

30th Anniversary of the Lawn Lake Dam Failure: A Look Back at the State and Federal Response

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ABSTRACT

On July 15, 1982, deep in Rocky Mountain National Park, the 26-foot high Lawn Lake Dam failed. The resulting flood charged down a mountain carving deep ravines and depositing huge fields of rock. It also wiped out campsites, tragically killing 3 people. The flood inundated businesses in the town of Estes Park and caused \$31 million in damages.

This paper describes how the State of Colorado (State) and Federal agencies responded to the event. The many impacts of this dam failure are explored so that the dam safety community can be better prepared to handle the myriad of issues associated with dam failures efficiently.

The paper reviews the State's response including communications immediately following the failure and the details of conducting a dam failure investigation, including the forensic analysis to determine likely failure mechanisms. Changes to the State dam safety program as a result of the failure are described. The effects of the failure on the NPS dam safety program, including the decision to remove other dams within Rocky Mountain National Park are also explored. The role of FEMA in coordinating post-failure research studies conducted by Federal agencies, including the USGS, USBR, and the NPS are also discussed. Finally, the paper describes the types of legal investigations conducted and lawsuits filed following the failure.

BACKGROUND

Lawn Lake stood at 10,987* feet (*dimensional and capacity data are not consistent across source documents. Data cited in this paper are generally from the reference ⁽¹⁾ unless noted otherwise.) above sea level on the east slope of the Colorado's Front Range upstream from the town of Estes Park where a natural lake was formed by a moraine.

In 1903, the Farmers Irrigation Ditch and Reservoir Company (FIDRC) of Loveland, Colorado began construction of a dam atop the glacial moraine to increase the storage of the high mountain lake. To release water from the bottom of the lake, a 3-foot-diameter riveted steel outlet works pipe and valve were placed in a 12-foot-deep trench in the moraine below the dam. The outlet works pipe and valve were hauled to the site via horse-drawn wagons up the steep Roaring River Valley. Figures 1 and 2 show the outlet works during installation. An uncontrolled spillway was excavated near the left abutment and a 7-foot-high embankment was constructed on the moraine to complete the dam.

The design specified that the valve be encased in concrete. However, this was not done. The completed dam was effectively 19 feet high and stored 498 acre-feet of water.



Figure 1: View of outlet in notch in moraine, 1903 photo (State Engineers Office (SEO) file).

In 1915, Rocky Mountain National Park (RMNP) was established. For miles in every direction from the dam, the land came under the ownership of the Federal government. But for Lawn Lake Dam and several other dams nearby, the lands under the reservoir and dam were retained by the irrigation companies/municipalities that owned the dams.

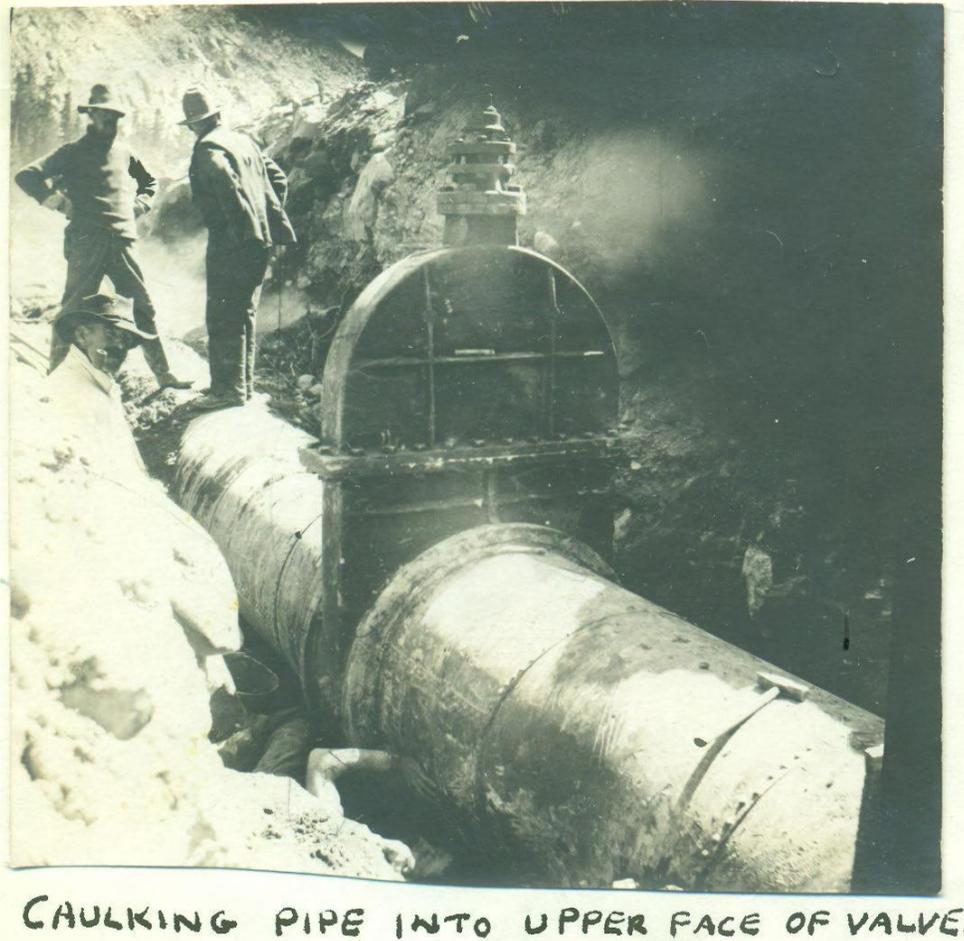


Figure 2: View of outlet valve and outlet works pipe, 1903 photo (SEO file).

In 1931, FIDRC raised the embankment by an additional six feet for a total dam height of 24 feet to the invert of the spillway. The new crest length was 560 feet and the total storage volume of the reservoir was increased to 817 acre-feet.

INSPECTION HISTORY

Due to very limited access, dam inspections were difficult at this site. Inspectors had to either access the site via foot or horseback over the 6 mile trail including 2500 vertical feet of elevation gain, or by helicopter. Following dam construction in 1903, documented physical inspections of Lawn Lake dam were performed in 1951, 1975, 1977, and 1978 ⁽²⁾. Items noted on the inspections reports included: narrow spillway, relatively low freeboard, uneven dam crest and steep downstream slope. Recommended actions over the years included lowering the spillway to increase freeboard, flattening the downstream slope, leveling the dam crest, monitoring seepage and increasing the frequency of inspections. A helicopter was used to perform an aerial survey of the floodplain as part of a hazard evaluation for the dam in September of 1979. The helicopter made a short stop at the dam so the dam safety engineer could

check a seepage issue identified in the 1978 inspection. No official report documented this brief inspection (until Jan 1984), "...since the suspected problem area appeared to be in satisfactory condition. Photos (in file) depict the condition of the dam" ⁽³⁾. Lawn Lake dam was rated as a "moderate" (now termed Significant) hazard dam in both the State Engineers Office (SEO) database and the (then recently completed) US Army Corps of Engineers National Inventory of Dams (NID) database ⁽⁵⁾.

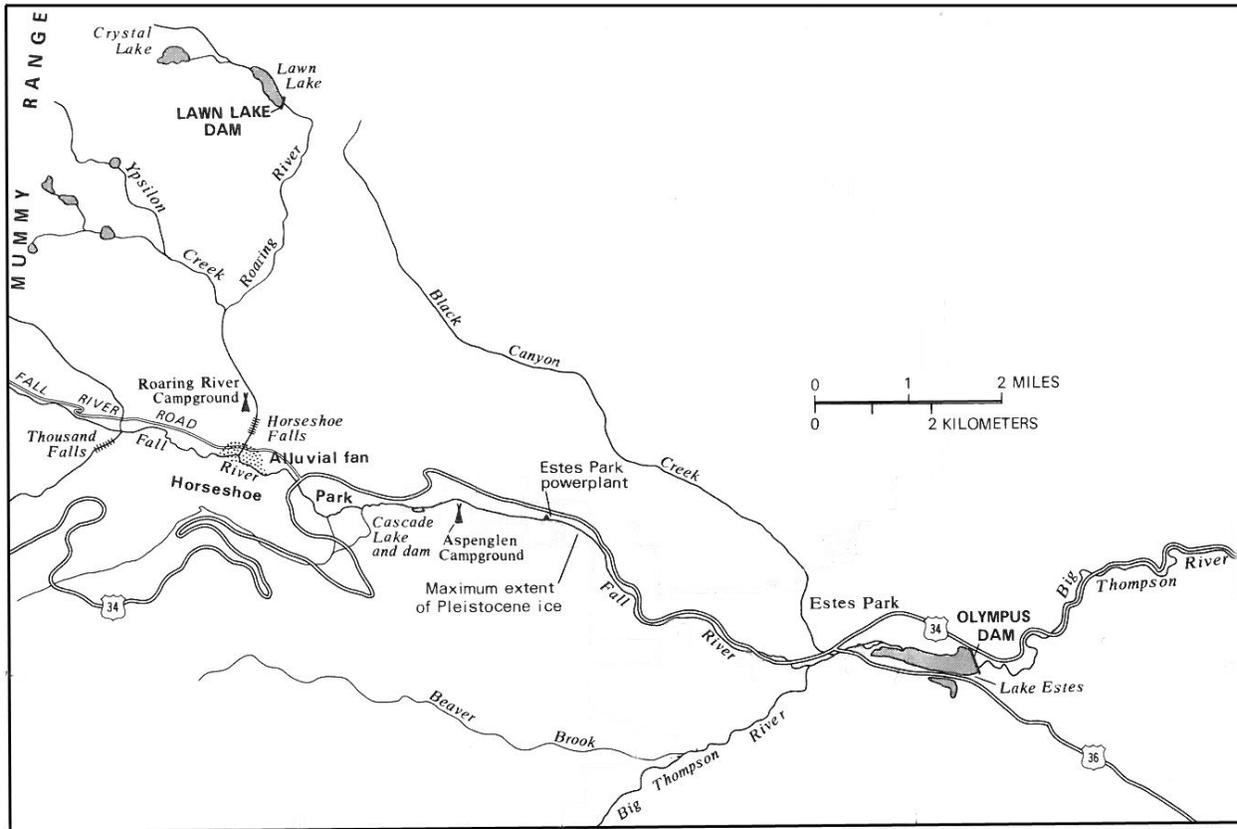


Figure 3: Map showing Lawn Lake Dam, Roaring River, Horseshoe Park, Cascade Dam, Fall River and Estes Park - [modified from p. 3 map in Costa/Jarrett Paleohydrology Report]

THE FAILURE AND THE FLOOD

Between 5 and 6 a.m. on Thursday July 15, 1982, the Lawn Lake Dam breached ⁽⁴⁾. Several campers near the reservoir had heard roaring sounds in the middle of the night. They awoke to find the reservoir nearly emptied. A total of 674 acre-feet of water was released in about an hour, resulting in a peak flood flow at the dam estimated at 18,000 cfs. One witness at a campground downstream recalled seeing a "wall" of water coming toward them" ⁽⁵⁾. The flood was very powerful as it flowed down the steep (average 10% slope) Roaring River causing erosion up to 50-feet-deep. In flatter sections, the flood made deposits up to 500 feet wide ⁽¹⁾. One camper, still in his tent, was killed by the flood.



Figure 4: Aerial view of the dam breach [USBR photo]

At the confluence of the Roaring River and the Fall River, the flood dropped its load of boulders and trees onto the relatively flat Horseshoe Valley. This created an alluvial fan 42 acres in size and up to 44 feet deep ⁽¹⁾. A man driving his truck into Horseshoe Valley to empty trash barrels at a trail head witnessed the flood and called NPS dispatch. After flowing out of Horseshoe Park, the flood continued down Fall River filling Cascade Reservoir until it overtopped its 17-foot-high, concrete gravity dam. After about 40 minutes of overtopping, Cascade dam toppled, sending a new surge of water (estimated to be 16,000 cfs) downstream ^(1,4).

The Aspen Glen Campground was located just downstream from Cascade Dam. Although people camping near the river had been warned and evacuated about an hour earlier, two campers went back into the river area to retrieve camping gear and drowned as the Cascade Dam failure flood swept through the campground sites located on islands in the braided river.



Figure 5: Roaring River erosion [USGS photo]



Figure 6: Alluvial fan at confluence of the Roaring River and the Fall river [USGS photo].

The flood then destroyed the State fish hatchery, a small hydropower plant, bridges and cabins/cottages along the Fall River. At about, 8:15AM, the debris-laden flood entered the town of Estes Park. The flood was up to 6-feet-deep down Main Street in Estes Park and later the peak flow was calculated to be 6,000 cfs ⁽¹⁾. Flooding deposited mud in 177 town businesses, inundated a total of 108 residences, and destroyed thirteen bridges ⁽⁶⁾. The flood waters entered Lake Estes and were contained by the Bureau of Reclamation's Olympus Dam. By 9:30 a.m. the flooding had passed, leaving behind damages estimated to be \$31 million.



Figure 7: Cascade Dam in process of breaching [J.D. George photo]

FEDERAL RESPONSE

National Park Service

The NPS had jurisdiction for warning and evacuating people in RMNP, including Aspenglen Campground. Once the flood was downstream from the campground, Larimer County and the City of Estes Park Police had jurisdiction. The RMNP park dispatch center kept both a log and an audio recording of radio communications during the event.



Figure 8: The Dam failure flood moving through downtown Estes Park at depths of up to 5 feet. [USBR photo]

The initial priority for the NPS was saving lives. During the flood, park rangers monitored the flood and blocked roads. They also warned people in Aspenglen Campground and assisted Larimer County with warning and evacuation.

Immediately after the flood, NPS performed search and rescue. The Roaring River area had four campsites and the NPS needed to confirm the safety of these campers. The list of registered campers in the area was compiled and rangers were sent to carry out rescue operations in the backcountry areas. At one point, crew members made a dangerous crossing of the damaged Roaring River, coming “...real close” to falling into the swift flood waters ⁽⁷⁾. Surviving campers along the Roaring River were evacuated by helicopter.

An off-duty park ranger responded to the flood and nearly lost his life. While backing his car up in a parking lot near the Fall River, the flood rose rapidly and floated his car downstream. He climbed out of the window and held on, spread-eagle on the roof of the car. When the car started to roll over he found himself swimming in ice cold water. He finally grasped a tree near the water’s edge and found safety. He later said to a reporter, “The way I figure it, there was 999 out of 1000 chances that I should have been killed ⁽⁸⁾.” Other rangers also put themselves at risk on the day of the failure.

The 275 campers at the Aspenglen Campground were cut-off by the access road bridge destroyed by the flood. It wasn’t until midnight (16 hours after the flood) that an

emergency road could be constructed to reach the campground. Most campers were not evacuated until the following morning.

To document the event and confirm those still missing, Park rangers interviewed witnesses. From these interviews, the rangers typed "Supplementary Case/Incident Record" reports. Each report included the person's name, their address, and a first-person written narrative of what the person witnessed. The NPS also interviewed and developed a report for the rangers involved in responding to the incident. One RMNP staff person described the method used to interview 25 campers who were at Lawn Lake or the campsites along the Roaring River ⁽⁹⁾.

"As the campers were evacuated by helicopter they were brought in groups to us at (park) Headquarters. We had each of them fill-out statements as well as making notes on a separate piece of paper which was attached to the statement. We asked questions of all trying to account for all campers or hikers who might have been in the drainage on 7-14-82 to 7-15-82. We basically followed the format of Who, What, Where, How and Why during the interviews. Most of the campers were cooperative...we asked them to relate their account of the flood."

There was, of course, a great deal of media coverage. The RMNP identified a public information officer to inform the press, other agencies, and the public.

The NPS carried out recovery searches throughout the flood path in the park. The victim's body from the Roaring River Campsite was found in Horseshoe Park on the day after the failure. The bodies of two other victims were located downstream from the Aspenglen Campground.

US Bureau of Reclamation

At 7:12 a.m. on the day of the dam failure, the US Bureau of Reclamation (Reclamation) was contacted to determine whether Lake Estes could contain the Lawn Lake flood waters. Lake Estes was four feet below its normal maximum water surface level. Reclamation shut off the Adams Tunnel under the Continental Divide and determined that Lake Estes would, in fact, be able to safely contain the flood flows ⁽¹⁰⁾. During the time flood entered Lake Estes, detailed measurements were made of the lake elevation. The lake rose two feet during the flood and the data collected were used to determine the volume of the flood.

On the day of the failure, the Western Area Power Administration (WAPA) made a helicopter and pilot available to Reclamation's office in Loveland, Colorado east of Estes Park. The helicopter reached the dam site about 9:00 a.m. on the day of the failure. The crew made a color motion picture film of the dam breach, the flood path, and the flood through the town. They also took a series of 48 still color photos documenting most of the flood path. The film and the flood series provided excellent documentation of the damage immediately during and immediately following the flood event.

The day after the failure, water quality became a major problem. In addition to debris in Lake Estes, raw sewage from the Estes Park city sewer plant was entering Lake Estes. A sewer plant below Olympus Dam was also discharging raw sewage after mud and sediment jammed the plant's system. Reclamation alerted downstream entities to take precautions before using water. Over the next four days, water quality improved and Reclamation awarded a \$36,717 contract for reservoir debris removal.

Federal Disaster Declaration

Four days after the failure, the Governor of Colorado, Richard Lamm, requested the Federal government declare a major disaster. Three days later, President Reagan issued the declaration. This declaration made Federal loans available for temporary housing and recovery. Under the declaration, the Federal government would pay 75% of the state and local governments' costs for reconstruction, including bridges and roads.

Additional RMNP Dam Inspections

Five days after the event, staff from the NPS, Reclamation and the State of Colorado examined three other dams high in RMNP. Two other dams were visited on the following day. Of the five dams inspected, four were found to have significant dam safety concerns. Four of the dams were breached over the next 8 years (see below).

STATE RESPONSE

Immediate Actions - July 15, 1982

Reports of the failure arrived in the Denver office of the Colorado Division of Water Resources, Dam Safety Branch at approximately 8:20 am on Thursday July 15, 1982. Within an hour, a plan was developed to send two teams of two-engineers each to the Town of Estes Park, approximately 2 hours from Denver. One team of engineers would go to the Lawn Lake Dam site, 13 miles upstream of Estes Park, the second team to the Cascade Lake Dam site, approximately 5 mile upstream of Estes Park. The teams of engineers were en route to the affected Town of Estes Park within 2 hours of confirming the failure of the dam (11).

In the Denver office the phone began ringing immediately and lines of communication were established. Requests for interviews, media representation, and requests for State Engineers Office (SEO) file information were fielded. Communication was made with the United States Bureau of Reclamation (Reclamation) Loveland Project office, Western Area Power Authority (WAPA), National Park Service (NPS), and State Division of Disaster Emergency Services (DODES). Communications lines were also opened with the US Army Corps of Engineers (COE), Federal Emergency Management Agency (FEMA), and the Federal Energy Regulatory Commission (FERC) ⁽¹²⁾.

The Reclamation owned Olympus Dam downstream of Estes Park, captured the floodwaters. Information regarding the change in reservoir level as the breach flood arrived helped establish the hydrograph at that location. The COE was near the end of

their 4-year mandate to update the National Inventory of Dams, which included physical inspection of all high hazard dams and all significant hazard dams located on federal lands, nationwide. Questions were being raised regarding why Lawn Lake, a Significant hazard dam located on federal lands, had not been inspected ⁽¹³⁾. FEMA was involved in the emergency response and disaster declaration. The FERC regulated power generation activities associated with Cascade Dam, which also failed as a result of the Lawn Lake failure.

Arrangements were made with WAPA for a helicopter to enable the team of engineers to more quickly get to the Lawn Lake dam site, normally a half day horseback ride or hike, in the roadless area of Rocky Mountain National Park. By 12:45 pm the Lawn Lake inspection team was en route to the dam site. The team performed the first of three dam inspections. On July 15 the team spent about 1.5 hours at the site. They were able to make a quick assessment of what had happened, ruling out an overtopping failure mechanism. They gathered what information they could to form initial impressions of potential causes, inventoried additional information gathering needs for future inspection trips, performed rudimentary mapping and surveying of the fresh exposures of the breach and embankment surfaces and took plenty of photos. The Cascade Dam inspection team performed similar information gathering activities at that site. By 3:30 pm both teams were back in Estes Park, where the preliminary information was then relayed back to the SEO office in Denver for further dissemination ⁽¹¹⁾.

By that time, the Town of Estes Park and the entire flood plain below the dam had been secured. At about 5:00 pm the two teams of engineers checked in with the command post that had been set up at the Stanley Hotel to obtain passes and authority to travel and conduct additional reconnaissance and information gathering within the flood-affected zone. The team met with hydrologists from the United States Geological Survey (USGS) also conducting surveys of the flood affected areas. The engineers talked with several eyewitnesses of the flood event and surveyed the Cascade Dam location. After completing reconnaissance and information gathering at the Horseshoe Falls area, the confluence of the Fall River and the Roaring River, the teams left Estes Park about 8:15 pm ⁽¹¹⁾.

Failure Investigation

With three lives lost, residents/businesses displaced and extensive property damage, elected and appointed officials quickly began to exercise their duties, take control and begin to ask the “How and Why” questions. On July 16, Governor Richard Lamm issued a memorandum to D. Monte Pascoe, Executive Director of the Department of Natural Resources (CDNR), (the Division of Water Resources and State Engineers Office reside within this Department) ⁽¹⁴⁾ asking that the official “personally review the specifics surrounding the Lawn Lake dam breakage to discern what precisely could or should be done to minimize any future such incident”. The memorandum allowed the Executive Director seven days for the review. The Governor went on to identify five issues he “hoped” could be included in the review:

1. What resources would be needed to inspect all 2200 dams on an annual basis? Is such an annual inspection a realistic requirement and would it ensure the desired level of safety?
2. In determining the desired frequency of dam inspections, should we expand the current “high hazard” designation (re potential damage and proximity to population centers) to include other criteria more directly linked to potential dam breakage or deterioration?
3. I support your decision to investigate immediately the status of all reservoirs in the Rocky Mountain National Park area. Are immediate inspections necessary of any other specific dams such as those in high visitation areas, of a particular design, or of an “antique” vintage? Can I facilitate those inspections with emergency funds or other Executive actions?
4. Are there any shortcomings in our current inspection procedures? Is there any indication that the state should revise administrative or statutory requirements of follow-up or compliance?
5. In summary form, how many high and moderate hazard dams in Colorado have not been inspected for more than 4 years, more than 2 years, and more than 1 year?

The Executive Director looked to the Director of the Division of Water Resources, the State Engineer, to assist with this review. The State Engineer relied heavily on the Chief of the Dam Safety Branch and his staff of engineers to complete the review within the specified time.

Also on July 16, a Dam Safety Branch (DSB) meeting was held to de-brief from the previous day’s activities, assign duties to produce a timely response to questions about the dam failure and dam safety program itself ⁽¹⁵⁾. It is interesting to note that “Memo of Meeting” documents exist documenting the discussions and establishing a chronology of actions taken during what must have been hectic or even frantic times. The July 16, 1982, Memo of Meeting also describes that the start of this three hour meeting was filmed and recorded by a Channel 9 television news crew. The documentation notes of the meeting included: verbal reports of the previous days field work and assignments and deadlines (July 19 at the latest) for formal documentation of those activities; discussion included how the significant hazard rating was developed; an understanding that the USGS was performing their own peak breach discharge analysis which could be compared to results from the DSB; the lack of recent inspections and follow-up on previous action items at Lawn Lake Dam; the need to quickly identify and then inspect all high and significant hazard dams not inspected since 1979; the need for faster turnaround in transcribing reports, letters, etc.; potential of having Water Commissioners perform “eyeball” inspections of dams with higher than normal water storage this year; the need to thank the USBR (WAPA) for their assistance with helicopter transportation for the engineers on the 15th; and finally on the logistics and timing for their next dam site inspection now scheduled for July 22nd.

In the afternoon on the 16th an engineer traveled back to Estes Park to assist DODES with a FEMA damage survey for the disaster declaration. That engineer spent the remainder of that day and all day Saturday the 17th on that assignment. The Governors

letter to the Executive Director of CDNR arrived in the afternoon, and engineers within the DSB began the necessary research to answer those questions ⁽¹⁶⁾.

Between July 17th and July 22nd the necessary research was conducted and all inquiries to date were addressed. The report of the initial inspection performed on the 15th was completed and included recommendation for additional study of the dam site. On July 22nd with arrangements finalized, a team consisting of members of the Dam Safety Branch, Geotechnical Services unit the Division of Water Resources, Colorado State University, Colorado Department of Highways, USBR, USGS and COE was assembled. The State representatives were divided into teams, each assigned specific tasks for the investigation. As with the inspection on the 15th, on this date the USBR again provided helicopter assistance to get the team to the dam site. Three helicopter shuttles were required to deliver all team members to the site. Using their own helicopters, representatives of Channel 7 news, Channel 9 news and the Rocky Mountain News were also on site. All team members were on site by 10:45 a.m., with the press corps there from 10:45 a.m. until noon asking questions of the engineers, videotaping responses and generally slowing the intended progress. The teams worked uninterrupted from noon until 4:00 p.m. when the helicopter shuttles began taking them back to Estes Park. Major activities completed by the teams on this date included: detailed geologic and geotechnical mapping of the exposed breach slopes and test pits excavated into the embankment at selected locations; sampling of embankment materials from all identified native and man-placed soil horizons; in-place nuclear density and moisture testing of the embankment at selected locations; excavations and mapping of all rodent tunnels in the embankment; detailed surveying of the embankment, breach, spillway, high water line and outlet works; a thorough investigation of the condition of the remaining outlet valve components ⁽¹⁷⁾.

Based on the results of the two field investigations the two principal failure modes being investigated included: (1) A piping failure; through pervious seams within the dam, or progressive sloughing of the downstream slope, or rodent activity, or failure of the outlet conduit at the connect with the control valve, or a combination of the above, (2) Failure as a result of an embankment slide, followed by collapse at the failed section ⁽¹¹⁾. The soil samples were taken to the Colorado Department of Highways laboratory for testing. A full suite of engineering properties and strength tests were performed for use in slope stability and seepage analyses. The results of the other investigations were also documented and additional analyses were planned to carefully investigate the possible failure modes ⁽¹⁸⁾.

During this time it also became known that a local geotechnical engineering firm had been hired by the insurance company for the dam owner. That engineering firm made their own site visit on July 20, 1982, to gather information for their own investigation ⁽¹⁶⁾.

The record indicates that throughout this period a nearly continuous stream of requests for information was fielded by members of the Dam Safety Branch in their Denver office ⁽¹⁶⁾.

A memorandum from August 17, 1982 ⁽¹⁸⁾, reports on the progress of the failure report being prepared by the Dam Safety Branch. Activities being pursued in support of that effort included; Stability/Permeability analysis; study of effects of rodent activity; study of the outlet works; compilation of USGS work on reservoir volume, dam breach estimates and embankment surveying; research on the history of the dam; review of NPS files including statements from witnesses; and work on report of failure of Cascade Dam. Factors negatively affecting the progress on the report included; difficulties with lab testing; obtaining satisfactory mapping of the reservoir and dam site; obtaining files from the NPS due to Solicitor General review of files before release; lack of response from the dam owner regarding requests for access to owners files; pressing needs to provide lists and records of dams, response to phone calls and meeting requests, requests for program information and general dam safety branch business.

As results of the investigation eliminated or reduced the probability of other failure modes as the cause of failure, the outlet valve and a connection between the valve and the outlet piping became the focus the investigation ⁽¹⁹⁾. The connection of the valve to the outlet piping was a slip connection sealed with lead. Upon consultation with a metallurgical expert over a piece of the lead seal found at the site it was determined that this seal might be the weak link. Although specifications indicated the seal was intended to be placed using hot fluid lead, the analysis suggested the lead was placed cold. An additional trip was made to the dam site on September 2, 1982, to gather additional evidence, including a relatively large volume of lead gathered with the aid of a metal detector ⁽²⁰⁾.

The CDNR Executive Directors office provided a response to the Governors inquiry as required on July 22 ⁽²¹⁾. In his response to the Governor, the Executive Director indicated that:

1. Adjustments and improvements could be made to the dam inspection scheduling especially by focusing on high and Significant hazard dams, but none would be able to guarantee against failure of dams.
2. Work had been done correlating the hazard classification of dams to the inspection frequency.
3. The review concluded that state dam inspection procedures had been steadily improving. The response indicated that beyond additional manpower to enable inspection of every dam every year, the following actions would enhance the existing program: (a) A provision for an automated data management system to allow engineers and managers to interact with the database containing information on the dams, (b) Provision for adequate air transport to place inspectors in a position to inspect those dams in remote areas in the shortest time possible, (c) Provision for soil boring and test equipment to allow determination of embankment properties, (d) Provision for sufficient opportunities for inspection personnel to participate in educational seminars and meetings in order to remain current on state-of-the-practice technology with respect to dam design, construction and inspection.

The response concluded that the examination of the reasons for the failure of Lawn Lake dam would continue. It also described that the State Engineer's dam inspection

program would be reviewed. New proposals for changes to the program would be studied and where appropriate implemented. It was noted that the burden of dam inspections must continue to fall on the dam owner's since they are in a much better position to watch during all cycles of normal operation. Lastly, a commitment was made for the CDNR to work helping prepare emergency plans for dam failures.

Work continued on the report of the investigation of the failure of Lawn Lake Dam through the fall of 1982. Review of NPS files was completed in September ⁽²²⁾, the geotechnical analyses were completed in November ⁽²³⁾, and the report entitled "AN INVESTIGATION OF THE FAILURE OF LAWN LAKE DAM, LARIMER COUNTY, COLORADO, CONDUCTED BY THE OFFICE OF THE STATE ENGINEER" was released on February 14, 1983 ⁽²⁴⁾. A press release issued March 2, 1983, announced the findings of the report: that the failure was "probably" caused by the deterioration of the lead caulking at the connection between the outlet pipe and the gate valve. The report and press release reported that deterioration led to the piping of embankment materials, causing backward erosion and sloughing of downstream slope and ultimately collapse ⁽²⁵⁾.

The report of the failure prepared by the geotechnical engineering firm hired by the owner's insurance company was provided in draft form to the owner's insurance company on January 1, 1983, and to the SEO on February 6, 1984 ⁽²⁶⁾. It reported the failure "probably" was the result of progressive sloughing of the downstream embankment toe as a result of high seepage pressures from the reservoir, with sloughing ultimately causing the embankment crest to fall below the level of the reservoir.

The report of the failure of Cascade Dam was provided as a simple memorandum with no public release. The memo reported that the dam failed due to hydrostatic forces of overtopping combined with erosion of the abutments, causing the dam to topple ⁽²⁷⁾.

FEMA RESPONSE AND INTERAGENCY COORDINATION

FEMA Disaster Centers

Immediately following the disaster, FEMA set up disaster center at the historic Stanley Hotel. From this location, FEMA issued permits to perform field work in the flood area. Later, a "Disaster Assistance Center" (DAC) was established at a middle school in Estes Park. The DAC provided advice and assistance from over 20 state and federal agencies.

Dam Safety Coordination

On August 5, three weeks post-failure, FEMA issued a memorandum entitled "Dam Safety Coordination in Conjunction with a Disaster." ⁽⁶⁾ The memo begins:

"Each flood disaster is marked by the presences of numerous Federal and State agencies which have highly technical interests in the flood or dam failure event. Data are collected, generated and analyzed for research purposes related to

dam break modeling and inundation mapping. This immediate response by the engineering and research professionals is important toward providing future opportunities for hazard mitigation and options for policy makers.”

On July 23rd, 8 days following the failure, FEMA held a meeting in Estes Park with representatives from three state agencies and five federal agencies. The objectives of the meeting were to exchange information and to avoid duplicative effort. A second meeting was held on August 3rd to review a “Summary of Data Collected” – a four-page table documenting the data each agency had, the studies they were planning to perform and contact information.

The FEMA memo concludes with the statement, “...these Dam Safety Coordination Meetings were highly productive and certainly consistent with FEMA’s responsibilities”.

Hazard Mitigation

On August 6th, about 3 weeks after the failure, FEMA issued the “Flood Hazard Mitigation Report”. This report was developed with contributions from the Town of Estes Park, the Department of Agriculture, Larimer County, Colorado Water Conservation Board, the US Army Corps of Engineers, the National Weather Service, the Department of Housing and Urban Development, the Department of the Interior, and the Small Business Administration. The purpose of the report was to provide a framework for flood hazard mitigation during the reconstruction and to reduce the potential for future flood losses. Twenty one recommendations were made with identification of the lead agency. Two work elements addressed dams: ⁽¹⁾ share dam information and ⁽²⁾ NPS will pursue the acquisition of the impoundment rights at Lawn Lake and four other dams in the Park.

In January 1983, a “Flood Warning Conference” was held in Estes Park. It was attended by representatives of the NWS, Reclamation, FEMA, the Town of Estes Park, and the State.

FEDERAL AND OTHER STUDIES

Reclamation – Warning and Evacuation

Reclamation’s Denver Office assigned an engineer and sociologist to document the event ⁽⁴⁾. Their focus was on the warning and evacuation process. Over the next weeks and months, they documented how people became aware of the dam/flood, the effectiveness of the alerts, the time available for evacuation and the flood wave travel times. Personal interviews, the audio recording of Park dispatch, and a recording of the KSIR radio live report helped to establish an accurate chronology of events.

USGS – Flood, Dam Break, and Geomorphology Studies

The USGS sent a team to the dam site and to damaged areas in the Park on the day of the flood and for several weeks after the flood. They gathered evidence of high water marks and other information for their hydraulic and geomorphological studies. High water marks and reservoir capacity were determined for both Lawn Lake Reservoir and

the Cascade Reservoir. Cross section measurements were made of the dam breaches. Manning's "n" values were determined and utilized to estimate peak breach flows at the dams and several locations using post-flood indirect measurements. The USGS routed the flood using the Dam Break Model from Lawn Lake to Estes Lake.

The USGS collected geomorphic and stratigraphic field data and performed analyses to better understand the changes to the Roaring River, Horseshoe Park and Fall River. Erosional features, sediment transport, depositional features, and channel recovery were mapped and evaluated ⁽¹⁾.

Ecological Studies

Following the flood, Colorado State University worked with the NPS to develop a research consortium. The goals were to investigate the physical and biological effects of the flood as well as the area's subsequent recovery. Twelve studies were conducted over the next eight years. The studies' subjects included: hydrology/geomorphology ⁽¹⁾, sediment movement, geochemistry, tree micronutrients, vegetation development, macroinvertebrate recovery, arthropod recover, amphibian recovery, bird breeding changes, mammal distribution changes, and changes in plant ecology. These studies were documented in a NPS-published book entitled *Ecological Effects of the Lawn Lake Flood of 1982* ⁽²⁸⁾. In the book foreword, the Superintendent of the Rocky Mountain National Park wrote:

"The physical and biological effects of the flood were profound, particularly within the park. As perturbations of this type in high-elevation ecosystems are rare, the flood captured the interests of local, national, and international scientists and scholars."

The physical areas studied varied by study and included the exposed shores of Lawn Lake, the Roaring River, the alluvial fan, and the Fall River in Horseshoe Park. Several of the studies were multi-year studies to evaluate change over time.

EFFECTS ON DAM SAFETY PROGRAMS – STATE

The questioning of the Colorado Dam Safety Program began almost immediately following the Lawn Lake dam failure. The questioning came from the victims of the disaster, federal, state and local officials playing the "blame game", and a variety of editorialists, some who defended the dam safety program and some who criticized it ⁽²⁹⁻³⁴⁾.

The Executive Directors memorandum responding to the Governor's request for review of the failure generated more questions than it answered. At the heart of the controversy was the reality of the Dam Safety Branch staff at the time. Seven dedicated field engineers had responsibility for annual inspections of approximately 2250 dams statewide ⁽²¹⁾. Editorialists commented negatively on the timing and content of the apparent "Christmas List" of additional staff, computers, and equipment suggested as being beneficial in the July 22 memorandum ⁽²⁵⁾. A similar number of editorialists expressed opinions that the government leaders and budget personnel should take the heightened awareness provided by the tragedy to do real good in the name of public

safety and fund the Dam Safety program to the levels requested ⁽²⁹⁻³²⁾. For a period of approximately two months, an almost endless stream of newspaper articles chronicled the back and forth of blaming public officials for shortcomings of government's dam safety programs, defenses of programs based on budgetary realities, and recognition that the ultimate responsibility for safety of any dam lies with the owner of the structure and not the government ⁽³⁵⁾.

The Dam Safety Branch was strongly questioned from internal leadership sources such as the State Engineer/Director of the CDWR ⁽³⁶⁾. The hazard classification of the dam was questioned, since the dam was classified as a Significant hazard structure, why had three lives been lost? The procedure for determining the hazard classification was reviewed. The files maintained by the inspectors also came into question. The State Engineer expressed disappointment for the fact that the files contained sometimes contradictory information, and also indicated that previous inspection reports recommendations for action had not been followed up on ⁽³⁶⁾.

On August 20 the Colorado General Assembly was given permission to study the dam safety program ⁽³⁷⁾. Their questions included ⁽³⁸⁾.

1. What are the inspection procedures?
2. What is the procedure if an inspection reveals a problem at the dam?
3. What is the procedure for restricting a dam?
4. What changes in procedures are being considered?
5. How effective is a dam inspection per se? Could a dam pass inspection one day and burst the next day?

The written procedures of the Colorado Dam Safety Branch in place at the time of failure were considerable ⁽³⁸⁾. The questions of the general assembly were answered adequately. The questioning described above resulted in a self-review and ultimate strengthening of the program. Of the eight additional engineers requested, four additional engineers were added to the program ⁽³⁹⁾. Modifications were made to the scheduling of inspections, but the stated desire of inspecting all dams annually was never realized, and a more risk-based approach, concentrating inspections on the dams with the greatest risk and consequences, continues to be utilized.

EFFECTS ON DAM SAFETY PROGRAMS - NPS

Dams in Rocky Mountain National Park

Dam Removals

As stated, several other high altitude dams were located in RMNP at the time of the Lawn Lake Dam failure:

- Glacier Dam No. 1 – rubble masonry – height: 11 feet – 138 ac-ft max capacity
- Sandbeach Lake Dam – rubble masonry – height: 25 feet – 369 ac-ft max capacity
- Pear Lake Dam – rockfill embankment – height: 28 feet – 451 ac-ft max capacity

- Bluebird Lake Dam – concrete arch – height: 58 feet - 991 ac-ft max capacity

The original construction of these dams predated the formation of the park in 1915. At the time of the Lawn Lake Dam failure they were very old and in poor condition. A NPS Internal Alert memorandum ⁽⁴⁰⁾ to the NPS Director dated 3 weeks before the Lawn Lake Dam failure discussed two of these dams: The memorandum states, “...two dams...represent...potentially serious hazards. Sandbeach Dam ... is leaking and presents sufficient hazard that the ... Sheriff’s Office evacuated the Copeland Lake Campground. Pear Lake Reservoir ...identified as unsafe.” Lawn Lake Dam was not identified in the memorandum. As a result of this concern, the outlet work valves of these dams were kept in an open position. There was concern that a hydrologic event (e.g. thunderstorm) or snowmelt would fill one of the reservoirs and result in dam failure.

Glacier Dam No. 1 at Lost Lake was breached during the summer of 1987 by NPS crews and equipment flown to the site by helicopter.

Soon after the Lawn Lake Dam failure, the NPS and the Department of the Interior began negotiations with the City of Longmont, CO to acquire land and water rights to Bluebird, Sandbeach and Pear dams. It was a difficult and slow negotiation. The purchase was finally completed in 1987 – five years after the Lawn Lake Dam failure.

In 1988, removal of the Sandbeach and Pear Dams was begun. The NPS partnered with the U.S. Army for the use of a CH47-D Chinook helicopter. This helicopter transported two bulldozers each weighing 14,500 pounds to the sites. The entire man-made portion of the dams, including the outlet pipes, were removed.

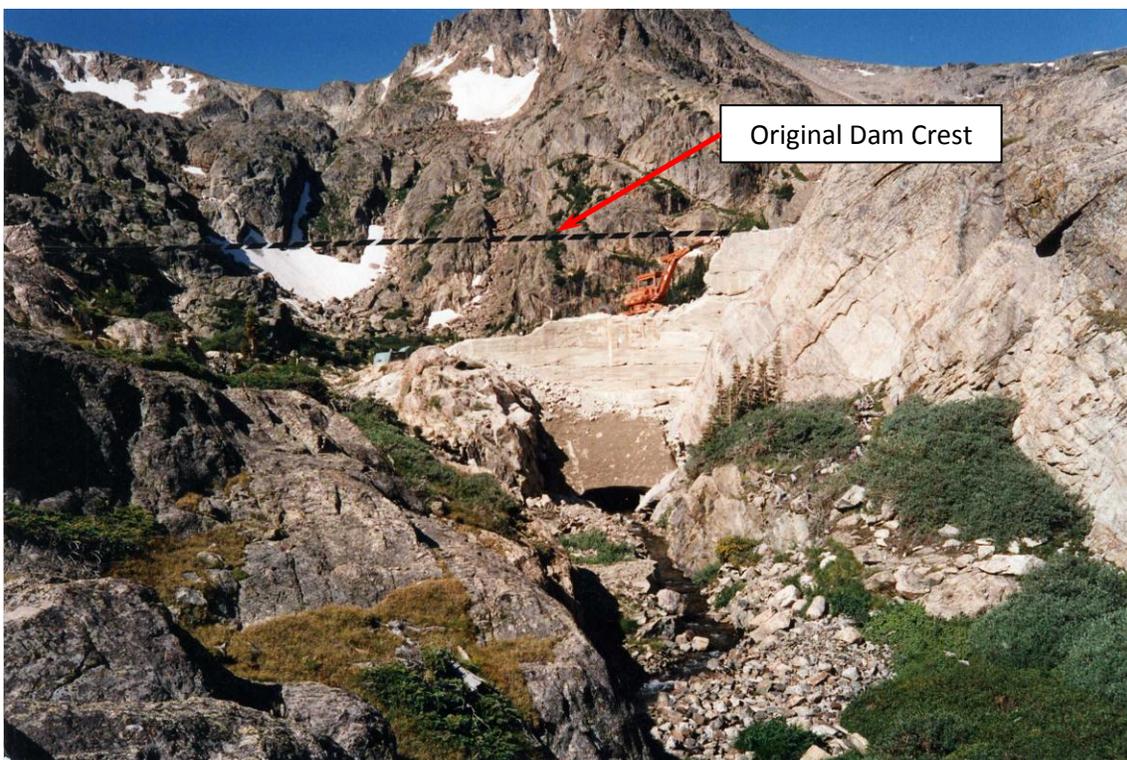


Figure 9: Removal of Bluebird Dam [NPS photo]

In 1989 and 1990, the 58-foot high Bluebird concrete arch dam was removed. Helicopters were used to transport equipment. The concrete rubble and rebar (5 million pounds) were flown out of the area. The materials were placed near Lily Lake in RMNP. The total cost was \$1.3 million.

Following the Lawn Lake Dam failure, the alluvial fan backed-up a new body of water called Fan Lake. It had an area of 17 acres. In 1995, high flows started to erode the dam. It was feared that the lake would suddenly be released. Due to this public safety concern, a breach was constructed through the lower part of the alluvial fan in 1996, thus permanently draining the lake.

Remaining Dams in RMNP

There are currently two dams and reservoirs in RMNP. Lily Lake is a High hazard potential dam and is scheduled for repairs in 2012. Sprague Lake Dam is a Low hazard potential dam. In 2011, Sprague Lake Dam experienced a dam safety incident when several large trees growing in the downstream face of the embankment fell over in a large wind event. One large hole in the embankment began to seep and the holes were repaired in April 2012. Both lakes have handicapped access trails around their reservoirs and are popular attractions in the park.

Lawn Lake Dam Remnant

The Farmers Ditch Co. went bankrupt as a result of the Lawn Lake dam failure and the company's remaining assets, including the water rights of Lawn Lake were acquired by a new owner. The new owners expressed an interest in rebuilding the dam, a concept strongly opposed by the NPS. Primary reasons for opposition included the need for construction of a six mile access road through RMNP, disruption of a threatened fish species, and new safety requirements.

In 1994, the NPS acquired the property rights to the dam. In 2000, two skid-steers and one mini excavator were helicoptered to the dam site and 5300 cubic yards of dam remnants were redistributed near the site. The lake was left at same elevation it was following the breach (the breach in the moraine underlying the pre-failure dam was not filled-in). This is because the NPS determined it was undesirable from a long term monitoring perspective to leave an impoundment at the site. The site was revegetated with native plant species harvested from the area.

Cascade Dam

The Cascade Dam was not rebuilt. The Town of Estes Park lost the ability to generate hydroelectric power. The Colorado State Historical Fund awarded over \$400,000 for restoration of the hydroelectric plant's buildings and original equipment. The facility currently is an educational and interpretive exhibit.

NPS Dam Safety Program

Reaction to the Event

The day of the failure, the Dam Safety Officer of the NPS was contacted by Reclamation requesting the capacity of Lawn Lake Dam. Later that day, he was called to a meeting with the NPS Director in Washington DC. The meeting was short and focused on the fact that the dam was not owned by the NPS. During the event and in the days following, all questions were directed to the NPS regional office in Lakewood, CO or to RMNP.

Short and Long Term Effects on the NPS Dam Safety Program

The year following the failure, the NPS Dam Safety Program released its first program guideline.

In the years following the Lawn Lake Dam failure, parks were more aware of the potential impacts of a dam failure. The number of dam repair projects increased and there was more focus on Emergency Action Plans. During the 1980's, many parks took advantage of NPS Dam Safety Program funds for dam removal. However, the surge of interest in dam safety gradually faded.

In 2012, the story of the Lawn Lake Dam failure is featured in a NPS-produced, 14-minute DVD film entitled *Managing the Risks of Dams*. This dam safety awareness film has been well-received and will be played for all NPS park staff (e.g. managers, superintendents and dam tenders) that have responsibility for dams. The lessons learned from the Lawn Lake Dam (and Cascade Dam) failure are continuing to be learned today.

LAWSUITS – STATE OF COLORADO

The first request for file information from a lawyer retained by a victim of the disaster was hand delivered to the Denver office of the State Engineer on July 16, 1982, just one day after the failure ⁽⁴¹⁾. The first Notice of Claim against the Department of Natural Resources, State Engineer and State Attorney General arrived on July 26, 1982 ⁽⁴²⁾. A Denver law firm was hired to represent the State against any civil litigation resulting from the dam failure. As early as July 29, the lawyers were beginning to prepare against allegations of negligent inspection, failure to inspect, failure to properly classify the dam, and failure to warn residents of the hazard associated with the dam ⁽⁴³⁾. CDNR lawyers issued warnings to take care with all dam safety branch staff statements regarding the failure, as all statements would likely be used at trial ⁽⁴³⁾.

Official complaints began being filed in District Court in the first week of August 1982. Table 1 shows a chronology of court filings from the records within the SEO, as well as records of newspaper articles regarding the case. The records extend from July 1982 until February of 1985.

From the beginning the cards were stacked against the victims of the disaster ^(44, 45, 46). A 1981 law, CRS 37-87-104 holds a dam owner liable only to the extent of their insurance coverage, which in the case of Farmers Irrigation and Ditch Company was \$1,000,000. The State of Colorado had a limitation of liability of \$400,000. Combined with the funds available from ditch company assets and local governments (Town of Estes Park) a total of no more than \$2.2 million dollars was available to reimburse victims for their losses ⁽⁴⁷⁾. As the summary of claims in Table 1 shows, the claims for relief far outnumbered the funds available.

To further exacerbate the problem, insurance companies providing flood insurance to businesses and individuals in the affected area interpreted their policies to provide coverage for natural flood events or “acts of god”, and refused to pay for the flooding caused by failure of this man-made structure ⁽⁴⁸⁾.

In February of 1983, a state Senator proposed a bill (S.B. 199 21-9) to remove the States immunity from negligence for the failure and provide for a fund of up to \$10 million dollars for victim relief ⁽⁴⁷⁾. Lawyers representing the flood victims argued that they should be allowed to sue because the State Engineer didn’t inspect the dam regularly as required by law. The State Engineer argued that the law did not expressly require annual dam inspections and that inspections have been cut back in recent years because of limitation on funding. Regardless, the bill was ultimately withdrawn and the lawsuit continued ⁽⁴⁹⁾.

The focus of the lawsuits was therefore to demonstrate negligence on the part of the dam owner, the Department of Natural Resources and the State Engineers Office. Those efforts followed standard legal procedures of affidavits, briefs, depositions, discovery, interrogatories, motions, and ultimately a trial.

Table 1 - Partial Summary of Lawsuits Filed

Date	Claimant	Defendants	Amount	Allegations
7/26/1982	Fall River Valley Mobile Home Park (Bob Filbey)	1,2	\$2,500,000	1-6
8/6/1982	Nick Pane et. al., (4 claimants)	1,2	\$2,000,000 \$500,000 \$400,000 \$350,000	1-6
8/11/1982	George W. Harrison et. al. (10 claimants)	1,2,3	\$50,000 \$100,000 \$100,000 \$100,000 \$50,000 \$50,000 \$100,000 \$100,000 \$100,000 \$100,000	1-7

8/27/1982	Jess Dubois	1,2,3	\$150,000	1-7
9/8/1982	Carl Birdsong et. al., (6 claimants)	1,2,3	\$50,000 \$50,000 \$75,000 \$25,000 \$25,000 \$50,000	1-7
9/13/1982	Herbert Blessman	1,2,3	\$642,060.71	1-7
9/24/1982	Cortlin Hauge et. al., (5 claimants)	1,2,3	\$275,000 \$56,000 \$10,000 \$35,000 \$15,000	1-7
10/6/1982	Lloyd Meyers	1	\$300,000	5-6
12/1/1982	Midwest Mutual Insurance Company and Gerald Kunzer, et. al. (3 claimants)	1,3	\$24,691.95 \$20,214.50 \$25,721.24	1-4,7
12/19/1982	Town of Estes Park	1,2	\$150,000	1-6
12/31/1982	Summit Home Insurance Co and Perry Blain et. al. (3 claimants)	1,2,3	\$9,165 \$19,395 \$14,314.65	1-7
1/4/1983	Leon Poore, et. al., (3 Claimants)	1,3	\$25,000 \$100,000 \$100,000	1-4,7
9/12/1983	Rachael Preston	1,2,3	\$1,500,000	1-7
9/12/1983	D.A. Lienemann (Fall River Estates)	1,2,3	\$5,500,000	1-7
9/16/1983	Estes Action Committee (74 claimants)	1,3,4	\$8,631,335	5-7
6/30/1984	Estes Park Families, et.al. (34 Claimants)	4	\$5,400,000	4-5
6/30/1984	D.A. Lienemann & JR Preston	4	\$5,000,000	4-5
8/8/1984	Leonard C. Molander	1,2	\$300,000	1-6
2/22/1985*	Rosemary Coates	4	\$480,000*	4-5
Total			\$35,638,503	

Defendants

1. State of Colorado, CDNR Executive Director, SEO State Engineer, CO Attorney General
2. Farmers Irrigation and Ditch and Reservoir Company; Ray Amen, Tom McKee, Ray DeGood, Henry Schmidt
3. Town of Estes Park
4. US Department of the Interior, National Park Service

Standard Claims for Relief - Allegations

1. Defendants (dam owners) are Strictly Liable for damage sustained by plaintiffs
2. Defendants (dam owner) owed plaintiffs the highest degree of care, defendants were negligent in design, repair and monitoring, conduct constitutes reckless endangerment of plaintiffs lives and property and that of their guests.
3. Defendants (dam owners) were negligent in matters including but not limited to, failing to keep the dam and reservoir in good condition so that the water stored therein should not escape from it to the injury of the plaintiffs and in storing unsafe amounts of water in the Lawn Lake Dam and Reservoir.
4. Defendants (dam owners) did knowingly and recklessly fail to maintain, repair, and inspect the dam; store excessive and unsafe amounts of water in said dam, fail to clear debris from the spillway, and failed to monitor and detect seepage and leakage from the dam and reservoir, in disregard of the rights and property of the plaintiffs.
5. Defendants (CDNR ED, DWR SE, NPS) were negligent in matters including but not limited to failing to properly and timely inspect the dam; failing to examine the reservoir and determine the amount of water that is safe to be impounded therein and the amount actually stored therein; failing to immediately cause water to be drawn from the reservoir to such extent as to render the dam safe; failing to take other actions as necessary to assure that the dam was safe and that the reservoir was not filled to such an extent as to render it unsafe; and otherwise not assuring proper maintenance, repair, monitoring and detection of leaks or seepage.
6. Defendants (State, CDNR ED, SEO SE, NPS) and their agents and employees acted recklessly in disregard of the rights and property of the plaintiffs, proximately resulting in the breakage of the dam and damage to plaintiffs as described.
7. Defendants (Town of Estes Park) by owning and maintaining the Cascade Lake Dam and reservoir assumed the risk of strict liability and are liable to claimants.

*From final Settlement

Of note is this process was the deposition of the State Engineer and two dam safety engineers from the Dam Safety Branch. Through the course of three days of deposition ⁽⁵⁰⁾, 404 pages of questions and answers were generated for a single dam safety engineer with the most ties to the case. The State Engineer's day-long deposition was recorded in 180 pages ⁽⁵¹⁾. Based on the results of the depositions additional requests for production of documents ensued. One request for information from the Dam Safety Branch files included a 17-item list ⁽⁵²⁾. The list included references to issues identified in the depositions. A typical request for documents from the State Engineers files, quoted from the list, is as follows:

“Any and all internal memos, written instructions, letters, manuals, written guidelines or other documents, setting forth or pertaining to the procedure for determining the amount of water that is safe to store in dams located in the State of Colorado from 1902 to the present, or setting forth or pertaining to the manner in which said determination is made, by whom it is made and how often such determination is to be made”.

The legal process ground along from January of 1984 until March of 1987 when a Colorado District judge found the States employees not liable personally or professionally for the failure ⁽⁵³⁾. The case was appealed to the Colorado Supreme Court and on February 1, 1990, the Colorado Supreme court issued an order dismissing, with prejudice, the Lawn Lake action brought against the State, State Engineer and other state officials. A similar judgment was reached in favor of the Town of Estes Park ⁽⁵⁴⁾.

The SEO records are by no means a complete source of information regarding the actual damages awarded as a result of the failure of Lawn Lake Dam. The final newspaper article found from August of 1994 described continuing frustration after 12 years from about 30 original flood victims who had yet to be compensated for their losses incurred that day. Those victims were hopeful to get a mere 6 cents on the dollar ⁽⁵⁵⁾.

One hopeful editorial appeared in the Denver Post newspaper on Saturday June 23, 1984 ⁽⁵⁶⁾. The editor noted that on the eve of the second anniversary of the failure, a significant dam-safety group had organized in Denver. The new organization, the “National Association of Dam Safety Officials” is interpreted to be the precursor to the Association of State Dam Safety Officials (ASDSO). In 1984, the Colorado State Engineer, deep in the midst of fallout from the failure of Lawn Lake Dam saw the wisdom of participating in the formation an association to provide for small (non-federal) dam owners and state dam safety programs alike. Through such an association, access to resources for owners and state officials alike could be made in the interest of safe dams. Those resources might reduce the potential for the future nightmare of dam failures. The editorialist suggests the new organization should tell its members to be tough and that hard regulation is probably the best answer. The editorial concludes that when human life is in the balance, owners of suspect dams must be handed a “fix or we’ll drain it” order. “As Lawn Lake makes us realize, such an approach is the only one that really works.”

LAWSUITS – NATIONAL PARK SERVICE

Approximately two years following the failure, the NPS was named in two lawsuits. In September 1983, an \$8.4 million lawsuit was filed listing the Town of Estes Park, US Department of the Interior (NPS) and the CO Department of Natural Resources as co-defendants ⁽⁵⁸⁾. On June 30, 1984, twenty-nine Estes Park residents and five insurance companies filed suit ⁽⁵⁹⁾. The suits alleged negligence and that the NPS was responsible for the dam failure and flood damages. The lawsuits claimed the NPS should have known that the dam was deteriorating and leaking and should have required the dam owner to repair the dam. The NPS denied these allegations, stating

that the dam maintenance was usurped by Colorado law and given to the dam owner and the State Engineer.

In February 1985, a federal judge awarded \$480,000 to the family of one of the people drowned in the Aspen Glen Campground^(60, 61). Reasons cited for the award included:

- Park rangers erred when they thought that the flood upstream from the campground had dissipated in the 5-square-mile Horseshoe Park.
- Park rangers did not warn all of the campers near the Fall River. The warning was given without a sense of urgency.
- By charging a fee to enter and camp at the park, the NPS created a duty “to develop orderly procedures for dealing with emergencies.”

The ruling continued,

“It is imperative to have a plan in place because in such situations there is little time for reflection. Priorities should be established before an emergency arises... Elementary lapses, obvious with the clarity of hindsight, could have been avoided through the development of orderly procedures for warning and evacuating people in the park in the event a crisis arose.”

The \$480,000 represented 60% of the potential award. The victim himself was held responsible for 40% for his own death given that he had been warned of the flood and decided to re-enter the river area.

SUMMARY AND CONCLUSIONS

This paper is intended as a review of the Lawn Lake Dam failure including the internal and public processes into how and why it happened and determining who might be at fault. The impacts to the affected parties were reviewed for the purpose of understanding the processes that follow such an event and how the various parties are ultimately affected. The review was less an exercise in reviewing mistakes made in the process, for there were few identified, than it was to review the processes and see where opportunities might exist to prepare for future handling of these events that will inevitably happen.

In Colorado, including RMNP, no significant failures (those resulting in extensive property damage or loss of life) have occurred in the 30 years since the Lawn Lake Dam failure. Normal personnel retirements and turnover have led to a complete change in leadership and technical resources of dam safety branches of both the State of Colorado and the National Park Service. As both authors are relatively new to their dam safety positions in the State and NPS and tasked with the same public safety mandate this review has been a beneficial exercise.

The review of this event shows the level of questioning and scrutiny that arises as victims of dam failure floods strive for compensation and public officials attempt to understand why these events happen and how they might be prevented from

reoccurring. Such scrutiny of a dam safety program is necessary and unavoidable at such times and it is important to recognize that this will happen following a dam failure.

The main conclusion from this review is not that dam safety officials should necessarily change their course from the technical aspects of providing for the safest dams and reservoirs possible toward a “cover your backside with paper” philosophy to continuously prepare for public scrutiny. Rather, the conclusions of this review are:

1. Dam Safety officials should always strive for the clearest and most consistent documentation of our activities. This will make the program effects on the safety of dams as great as possible and inevitably create a program that can withstand the scrutiny of events such as those described in this paper.
2. Dam safety and risk reduction processes should be action oriented, always striving to identify needs for actions to ensure the safest possible dams and seeing those actions through. Remedies for the victims of such disasters are limited and the best possible scenario is to take the necessary actions to avoid them in the first place.
3. The benefit of the storage of water behind dams outweighs the inherent risk associated with that storage only when the risk is managed to the lowest levels possible. All dams need to be properly maintained – even dams in roadless areas.
4. There are opportunities for increasing public awareness of the inherent risks associated with the storage and beneficial use of the water behind dams, and thereby reducing the consequences through preparedness.
5. Dam failure floods create sudden physical changes to the areas downstream. Sedimentation and depositional processes occur in a short time. Dam failures create unique opportunities for scientists to study these changes.
6. Prompt communication and coordination within an agency and amongst multiple agencies is important following a dam failure.
7. Dams upstream from people should have dam owner-developed Emergency Action Plans.

Demonstrating and documenting well-reasoned actions in the pursuit of safe and beneficial storage of water behind dams will provide the public with the knowledge and confidence that the benefits of beneficial storage outweigh the associated risks.

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