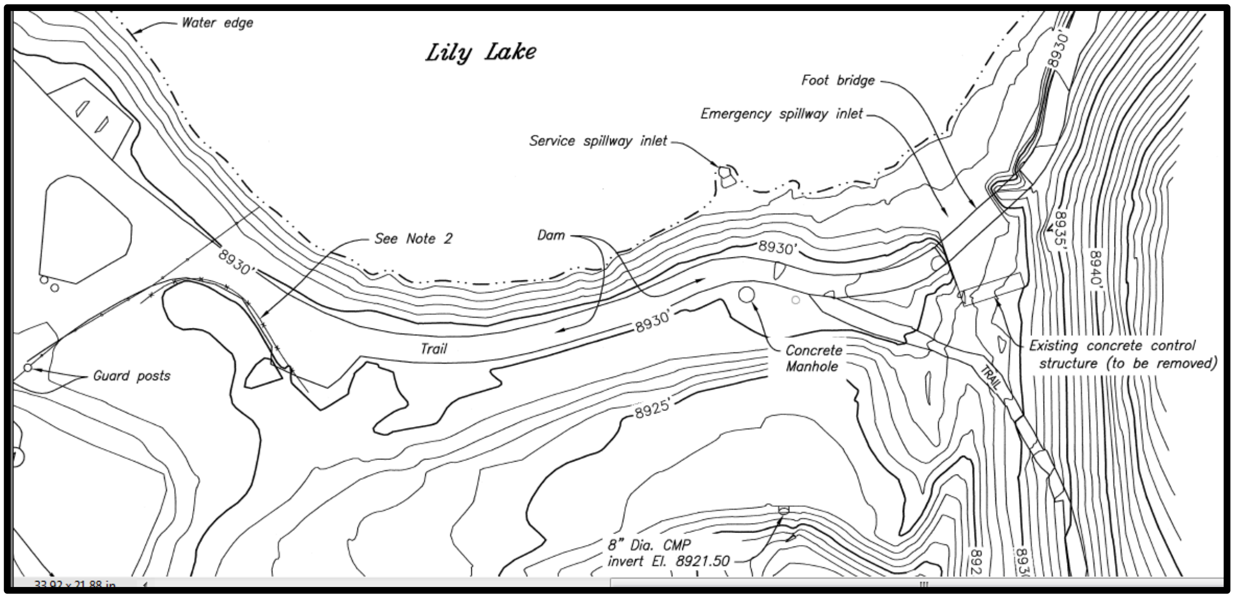


Figure 1 - Survey of Lily Lake Dam before repair (Reclamation)

<u>1951 Dam failure</u>

The then privately-owned dam failed in May of 1951. An investigation found that "The failure of the dike of Lily Lake was caused by wave action resulting from high winds that occurred … Terrific lashing waves pounded a hole through the earth dike sometime prior to 0500[AM] … releasing lake water." A witness saw waves 2 to 3 feet high rolling across the lake. [2] About 75 ac-ft of water was released.

An eye witness just downstream related that when he arrived the water was overflowing State Highway No. 7, and that within 10 minutes, "the paved surface was lifted and was carried down into the canyon, trees and boulders crashing with it." [3] There were no injuries or loss of life although 2 homes and a county road were also flooded. Damages were estimated at $10,000.

Figure 2 - Breach in State Highway 7 just downstream from the dam. (1951)

In the 1990's the land and the dam came under ownership of the National Park Service (NPS). An 8-inch diameter PVC drop-inlet spillway pipe was installed 3.5 feet below the dam crest.

Potential Downstream Hazard Classification History

The 1992 Bureau of Reclamation (Reclamation) hazard classification report [2] stated that the State of Colorado hazard classification of *Significant* continues to be valid. It was believed that there would be time to warn motorists on Highway 7 and that flood flows would spread out in the downstream agricultural valley. The report also stated that as a result of a seepage and sloughing problem, there was a reservoir restriction in place. The *Significant* hazard rating indicated from 1 to 6 lives were at risk from dam failure.

In 2010, Reclamation reviewed the hazard classification [4] using newer FEMA 333 hazard classification guidelines. These FEMA 333 guidelines indicate a dam should be assigned a *High* hazard classification if it is probable that at least 1 life will be lost. The Reclamation report states that there has been a great deal of new development downstream from the dam since the 1951 failure and lists 29 homes in the flood path below the dam. Beavers have also taken up residence in Fish Creek. Dam failure would result in beaver pond dam failures and release of debris-laden flows. People caught in vehicles during flood flows would have difficulty escaping because Fish Creek runs along the main road through this area. Based on this report, the NPS changed the hazard classification of Lily Lake Dam to *High.*

2009 Risk Screening Report

At the request of the NPS, Reclamation completed a screening-risk study of Lily Lake Dam in 2009. [5]

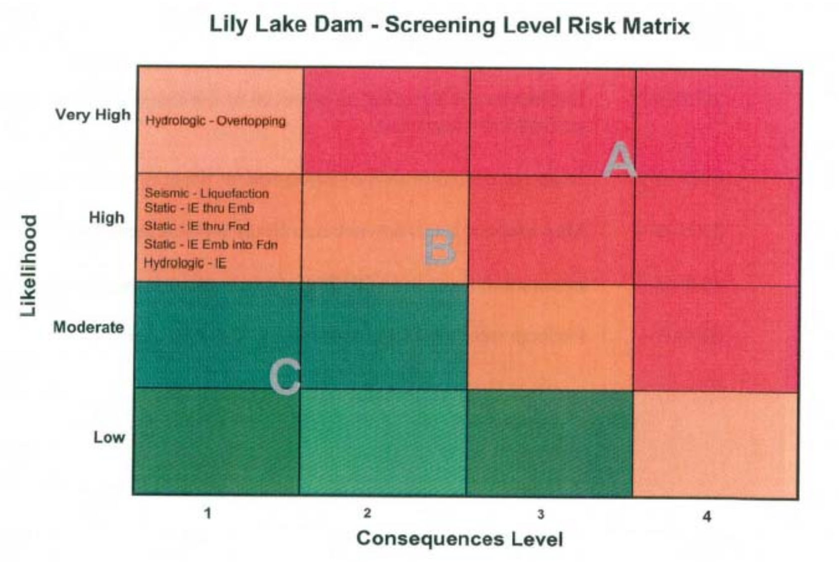


Figure 3: Risk Screening Report Results for Lily Lake Dam, (2011 Reclamation)

The hydrologic overtopping failure mode had the highest risk. Seismic liquefaction and 4 internal erosion-related failure modes also had high risk.

The report stated that overtopping occurs at approximately the 1:100 chance-per-year flood. For the hydrologic overtopping failure mode, progression is described as: “During a large flood, the dam is overtopped starting at the overflow spillways on each abutment, eroding the downstream slope until the crest is breached and erosion of the embankment occurs to the base of the dam at about elevation 8915.” The report made recommendations for additional studies but also stated that these studies were unlikely to change the existing high risk estimations for the dam (especially hydrologic overtopping).

2012 Issue Evaluation Report

At the request of the NPS, Reclamation completed an Issue Evaluation [6] study of Lily Lake Dam and issued the report in February 2012. The consequence level was raised from 1 to 2 to reflect the revised hazard classification rating. A failure mode was added for wave erosion of the crest to reflect the failure mode from the 1951 failure.

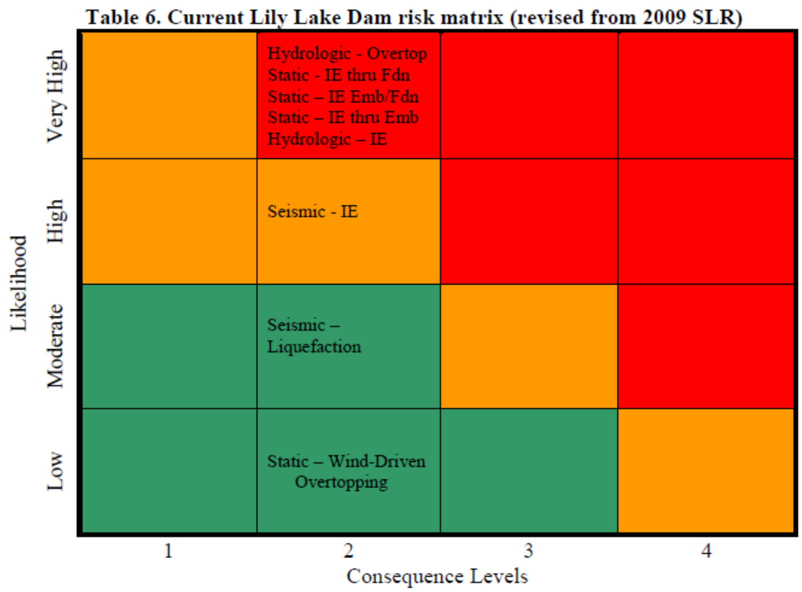


Figure 4: Revised risk chart from Issue Evaluation report (2012 Reclamation)

<u>Risk Context and Program Response</u>

It is the mission of the NPS Dam Safety Program (DSP) to ensure risks do not present unacceptable risks to NPS resources and the public. With the new 2012 risk chart and the 2011 hazard classification report, the NPS Dam Safety Officer (DSO) became very concerned about the high risks of the dam for failure during floods and internal erosion failure modes.

The situation was not favorable for the dam. In 2011 (when a new DSO was assigned) there was no dam tender assigned for the dam. There was also no training, no routine dam monitoring, no Emergency Action Plan, no inundation map, no outlet works camera inspection, and no Early Warning System. No dam repair designs were being considered.

The risks of Lily Lake dam failing were the highest in the NPS inventory of dams. According to Reclamation guidelines, dams with *High* hazard classification ratings should be able to pass the 1:10,000 chance-per-year flood and Lily Lake Dam could only pass approximately the 1:100 chance-per-year flood.

The internal erosion risks were also a great concern. The dam was believed to be homogeneous and the area downstream indicated some seepage was making its way through or under the dam. The condition of the downstream end of the corrugated metal pipe (CMP) outlet pipe increased concerns about internal erosion failure modes.

Figure 5: Corroded interior of the outlet works pipe viewed from the downstream end (2011 Reclamation)

Figure 6: View of outlet works conduit 43 feet upstream from downstream end (5/23/12 Reclamation)

<u>"EXPEDITED"</u>

While the risks at the dam were high to very high, the program did not have an emergency to respond to. The program considered how to get the appropriate high priority for risk reduction measures. Park staff has many responsibilities and priorities and the program was concerned that the risks at the dam would not be addressed for a long period. The dam and reservoir are small and the risks of dam failure are not obvious to the people not experienced in the destructive power of dam failure floods.

To provide recurring reminders to people about the need for promptly addressing the risks, the DSO began putting the word "EXPEDITED" in all caps on the subject line of dam documents including emails.

B. Responding to Risk

The program employed several strategies to "buy down" the risk. Some strategies could be implemented quickly while others would require months and years to accomplish.

Strategy 1: Ensure park staff are alert for a problem developing at the dam and be prepared to respond.

In early 2011, the program requested the park to do the following:

1. Assign a dam tender and visually inspect the dam once per month.
2. If a rain-fall event that would cause the reservoir water surface elevation (RWSE) to rise significantly is about to occur, or is occurring, the dam tender should go to the dam and inspect for the following:
   - Sloughs, slides, depressions, or cracks
   - Evidence of seepage, piping, or boils on downstream slopes, groins, and for a distance of 100 feet downstream of the embankment toe
   - Sinkholes
   - Whirlpools in the reservoir
3. The park should proceed with purchasing a pump to draw down the reservoir if a seepage or other threatening event were to occur.
4. Identify reasonably close source(s) for free draining sand and gravel to address a seepage problem that could develop.

Strategy 2: Get a new Probable Maximum Flood Study (PMF) completed

It was obvious to the program that the dam would need to be modified to safely pass a much larger flood. As stated, if we used the Reclamation standard for a high hazard dam the dam would need to be modified to be able to pass at least the 1:10,000 flood. Developing PMF-level floods are straight forward in the dam safety industry. Developing the 1:10,000-level flood would be challenging, involving interpretation of nearby flood frequency studies (if there were any) or new paleoflood work. Because Lily Lake Dam is a small dam and time was of the essence, the program decided that it was more important to proceed with a dam repair based on the hydrologic design loading for a PMF-level flood rather than spend the time and money on the slim possibility that the 1:10,000 study would result in a significant cost savings.

The program therefore requested Reclamation to complete a new PMF study which was available in June 2011. [7] The study showed that the dam would experience from 0.4 to 0.9 feet of overtopping for up to 49 hours in a PMF event. No threshold flood (flood frequency at which the dam would overtop) was identified.

Strategy 3: Develop a NPS Flood Awareness Video

Because Lily Lake was a small dam and people are not experienced with the potential massive damage and loss of life that can occur from dam failure, the program developed a 14-minute NPS dam safety awareness video called *Managing the Risks of Dams*. [8] Over 9 minutes of the video were about the 1982 Lawn Lake Dam failure also in RMNP. There were 3 lives lost in this event, flooding of downtown Estes Park and over $30 million in damages. The first showing of this film was during the Lily Lake Emergency Action Plan exercise (described next). The film added realism to the exercise and increased the credibility of the dam safety concerns at Lily Lake Dam.

Strategy 4: Develop and Exercise an Emergency Action Plan (EAP)

Federal Guidelines for Dam Safety and Department of the Interior/NPS policy requires EAPs and exercises for all High hazard potential dams. The program procured Reclamation under an interagency agreement to develop and exercise an EAP for Lily Lake Dam.

Following several planning meetings, the exercise was held on April 5, 2012. The exercise was attended by 21 entities including: NPS, National Weather Service, police dispatch, the Red Cross, the Town of Estes Park, Larimer County, and the State of Colorado.

Strategy 5: Install an Early Warning System (EWS)

Although Lily Lake Dam is located adjacent to a highway, it is not monitored frequently by park staff. Because internal erosion and hydrologic failure modes were identified as high risks, the DSP and park decided to install a remote monitoring system for the dam. Reclamation installed a system consisting of:

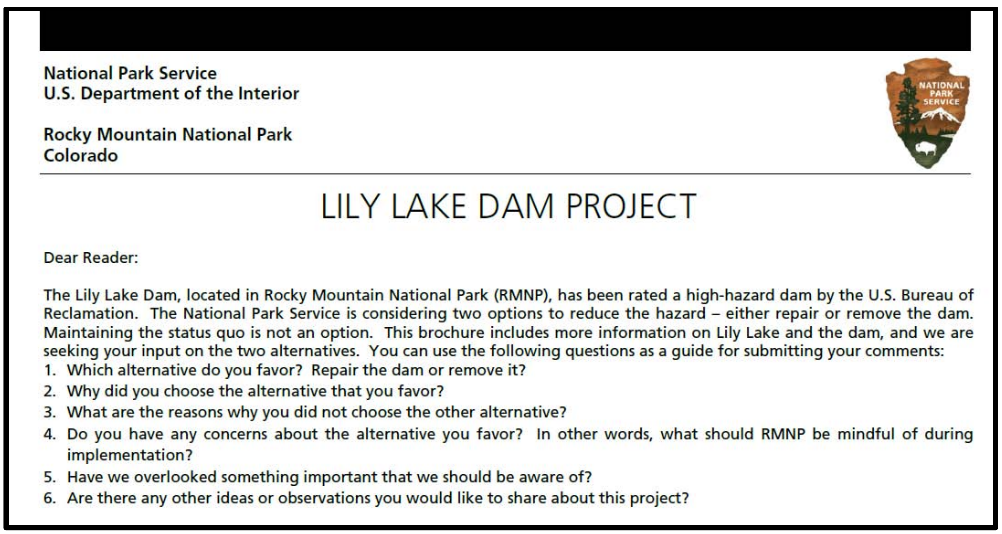
- Three float switches in the channel below the dam just upstream from the highway inlet culvert,
- A precipitation gauge with tipping bucket
- Solar panels and battery for power
- A satellite transmitter

Importantly, Reclamation also developed decision criteria to determine when alarms should be sent to park and program staff and establish notification protocols. System data would be transmitted to the Bureau of Indian Affairs National Monitoring Center in Ronan, MT.

Strategy 6: Help the Park Promptly Decide whether to Breach or Keep the Dam

Manmade dams within national parks may need to be removed unless they provide significant value to visitor experience or natural resources. RMNP was not sure the public would want to keep or remove the dam.

The park pulled together a team of senior park management, facilities and public affairs staff to develop a brochure about the dam (and its concerns) and the options. Many comments received and approximately equal numbers were for keeping the dam as for removing the dam.


National Park Service
U.S. Department of the Interior

Rocky Mountain National Park
Colorado

LILY LAKE DAM PROJECT

Dear Reader:

The Lily Lake Dam, located in Rocky Mountain National Park (RMNP), has been rated a high-hazard dam by the U.S. Bureau of Reclamation. The National Park Service is considering two options to reduce the hazard – either repair or remove the dam. Maintaining the status quo is not an option. This brochure includes more information on Lily Lake and the dam, and we are seeking your input on the two alternatives. You can use the following questions as a guide for submitting your comments:

1. Which alternative do you favor? Repair the dam or remove it?
2. Why did you choose the alternative that you favor?
3. What are the reasons why you did not choose the other alternative?
4. Do you have any concerns about the alternative you favor? In other words, what should RMNP be mindful of during implementation?
5. Have we overlooked something important that we should be aware of?
6. Are there any other ideas or observations you would like to share about this project?

Figure 7: RMNP solicited public comment for whether the dam should be breached or repaired

However, during the time of public review, the park discovered that there were water rights associated with the purchase of the dam and land during the 1990's. Legal staff determined that the NPS could not divest itself of the dam. The park made the decision to repair the dam.

Strategy 7: Fix Rather than Study

One effective strategy for small dams is to assume worst case and to proceed to repair. Many small embankment dams (including Lily Lake) were constructed before the use of modern internal filters and drains to control and safely carry away seepage. Additional exploration of old embankment dams usually uncovers worse conditions rather than better conditions. Conservative repair decisions can be made more quickly than waiting for expensive explorations, testing and analysis. The additional cost of conservatism is smaller for smaller dams.

Strategy 8: Be Strategic in Repair Decisions for All Failure Modes

For Lily Lake Dam, we made the following repair decisions:

For hydrologic analysis, we would repair for the full Probable Maximum Flood 1080 cfs. This worst case rainfall event (thunderstorm) would result in overtopping of the dam for 4 hours with a maximum depth of 0.4 to 0.9 feet. Fortunately, the NPS has experience with articulated concrete block (ACB) overtopping protection (see figure 8). This system works well with small dam, small depth applications. The NPS likes this system because soil and vegetation is put on top of the ACBs during construction gives a natural appearance to the completed dam. Furthermore, we draped the ACBs over not only the entire crest and downstream slope of the dam, but in a continuous blanket through the spillway as well. This eliminated any weakness between the dam downstream slope and the spillway reducing spillway lateral erosion concerns (a key decision as it later turned out). This decision also allowed us to use the existing timber pedestrian bridge over the spillway and minimize public perceived changes to the heavily visited dam. Boulders removed from the spillway during the repair project would be placed back on the sides of the spillway following installation of the ACBs to maintain historical appearance.

For internal erosion failure modes, we decided to construct a filter/drain along the downstream toe of the dam (see figure 8). There had been wet areas below the dam and this toe drain would provide the state-of-practice protection for seepage through or under the dam.

For the outlet works pipe-related failure modes, we used another small dams strategy. All dams should have a means to evacuate the reservoir if there is a problem with the dam. For most dam owners and regulators, this means that the dam must have adequate outlet works capacity to drain the reservoir in a specified period of time (Bureau of Reclamation requires 30 days). But there is another way of evacuating the reservoir: pumps. The dam is located next to a state highway and the park’s Emergency Action Plan has the names and contact information for pump rental companies to send pumps to the dam. These pumps can evacuate the reservoir much more quickly than the 10-inch outlet works. The internal video camera inspection of the outlet works showed even worse corrosion that at the downstream end. So, we decided to abandon the outlet works by grouting it shut. The failure mode of internal erosion along the outside of the conduit would be addressed by covering the downstream end of the conduit with the filter/drain.

Strategy 9: Address Environmental Permitting Early and Often

The project team knew from experience that if we did not get the right environmental compliance permits in hand, the construction contract would not be awarded. We made the decision early to engage with park environmental permitting staff. They (and Denver Service Center environmental resource staff) met with the project team in our every-two-week meetings. We had wetlands delineation work done early in the design process so that the spillway design would be compatible with plant, fish and wildlife needs. We obtained the 401 water quality permit and the 404 working in a wetland/navigable waters permit.

Repair Design and Construction

The dam repair design was performed by the Bureau of Reclamation beginning in late 2011 and completing in June 2012. The contract was awarded to Ayuda Management Corporation. Construction took place between July and December 2012. As stated, the design featured ACB overtopping protection, a filter/drain zone excavated at the toe of the dam and grouting of the outlet works pipe.

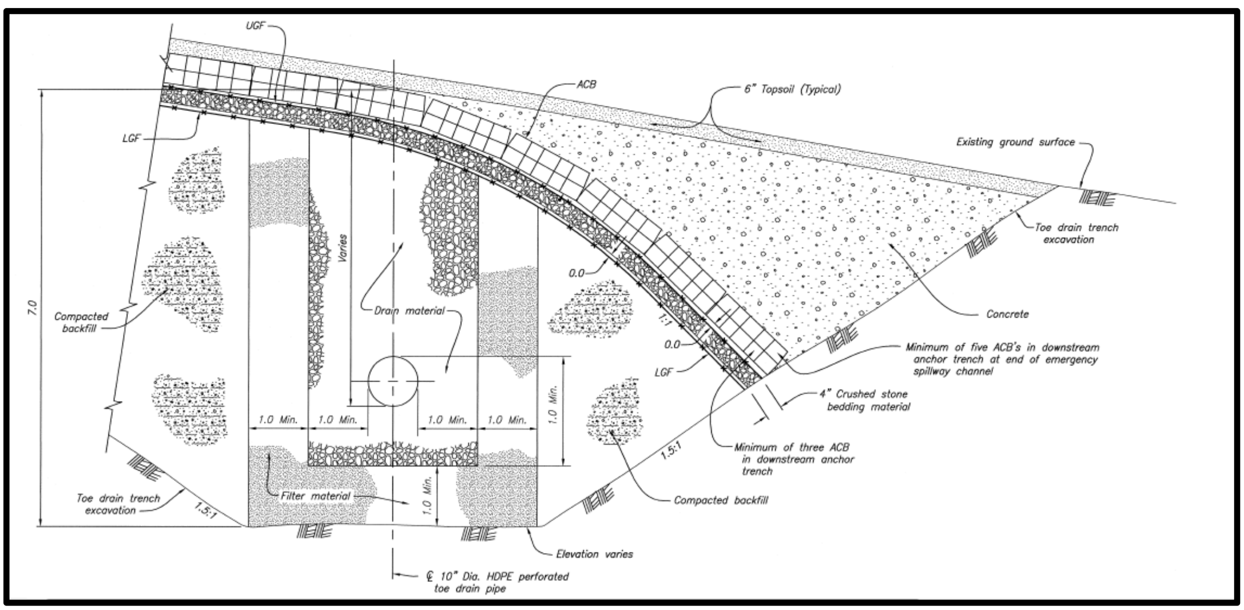


Figure 8: Design detail section of two-stage filter/toe drain and downstream end of ACB blanket (Reclamation)

One of the most important strategies used to move quickly through the environmental permitting, procurement, design and construction activities was the every-other-week phone call. These conference calls were between the NPS Dam Safety Officer, the Intermountain Regional Dam Safety Coordinator, the NPS Denver Service Center (DSC) (contracting), RMNP (permitting, access, visitation control, and other park issues) and the Reclamation’s Technical Service Center (TSC) (design). By having all of the involved parties involved from the beginning of design, we were able to identify project risks early and address them before they impacted our schedule.

Figure 9: Installation of the ACB overtopping protection system. The spillway is in the foreground – photo dated November 5, 2012 (Reclamation).

One of the biggest challenges of the project was completing construction before winter set in. The contractor did not start work until August, so completing the work before November was a concern. We did not want to wait until 2013 to repair the dam because that would mean another year of living with identified and verified high dam safety risks.

Although work was delayed due to a snowstorm in October, it was a relatively mild fall and the construction was substantially complete by the end of November.

Figure 10: Lily Lake Dam following dam repair – circa December 2012 (Reclamation)

C. Lily Lake Dam and the Colorado Flood of 2013

Flood and Initial Response

Fast-forward nine months to September 2013. The dam had been repaired and was functioning well. The dam was exactly 100 years old.

On September 9, 2013, a large and slow-moving storm system stalled over Colorado. In the early morning hours of September 12 the NPS Dam Safety Officer (DSO) received text messages from the BIA National Monitoring Center (NMC) that "The LILY LAKE PRECIPITATION ACCUMULATION is greater than 2.4 inches in the past 6 hours, which is greater than the 25 year rainfall event."

Five minutes later, another message indicated 3.5 inches had fallen in the last 24 hours.

An hour later, a third message stated that 4.3 inches had fallen in the last 24 hours which corresponded to the 100 year rainfall event. The message also stated that the Lily Lake EAP may need to be activated to level 2.

Soon after, the DSO received a voice call from the NMC about the event. The NMC stated that they were unable to contact anyone at the park. The DSO called the park facilities engineer who proceeding up to the dam site in their personal vehicle from their home in Estes Park. They encountered debris on the road to the dam and heavy rain. At the dam site the park engineer found high spillway flows and some rock being eroded in the spillway, but the ACB system was performing well.

Throughout the night, the Reclamation EWS engineer in Denver monitored the storm.

The Lily Lake EWS initiated not only a response at Lily Lake Dam, but also to many park staff. Reclamation was also alerted that a major flood event was underway and that they should dispatch staff to operate the gates at Olympus Dam.

The DSO and park staff discussed the appropriate EAP level for the dam. While the EWS suggested an EAP response level of 2, the dam was performing well and was being monitored full time so the park decided an EAP level of 1. The downstream public along Fish Creek was being heavily impacted by the flood and we did not need to add to their concerns (or add to any sense of panic).

Flood Scale and Scope

This flood was not a brief thunderstorm event. This was a general storm flood affecting much of the Colorado Front Range for about 10 days. Hydrologists were surprised at the large rainfall totals for the high elevations – such as Lily Lake.

The National Oceanic and Atmospheric Administration identified the event as exceeding the 1:1000 chance-per-year flood (see figure 11).

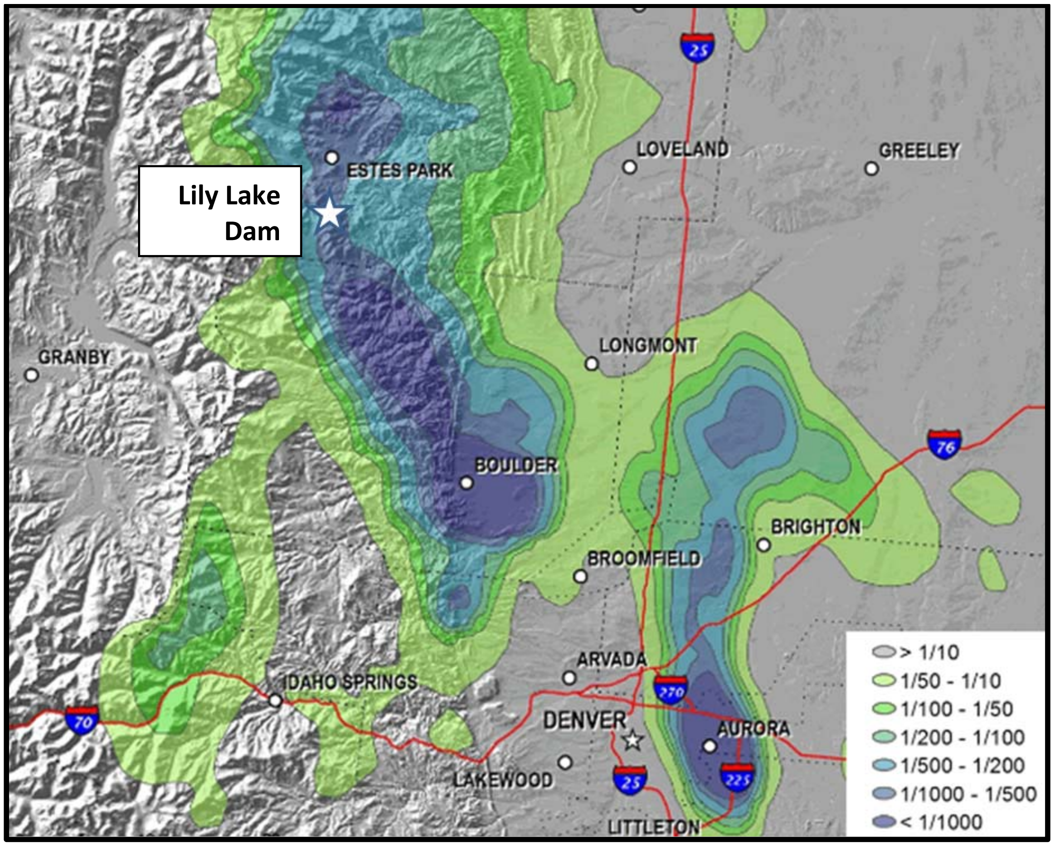


Figure 11: Colorado Floods of 2013 probability hill diagram. (NOAA)

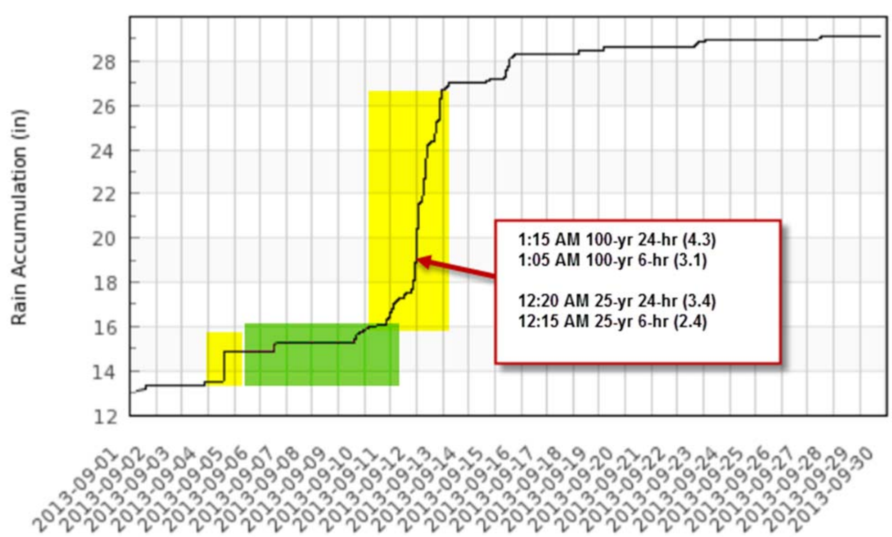


Figure 12: Cumulative rainfall measured by the Lily Lake EWS (Reclamation)

A total of 10-1/2 inches of rain fell from late September 11 to September 14. The flood destroyed all of the canyon access routes to Estes Park except for Highway 7. Thus, the park played an important role in also monitoring the badly corroded Highway 7 culvert just below Lily Lake Dam.

Dam Performance during the Flood

Park staff closely monitored the dam full time for the next several days. They also monitored the culvert in the downstream road embankment. Spillway flows were about 18-inches deep for days. The decorative gravel on top of the ACBs was eroded away. Some gravel within the ACB matrix was plucked out, but not to the extent to expose the underlying geotextile.

Figure 13: Pre-repair spillway channel from bridge (2011 Reclamation)

Figure 14: Post-repair spillway channel) from bridge one week after flood peak (9/19/13 NPS)

Figure 15: Looking right across the spillway chute after dam repair and before flood (circa 12/1/12 NPS)

Figure 16: Flood flows down spillway chute (9/12/13 NPS)

Figure 17: Spillway channel before flood (after dam repair) (11/21/12 NPS)

Figure 18: Spillway channel after flood. Note exposed ACBs, gravel/soil eroded away, and relocated boulders (9/16/13 Reclamation)

Material was also eroded from around the downstream toe outfall and inspection well area (see figures 19 and 20). This area will require a repair.

Figure 19: Inspection well area after modification and before flood (NPS circa 12/1/12)

Figure 20: Inspection well area erosion damage after flood (Reclamation 9/16/13)

On September 14, the NPS Regional Dam Safety Coordinator contacted Reclamation and requested an inspection team be sent to the dam. Using an existing task order for emergency response, an inspection team visited the dam on September 16. The Reclamation engineer issued a travel report [9] with observations and recommendations. Repairs are planned for the inspection well area and replacement of gravel in the spillway chute.

The Reclamation engineer also commented to the DSO that had we not repaired the dam, the dam would have likely failed by spillway erosion and head cutting.

D. Lessons Learned and Conclusion

It is industry best practice to conduct a lessons learned meeting following a dam failure or incident. A Lily Lake Dam incident lessons learned meeting was conducted on February 11, 2013 with RMNP, NPS DSC, DSO, IMR and Reclamation. The following lessons learned were developed [10]:

- So that we can be awakened for emergency events, keep your cell phone on ring and near your bed.
- The EWS notifications that stated it is a “1:25 year event” or “1:100 year event”, gave a better impression of the seriousness of the event (better than “2.5 inches in the last hour”).
- Travel with another person after hours to inspect a dam during a major rain event. Take a larger vehicle (truck, not a passenger car).

- Middle-of-the-night emergencies thrust bleary-eyed, incoherent people into a natural disaster. People responding in the middle of the night need to be extra careful because they have attention and decision-making deficits.
- During the first hours of this event, park staff called relatives and told them not to travel up canyon roads because of the dangerous flooding. During a flood, employees may need to warn family members and other off-site co-workers.
- Install a new staff gauge in the reservoir to facilitate monitoring.
- Have an emergency response task order or other pre-arranged contracting method in place to quickly obtain dam safety technical assistance.

The author offers one other lesson learned:

- Identification of all possible failure modes is crucial.

When a dam owner/regulator (such as the NPS) has a dam with high risks, we need to mitigate those risks. We can and should repair such dams. Repair projects can proceed faster when people are brought together on a regular basis to coordinate the many facets of the project and to identify/address risks that could slow or stop a project. These projects should be completed as soon as practicable to reduce the risk exposure period. At Lily Lake Dam, we finished repairing the dam just 9 months before the flood.

To lower the exposure period, we can decide to repair to conservative levels (e.g. deciding to repair for the full PMF) rather than take the time perform additional exploration and technical studies.

During the time it takes to modify a dam (many months to 3 years) there are many other strategies that dam safety officials can use to mitigate the risk during the exposure period. We can better monitor the dam using trained staff and electronic equipment (EWS) so that we can discover any developing projects early and can take actions to save the dam. We can identify sources of materials and equipment to use in case the dam needs an emergency repair. We can protect the public by having and exercising EAPs. These many activities can be done in parallel rather than one at a time.

Of utmost importance to getting an expedited project completed in a timely manner is the formation and maintenance of a highly motivated team of professionals. We were fortunate to have just such a team for the Lily Lake Dam repair project. We all had a sense of accomplishment when the project construction was complete. And then, nine months later, we all had a sense of relief when the dam survived the flood.

The park engineer said the following during the lessons learned meeting:

> *"If we hadn't fixed the dam, it would be downstream. If we hadn't exercised the EAP, we would have been standing there wondering what to do. If we hadn't had the EWS, we wouldn't have been able to monitor."*
>
> *"These things can actually happen."*
>
> *"There wasn't a single second when I was up there [during the flood] that I didn't think: 'Thank God we fixed this thing.'"*

<END>

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