RECLAMATION

Managing Water in the West

RCEM – Reclamation Consequence Estimating Methodology

Interim

Dam Failure and Flood Event Case History Compilation

Lawn Lake Dam failure flood in 1982 at Estes Park, CO (Reclamation photograph)

U.S. Department of the Interior
Bureau of Reclamation

June 2015

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Table of Contents

List of Figures

Introduction

Dam failure and non-dam related flooding case histories can form the basis of an empirical method of estimating dam failure flood fatalities. The DSO-99-06 was developed in 1999 by Reclamation, and is based on forty such case histories. All of the original case histories presented in DSO-99-06 are contained in this document, plus an additional twenty cases. Most of the case histories are located in the United States, but included are notable dam failure or other types of flooding events which occurred in places such as Europe, South America, India, China, Indonesia and Japan.

The estimation of life loss from dam failure is an important part of the risk analysis process which attempts to evaluate a group of dams within a portfolio on equal terms. Potential failure modes (PFM) are developed, and an annual failure probability is estimated for each PFM. Estimated life loss numbers are generated for the PFM and the analysis results are plotted on an f-N chart to evaluate the need for further action and to develop a ranking of the dam's needs relative to other dams in the portfolio.

This document contains a brief summary of every case history that was used to develop DSO-99-06 as well as additional case histories which expand the empirical data set. Relevant and unique information is provided, where available for each case. The purpose of this document is to allow the reader to become familiar with these cases and to possibly create insight into whether a particular case history has similarities to a dam being examined through risk analysis. Each case history description contains a summary table with key parameters, and references are provided if more information is needed. Note that the Reclamation Flood Event Case History Archive, consisting of scanned pdf files of documents used to develop DSO-99-06, contains a great deal of information on many of these case histories.

The estimation of life loss, for a given dam, is often based on parameters which are developed through numeric hydraulic analysis. Key parameters are: flood depth multiplied by flood velocity (DV), which can be used to quantify the intensity and destructiveness of flooding; and flood wave travel time, can be combined with other information to estimate warning and evacuation. DSO-99-06 also used a flood severity understanding parameter that is intended to help adjust fatality rates based on how well the downstream public may perceive the risks. While the flood severity understanding is an excellent concept, it is not currently supported with a lot of empirical data. Reclamation's revised, 2014 empirical method does not explicitly use the flood severity understanding concept.

DV is an important parameter that is used to help characterize the DSO-99-06 concept of flood severity, which is categorized as being high, medium or low. In descriptive terms, DSO-99-06 provided the following criteria for flood severity classification:

- Low severity occurs when no buildings are washed off their foundations.
- Medium severity occurs when homes are destroyed but trees or mangled homes remain for people to seek refuge in or on.
- High severity occurs when the flood sweeps the area clean and nothing remains. Although rare, this type of flooding occurred below St. Francis Dam and Vajont Dam.

Various research studies have correlated DV with the stability of structures, motor vehicles and people (RESCDAM, Abt, etc.). These studies have helped to form a basis for the numeric definitions of flood severity categories used by Reclamation. DV in relation to building structural stability is considered to be a particularly significant parameter, since the damage or destruction of a house can be considered an indication of potential lethality.

Numerically, flood severity has been described as:

- Low severity where DV is less than 50 ft^2/s
- Medium severity for DV greater than 50 ft^2/s
- High severity for DV greater than 160 ft^2/s combined with rate of rise of at least 10 feet in 5 minutes

Regarding the case histories, several items should be noted:

- For cases of DV greater than 160 ft^2/s where adequate warning was issued, the fatality rate range is very large, from zero [e.g. Teton Dam (Sugar City) and Big Bay Dam] to almost 20 percent [Liujiatai Dam (Gaoshi, Haoshan and Zhigushi Villages)].
- Fatality rates are based on estimates of PAR which can be very approximate.
- Other information, such as DV and warning time are, in some cases, based on anecdotal information.
- For many of the case histories, varied flood severity may have been present. This may be true for some of the low severity dam failure cases where medium severity flooding may have existed in some areas, typically closer to the dam.
- Some of the low severity flash flood cases only examined fatalities in a particular area of interest, but there may have been additional fatalities occurring within other areas affected by the flood.
- A lot of case histories lack DV information. For these cases, the flood severity classification was based on various methods of DV estimation which are described below. There is a certain amount of subjectivity associated with the flood severity designation for some of these case histories.

Several methods were used to estimate DV for the cases contained in this report. Often there is reported information available for downstream locations concerning maximum depths and flood wave arrival time, which can be converted to a velocity. Many of the DV values were estimated using this data. One should realize though, that this information is often anecdotal, and was often reported by observers who may have been in a state of confusion at the time of observation.

Hydraulic re-creation analysis has been performed for a number of the case histories. For these cases, the estimates of DV are based on modeling results.

Where depth and velocity information was not available, maximum discharge estimations divided by the flood plain width were used to estimate DV at a particular location.

In situations where data is very limited, a range of estimated DV has been based on photos and verbal descriptions of the flood.

Additionally, the location of the PAR may sometimes have been away from locations where the maximum DV had occurred. For some of the case histories, attempts were made to account for this and to reduce the DV estimate.

The case histories do not contain any events which affected large urbanized populations. In this type of situation, evacuation may be restricted by roadway capacity and traffic congestion. For the most part, estimates of fatalities for cases with large, urban populations fall outside the range of existing case history data. The application of empirical data to cases such as this should be approached cautiously. In situations where critical decisions may be affected by the life loss estimate, fatality rates might be better estimated using a numeric model such as the Life Safety Model (LSM, HR Wallingford).

Note that many of the reference documents used to develop the descriptions of these case history descriptions can be found in what is being referred to as the "Reclamation Flood Event Case History Archive." The archive is a collection of reports, papers, newspaper articles and other information that was compiled by Reclamation employee Wayne Graham before his retirement. Another significant contributor to the archive was Reclamation employee Earl (Bud) Bay, also now retired. This information, originally in hardcopy form, has been scanned and is now digitally available in pdf format.

High Severity Dam Failure and Flooding Case Histories

Vega de Tera Dam - Failed January 9, 1959

Vega de Tera Dam was a concrete slab and buttress structure located in the northwestern zone of the Iberian Peninsula, in the Zamora district of Spain. The 112 foot high dam was constructed from 1954 to 1958. The dam failed suddenly and without warning near midnight, releasing the full storage of the reservoir. The village of Ribadelago, located five miles downstream, was almost completely destroyed. There were 144 deaths at Ribadelago and the fatality rate was about 30 percent. The builders of the dam followed the practice of suspending work during winter. As a result of inadequate preparation of joints on resumption of placement, poor bond was established between old and new masonry. The subsequent heavy leakage through the masonry marked the zones of weakness in the dam. Failure was said to have started in a buttress standing on a sloping foundation near the left abutment at a joint between the masonry and the concrete. This triggered the collapse of 17 buttresses in succession. A 330-foot long section of the structure, including a ski-jump spillway, broke apart and was washed away. The breach width covered about one-half the length of the dam's crest. The powerplant at the site was also demolished.

Runoff from intense rainfall had just completed the initial filling of the 6,300 acre-foot reservoir, which had been placed into operation 2 years previously. The dam reportedly was breached at the moment of overtopping of the crest. Most of the contents of the lake were spilled within a period of 20 minutes. Nearly 6,500 acre-feet of water surged down upon the village of Ribadelago, at an elevation 1700 feet below the damsite. A wall of water 20 feet high was reported at Ribadelago. The momentum of this flood rushing down the precipitous canyon destroyed about 125 of the town's 150 buildings. Because the deluge struck in the early morning hours when most of the 500 townspeople were still asleep, the list of the dead was long. Only a few were able to climb to higher ground. Others rode out the torrent and survived. The people had been unaware of any danger. The damsite is in one of the most isolated regions of Spain. Rescue efforts were hampered as the unrelenting rainstorm limited access to the stricken area. The catastrophe came in the middle of a severe winter.

DV and rate of rise is not precisely estimated, but DSO-99-06 considered this dam failure flood event to be high severity. Reasons for this are probably due to the sudden failure of the relatively tall concrete dam and the resulting devastation in Ribadelago. Travel times are not known, but maximum depth is cited as having been about 20 feet at a location 3.1 miles downstream from the dam.

Figure 1. Remains of Vega de Tera Dam
Source: Photograph by Raiden32 (Own work)
http://commons.wikimedia.org/wiki/File%3AEmbalse_de_Vega_de_Tera_(Presa_Rota).JPG

Summary Table 1. Vega de Tera Dam

Flood Severity Rating	High
Warning Time	No warning at Ribadelago
Time of day	Midnight
Failure scenario	Static Failure with elevated reservoir level
Fatalities	144
Fatality Rate	0.30
Dam Height	112 feet
Reservoir Storage	6,500 acre-feet
Breach Formation Time	Instantaneous
Total PAR	500
Downstream Distance to PAR	3 miles
Flood Severity Understanding	n/a
Maximum DV	Estimated at 200 to 400 ft^2/s (20 foot max. depth with max velocity estimated to have been 10 to 20 ft./s)
Confidence in data	good

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- Engineering News Record, "Masonry Dam Crumbles in Spain," Jan 15, 1959
- es.wikipedia.org (Spanish)

- International Federation of Building Trades, Employers and Civil Engineering Contractors. Review No. 45, 1st Quarter, 1965, Technical Study of the Bursting of Vega de Tera Dam, by M.F. Bollo

St. Francis Dam – Failed March 12-13, 1928

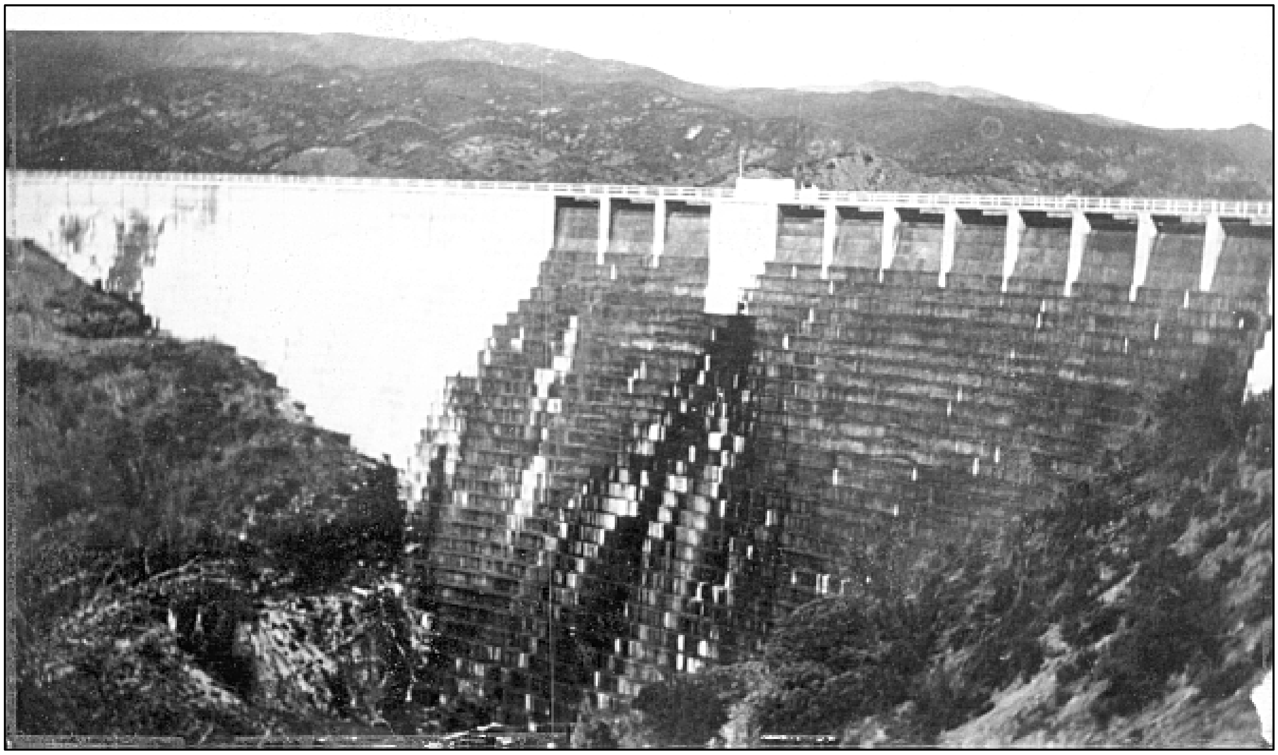


Figure 2. St. Francis Dam before Failure
Source: Photo courtesy of SCV Historical Society, www.scvhistory.com/scvhistory/hs2809.htm

St. Francis Dam was located about 37 miles north-northwest of downtown Los Angeles. The arched concrete gravity dam was constructed to augment the Los Angeles water supply.

St. Francis failed at about midnight, March 12-13, 1928. The flood traveled 54 miles from the dam to the Pacific Ocean in a five and one-half hour period during the early morning hours of Tuesday, March 13. The dam had been completed in 1926, and was 2 years old when it failed. Failure of this dam was caused by sliding along a weak foliation planes within the schist comprising the left abutment, suspected of being part of an old landslide.

Figure 3. The breached St. Francis Dam, looking downstream
Source: Los Angeles Public Library Photo Collection, http://jpg1.lapl.org/pics20/00009817.jpg

St. Francis Dam had a height of 188 feet, and the reservoir volume at the time of failure was about 38,000 acre-feet. The reservoir was about 3 feet below the crest of the parapet at the initiation of dam failure.

The failure sequence for this dam can be considered a worst case scenario. The event occurred in the middle of the night when many people would have been asleep and darkness prevented people from observing the events that were occurring. The dam failed suddenly with no warning being issued before failure, and the entire contents of the reservoir drained in less than 72 minutes. The dam tender was unable to alert anyone of the danger. He and his family lived in the valley downstream from the dam and perished in the flood.

The Ventura County Sheriff's Office was informed at 1:20 a.m. Telephone operators called local police, highway patrol and phone company customers. Warning was spread by word of mouth, phone, siren and by law enforcement officers in motor vehicles.

Flooding was severe through the entire 54-mile reach from the dam to the ocean. The leading edge of the flooding moved at about 18 miles per hour near the dam and 6 miles per hour nearer the ocean. There were about 3,000 people at risk and about 420 fatalities, although the number of fatalities reported varies significantly. The fatality rate for the entire reach was about 0.14. It was much higher than this near the dam and much lower as the flood neared the Pacific Ocean. The dam was not rebuilt.

Two downstream areas are of particular interest. Powerhouse No. 2 was located in the San Francisquito Canyon, about 1.4 miles downstream from the dam. The flood arrived at this location as a wall of water, about five minutes after the dam had failed. This was the classic example of high severity flooding with an estimated maximum flood depth of 120 feet and peak discharge of 1.3 million ft^3/s. The 60-foot tall concrete powerhouse was "crushed like an eggshell" and the area swept clean. Warning time was zero. Twenty eight workers and their families had lived at the site. There were three survivors.

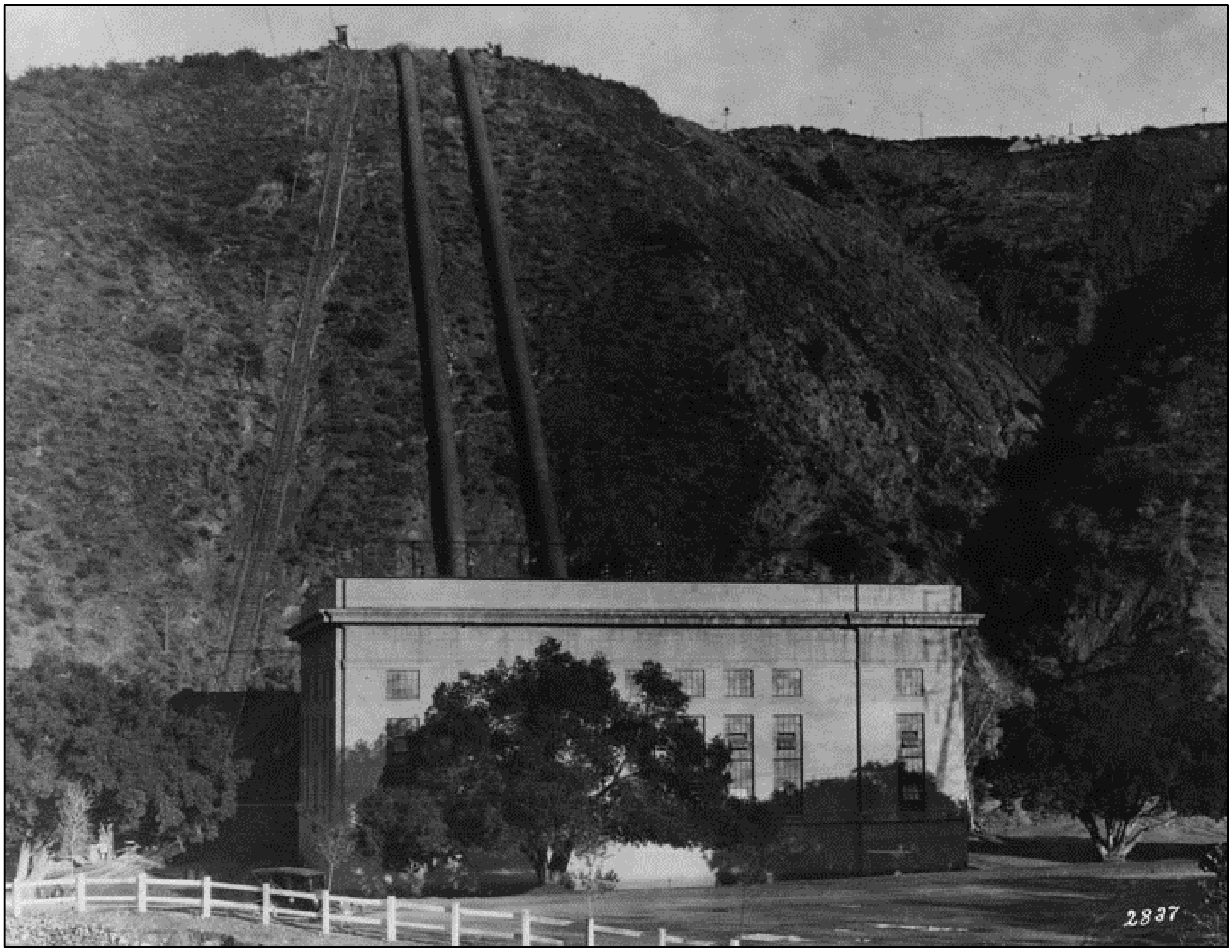


Figure 4. Powerhouse No. 2 before its collapse
Source: Los Angeles Public Library Photo Collection, http://jpg1.lapl.org/pics20/00009837.jpg

Figure 5. Location of Powerhouse No. 2, area swept clean after flooding
Source: U.S. Geological Survey/photo by H.T. Stearns
http://libraryphoto.cr.usgs.gov/htmlorg/lpb212/land/sht00685.jpg

Another area of interest was the Edison Construction Camp located 18.5 miles downstream where 150 men slept in tents along the banks of the river. The flooding at this location was described as a 60-foot wall of water. An effort to issue advance warning to the site was unsuccessful. As the flood approached, a night watchman became alerted and attempted to wake the sleeping men, but it was mostly too late. An estimated eighty-four fatalities occurred at this site.

Figure 6 Aftermath of flooding at the Edison Construction Camp
Source: U.S. Geological Survey/photo by H.T. Stearns
http://libraryphoto.cr.usgs.gov/htmlorg/lpb212/land/sht00694.jpg

The flooding downstream of St. Francis Dam is considered to have been high severity from the dam to downstream of the Edison Camp for the following reasons: The sudden dam breach created a wall of water. The river channel was swept clean, with all buildings completely destroyed for areas from the dam, through the Powerhouse No. 2 location and past the Edison Construction Camp. Maximum DV at Powerhouse No. 2 is estimated to have been about 2,960 ft^2/s with extremely steep rate of rise. DV and rate of rise stayed in the high severity zone for at least several miles past the Edison Camp.

A hydraulic modeling re-creation of the St. Francis Dam failure flood was performed by Reclamation in 2012 using the MIKE21 two-dimensional hydraulic model. A reconstructed hydrograph (Rogers) from the Powerhouse No. 2 location was used as an inflow boundary condition to the model. Based on the modeling results, flood severity was calculated along the downstream floodplain. These DV and rate of rise data indicate that flooding met the high severity classification criteria for locations from the dam to just upstream of the town of Fillmore, a total distance of about 29 river miles. At the town of Piru, about 24 miles from the dam, the flood begins to exhibit significant lateral variation in flood severity with zones of medium and low severity flooding as distance increases from the river thalweg. At Fillmore (mile 32) and other locations further downstream, the modeling results indicate medium and low severity flooding. The flooding at the Oxnard Plain (mile 52), near the ocean, is almost completely low severity. This information is, for the most part, consistent with photographs and written accounts of the flood disaster.

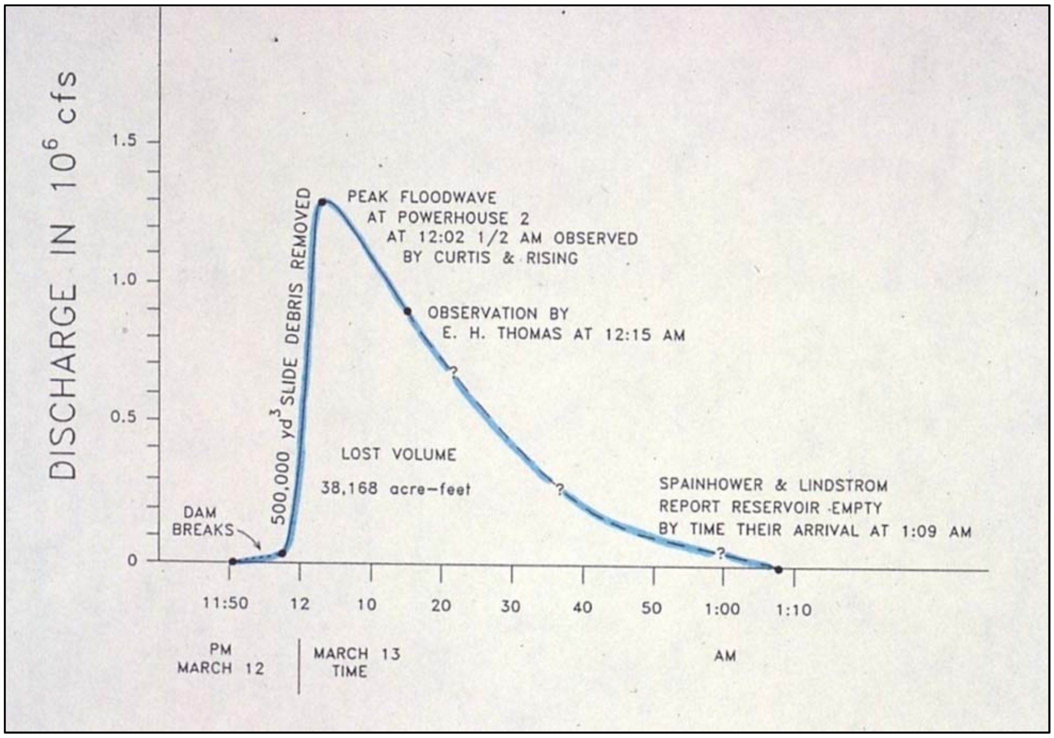


Figure 7. Reconstructed hydrograph at Powerhouse No. 2
Source: *Reassessment of the St. Francis Dam Failure*, J. David Rogers

Summary Table 2. St. Francis Dam Summary

Flood Severity Rating	High for upstream areas including Powerhouse No. 2 and the Edison Camp
Warning Time	No warning at Powerhouse No. 2 and the Edison Construction Camp, Fillmore – some warning, Santa Paula – some to adequate warning, Saticoy and beyond – adequate warning
Time of day	Dam failure occurred just after midnight
Failure scenario	Sudden failure
Fatalities	Exact numbers unknown at Powerhouse No. 2, 84 at Edison Camp, estimate of total flood fatalities ranges from 420 to more than 600
Fatality Rate	> 90% at Powerhouse No.2, 56% at Edison Camp
Dam Height	188 feet
Reservoir Storage	38,000 acre-feet
Breach Formation Time	instantaneous
Total PAR	About 3,000
Downstream Distance to PAR	1.4 miles to Powerhouse No. 2, 18.6 miles to Edison Camp, 31.7 miles to Fillmore, 40.1 miles to Santa Paula
Flood severity understanding	Varied
Maximum DV	2,960 ft^2/s at Powerhouse No. 2 Edison Camp:100 to 1,240 ft^2/s (based on MIKE21 model)
Confidence in data	good

<u>References:</u>

- Man Made Disaster, by Charles Outland
- Reassessment of the St. Francis Dam Failure, J. David Rogers

Nevado del Ruiz Lahar Mudflow – November 13, 1985

Figure 8. The town of Armero, Columbia and the aftermath of the Nevado del Ruiz Lahar mudflow
Source: U.S. Geological Survey, http://volcanoes.usgs.gov/vdap/images/ruiz/armero85.jpg

On November 13, 1985, the Nevado del Ruiz Volcano erupted causing a small portion of its icecap to melt, and setting off a massive mudflow (lahar flow) which resulted in the deaths of about 22,000 people at the town of Armero, Columbia.

This event had many similarities to a dam failure event in that:

- Lahar flows move down river drainages and into flood plain areas
- DV was very high and the wave front rate of rise was steep
- The emergency planning and response activities were similar to what is done for dam failure preparedness planning and response.

The potential for volcanic eruption and possible lahar flooding was known well in advance. An emergency plan was developed, complete with evacuation zone maps which showed Armero being located in the heart of the most heavily affected area. Local officials downplayed the risks reportedly because of concern over damage to the economic vitality of the community. Most of the residents of Armero did not appear to have fully understood the potential severity of the event due to mixed messages being received from the scientists/planners and from community leaders. On the night of the eruption, a storm unrelated to the volcanic eruption, commenced in the vicinity of Armero which created heavy rain, thunder and lightning.

Visibility was limited, power outages occurred and communications were intermittent on the evening of November 13. As a result of storm, a bad situation was made even worse. There was a general lack of support from community leaders, mixed messages regarding the severity of the threat were being received by the public, and communications were disrupted by the storm. Due to all of these problems, the issuance of warning was delayed until the last minute. The results of this botched planning were catastrophic. Roughly 22,000 people were killed as the destructive mud and debris flow moved through Armero at about 11:00 pm on November 13.

At 11:00 p.m., the mayor of Armero was overheard on a radio transmission voicing his disbelief in the severity of the lahar's possible impact on Armero. At that same moment, Armero is inundated by a swift flow of watery mud, rocks, and other debris. The mayor was killed.

The flooding at Armero is considered to have been high severity due to the high DV which was estimated to be about 950 ft^2/s. The maximum depth of the mud-laden flow was reported to be about 23 to 26 feet, with velocities up to about 36 ft./s. The flooding swept the area clean, with buildings completely destroyed.

Summary Table 3 Nevado del Ruiz Lahar Mudflow Summary

Flood Severity Rating	High
Warning Time	Zero for most of the PAR
Time of day	Eruption occurred just after 9:00 pm, and mudflow reached Armero at about 11:00 pm
Scenario	Volcanic eruption resulting in lahar mudflow
Fatalities	About 22,000 at Armero , about 1,000 at neighboring community of Chinchina on a separate drainage
Fatality Rate	85% at Armero
Downstream Distance to PAR	30 miles
Total PAR	Roughly 26,000
Maximum DV	950 ft^2/s
Flood severity understanding	n/a, the majority of PAR did not receive warning
Confidence in data	Good. The story of Armero is well documented

References:

- The Eruption of Nevado Del Ruiz Volcano, Columbia, South America, November 13, 1985, Natural Disaster Studies, An Investigative Series of the Committee on Natural Disasters, Volume Four, Committee on Natural Disasters, Division of Natural Mitigation, Commission on Engineering and Technical Systems, National Research Council, 1991
- No Apparent Danger: The True Story of the Volcanic Disaster at Galeras and Nevado Del Ruiz, by Victoria Bruce, Harper Perennial Press, 2002

Stava Tailings Dam – Failed July 19, 1985

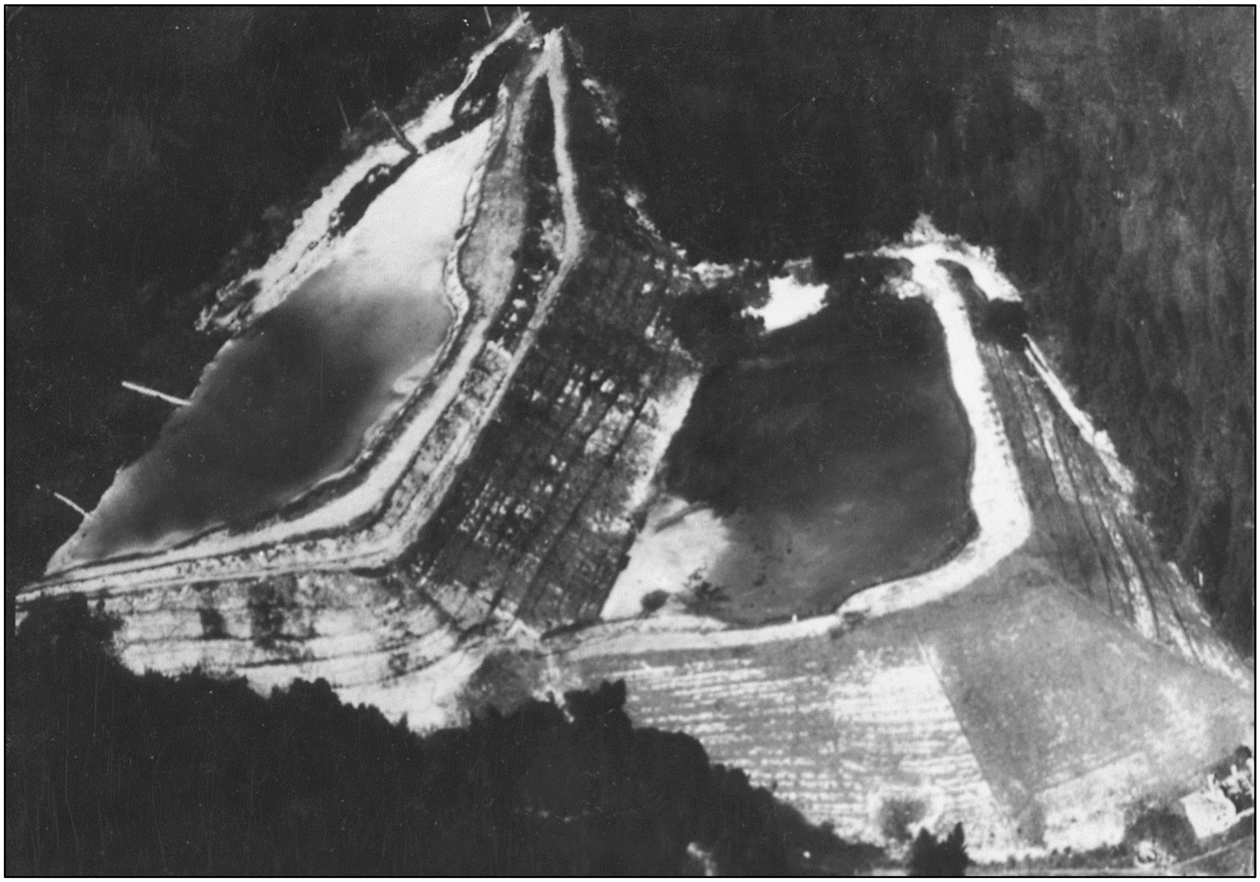


Figure 9. Upper and Lower Stava Tailings Dams
Source: Fondazione Stava 1985 Archives, http://www.stava1985.it/

On July 19, 1985, a fluorite tailings dam failed at Stava, Trento, Italy. The tailings dam consisted of two basins built on a slope. The failure started at just after noon at about 12:20 pm with a collapse of the up-slope basin. The inflow of the released material caused the overtopping and subsequent collapse of the lower basin. The resulting slurry wave traveled to Stava at an estimated speed of 26 ft./s; later it is reported to have reached almost 80 ft./s.

The flood wave killed people, destroyed trees, buildings and everything in its path, until it reached the river Avisio. Few of those hit by this wave of destruction survived. Along its path, the mud killed 268 people and completely destroyed 3 hotels, 53 homes, and six industrial buildings; 8 bridges were demolished and 9 buildings were seriously damaged. The mudflow reached the village of Stava after 50 seconds, and then continued for three minutes until it reached the Avisio River 2.5 miles away.

A thick layer of mud measuring between 8 to 16 inches in thickness covered an area downstream over 2.5 miles.

Figure 10. Destruction in the valley, downstream from Stava Tailings Dam
Source: Fondazione Stava 1985 Archives, http://www.stava1985.it/

The failure of Stava Tailings Dam is considered to have been high severity flooding due to the rapid failure of the embankments which resulted in very fast flood flow velocities and the complete destruction of the downstream community. Maximum flooding depths appear to be unavailable, but the river valley at the community of Stava was "swept clean" and this is another classic example of high severity flooding.

Summary Table 4. Stava Tailings Dam Summary

Flood Severity Rating	High
Warning Time	Zero at town of Stava, 1 mile downstream
Time of day	Midday
Failure scenario	Sudden Failure
Fatalities	268
Fatality Rate	unknown
Dam Height	164.4 feet total for both dams
Reservoir Storage	146 acre-feet
Breach Formation Time	Sudden, exact formation time unknown
Total PAR	unknown
Downstream Distance to PAR	Beginning at 0.5 miles downstream
Maximum DV	3,250 ft^2/s
Flood severity understanding	n/a
Confidence in data	Good in terms of number of fatalities and severity of flooding. Travel times are based on seismogram readings, maximum depths are not known.

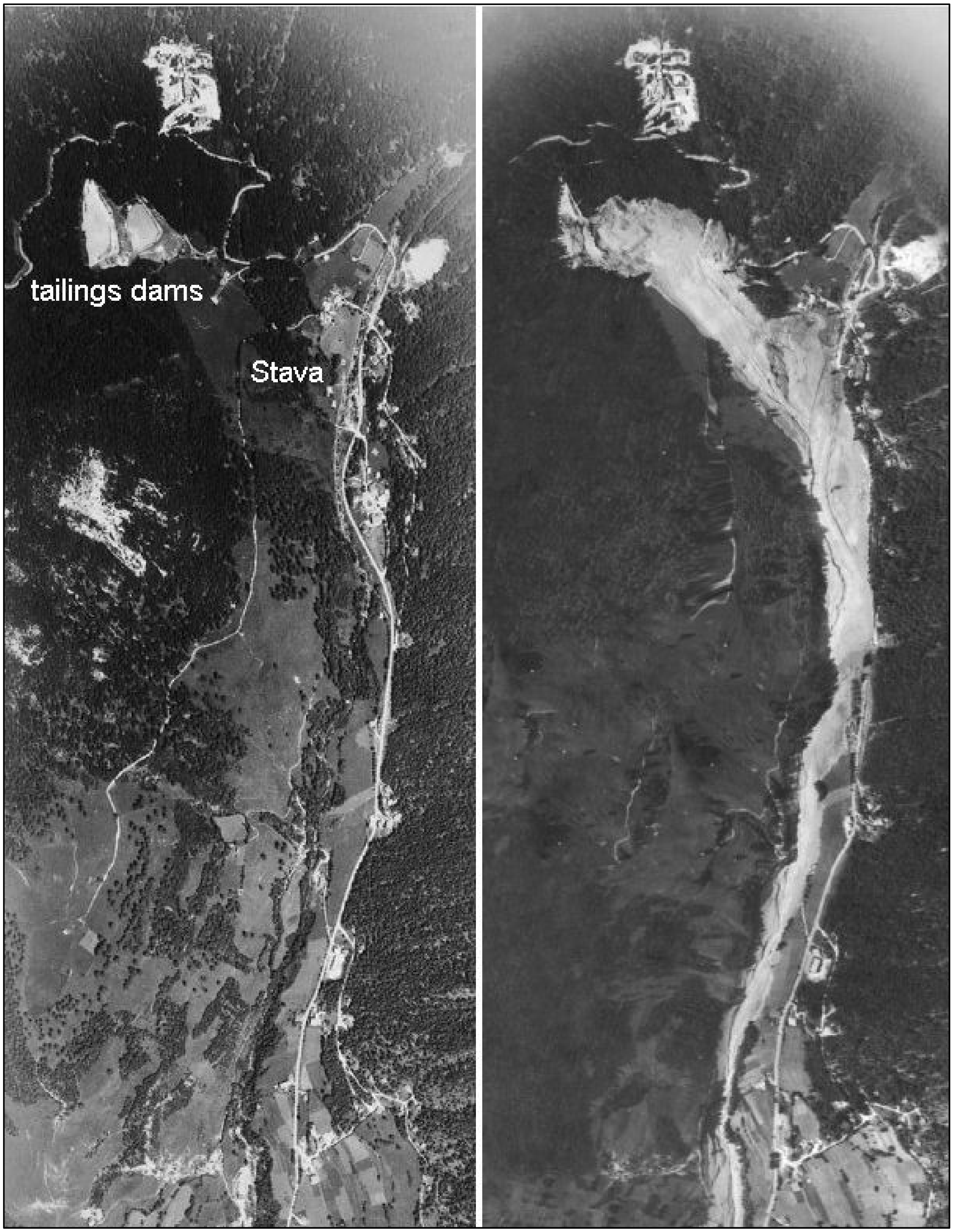


Figure 11 Before and after aerial imagery of Stava Dam and the downstream town of Stava
Source: Peter Diehl/WISE Uranium project (image was manipulated from original images provided to Diehl by Fondazione Stava), http://www.wise-uranium.org/mdafst.html

References:

- Foundation Stava 1985: http://www.stava1985.it/
- Various Newspaper Articles, Reclamation Flood Event Case History Archive
- www.wikipedia.com
- http://historyofgeology.fieldofscience.com/2010/07/july-19-1985-val-di-stava-dam-collapse.html

Vajont Dam – Landslide Induced Overtopping, October 9, 1963

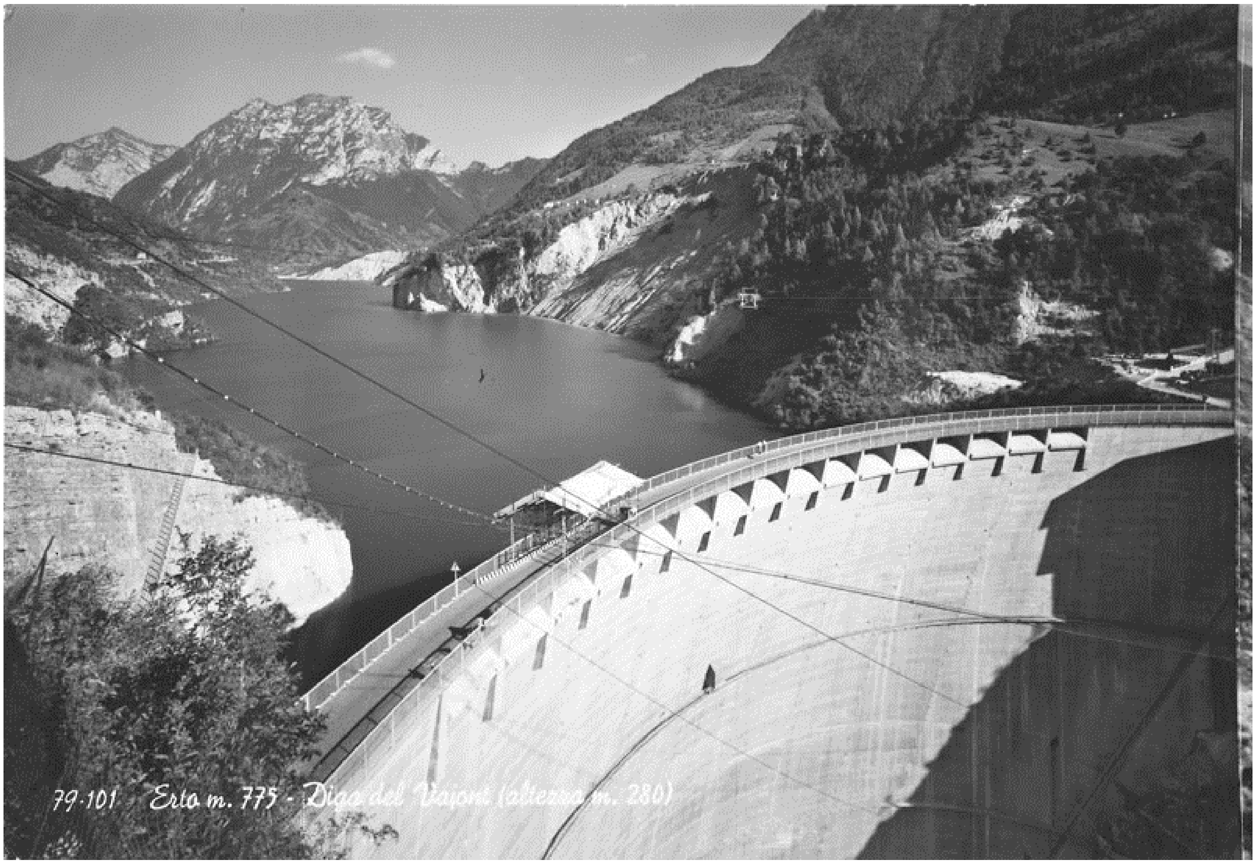


Figure 12. Vajont Dam before the Landslide
Source: Wikipedia, http://commons.wikimedia.org/wiki/File:Vajont_Dam_1960_panorama.jpg

One of the most damaging reservoir disasters of all time occurred on October 9, 1963, at Vajont Dam near Belluno in Veneto Province in Italy, when about 2,600 human lives were lost. During the night, a tremendous landslide fell into the reservoir. The impact of the great mass, moving with terrifying speed raised gigantic waves which overtopped the structure. Tremors caused by the slide triggered seismological instruments throughout a vast area of western and central Europe. The dam itself sustained no major damage even though it was hit by a total water force of about 4,000,000 tons from the impacts of overtopping.

The dam, with a height of 869 feet was reported, at the time of construction to be the world's highest thin arch and the second highest dam of any kind. It was completed in the fall of 1960. The arch is 11.2 feet thick at the top and 74.5 feet thick in the bottom of the canyon

A landslide into the reservoir first occurred in November 1960. After this event, the reservoir level was restricted and the landslide areas were monitored. In the fall of 1963, the rate of movement of the landslide had decreased. At this time, the reservoir level was raised an additional 66 feet. This filling may have led to the landslide into the reservoir, which created a wave that brought massive flooding and destruction to the Piave valley below, wiping out several villages completely.

Water displaced by the slide material was thrown up the right canyon wall to the village of Casso, where it washed through buildings. It spilled over the dam to a height of about 330 feet above the crest. The spillway bridge was torn away and the crest was damaged, but the dam itself did not fail.

Figure 13. The town of Longarone, before the landslide
Source: Photo courtesy of Polizia di Stato – Italian National Police, http://www.poliziadistato.it/

The flood wave was more than 230 feet high where the Vajont River enters the Piave River, 1 mile downstream. After obliterating the town of Longarone at that junction, the flood wave left practically total devastation in its course for many miles down the Piave valley.

The landslide occurred at 10:39 pm. Surviving witnesses from Longarone said that a flood wave came down the canyon at 10:43 p.m., and that a strong wind broke windows. There were strong earth tremors caused by the flood. By 10:55 p.m. the flood had passed, and the valley was silent.

Figure 14. Remains of Longarone
Source: Photo courtesy of Polizia di Stato – Italian National Police, http://www.poliziadistato.it/

About three years prior to the event, a landslide had occurred into the reservoir and there was an awareness of the potential for a landslide generated flood wave. Heavy rainfall prior to the 1963 landslide combined with significant monitoring data which indicated increasing movement of landslide mass, could have promoted actions to protect the downstream population at risk. There is no known record of any warning or evacuation order being issued to the downstream population.

The flooding in the Piave valley destroyed the villages of Longarone, Pirago, Rivalta, Villanova and Faè, killing around 2,600 people.

This flood is considered to have been high severity because of the high velocities, the very deep depth of flooding and the complete destruction of the town of Longarone which occurred within minutes following the generation of the landslide overtopping flood wave.

Summary Table 5 Vajont Dam Summary

Flood Severity Rating	High
Warning Time	Zero at town of Longarone and other downstream communities
Time of day	10 to 11 pm
Failure scenario	Landslide generated overtopping flood wave
Fatalities	Approx. 2,600 including all communities (1,269 from DSO-99-06, for only Longarone)
Fatality Rate	0.94 at Longarone, according to DSO-99-06
Dam Height	869 feet, dam overtopped, but did not fail

Breach Formation Time	Sudden overtopping of dam, no breach
Reservoir storage	122,000 acre-feet
Total PAR	1350 at Longarone based on DSO-99-06 fatality rate and total fatalities
Flood severity understanding	n/a
Downstream Distance to PAR	Approx. 1 mile to Longarone
Maximum DV	5,060 ft^2/s, based on flood traveling 1mile in 4 minutes and max depth of 230 feet
Confidence in data	Good, event was well documented

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- Civil Engineering, March 1964
- Numerous Articles – Reclamation Flood Event Case History Archive

Malpasset Dam – Failed December 2, 1959

Figure 15. The failed remains of Malpasset Dam
Source: Photo courtesy of Derek Sakamoto

Malpasset Dam was a thin arch concrete dam, 200 feet high, located about 6 miles upstream of the French Riviera town of Frejus, on the Reyran River. The reservoir held about 18,000 acre-feet of storage. Construction of the dam was completed in 1954.

The dam was experiencing previously untested reservoir levels, and failed suddenly at 9:10 pm on December 2, 1959. Heavy rainfall had been occurring since at least November, and prior to the failure of the dam there was increasing seepage noted on the right abutment. Attempts were made to lower the reservoir by opening the outlet works gates. The dam's operators were concerned about the elevated reservoir levels and at least some of the residents in the town of Frejus had concerns regarding the dam's safety.

A 50 mph, 100-foot high wall of water reportedly descended on downstream areas. A large number of people were killed in Frejus, and some who heard the crashing of the approaching flood wave knew what it was, but no warning was issued. Many of the fatalities at Frejus were people in houses which either collapsed or filled with water.

Figure 16. Flood Damage near Frejus
Source: Licensed by Corbis Images

Figure 17. Remains of destroyed home, upstream of Frejus
Source: Photo courtesy of Derek Sakamoto

High severity flooding is thought to have occurred in the reach of the Reyran River from the dam to the upstream outskirts of Frejus. A highway construction camp was located several hundred yards downstream of the dam which contained more than 30 workers. Most of the workers were reported to have been killed by the flood**.** The flooding at Frejus was probably a combination of high and medium severity, based on a B.C. Hydro hydraulic re-creation of the flood which indicated DV lower than 160 ft^2/s for much of the community. Many homes at Frejus collapsed when subjected to the flooding, including houses located in the zone of medium flood severity.

The Malpasset Dam flooding is considered to have been high severity at the construction camp due to the sudden failure of the dam and the resulting wall of water on the upper Reyran River. Maximum DV is estimated to have been as high as 1,100 ft^2/s close to the dam.

The B.C. hydro study included a hydraulic re-creation of the flooding, and also provided the following information:

- The Upper Reyran River, 0 to 2.2 miles contained 6% of the PAR, but experienced 34% of the life loss. Few bodies of victims were recovered from this zone. The PAR was approximately 220, life loss was approximately 155. The fatality rate for this reach was about 70 percent. DV is estimated to have ranged from 220 to 1,100 ft^2/s.
- The Lower Reyran River, 2.2 to 5.9 miles contained 9% of the PAR and 15% of the life loss. The PAR was approximately 330, life loss was approximately 69. The fatality rate for this reach was about 21 percent. DV is estimated to have ranged from 40 to 220 ft^2/s.
- The town of Frejus and its surrounding area, 5.9 to 6.8 miles contained 17% of the PAR, but experienced 46% of the life loss. This is the worst impact area and also where many bodies were recovered. The available data regarding fatalities that was collected by B.C. Hydro, did not allow the study to relate where fatalities occurred relative to where their bodies were recovered. PAR was approximately 624, life loss was approximately 210. The fatality rate for this reach was about 34 percent. DV is estimated to have ranged from 40 to 220 ft^2/s.
- From the Argens River to the Sea, 6.8 to 8.7 miles, contained 68% of the structures, but only 5% of the life loss. The PAR was approximately 2494, life loss was approximately 23. The fatality rate for this reach was about 1 percent. DV is estimated to have ranged from 10 to 40 ft^2/s.

Summary Table 6 Malpasset Dam

Flood Severity Rating	High, medium, and low, varied by location
Warning Time	Zero for the Upper Reyran Valley and for many of the PAR at Frejus
Time of day	Dam failed at 9:10 pm
Failure scenario	Sudden failure, elevated reservoir levels due to extended period of rainfall
Fatalities	Estimated 423 to 550, Total PAR estimated at 3668
Fatality Rate	Very high at construction camp, about 36% in the Reyran River Valley and at Frejus.
Dam Height	200 feet
Reservoir Storage	18,000 acre-feet
Breach Formation Time	Instantaneous
Total PAR	BC Hydro research has estimated: 553 in the Reyan River Valley (including 96 at construction camp) 625 at Frejus

	2490 from Argens River to the sea
Downstream Distance to PAR	Construction camp immediately downstream, Frejus upstream outskirts at about 6 miles downstream
Maximum DV	1,100 ft^2/s close to dam, construction camp right below dam may have been located in medium severity fringe zone, upper portion of Frejus had DV in the range of 40 to 220 ft^2/s, less than 160 ft^2/s for a large part of Frejus. BC Hydro DV map has much detail (see pg. 26 for more info)
Flood severity understanding	n/a for most
Confidence in data	Good – well documented case history

<u>References:</u>

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- Reclamation Flood Event Case History Archive
- BC Hydro Investigations, Malpasset Study, Life Safety Model v1.0, Appendix F Maps and Spreadsheet titled: LOL Comparisons A6.xls

Walnut Grove Dam, Overtopping Failure, February 21, 1890

Walnut Grove Dam was located on the Hassayampa River about 30 river miles upstream from Wickenburg, Arizona. Most of the area between the dam and Wickenburg was sparsely populated in 1890, just as it is today. The rockfill dam was constructed to provide water for irrigation and gold placer mining.

The dam failed due to overtopping during a large inflow event, at about 2:00 a.m. on Saturday, February 22, 1890. Construction was completed in October 1887, and the dam was only 2 years old when it failed. The dam withstood 3 feet of overtopping for 6 hours before failing. Spillway capacity was reduced from the original design during construction to save money. It is not known if the original spillway design capacity would have been adequate to prevent the dam from overtopping.

Upon failure of the dam, the reservoir is reported to have drained in 1 to 2 hours.

Walnut Grove Dam had a height of 110 feet and the reservoir volume at the time of failure was about 60,000 acre-feet. The drainage area upstream from the dam was estimated to be 262 square miles.

Approximately 11 hours before dam failure, the superintendent of the water storage company directed an employee to ride by horseback to issue warning of an impending dam breach flood. His destination was a construction camp for another dam that was located about 15 miles downstream. The rider on horseback never reached the construction camp. This was partially due to flooding on his route to the camp, but anecdotal accounts claim that the rider stopped at a saloon to get drunk on his way down the river! The majority of the people in the construction camp were asleep when the flood arrived. Some heard the roar of the approaching flood and scrambled up the hillside through rocks and cactus. Most of the fatalities occurred at the construction camp and its downstream headquarters. These locations were upstream of Wickenburg. The number of people at risk is not known. There were between 70 to 100 fatalities, but record keeping was not precise. Walnut Grove Dam was not rebuilt.

Fish were found in walls of Box Canyon, 80 feet above the Hassayampa. When it reached Wickenburg, a distance of 30 miles, in two hours, the wall of water was 40 feet deep.

Those who saw the flood say that it came down in almost a perpendicular wall 90 or 100 feet high and apparently crushed down, instead of sweeping everything away before it. Immense boulders weighing tons were thrown around as a child might toss a ball. Enormous trees were broken in two or broken into shreds. Iron bars were broken or twisted out of shape and pieces of iron were picked up and carried five miles and then embedded in the walls of the canyon eighty feet above the present level of the stream.

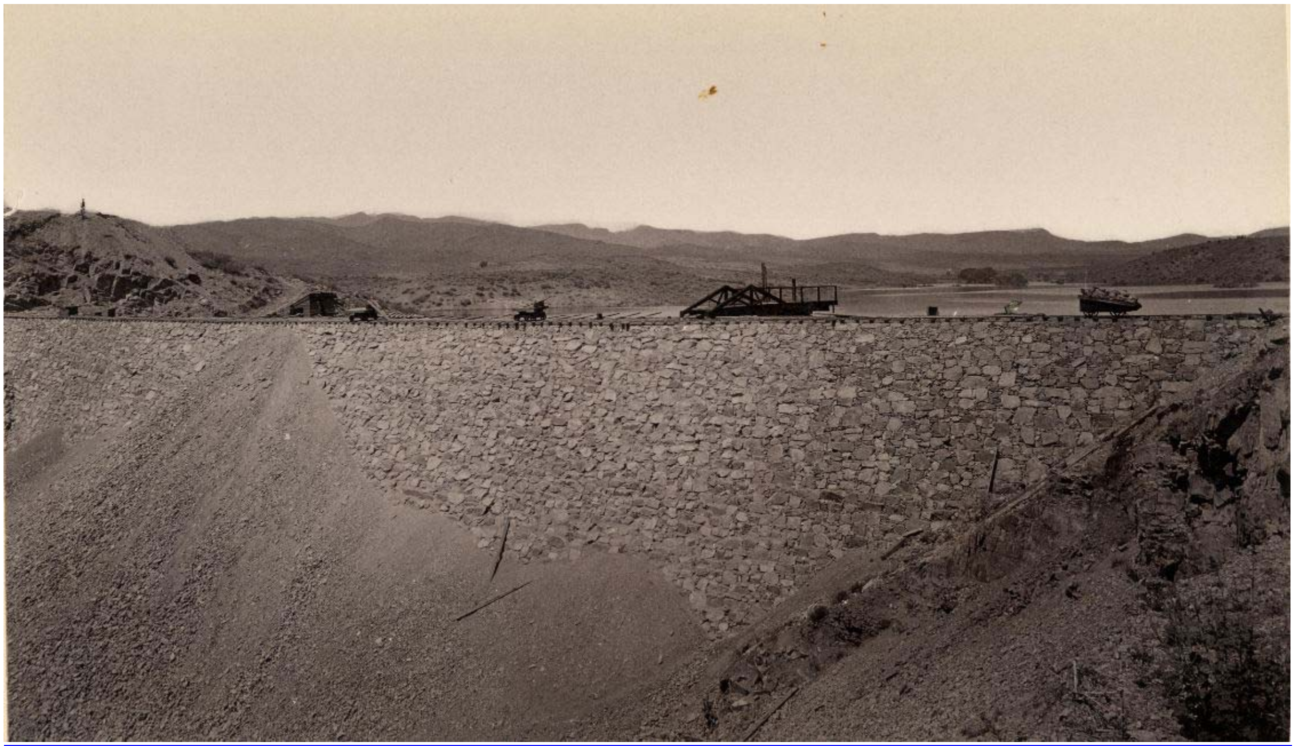


Figure 18. Downstream face of Walnut Grove Dam
Source: Photo courtesy of Sharlot Hall Museum Library and Archives, Prescott, Arizona, SHM Photograph Collection

Figure 19. Walnut Grove Dam, spillway in operation prior to the dam failure event
Source: Photo courtesy of Sharlot Hall Museum Library and Archives, Prescott, Arizona, SHM Photograph Collection

Summary Table 7 Walnut Grove Dam

Flood Severity Rating	High
Warning Time	No warning
Time of day	Nighttime
Failure scenario	Overtopping
Fatalities	70 to 100
Fatality Rate	Unknown
Dam Height	110 feet
Reservoir Storage	60,000 acre-feet
Breach Formation Time	Unknown
Total PAR	Unknown
Downstream Distance to PAR	30 miles to Wickenburg, most fatalities occurred upstream of this.
Flood severity understanding	n/a
Maximum DV	900 ft^2/s at Wickenburg
Confidence in data	Fair

References:

- Dams Sector, Estimating Loss of Life for Dam Failure Scenarios, September 2011, U.S. Department of Homeland Security, pages 65-66, http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-LossofLife.pdf
- Arizona's 1890 dam disaster killed more than 100 people, http://www.dcourier.com/main.asp?SectionID=1&SubSectionID=1&ArticleID=48987
- The Walnut Grove Dam, http://www.wickenburg-az.com/2009/06/the-walnut-grove-dam/
- Rouarks Ranch, AZ Walnut Grove Dam Burst, Feb 1890, http://www3.gendisasters.com/arizona/8803/rouarks-ranch-az-walnut-grove-dam-burst-feb-1890

Taum Sauk Upper Dam, Failed, December 14, 2005

Figure 20. Taum Sauk Upper Dam prior to failure
Source: U.S. Geological Survey, http://water.usgs.gov/osw/conference2007/images/flood16.jpe

Taum Sauk Upper Dam, part of the Taum Sauk Project is located in Reynolds County, Missouri, on the East Fork of the Black River approximately 90 miles southwest of St. Louis, Missouri. The project is a reversible pumped storage project used to supplement the generation and transmission facilities of Ameren UE, and consists basically of a mountain ridge top upper reservoir (Taum Sauk Upper Dam and Reservoir), a shaft and tunnel conduit, a 450-MW, two-unit pump turbine motor-generator plant, and a lower reservoir (Taum Sauk Lower Dam and Reservoir). It was the first of the large capacity pumped-storage stations to begin operation in the United States.

The Upper Dam was a continuous hilltop dike 6,562-ft-long forming a kidney shaped reservoir. The dike was a concrete-faced dumped rockfill in its upper portion, and a rolled rockfill below. The crest of the dam was a 10-foot-high, l-foot-thick reinforced concrete parapet wall. The dam was 94 feet high. The upper dam did not have a spillway.

The Taum Sauk project is a peaking and emergency reserve facility. During a typical 24 hour period of operation at Taum Sauk, pump back to the upper reservoir began around 9:30 pm to 10:00 pm as excess power from the grid became available for pumping. Pumping continued through the night until around 5:00 am to 6:30 am as either the upper reservoir limit level was reached or excess grid power was no longer available.

At about 5:15 am on December 14, 2005, the upper dam overtopped and breached due to an instrumentation malfunction which overfilled the reservoir with flow pumped from the lower reservoir. The breach occurred rapidly and released 4,300 acre feet of water.
Maximum overtopping of the embankment is thought to have been in the range of about 1 foot. This included the influence of wind induced waves in the reservoir.

The weather information for the early morning of December 14 indicated light snow, rain, and drizzle with temperatures in the mid-30s. At Farmington Regional Airport about 0.08 inches of precipitation occurred during the early morning. The recorded steady wind speeds ranged from 12-16 mph with gusts to 25 mph. Winds originated from 140-180 degrees from North.

Table 8. Taum Sauk Upper, Breach Parameters (FERC)

Breach Depth	103 feet
Breach Bottom Width	496 feet
Breach Side Slopes	Approx. 1:1 horz:vert
Breach Formation Time	Approx. 20 min
Maximum Breach Discharge	273,000 ft3/s
Time to Drain Reservoir	35 min

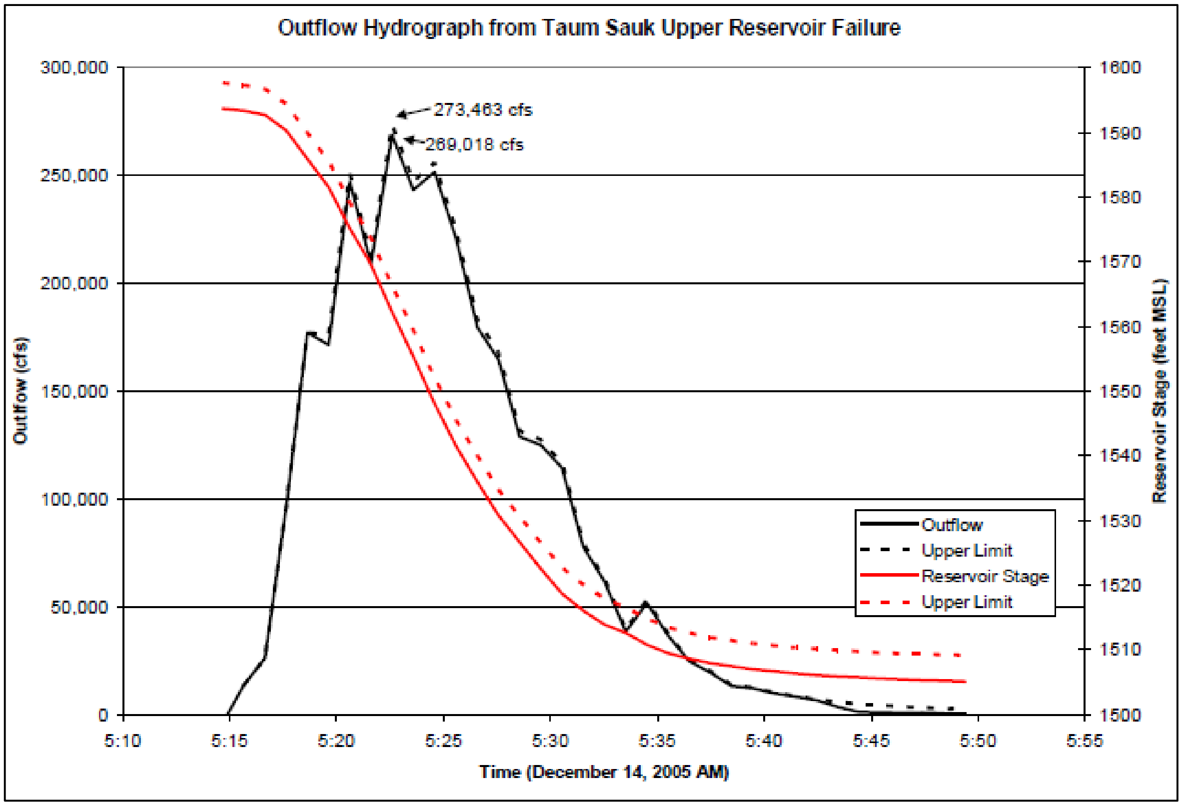


Figure 21. Taum Sauk Upper Dam, calculated breach outflow hydrograph
Source: Federal Energy Regulatory Commission Report 2277
http://www.ferc.gov/industries/hydropower/safety/projects/taum-sauk.asp

Figure 22. Swath of flood zone, downstream of Taum Sauk Upper Dam
Source: U.S. Geological Survey, http://water.usgs.gov/osw/conference2007/images/flood12.jpe

Flooding from the breach moved down the steep hillside, destroying everything in its path. The flood overwhelmed the east fork of the Black River and the lower ground of Johnson's Shut-Ins State Park. It swept the park superintendent's home containing the family of five, off its foundation and to a location at least a quarter-mile away. The superintendent and three children, aged 5 years old, 3 years old, and 7 months, were found clinging to a tree. All were injured and the three children required hospitalization. All five survived. There were no fatalities from this event. Two trucks and a car were reported to have been submerged while traveling along Highway N, which was inundated by the flooding.

The National Weather Service sent an assessment team on the day following the failure and according to their observations, the water level was at least 20 feet high as the wall of flood water passed through Johnson's Shut-Ins State Park.

Fortunately, it was the middle of December and no campers were using the State Park. Had it been summertime, hundreds of campers at Johnson’s Shut-Ins may have been endangered by the water.

The flood water was reported to have receded within minutes.

Figure 23. Flooding in the vicinity Johnsons Shut-Ins State Park
Source: Photo courtesy of Conor Watkins, http://www.rollanet.org/~conorw/cwome/article6&7.htm

Taum Sauk Upper Dam was rebuilt as an RCC structure and is back in operation with a higher crest (more freeboard) and improved safety features.

Summary Table 9 – Taum Sauk Upper Dam

Flood Severity Rating	Medium to High at location where house was destroyed
Warning Time	No warning
Time of day	Dam failed at 5:15 am
Failure scenario	Overtopping failure due to mis-operation of pumped storage facility
Fatalities	0
Fatality Rate	0
Dam Height	94 feet
Reservoir Storage	4,300 acre-feet
Breach Formation Time	20 minutes
Total PAR	Unknown, some PAR existed at downstream highway in addition to the family of five.
Downstream Distance to PAR	0.25 miles to park superintendent residence
Flood severity understanding	n/a
Maximum DV	Estimated at 160 to 200 ft^2/s. DV at residence estimated at 80 ft^2/s.
Confidence in data	Good

<u>References:</u>

- Report of Findings on the Overtopping and Embankment Breach of the Upper Dam - Taum Sauk Pumped Storage Project, Federal Energy Regulatory Commission Report No. 2277
- KDSK Television, online article describing the event http://www.ksdk.com/news/story.aspx?storyid=89311
- NOAA Webpage, December 14th, 2005 Taum Sauk Dam Failure at Johnson's Shut-In Park in Southeast Missouri, http://www.crh.noaa.gov/lsx/?n=12_14_2005

Gleno Dam - Failed December 1, 1923

Gleno Dam was a multiple arch, concrete dam located about 30 miles northeast of the town of Bergamo in the Alps of north-central Italy. The dam had been completed in the same year of its failure which occurred 30 or 40 days after first filling and following a period of heavy rainfall. Destruction was widespread along the Dezzo River in the 13 mile reach to its confluence with the Oglio River at the town of Darfo. Lesser flood damage occurred in the Oglio Valley, for the remaining 5 to 6 miles to Lake Iseo. (Dams and Public Safety)

Figure 24. The breached Gleno Dam
Source: Foto Giorgio, www.scalve.it

The flood wave took 45 minutes to reach Darfo. Total fatalities were estimated to be at least 356. Along with the death toll, the flood destroyed three villages, five power stations, and finally a high number of isolated buildings and factories. (Case Study and Numerical Modeling)

Figure 25. Aftermath of flooding, downstream of Gleno Dam
Source: Newspaper Eco di Bergamo, www.scalve.it

Table 10 Calculated Hydraulic Properties Downstream of Gleno Dam (Case Study and Numerical Modeling)

Location	Distance (miles)	Max. Discharge (ft^3/s)	Time to Max Discharge (min)	Max Depth (feet)	Max. Velocity (ft^2/s)	Max DV (ft^2/s)
Bueggio	1.1	735,400	2	60	47	2,826
Dezzo	3.5	410,000	7	61	44	2,714
Mazzunno	11.1	135,100	34.5	29	28	808
Darfo	13.3	96,800	47	46	25	1,150

The bed slope was very steep. Above Bueggio, the slope was about 26% and the overall average slope for the entire flooded reach was about 6%.

DV has been calculated to be in the range of high severity. Rate of rise is not known, but photographs of the flood aftermath indicate that the flood zone was “swept clean”. Considering also the steep narrow channel, and the high DV values it seems reasonable to assume that the flooding was high severity.

Figure 26. Flooding Aftermath at Darfo
Source: Newspaper Eco di Bergamo, www.scalve.it

Summary Table 11– Gleno Dam

Flood Severity Rating	High
Warning Time	No warning
Time of day	Dam failed at 6:30 am
Failure scenario	Sudden failure
Fatalities	Officially 356 total, 10 at Bueggio Village, 209 at Dezzo Village, 137 or more at Darfo Boario Terme (Actual fatalities may have been up to 500)
Fatality Rate	0.42 at Dezzo Village, 3.5 miles downstream
Dam Height	143 feet
Reservoir Storage	4,400 acre-feet
Breach Formation Time	Rapid
Total PAR	500 at Dezzo Village, total downstream PAR estimated at 12,631, but this includes an unknown number of people (likely a large percentage) that were not located within the flooded area.
Downstream Distance to PAR	Bueggio at 1.1 miles with continued PAR to Darfo at 13.3 miles and beyond.
Flood severity understanding	n/a
Maximum DV	2,800 ft^2/s at Bueggio, 2,700 ft^2/s at Dezzo, 1,200 ft^2/s at Darfo
Confidence in data	Good

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983

- 1923 Gleno Dam Break: Case Study and Numerical Modeling, Marco Pilotti; Andrea Maranzoni; Massimo Tomirotti; and Giulia Valerio, Journal of Hydraulic Engineering, ASCE, April 2011
- Wikipedia, http://en.wikipedia.org/wiki/Gleno_Dam
- Population and Fatality Information Obtained from Paola Salvati, Geomorphology Research Group, IRPI CNR, Perugia, Italy, http://geomorphology.irpi.cnr.it

Japan Tsunami – Coastal Flooding March 11, 2011

A 9.0 magnitude earthquake occurred on March 11, 2011 at 14:46 JST in the north-western Pacific Ocean at a relatively shallow depth of 19.9 miles, with its epicenter approximately 45 miles east of the Oshika Peninsula of Tōhoku, Japan, lasting approximately six minutes. Sendai was the nearest major city to the earthquake, 81 miles from the epicenter; the earthquake occurred 232 miles from Tokyo (Wikipedia).

The earthquake resulted in a major tsunami that brought destruction along the Pacific coastline of Japan's northern islands. Thousands of lives were lost and entire towns were devastated. The tsunami propagated throughout the Pacific Ocean region reaching the entire Pacific coast of North and South America from Alaska to Chile. Warnings were issued and evacuations carried out in many countries bordering the Pacific. However, while the tsunami affected many of these places, the extent was minor (Wikipedia).

Minami Sanriku is a town in Motoyoshi District, Miyagi Prefecture, Japan. It is a resort town on a coastline of wooded islands and mountainous inlets. As of October 1, 2004 the population of the area was 19,170.

Minami Sanriku was largely destroyed by the tsunami, with most buildings swept away by waves of 52 feet or more. There were an estimated 902 fatalities. Immediate aftermath accounts suggested 95 percent of the town was destroyed. Only the tallest buildings remained and roughly half the population was unaccounted for during the days following the disaster.

The town had two evacuation centers where residents could go in the event of a tsunami, one on the southern headland overlooking the town, the other back from the center of the town. However, although both were 66 feet above sea level, the tsunami inundated them and washed people away. At least 31 of the town's 80 designated evacuation sites were inundated by the tsunami.

According to an English teacher at the local high school located on a hill above the tsunami, "The entire town was simply swept away. It just no longer exists. There were around 7,000 of us on the hill that day. Since the schools were all on high ground, many children were orphaned.”

Figure 27. Tsunami flooding aftermath at Minami Sanriku
Source: Licensed by the Associated Press

Figure 28. Flooding aftermath, Minami Sanriku
Source: Courtesy Image ©2014 World Vision, Inc. All Rights Reserved.

When the earthquake struck, the mayor of Minami Sanriku was talking at the town assembly about the (much smaller) tsunami caused by the March 9 foreshock of the March 11 earthquake. The three-story building of the town's Crisis Management Department which the mayor escaped to was submerged by the tsunami, and out of the 130 people who worked at the town hall, the mayor was one of only 30 who reached the roof and one of only 10 who survived. He endured the torrent under the tsunami for about 3 minutes.

Shizugawa hospital was one of few major buildings which survived the tsunami at Minami Sanriku, but was partly inundated, and 74 out of 109 patients died. Close to 200 people were rescued from the roof of the building.

The city of Ishinomaki, also located in Miyagi Prefecture, was seriously affected by the tsunami. Tsunami waves, up to about 33 feet high traveled inland up to 3.1 miles from the coast. Approximately 46% of the city was inundated.

One elementary school, Okawa Elementary, was completely destroyed, killing 70 of 108 students and nine of 13 teachers and staff. The teachers had decided to get to higher ground away from the school which necessitated crossing a nearby river bridge. It was while crossing the bridge that both the teachers and students were swept away by the tsunami. This decision was deemed unreasonable by many of the parents because there was a hill right behind the school to which they could have reached in less than a minute. One of the teachers had tried to persuade the other teachers to bring the students to safety uphill soon after the earthquake; when he was unsuccessful, he evacuated himself, managing to persuade one of the students to go with him - both survived.

The tsunami flooding resulted in a total of 3,092 deaths at Ishinomaki. Approximately 29,000 city residents lost their homes.

Onagawa city, located in the Oshika District, Miyagi Prefecture was hit hard as well. Onagawa is a port town, at the intersection of two major ocean currents. It is also the location of a nuclear power plant, the Onagawa Nuclear Power Plant.

As of 2003, the town had an estimated population of 11,186. The town was heavily damaged in the tsunami. Wave heights reached 49 feet swept 0.6 miles inland, destroying the town center. About 980 people were killed. At least 12 of the town's 25 designated evacuation sites were inundated by the tsunami. The city had previously been hit and partially destroyed by the tsunami caused by 1960 Valdivia earthquake.

Higashimatsushima in Miyagi Prefecture was another site where the disaster occurred. As of 2010, the city had an estimated population of 42,762. An estimated 27,368 were affected by the flood. The town was hit hard by the tsunami, resulting in 1,138 deaths. During the tsunami, a 150 foot ship, the *Chōkai Maru*, was hurled over a pier and left aground in the town. At the time of the disaster, Higashimatsushima had still not fully recovered from a previous major earthquake in 2003. About 63% of the town was inundated by the tsunami.

Summary Table 12– Japan Tsunami, 2011

Flood Severity Rating	High
Warning Time	Some warning
Time of day	Daytime
Failure scenario	Tsunami floodwave due to earthquake
Fatalities	Minami Sanriku: 902 Onagawa: 980 Ishinomaki: 3,892 Higashimatsushima: 1,138
Fatality Rate	Minami Sanriku: 0.047 Onagawa: 0.088 Ishinomaki: 0.05 Higashimatsushima: 0.042
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Total PAR	Minami Sanriku: 19,170 Onagawa: 11,186 Ishinomaki: 77,080 Higashimatsushima: 27,368
Downstream Distance to PAR	Varied
Flood severity understanding	unknown
Maximum DV	Minami Sanriku: 900 ft^2/s Onagawa: 800 ft^2/s Ishinomaki: 540 ft^2/s Higashimatsushima: 270 ft^2/s
Confidence in data	Good

References:

- Hideomi Gokon, Shunichi Koshimura: Structural vulnerability in the affected area of the 2011 Tohoku earthquake tsunami, inferred from the post-event aerial photos. Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International
- http://www.youtube.com/watch?v=wymX0J4G8r8&feature=youtu.be
- http://en.wikipedia.org/wiki/Higashimatsushima
- http://en.wikipedia.org/wiki/Ishinomaki
- http://en.wikipedia.org/wiki/Onagawa
- http://en.wikipedia.org/wiki/Minamisanriku,_Miyagi

Medium Severity Dam Failure and Flooding Case Histories

Austin (Bayless) Dam – Failed September 30, 1911

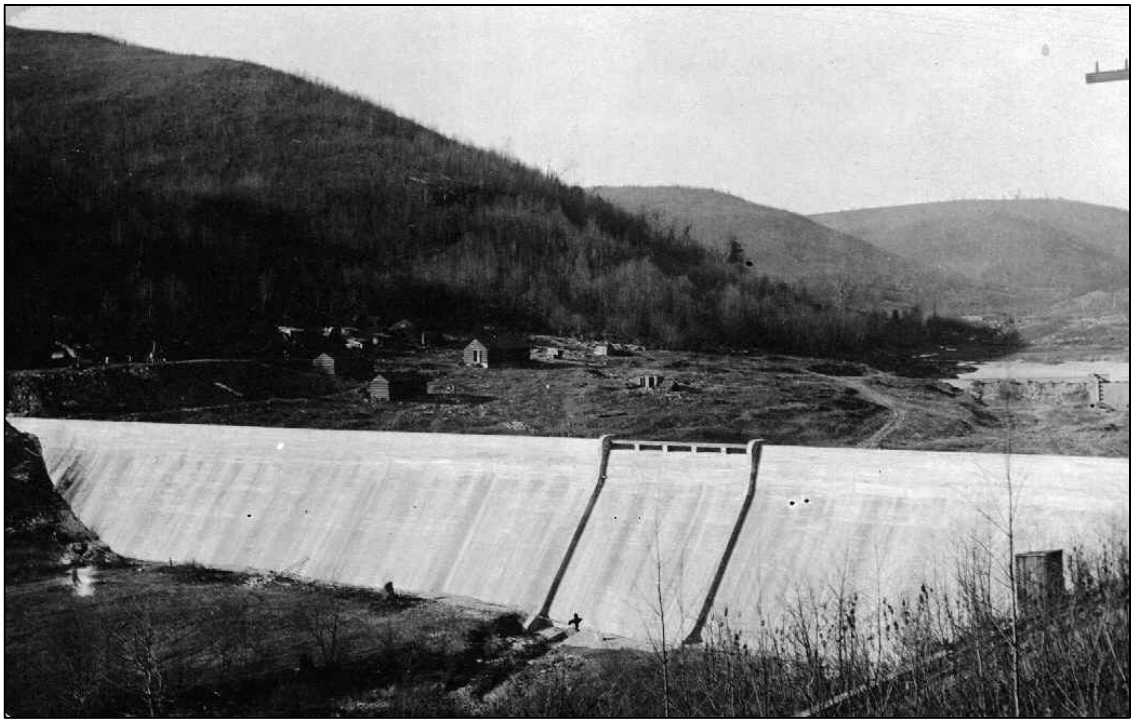


Figure 29. Austin Dam
Source: Potter County Pennsylvania Board of Commissioners
http://www.pottercountypa.net/photos/austin_dam_before.jpg

The concrete gravity dam on a stream known as Freeman's Run near Austin, Pennsylvania, failed suddenly on September 30, 1911, with the loss of at least 78 human lives. The dam was 50 feet high, 30 feet thick at the base, 2.5 feet thick at the top, and had a crest length of 544 feet. The structure, completed in 1909 was composed of cyclopean concrete buttressed by a rolled earthfill. The foundation consisted of interbedded shale and sandstone. The initial trouble occurred during the dam's first year of operation. In January 1910, when the reservoir had reached full capacity for the first time, the dam began to slide downstream. Disaster was reportedly averted by blasting holes in the structure. Evidently, during the initial introduction of water into the reservoir, the dam was loaded before the concrete had set sufficiently. This caused the opening of cracks and the development of excessive pressures under the dam. As a consequence, in the 1910 incident the dam settled about 6 inches at the toe and slid out on the foundation, a distance of about 18 inches at the spillway. The paper company which owned the dam allegedly did not strengthen the structure, and allowed the reservoir to fill again. Presumably, the holes in the dam were plugged, but adequate repairs were not made; and the structure remained in this hazardous condition until its sliding collapse on September 30, 1911. There was about 40 feet of head on the dam at the time of failure.

Figure 30. Austin Dam, after failure (1911)
Source: Library of Congress/A. Newman, http://www.loc.gov/pictures/resource/pan.6a09293/

The town of Austin was located 1-1/2 miles downstream and the town of Costello was 3 miles downstream. The PAR at Austin is reported to have been about 2,300. Maximum downstream depths were 47 feet and the estimated maximum velocity at Austin was either 5.9, 8.8, or 12 ft./s as reported by various sources. The velocities are based on accounts of either 11 minutes to travel 1.5 miles or 20 to 30 minutes to travel 2 miles downstream from the dam. Large piles of pulp wood at the pulp mill downstream of the dam caused a massive debris flow.

In Austin, on September 30, 1911, the telephone company was repairing the lines and twice during the morning the paper mill whistle blew the fire alarm, having received false signals from the workmen on the poles. Those two false alarms were the cause of many people losing their lives that afternoon when the alarm was sounded at the mill to signify that the dam had broken. People assumed it was another false alarm and kept on with their work instead of fleeing uphill to the mountains. Sometime after 2:00 pm, the paper mill whistle gave the alarm based on a telephone call which provided notice of the dam breach. The dam failure flood arrived in minutes and many were killed attempting to flee up the steep hillsides surrounding the town.

No fatalities were reported at Costello.

This event is considered to have been medium severity flooding. Maximum DV is estimated to be either 560, 400 or 280 ft^2/s (depending on the source of the estimate). These values are in the range of high severity, but the event was not considered to be high due to the fact that buildings were fully or in many cases partially destroyed, but the area was not “swept clean”. Rate of rise was possibly lower than for the high severity cases contained in this data base. The channel slope was estimated to be 0.013. Figures 23 and 24 show the aftermath of flooding at the town of Austin.

Figure 31. Remains of flooding at Austin, note the proximity to high ground
Source: Austin Dam Memorial Association, http://austindam.net/

Figure 32. Remains of flooding at Austin
Source: Library of Congress/George Grantham Bain Collection,
http://www.loc.gov/pictures/resource/ggbain.09763/

Summary Table 13 Austin Dam

Flood Severity Rating	Medium
Warning Time	Some minimal warning was issued, but maybe not understood by the entire community.
Time of day	Dam failure at 2:00 or 2:20 pm
Failure scenario	Static Failure
Fatalities	Officially 78, but may have been higher
Fatality Rate	0.034
Dam Height	About 50 feet
Reservoir Storage	Approx. 1,500 acre-feet
Breach Formation Time	"Sudden"
Total PAR	2300 at Austin
Downstream Distance to PAR	1.5 miles to Austin
Maximum DV	560, 400 or 280 ft^2/s near river channel, but maybe 80 to 160 ft^2/s where structures were located (based on photos of the aftermath)
Flood severity understanding	Vague for many who received warning due to previous false alarms
Confidence in data	Good level of confidence. Event was well documented.

References:

- The Dam That Could Not Break, An Eye-Witness Account of the 1911 Austin Flood, by Marie Kathern Nuschke, 1960
- Engineering News Record, March 17, 1910 and October 7, 1911

Bear Wallow Dam – Failed February 22, 1976

Bear Wallow Dam was a 36-foot high embankment structure which impounded about 30 to 40 acre-feet of water. The dam, built in 1963, was located in a mountainous area near Asheville, North Carolina. The crest of the dam may have been 50 feet wide. Failure of the dam occurred at about 2:30 am on a Sunday morning.

Rainfall had been occurring and the reservoir had risen to about 0.2 feet below the emergency spillway crest which was 1.2 feet below the crest of the dam. The embankment was reported to have been saturated and the failure may have been by a combination of dam crest slumping and internal erosion. A 25-foot wide chunk of the dam “broke out” and the reservoir “dropped 15 feet in minutes”.

Flood flows downstream of the dam traveled through steep terrain. Four persons were killed in a house that collapsed due to the flooding. Tons of mud and boulders reportedly crashed into the wooden home. The house was located 0.8 miles downstream and 50 feet from the stream channel. There was a 900 foot drop in elevation between the dam and the location where the fatalities occurred. Another house in this area was destroyed, but without additional fatalities. A resident who lived upstream of the fatalities location reported seeing a “wall of water” about 100 feet high and filled with stones, boulders and trees. While the 100 foot high of the wall of water is probably an over-estimation, this description does help to characterize the severity of the flooding. Other property damage in the valley was described as extensive.

DV and rate of rise are unknown, but this dam failure flood event is considered to have been medium severity. The downstream channel contained the very steep slopes and there was a reported wall of water. However, based on photos of the aftermath, the destruction of houses and other property downstream was not complete and the area was not “swept clean”. Remains of damaged structures and cars were present.

Summary Table 14 Bear Wallow Dam

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	2:30 am
Failure scenario	Hydrologically induced internal erosion/crest slump
Fatalities	4
DSO-99-06 Fatality Rate	0.5
Dam Height	36 feet
Reservoir Storage	30 to 40 acre-feet
Breach Formation Time	Unknown, but likely to have been rapid
Total PAR	8 (DSO-99-06 estimate)
Downstream Distance to PAR	0.8 miles
Flood Severity Understanding	n/a
Maximum DV	Estimated at 50 to 100 ft^2/s, based on steepness of channel and photos of damages. Maximum discharge may have been as high as 10,000 ft^3/s
Confidence in data	Good

—Photo By Malcolm Gamble

FOUR MEMBERS OF THE LEDBETTER FAMILY WERE SWEPT AWAY FROM THIS NEWFOUND COMMUNITY HOME.

Figure 33. Bear Wallow Dam, remains of house where fatalities occurred
Source: The Asheville Citizen, February 23, 1976

—Photos By Malcolm Gamble

COMMISSIONERS OWEN AND TRANTHAM INSPECT HALF-EMPTY LAKE. DAM BREAK IS BEHIND GROUP ON RIGHT

Figure 34. Bear Wallow Reservoir after failure
Source: The Asheville Citizen, February 23, 1976

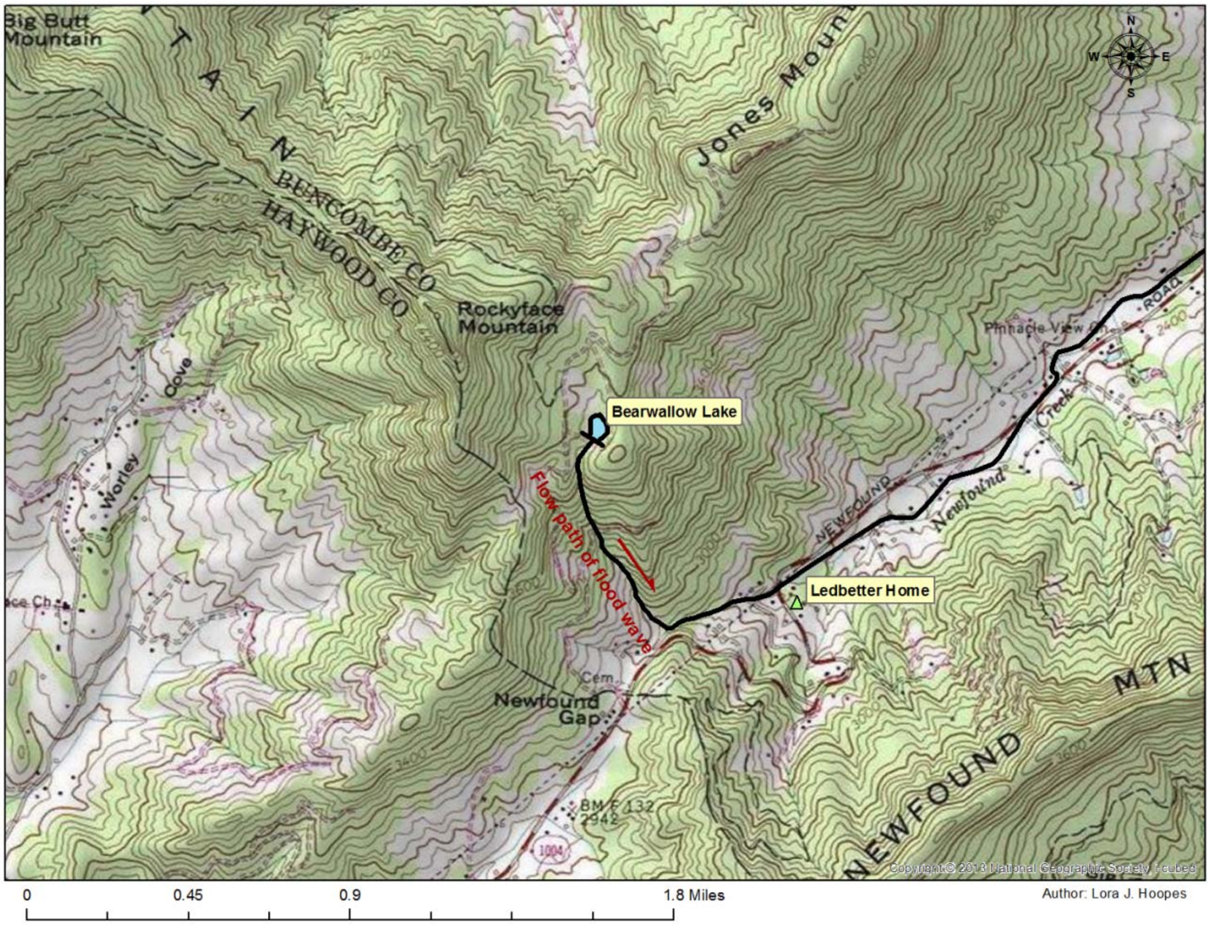


Figure 35. Bear Wallow Dam, location map
Source: Image created using ArcMap [GIS software] Version 10.1, with streaming ESRI data

Figure 36. Bear Wallow Dam, photo showing dam breach
Source: The Asheville Citizen, February 21, 1976

References:

- Asheville Citizen Articles, February 23, 1976, Reclamation Flood Event Case History Archive
- Jim Leumas email to Wayne Graham, January 2, 1997, Reclamation Flood Event Case History Archive

Little Deer Creek Dam –Failed June 16, 1963

Little Deer Creek Dam failed on a Sunday morning at 6:13 am. The dam was an 86 foot high rolled earth, homogeneous embankment which failed at maximum section near the outlet works. Construction of the dam was completed in August, 1962. The cause of failure is not exactly known, but was either internal erosion or a shear failure in the embankment. One thousand acre-feet of storage was released and the dam was reported to have been drained in 20 minutes. Peak discharge from the breach was 47,000 ft^3/s.

The dam failure resulted in a single fatality. A 4 year old boy, camping with his family of seven people (two adults, five children) at Iron Mine campground, on the Duchesne River about 5 miles downstream from the mouth of Little Deer Creek, was swept away by the flood. There was no warning. Maximum discharge at the Iron Mine Campground was estimated to have been 38,700 ft^3/s.

A forest ranger drove through downstream areas warning campers. This may have prevented additional fatalities.

The flooding, with rapidly decreasing magnitude, extended for about 48 miles downstream.

This flood is considered to have been medium severity due to the high breach discharge and the relatively steep, confined downstream channel.

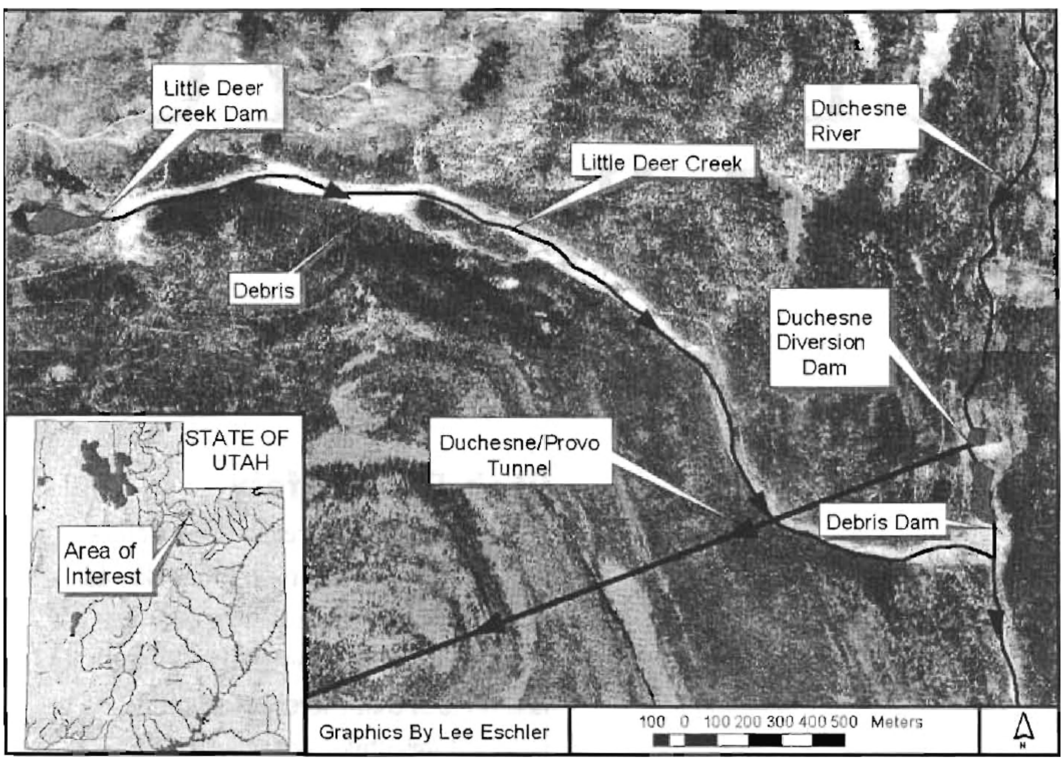


Figure 37. Overview of Downstream Area
Source: Lee Eschler, Association of State Dam Safety Officials, Journal of Dam Safety, Winter 2004 (V. 2 N. 1)

Summary Table 15. Little Deer Creek Dam

Flood Severity Rating	Medium
Warning Time	None at Iron Mine Campground. Some warning at other campsites further downstream
Time of day	Dam failure at 6:13 am
Failure scenario	Static Failure
Fatalities	1
Fatality Rate	0.14 if considering only the family of seven at Iron Mine Campground (DSO-99-06 assumed 0.02)
Dam Height	86 feet
Reservoir Storage	1,100 acre-feet
Breach Formation Time	Unknown
Total PAR	Unknown, but seven people at Iron Mine Campground (DSO-99-06 assumed 50)
Downstream Distance to PAR	7.2 miles to Iron Mine Campground
Maximum DV	Estimated DV at 7.2 miles downstream from dam near the Iron Mine Campground was 130, 180 and 200 ft^2/s, based on three analyzed cross sections[1]. This is the maximum DV at the center of the river channel. DV in the campground was likely lower
Flood Severity Understanding	n/a for Iron Mine Campground. Maybe precise understanding for campground occupants located further downstream and who received warning.
Confidence in data	Good. Reasonably well reported and investigated

1. Earl M. Bay Hydraulic Behavior Report

Figure 38. Little Deer Creek Dam, breach in maximum section
Source: Bureau of Reclamation Report (1964)

Note – an ASDSO paper (The Little Deer Creek Dam Failure, A Forensic Review of a Fatality, The Journal of Dam Safety, Winter 2004) cites an estimated breach formation time of 1 to 1.5 hours with maximum breach discharge between 14,000 and 17,000 ft^3/s. This information is not consistent with other available reporting.

References:

- Report on the failure of Little Deer Creek Dam, August 1964, Reclamation
- USGS Water Supply Paper 1830B, Floods of 1963 in the United States
- Deseret News, June 17, 1963, Reclamation Flood Event Case History Archive
- Salt Lake Tribune, June 17, 1963, Reclamation Flood Event Case History Archive
- Memo to Chief, Special Studies Branch, from Earl M. Bay, Flood of June 16, 1963 Caused by Failure of Little Deer Creek Dam, Utah, US Bureau of Reclamation, January 27, 1964 (Note: Little Deer Creek Dam was not a Reclamation Dam)
- The Little Deer Creek Dam Failure, A Forensic Review of a Fatality. The Journal of Dam Safety, Association of State Dam Safety Officials, Winter 2004.

Laurel Run Dam – Failed July 20, 1977

Laurel Run Dam was located on a stream known as Laurel Run in west-central Pennsylvania, near the city of Johnstown. The earthen dam was 42 feet high with a 623 foot crest length and the reservoir typically held about 300 acre-feet of storage. 450 acre-feet of storage was reported to be in the reservoir at the time of its failure. The dam failed from overtopping.

Laurel Run had the largest reservoir of the seven dams to fail between July 19 and 20, 1977. The dam is reported to have failed at 2:35 am on the morning of July 20, after a period of heavy rain. 11.82 inches of rain fell over the Laurel Run basin in 10 hours, and this was estimated to be between a 5,000 to 10,000 year rainfall event. About 41 people were killed in the town of Tanneryville, located in a three-mile long valley, immediately downstream of the dam. Most residents were asleep when the dam failed and no warning was issued. In addition, the rain and night-time conditions limited any escape. Many of the homes in Tanneryville were either damaged or destroyed. Laurel Run Dam was not rebuilt.

Figure 39. Remains of Laurel Run Dam
Source: Vintage Johnstown, http://johnstownhistory.blogspot.com/2012/04/laurel-run-dam-tanneryville.html

Another dam, Sandy Run Dam, may have been responsible for several deaths. Overall, there were more than 70 deaths in the area resulting from the effects of this regional flood. The town of Johnstown along the Conemaugh River, famous for the flooding from the 1889 failure of South Fork Dam, was heavily flooded. Damage to Johnstown was extensive, but without fatalities. Looting was rampant at Johnstown. The mayor gave the order to "shoot to kill" looters!
The area experienced widespread power outages the night of the flood. Telephone service was intermittent in some communities as well.

A hydraulic re-creation done by Cheng and Armbruster estimated velocities at the downstream end of Laurel Run to have been 24 ft./s. Peak breach discharge was estimated to have been maybe 56,000 ft^3/s. A gage below Laurel Run Dam, at Coopersdale Bridge in Tanneryville, indicated that the flood had attenuated to 37,000 ft^3/s maximum discharge.

This dam failure flood is considered to have been medium severity due to the fact that buildings were destroyed, but the area was not completely swept clean. Maximum breach discharge was estimated by a hydraulic re-creation to be about 56,000 ft^3/s, but this flow rapidly attenuated to 37,000 ft^3/s near the town of Coopersdale and the confluence with the Conemaugh River. Flood velocity along Laurel Run was estimated, but there are no depths available and precise DV values are unknown. Some information is available in a USGS report which cites maximum stage at various locations along Laurel Run, but it is difficult to establish estimates of actual flood depths due to limited ground surface elevation data along the Laurel Run stream.

Summary Table 15 Laurel Run Dam

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	Dam failure at 2:35 am
Failure scenario	Overtopping
Fatalities	41 from failure of the dam, more than 70 regionally
Fatality Rate	0.27 (DSO-99-06)
Dam Height	42 feet
Reservoir Storage	300 acre-feet, 450 acre-feet at time of failure
Breach Formation Time	Unknown
Total PAR	150 at Tanneryville (DSO-99-06)
Downstream Distance to PAR	Tanneryville was located along a 3-mile valley between the dam and the Conemaugh River confluence.
Maximum DV	Estimated to have been 80 to 160 ft^2/s based on photos of destruction
Flood severity understanding	n/a at Tanneryville
Confidence in data	Good. Case is well documented.

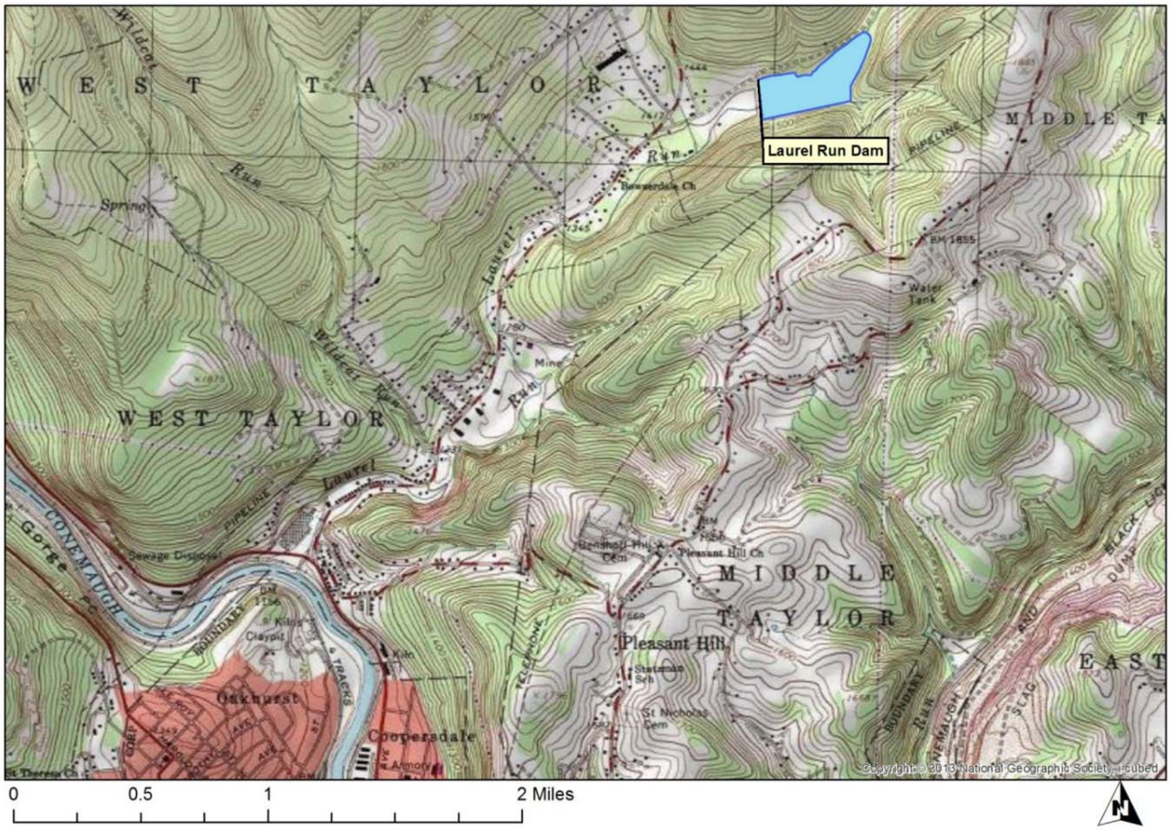


Figure 40. Laurel Run Dam location map
Source: Image created using ArcMap [GIS software] Version 10.1 with streaming ESRI data

Figure 41. Flooding aftermath at Tanneryville
Source: Vintage Johnstown, http://johnstownhistory.blogspot.com/2012/02/tanneryville-1977.html

Figure 42. Aerial view of flooding aftermath at Tanneryville
Source: Vintage Johnstown, http://johnstownhistory.blogspot.com/2012/04/tanneryville-1977_05.html

References:

- www.wikipedia.com
- Adventures in Flood Control: the Johnstown, Pennsylvania Story, Joseph P. Kozlovac, Urban Areas as Environments, April 19, 1995
- Model of the Flooding Caused by the Failure of the Laurel Run Reservoir Dam, July 19-20, 1977, Near Johnstown, PA, by Jeffrey t. Armbruster, USGS

Kelly Barnes Dam –Failed November 6, 1977

Kelly Barnes Dam, located near Toccoa, Georgia, failed on Sunday morning, November 6, 1977 at 1:20 am.

Kelly Barnes Dam was initially a rock crib dam completed in 1899. In 1937, an earthen dam was constructed over the rock crib dam, and then its crest was raised again sometime after World War II. The dam was 38 feet high at its maximum section, with a 400 foot crest length. Kelly Barnes Dam generated hydropower until 1957, after which the reservoir was used for recreation.

Toccoa Falls Bible College was the location where most of the fatalities occurred. The college was situated along Toccoa Creek, less than one mile from the dam. Thirty six members of the college community perished, including three residents of a multistory, brick dormitory building known as Forest Hall.

About 7 inches of rain had fallen over the six days prior to the breach. Almost 3.5 inches of rain fell between 6:00 pm and midnight on November 5. The drainage basin size was roughly 4.5 square miles, and the reservoir contained about 630 acre feet of storage when it breached. The dam's two spillways were releasing a maximum flow of about 400 ft^3/s prior to the breach. Peak discharge was estimated to be about 24,000 ft^3/s at a location 800 to 1,000 feet downstream from the dam. The dam did not overtop, but was in poor condition prior to the breach event.

The dam breach was trapezoidal shaped with a 57-foot wide base width and 0.56:1 side slopes. (Mathematical Simulations of the Toccoa Falls paper) Maximum flood depths for the first mile were 20-22 feet. At 6.2 miles downstream the flow attenuated to 3,500 ft^3/s.

The exact cause of failure is unknown. The failure is thought to have been due to a combination of sloughing off of the dam's downstream face combined with saturation of the embankment, both of which led to initiating internal erosion and the collapse of the dam.

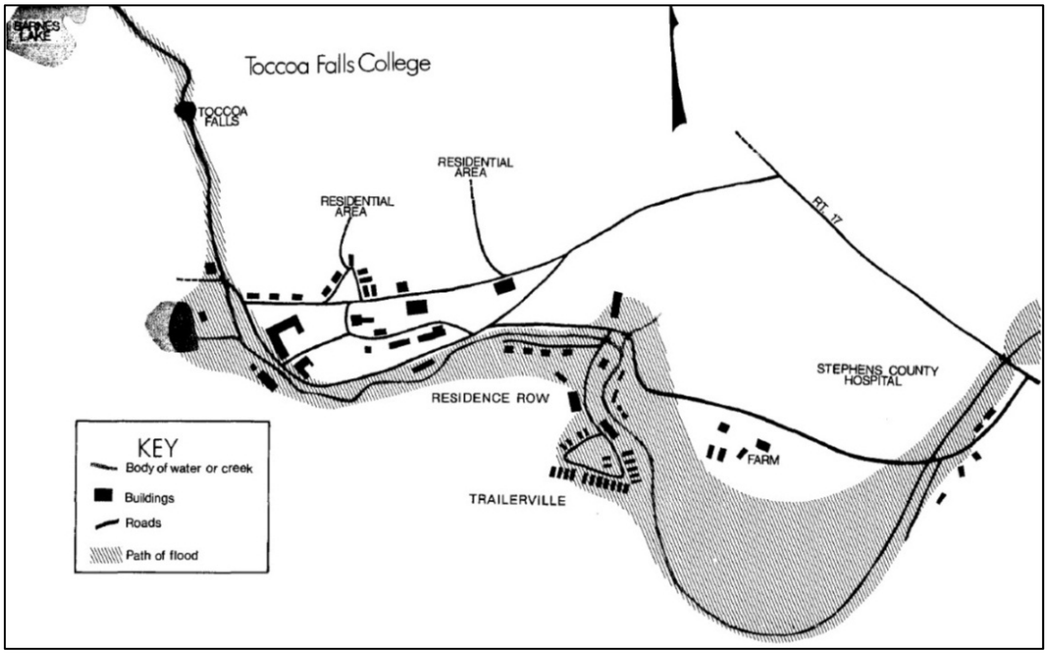


Figure 43. Toccoa Falls College campus
Source: *Dam Break in Georgia* by K. Neil Foster

Two volunteer firemen, associated with the college, were sufficiently alarmed to examine the dam shortly after midnight Sunday, November 6. They could see nothing. However, continued rain caused them to remain alarmed. They were warning the residents in the flood plain below the dam of the potential for trouble when the dam breached.

Apparently, failure was sudden. According to the residents below the dam, a roar was heard accompanied by popping sounds probably from breaking of trees and impact of the old crib logs on the walls of the gorge. Some of the persons living in the flood plain heard the sound and were able to scramble for higher ground before the flood reached them. Others were not so fortunate.

The Forest Hall dormitory building was partially in the flood plain. The flood wave reached a height of about eight feet in the ground floor. Three of the students occupying this floor were drowned; others were able to swim or scramble to safety. The upper floors were not damaged. Forest Hall dormitory was about 0.8 miles below the dam. Flooding width was maybe 200 feet wide (USGS hydrologic investigations). Using the flood width method suggested in DSO-99-06 with maximum discharge equal to 24,000 ft^3/s, the maximum DV is estimated to be 120 ft^2/s. This would be considered medium severity flooding.

Average depths in the main channel above Toccoa Falls were about 17 feet. Depths in the vicinity of the college ranged from about 21 feet at Forrest Hall Dormitory to about 18 feet at the trailer village (USGS hydrologic investigations).

Further downstream, a wood frame garage and maintenance building were partially demolished by water impact. A trailer park on the right flood plain near the garage was demolished. Debris marks in this area indicate that the water depth was about 10 feet. Some of the trailers floated away, others were smashed. Most of the fatalities were to the occupants of this trailer village. The flood velocity at this point was great enough to carry a large inter-city bus nearly one-half mile downstream. (USCOLD 1977)

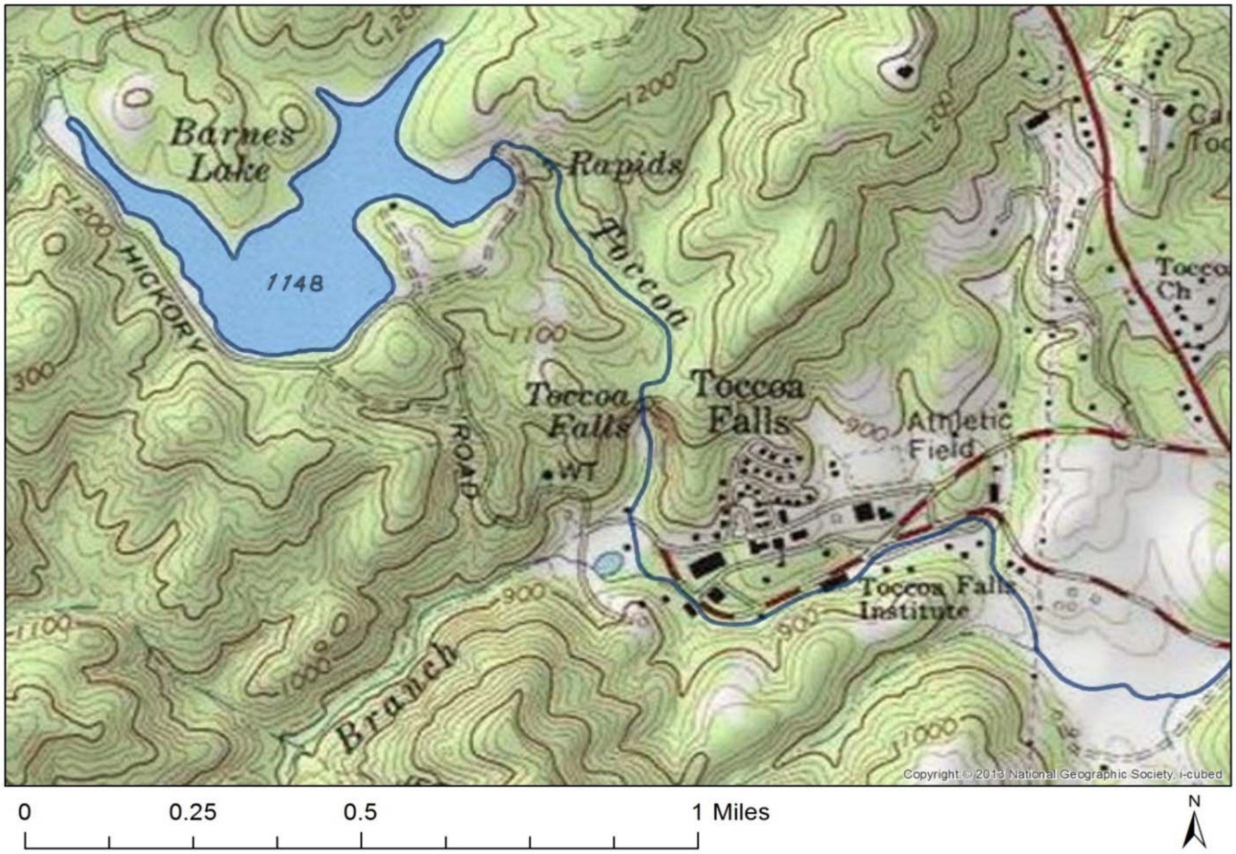


Figure 44. Kelly Barnes Dam location map
Source: Image created using ArcMap [GIS software] Version 10.1, and streaming ESRI data

This flood is considered to have been medium severity. Downstream areas on the college campus were severely damaged, but debris and many structures remained after the flood passed. The area was not “swept clean”. Maximum DV at the Forest Hall Dormitory area is estimated to have been 120 ft^2/s.

Summary Table 16 Kelly Barnes Dam

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	Dam failure at 1:20 am
Failure scenario	Sudden failure due to elevated reservoir levels from hydrologic inflow
Fatalities	36
Fatality Rate	0.36
Dam Height	38 feet
Reservoir Storage	630 acre-feet
Breach Formation Time	Unknown, but likely to have been sudden
Total PAR	100 based on DSO-99-06
Downstream Distance to PAR	Beginning at less than 1 mile
Maximum DV	Approx. 120 ft^2/s
Flood severity understanding	n/a
Confidence in data	Good. Case is well documented

Figure 45. Forest Hall Dormitory on left, Toccoa Creek on right
Source: Wayne Graham, Bureau of Reclamation

Figure 46. Flooding debris at bridge, downstream of Kelly Barnes Dam
Source: ***Dam Break in Georgia*** **by K. Neil Foster**

References:

- Report of Failure of Kelly Barnes Dam and Findings, Federal Investigative Board, US Army Corps of Engineers, Atlanta, Georgia, December 21, 1977
- USCOLD News, November 1977, Dam Failure at Toccoa Falls
- Dam Break in Georgia, Sadness and Joy at Toccoa Falls, K. Neil Foster, Horizon House Publishers, 1978
- Kelly Barnes Dam Flood of November 6, 1977, Near Toccoa, GA, by C.L Sanders and V.B. Sauer, USGS hydrologic Investigations, 1979, ATLASHA – 613
- Mathematical Simulations of the Toccoa Falls, Georgia Dam Break Flood, by Larry F. Land, American Water Resources Association, Water Resources Bulletin, Volume 16, No. 6, December 1980

Mill River Dam (Williamsburg Dam) – Failed May 16, 1874

Mill River Dam, completed in 1865, was located on the east branch of the Mill River, three miles north of Williamsburg, Massachusetts. The dam was constructed of earthfill, with a masonry core, and was 43 feet high. The crest length of the dam was 600 feet and the reservoir held 307 acre-feet of water.

Failure of the dam was due to seepage and internal erosion which resulted in a slide on the dam's downstream face. Approximately 20 minutes following the slide, the dam's masonry core wall collapsed and the dam was breached.

The dam's gatekeeper observed the slide and rode three miles on horseback to Williamsburg to issue warning. Another individual, after witnessing the top of the dam give way, ran two miles in fifteen minutes to alert persons downstream. Many persons at risk received only a few minutes advance warning or no warning at all.

The depths of flooding were reported to range from 20 to 40 feet. The flooding was estimated to have been 300 feet wide at Williamsburg. 138 people were killed, 750 left homeless. Table 18 provides information regarding flood wave travel times and fatalities at downstream locations. All recorded fatalities occurred within seven miles from the dam.

Table 17 . Mill River Dam Travel Times and Fatalities

Location	Distance from dam	Approx. flood arrival time	Fatalities
Dam breach	0	7:20 am	-
Williamsburg	3	7:40 am	57
Skinnerville	4	-	4
Haydenville	5	7:45 am	27
Leeds	7	8:05 am	50
Florence	10	8:35 am	0

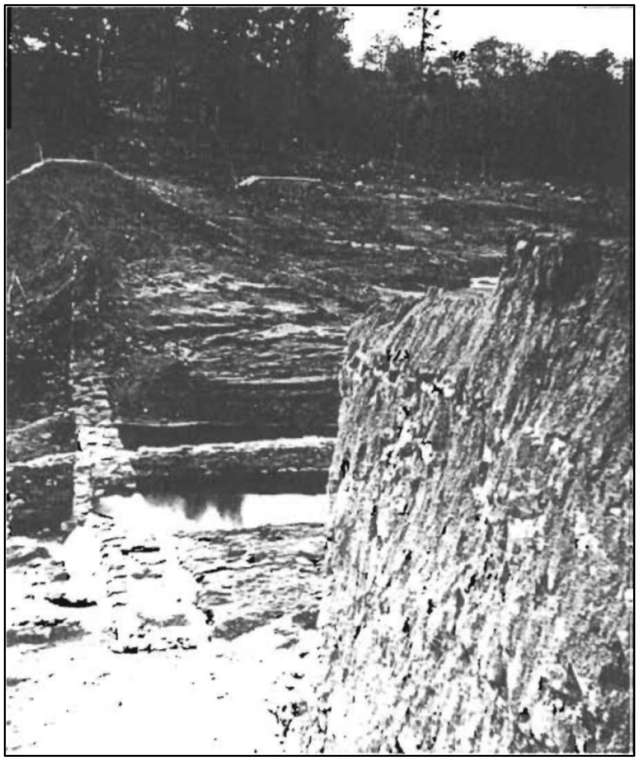


Figure 47. Remains of Mill River Dam
Source: Knowlton Brothers Photographers, Northampton, MA

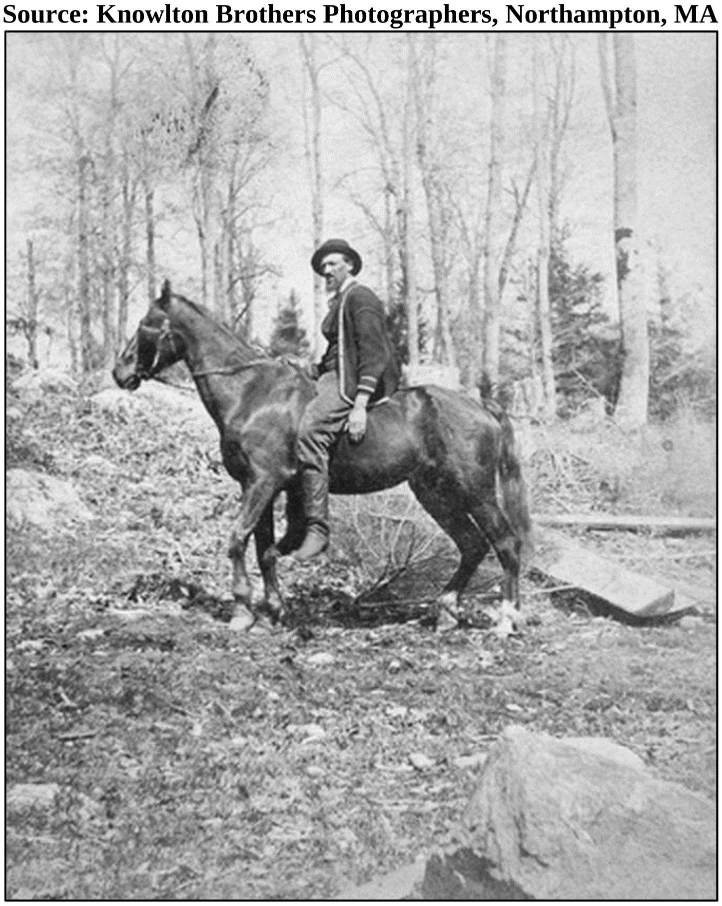


Figure 48. Gatekeeper who rode on horseback to issue warning
Source: Knowlton Brothers Photographers, Northampton, MA

DSO-99-06 considered this flood to have been medium severity. DV was high, at least in the upper reach of the flood, but there is limited information available. It is generally less likely that a dam of this size might produce high severity flooding unless special conditions exist such as a very rapid breach of the dam and/or very steep downstream channel slopes.

Summary Table 19 Mill River Dam

Flood Severity Rating	Medium
Warning Time	A few minutes for some, zero for others
Time of day	Daytime
Failure scenario	Sudden failure due to seepage and internal erosion
Fatalities	138
Fatality Rate	0.155
Dam Height	43 feet
Reservoir Storage	307 acre-feet
Breach Formation Time	> 20 minutes
Total PAR	888
Downstream Distance to PAR	3 to 10 miles
Maximum DV	260 ft^2/s assuming 20 foot depth at Williamsburg and 20 minute travel time. This anecdotal information produces a very high DV. 50 to 160 ft^2/s may be more realistic.
Flood severity understanding	Unknown. Many received no warning.
Confidence in data	Good. Some good documentation exists, but this event occurred a long time ago.

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- Capitalism and Calamity, The Mill River Flood of 1874, Doctoral Dissertation by Elizabeth M. Sharpe, University of Delaware, Spring 1995

Lawn Lake Dam and Cascade Lake Dam – Failed July 15, 1982

Lawn Lake Dam was located at about an 11,000 foot elevation, in Rocky Mountain National Park, Colorado, just west of the town of Estes Park. Access to the dam was by way of a 6.3 mile hiking and equestrian trail. The dam was an embankment structure which raised a natural lake, and stored water for irrigation. The twenty-six-foot-high dam held a reported 674 acre-feet of storage and was 79 years old at the time of its failure. Breaching of the dam was due to piping which was initiated along the outlet works conduit that ran through the embankment. Lawn Lake Dam failed at about 5:30 am, Thursday July 15, 1982.

Figure 49. Lawn Lake in 2012
Source: Bruce Feinberg, Bureau of Reclamation, taken July 2012

The dam failure flood followed the path of the Roaring River for 4.7 miles to its confluence with the Fall River. No warning was issued along this reach and a camper, located in his tent, was swept away by the flooding and killed.

At the confluence of the Roaring River with Fall River, a trash collector who heard loud noises thought the sound of flooding was an airplane crashing. Upon investigation, he witnessed the arrival of the flood which was accompanied by mud and debris. The trash collector used a nearby emergency phone to report the event at about 6:23 am. At 6:50 am, a ranger began to warn portions of the Aspenglen Campground which is about 7 miles downstream from the dam. When this initial warning was made, it was not known that Cascade Lake Dam would also fail and that its failure would increase the extent and severity of flooding at the campground. The peak breach discharge from the Lawn Lake failure is estimated to have been 18,000 ft^3/s at the dam. At about seven miles downstream, the discharge is thought to have attenuated to about 7,200 ft^3/s. Failure of Cascade

Lake Dam increased this discharge to an estimated 16,000 ft^3/s. Cascade Lake Dam was a concrete diversion dam that was 17-feet high and stored about 12 acre-feet of water. The warnings at Aspenglen Campground were reported to have been "weak". Persons were warned, but fatalities of two individuals occurred when they decided to return to a campsite to retrieve possessions.

Further downstream along the Fall River Road and in the town of Estes Park, damage was extensive. The warnings in this area were successful though and no additional fatalities occurred. Flooding was fully contained in Lake Estes, the reservoir formed by Reclamation's Olympus Dam.

Note that downstream of Estes Park is the location of the Big Thompson flood which occurred six years earlier in 1976. The Big Thompson flood was a flash flood event which killed 144 people and did extensive damage to developed areas of the Big Thompson Canyon and the city of Loveland, Colorado. Recent memory of this event may have been one reason why the emergency response and evacuation efforts were so successful along the Fall River and in the town of Estes Park.

Figure 50. Aspenglen Campground site near where two fatalities occurred.
Source: Bruce Feinberg, Bureau of Reclamation, taken July 2012

Figure 51. Flood damage at Estes Park
Source: Wayne Graham, Bureau of Reclamation, taken July 15, 1982

TABLE 4.—*Peak flow data at selected cross sections*

Distance downstream from Lawn Lake dam, in miles	Average velocity,[a] in feet per second	Maximum depth, in feet	Top width, in feet	Cross section area, in square feet
0.55	[b] 8.0	[b]23.8	185	[b]2,070
1.50	[b]11.3	[b]18.6	97	[b]1,340
3.83	[b] 9.9	[b]14.0	348	[b]1,270
5.36	3.6	9.0	927	2,980
5.78	3.3	7.9	1,112	2,250
6.50	4.6	10.1	328	1,560
7.68	[b]11.2	[b]10.8	148	[b]1,170
7.74	12.6	9.9	227	1,020
8.78	12.1	10.6	170	910
10.28	12.0	7.8	175	710
11.45	7.4	6.4	336	880
12.50	6.8	10.5	99	810

[a]Based on the peak discharge profile in figure 11.
[b]Severe channel erosion may have influenced value.

Figure 52. Peak flow data from USGS Professional Paper 1369
Source: U.S. Geological Survey

Summary Table 20 – DV at Locations Downstream of Lawn Lake Dam

Distance from Lawn Lake Dam (miles)	Calculated DV based on Fig. 40 data (ft^2/s)	Location	Flood Severity
0.55	190		Possibly high
1.5	210		Possibly high
3.83	139	Roaring River Campground	Medium
5.36	32	0.7 miles Downstream of Fall River Junction	Low
5.78	26		Low
6.50	46	Upstream of Cascade Lake Dam	Low
7.68	121	0.7 miles Downstream of Aspenglen Campground	Medium
7.74	125	Estes Park Powerplant	Medium
8.78	128		Medium
10.28	94		Medium
11.45	47		Low
12.50	71	0.25 miles Downstream of Big Thompson River Junction at Estes Park	Medium

Note that the values given in the DV Table 20 may provide differences in flood severity from what is presented in DSO-99-06.

Bed slopes were very steep downstream of Lawn Lake Dam and this contributed to the high DV values. Flows along the Roaring River averaged about 0.11. Fall River, upstream of the Aspenglen Campground, had an average slope of about 0.006.

Summary Table 18 – Lawn Lake Dam

Flood Severity Rating	High along Roaring River, Medium along Fall River and the Aspenglen Campground.
Warning Time	Zero along Roaring River, about 30 minutes at all locations along Fall River
Time of day	Morning
Failure scenario	Static failure – piping along outlet works conduit
Fatalities	3
Fatality Rate	Roughly: 0.04 along Roaring River, 0.007 at Aspenglen Campground, 0 further downstream
Dam Height	26 feet
Reservoir Storage	674 acre-feet
Breach Formation Time	unknown
Total PAR	RM 1 to 3, 25; Aspenglen campground, 275; Downstream of National Park, 4,000 (based on DSO-99-06 estimates)
Downstream Distance to PAR	3 to 13 miles
Maximum DV	Estimated : 140 to 210 ft^2/s along Roaring River, 120 ft^2/s at Aspenglen Campground, and 70 ft^2/s at Estes Park
Flood severity understanding	Vague at Aspenglen Campground, Precise at Estes Park
Confidence in data	Very good. Event has been thoroughly studied and well documented.

References:

- Hydrology, Geomorphology, and Dam-Break Modeling of the July 15, 1982 Lawn Lake Dam and Cascade Lake Dam Failures, Larimer County, Colorado, by Robert D. Jarrett and John E. Costa, USGS Professional Paper 1369
- Graham and Brown, The Lawn Lake Dam Failure – A Description of the Major Flooding Events and an Evaluation of the Warning Process, U.S. Bureau of Reclamation, Denver, CO, December 1982

South Fork Dam (Johnstown Flood) – Failed May 31, 1889

The failure of South Fork Dam catastrophically flooded the town of Johnstown, Pennsylvania and this event has become widely known as the Johnstown Flood. South Fork Dam was an earthfill embankment, 72 feet high with 11,500 acre-feet of reservoir storage (ASCE 1974). Construction of the dam was completed in 1853. A breach of the dam, with a less than full reservoir occurred in 1862. After that, the reservoir remained empty for many years. The property was sold to a private hunting and fishing club and the dam was rebuilt in 1880. Spillway capacity, which was reported to be capable of passing the 100-year inflow, was reduced by adding fish retaining screens on the spillway's crest. With the screens in place, the capacity of the spillway was only able to handle a 25-year storm or less (ASCE 1974). South Fork Dam failed from overtopping on Friday, May 31 at about 3:10 pm. On May 30 and 31, 6.6 inches of rain fell over the South Fork watershed and large amounts of rain also fell over the Conemaugh River basin at Johnstown. Major flooding occurred in downstream areas before the dam failed and many streets were impassible prior to the arrival of the dam breach flows.

Once breached, the reservoir emptied in 45 minutes, peak breach discharge was estimated to be 200,000 to 300,000 ft^3/s (ASCE, 1974). 40-foot high flood depths were noted (McCullough, 1968). Flooding has been described as a "wall of water" (Connelly and Jenks, 1889)

Failure of the dam was detected by the dam tender. Warning was issued prior to the breach initiation at 11:15 am (McCullough, 1968, pg. 93). Warning was not widely disseminated and was not considered to have been very effective, especially in light of the large numbers of fatalities that occurred. Many who received the warning thought it to be an unsubstantiated rumor (McCullough, 1968, pg. 117).The total fatalities were estimated to have been 2,209 (Richardson) and PAR is estimated to have been 23,000 (McCullough, 1968, pg. 196).

At 5.2 miles downstream from South Fork Dam, the Conemaugh Viaduct, a 78 foot high railroad bridge (www.wikipedia.org) , became clogged with debris. Flood water built up behind the viaduct and its collapse created an intensified, secondary surge of flooding.

Figure 53. Aftermath of the South Fork Dam failure flood
Source: ***A Photographic Story of the 1889 Johnstown Flood*** **by Harold H. Strayer and Irving L. London,**
http://www.swartzentrover.com/cotor/e-books/misc/JTF/6as.jpg

Figure 54. Destroyed and damaged houses
Source: National Park Service

Figure 55. Debris piled up at the "Stone Bridge"
Source: National Park Service

Figure 56. Destroyed houses and the flooding aftermath
Source: Copyright © 2012 Commonwealth of Pennsylvania, Pennsylvania Historical and Museum Commission
http://www.phmc.state.pa.us/bah/dam/rg/di/LindaRiesPhotoGuide/PhotographGuideArchives.htm

Summary Table 19 South Fork Dam

Flood Severity Rating	Medium and high
Warning Time	Greater than three hours for some people at some locations.
Time of day	Dam failed at 3:10 pm
Failure scenario	Overtopping
Fatalities	2,209
Fatality Rate	About 9 percent overall South Fork – 0.01 Mineral Point (RM 6.5) – 0.035 East Conemaugh (RM 11.5) – 0.006 Woodvale (RM 12.5) – 0.252 Johnstown (RM13.7 – 0.089
Dam Height	72 feet
Reservoir Storage	11,500 acre-feet
Breach Formation Time	45 minutes
Total PAR	23,453 (approx.)
Downstream Distance to PAR	Two to fifteen miles
Maximum DV	South Fork – 250 ft^2/s Mineral Point (RM 6.5) – 360 ft^2/s East Conemaugh (RM 11.5) – 210 ft^2/s Woodvale (RM 12.5) – 180 ft^2/s Johnstown (RM 14 – 100 to 170 ft^2/s (All based on max discharge/flood plain width)
Flood severity understanding	varied
Confidence in data	Good. Event is well documented, although it did occur a long time ago.

The flooding is generally considered to be medium severity maybe due to the fact that the downstream areas were heavily damaged, but was not “swept clean”. The rate of rise and DV may have indicated high severity flooding in some locations though. Damage was extensive within the flooded areas.

This case history brings to light a question regarding the DSO-99-06 definition of high severity flooding. Does “high severity” flooding necessarily need to be qualified by the “downstream areas swept clean” description to justify higher fatality rates than medium? Perhaps not. The DV and rate of rise for portions of the flooding implies high intensity flooding. The South Fork Dam failure flooding is considered to have included locations with high severity flooding and some warning.

<u>References:</u>

- ASCE, Transactions, 477, Volume XXIV, June 1891, Report of the Committee on the Cause of the Failure of the South Fork Dam
- ASCE, Civil Engineering Magazine, August 1974
- Through the Johnstown Flood, Rev. David J. Beale, Edgewood Publishing Company, 1890
- The Johnstown Flood, David McCullough, Touchstone Books, Simon and Schuster, 1968

Big Thompson River Flash Flood – July 31/August 1, 1976

In the early evening hours of July 31, 1976, localized thunderstorm activity that was stationary and severe in nature, produced flooding which killed 144 people along the Big Thompson and North Fork Big Thompson Rivers in north central Colorado. Rainfall, which was as high as 12 inches over several hours, produced high discharge flow and flash flooding in these river canyons. The rainfall started between six and seven o'clock on the evening of July 31. Maximum discharge in the main canyon was about 31,000 ft^3/s. Many area motels were booked to capacity due to the peak summer season. August 1 was Colorado's 100th anniversary and local celebrations were planned. Total PAR was estimated to have been 3,500 (USGS Fact Sheet 2006-3095)

The Big Thompson Canyon is located downstream of the town of Estes Park, Colorado. The canyon is about 25 miles long and drops about 2,500 feet from its head to its mouth. The North Fork tributary comes into the main canyon at the town of Drake, located roughly 10 miles down the main canyon from Estes Park. At the head of the canyon is Reclamation's Olympus Dam. Fatalities were primarily confined to the main canyon and its tributary North Fork canyon.

A significant portion of the PAR in downstream areas received no warning. According to several of the deputies and highway patrolmen who issued warnings, most of the people in the Big Thompson Canyon were not warned officially. The person-to-person warning concentrated on the area at the mouth of the canyon (Gruntfest, 1977). Many survived by climbing up the steep slopes of the canyon.

Out of 53 groups of people who died, nine groups (17 people total) received an unofficial warning and five groups (14 people total) received an official warning. It is difficult to tell how many people who lost their lives that night received no warning at all (Gruntfest).

U.S. Highway 34, a two-lane paved road which runs through the canyon, was completely washed out along multiple reaches of the flood areas.

This event occurred five weeks after the collapse of Teton Dam in Idaho. The recent memory of the Teton disaster may have prompted people to evacuate.

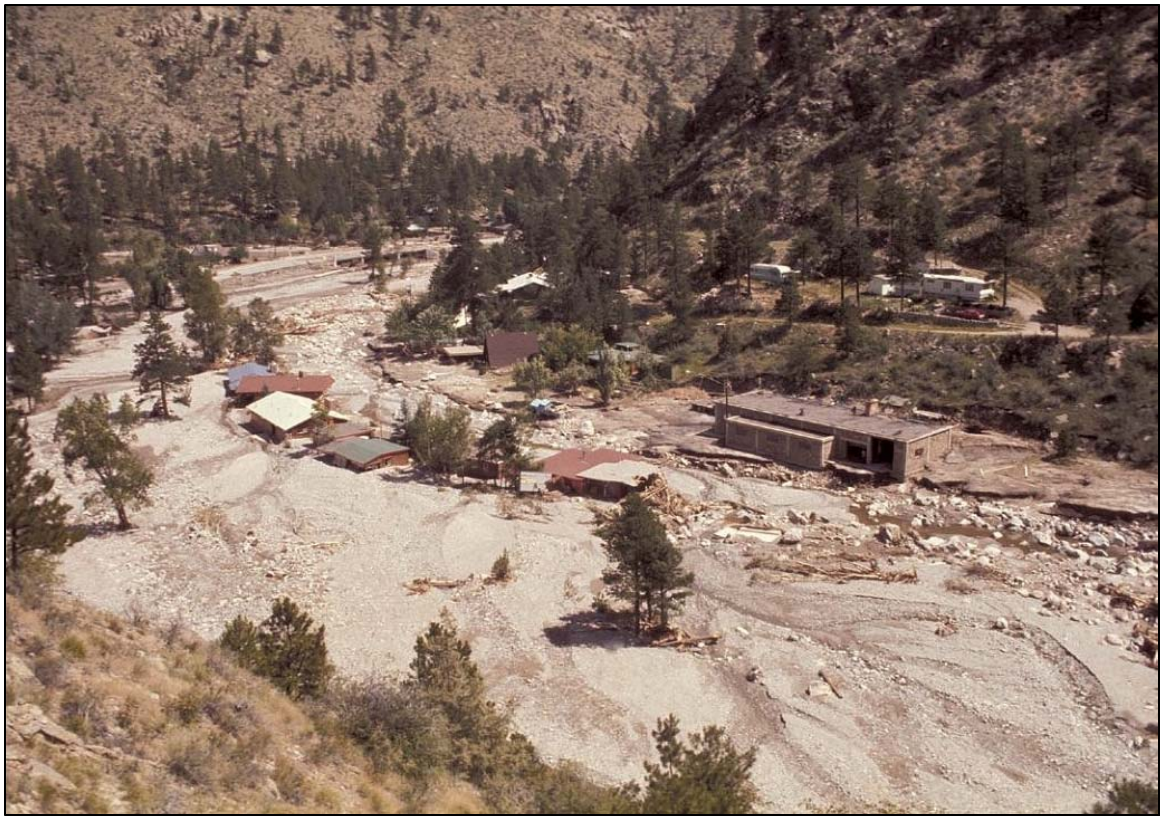


Figure 57. Flooded homes in the Big Thompson Canyon
Source: U.S. Geological Survey Fact Sheet 2006-3095, http://pubs.usgs.gov/fs/2006/3095/pdf/FS06-3095_508.pdf

Figure 58. Destroyed house and mobile home remains at private bridge crossing in the Big Thompson Canyon
Source: U.S. Geological Survey, https://www.sciencebase.gov/catalog/item/51dc1c75e4b0f81004b7839e

Figure 59. Destroyed portion of Highway 34 in the Big Thompson Canyon
Source: Licensed by Corbis Images

TABLE 4.—*Hydrologic data for selected flood-data sites*

Site No.	Station No.	Stream and Location	Drainage area (mi^2)	Discharge (ft^3/s)	Unit discharge ((ft^3/s)/mi^2)	Average velocity (ft/s)	Average depth (ft)
4	....	Dry Gulch near Estes Park, Colo	2.00	3,210	1,600	12	3.3
6	....	Big Thompson River below Estes Park, Colo	[a] 9	4,330	481	8	4.6
7	....	Big Thompson River tributary below Loveland Heights, Colo	1.37	8,700	6,350	26	5.5
8	....	Dark Gulch at Glen Comfort, Colo	1.00	7,210	7,210	28	5.1
9	....	Noels Draw at Glen Comfort, Colo	3.37	6,910	2,050	21	5.7
10	....	Rabbit Gulch near Drake, Colo	3.41	3,540	1,040	13	4.7
11	....	Long Gulch near Drake, Colo	1.99	5,500	2,760	19	5.8
12	....	Big Thompson River above Drake, Colo.	189 [a]34	28,200	829	22	8.3
13	....	North Fork Big Thompson River at Glen Haven, Colo.	[b]18.5	888	.....	8	2.2
14	....	Fox Creek at Glen Haven, Colo.	[b]7.18	1,300	.....	9	2.8
15	....	West Creek near Glen Haven, Colo.	[b]23.1	2,320	.....	7	3.0
16	....	Devils Gulch near Glen Haven, Colo.	.91	2,810	3,090	12	2.1
17	....	North Fork Big Thompson River tributary near Glen Haven, Colo	1.38	9,670	7,010	29	5.6
18	....	Black Creek near Glen Haven, Colo.	3.17	1,990	628	11	4.5
19	....	Miller Fork near Glen Haven, Colo	[b]13.9	2,060	.....	12	3.6
20	....	North Fork Big Thompson River tributary near Drake, Colo	1.26	3,240	2,570	18	3.0
21	06736000	North Fork Big Thompson River at Drake, Colo	[b]85.1	8,710	.....	12	5.2
22	....	Big Thompson River below Drake, Colo.	[b]276	30,100	.....	16	10.3
23	06738000	Big Thompson River at mouth of canyon, near Drake, Colo	[b]305	31,200	.....	26	10.6
24	....	Big Thompson River below Green Ridge Glade, near Loveland, Colo	[b]311	27,000	.....	12	6.7
25	....	Redstone Creek near Masonville, Colo.	[b]29.1	2,640	.....	10	4.2
27	....	Little Thompson River near Estes Park, Colo	2.77	1,940	700	10	1.6
30	....	Deadman Creek near Virginia Dale, Colo	[b]23.7	7,400	.....	10	4.0
31	....	Stonewall Creek near Livermore, Colo	[b]31.9	3,470	.....	12	3.7
32	....	Lone Pine Creek near Livermore, Colo	[b]86.3	2,590	.....	7	3.5
33	....	North Fork Cache la Poudre River at Livermore, Colo	[b]539	9,460	.....	9	5.3
34	06752000	Cache la Poudre River at mouth of canyon, near Fort Collins, Colo	[b]1,056	7,340	.....	9	6.2
35	....	Rist Canyon near Bellvue, Colo	5.27	2,710	514	12	3.4
36	06752260	Cache la Poudre River at Fort Collins, Colo	[b]1,129	5,700	.....	8	6.7

[a] Approximate contributing drainage area during flood of July 31–August 1, 1976.
[b] Contributing drainage area for flood of July 31–August 1, 1976, unknown.

Figure 60. Depth and velocity data from USGS Professional Paper 1115
Source: U.S. Geological Survey

Table 23 DV Values Developed From Figure 48 Data[1]

Site No.	DV ft^2/s	Site No.	DV ft^2/s
4	40	20	62
6	37	21	165
7	143	22	276
8	143	23	80
9	120	24	42
10	61	25	16
11	110	27	40
12	183	30	44
13	18	31	25
14	25	32	48
15	21	33	56
16	25	34	41
17	162	35	54
18	50	36	62
19	43		

1. Note that only sites 6, 12, 13, 21, 22, 23 and 24 were located on the Big Thompson or the North Fork Big Thompson Rivers. Fatalities occurred along these two rivers.

Summary Table 20 Big Thompson Flood of 1976

Flood Severity Rating	Medium
Warning Time	Varied from some to none
Time of day	Evening
Failure scenario	Flash flood – no dam was involved
Fatalities	144
Fatality Rate	0.04 assuming a PAR of 3,500
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	3,500
Downstream Distance to PAR	Not applicable
Maximum DV	280 ft^2/s along Big Thompson River, below Drake, CO. See Table 23
Flood severity understanding	n/a for many, possibly vague for those who did receive warning
Confidence in data	Good. Event has been well researched and documented

This flood event is considered to have been medium severity. Damage was extensive in many locations. However, in many of the historic photos of the flooding aftermath, some traces of development remain. The available numeric information regarding DV and rate of rise indicate that portions of the flooding may have fit more current criteria for high severity. The possibility of high severity may be further illustrated by examining the aerial photos from the 1976 USGS Flood Information Report, which shows sections of Highway 34 completely washed out.

References:

- Storm and Flood of July 31 – August 1, 1976, in the Big Thompson River and Cache le Poudre River Basins, Larimer and Weld Counties, Colorado. USGS Professional Paper 1115
- The Big Thompson River Flood, Flood Information Report, October 1976, Prepared by U.S. Geological Survey and the Colorado Conservation Board
- What People Did During the Big Thompson Flood, Eve C. Gruntfest, Institute of Behavioral Science, University of Colorado, Prepared for the Urban Drainage and Flood Control District, Working Paper #32, August 1977
- Wikipedia page on the Big Thompson Flood

Buffalo Creek Coal Waste Dam – Failed February 26 1972

The Buffalo Creek Flood was a disaster which occurred on February 26, 1972, when the Pittston Coal Company's coal slurry impoundment Dam #3 burst, four days after having been declared "satisfactory" by a federal mine inspector. The dam was located on a hillside near the community of Saunders in Logan County, West Virginia,

The resulting flood unleashed 404 acre-feet of water, laden with coal mine waste, upon the residents of 16 coal mining hamlets in Buffalo Creek Hollow. Out of a population of 5,000 people, 125 were killed, 1,121 were injured, and over 4,000 were left homeless. 507 houses were destroyed, in addition to forty-four mobile homes and 30 businesses (Wikipedia).

The main dam on Buffalo Creek, known as Dam #3, was constructed of coarse mining refuse dumped into the Middle Fork of Buffalo Creek. Dam #3 failed first, following heavy rains. The water from Dam #3 then overwhelmed Dams #2 and #1. Dam #3 had been built on top of coal slurry sediment that had collected behind dams # 1 and #2.(Wikipedia)

Dam #3, which was about 45 feet high with a 550 foot crest length, failed at 8:00 am on Saturday February 26, 1972. The failure of the dam was attributed to a flood inflow that was roughly equal to the 2-year storm. Water was close to the dam's crest. Sliding and slumping of the downstream face of the dam was followed by an uncontrolled release of the reservoir and a complete breaching of the dam. There were no witnesses to the actual failure of the dam. At Buffalo Creek, below Saunders, 4,500 feet downstream from the Middle Fork confluence, the peak flow was computed to be 50,000 ft^3/s. (USGS 667).

Upon failure of the dam, the reservoir was emptied in 15 minutes or less. (CE 1973)

Flood depths were estimated to be 10 to 12 feet for first three miles. The flood traveled through the 15 mile long Buffalo Creek valley with an average velocity of about 7 ft./s, though it was likely to have been much higher close to the dam.

Warning began after the structure failed. Reaction to the warnings was meager, because there had been at least four previous false alarms. (DSO-99-06)

Most of the fatalities (82%) occurred within the first six miles from the dam, at the communities of Lorado and Lundale. Many residents in flooded areas could have escaped the flooding by walking several minutes uphill. However, during early morning in February, most residents were probably located inside with windows closed. As a result, they were less likely to have had the benefit of visual or audible cues which might have alerted them of the approaching flood.

Maximum DV is estimated to have been 300 to 400 ft^2/s with rate of rise equal to about 2.5 ft./min at Saunders (Report of failure of dam No.3 and Wayne Graham's analysis of USGS 667).

At the community of Lorado, about 1-1/2 miles below the dams, the maximum DV is estimated to have been 90 to 160 ft^2/s, probably with decreased rate of rise when compared to Saunders. (DOI Investigation Report)

Figure 61. Reconstructed view of the damsite.
Source: U.S. Geological Survey, Circular 667

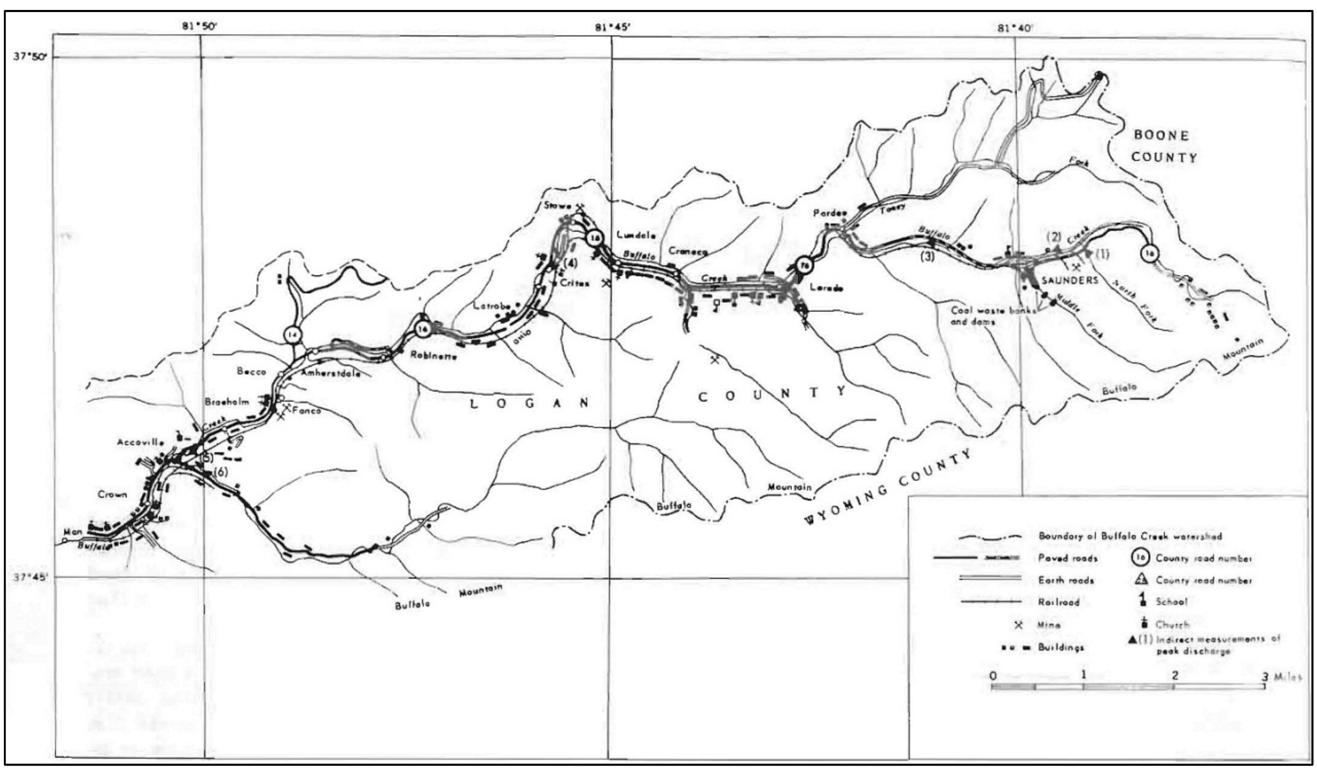


Figure 62. Overview of affected area
Source: U.S. Geological Survey, Circular 667

Figure 63. Aftermath of the Buffalo Creek Dam failure flood
Source: The Herald Dispatch, http://www.herald-dispatch.com/specialsections/100years/x1107815709/Gallery-The-Buffalo-Creek-Flood?photo=21

Summary Table 21 Buffalo Creek Dam

Flood Severity Rating	Medium
Warning Time	None to some
Time of day	Morning, 8:00 am
Failure scenario	Hydrologic induced slumping of dam crest
Fatalities	125
Fatality Rate	0.025
Dam Height	45 feet
Reservoir Storage	404 acre-feet
Breach Formation Time	rapid
Total PAR	5,000
Downstream Distance to PAR	From less than one mile to fifteen miles
Maximum DV	At Saunders/Lorado, 300 to 400 ft^2/s with high rate of rise at Saunders, but not at Lorado
Flood severity understanding	Vague
Confidence in data	Good, the case has been extensively studied, and the events seem to have been reported fairly consistently between sources.

Overall, this flood is considered to have been medium severity. Throughout the flooded area damage was extensive, but the area was not “swept clean”. High DV and rate of rise is thought to have occurred at Saunders, but not enough information is available to analyze the event at that location in detail.

<u>References:</u>

- Buffalo Creek Dam Disaster: Why it Happened, William E. Davies, Civil Engineering Magazine, July 1973
- USGS Circular 667, West Virginia's Buffalo Creek Flood: A study of the Hydrology and Engineering Geology, February 26, 1972
- Analysis of Where Fatalities Occurred by Duane McClelland, Reclamation Flood Event Case History Archive
- Preliminary Analysis of the Coal Refuse Dam Failure at Saunders, West Virginia, February 26, 1972, U.S. Department of the Interior, 3/12/1972
- Analysis by Wayne Graham of Rate of Rise in Flood Depths Using Data from USGS Circular 667, Undated, Reclamation Flood Event Case History Archive
- Report on the Failure of Dam Number 3, on the Middle Fork of Buffalo Creek, Near Saunders, West Virginia on February 26, 1972, Committee on Natural Disasters, National Academy of Engineering, 1972
- http://en.wikipedia.org/wiki/Buffalo_Creek_Flood

Teton Dam – Failed June 5, 1976

Teton Dam, constructed, owned and operated by Reclamation, failed during first filling on Saturday June 5, 1976. The dam was located on the Teton River, about three miles northeast of the town of Newdale, Idaho. Teton Dam was a central-core, zoned embankment dam with a 305 foot structural height (not including 100 feet of additional foundation excavation), and contained 251,700 acre-feet of storage at the time of failure. The cause of failure was internal erosion of the core of the dam, initiated within the foundation key trench. (Dams and Public Safety)

During the night of June 4, water evidently flowed down the right groin and a shallow, damp channel was noticed early on the morning of June 5. Shortly after 7 am on June 5, muddy water was flowing at about 20 to 30 ft^3/s from talus on the right abutment. At about 10:30 a.m., a large leak of about 15 ft^3/s appeared on the face of the embankment, possibly associated with a "loud burst" heard at that time. The new leak increased and appeared to emerge from a "tunnel" about 6-feet in diameter, roughly perpendicular to the dam axis and extending at least 35 feet into the embankment. The tunnel became an erosion gully developing headward up the embankment and curving toward the abutment. At about 11 a.m., a vortex appeared in the reservoir, above the upstream slope of the embankment. At 11:30 a.m., a small sinkhole appeared temporarily, ahead of the gully developing on the downstream slope, near the top of the dam. Shortly thereafter, at 11:57 a.m., the top of the dam collapsed and the reservoir was breached. (Dams and Public Safety)

Failure of the dam released 240,000 acre-feet in about six hours. Flooding reached the town of Wilford, 8.4 miles downstream, within 30 minutes or so. Five fatalities occurred at Wilford and 120 of 154 homes were swept away. Flooding 12.3 miles downstream at Sugar City arrived at 1:30 pm and was described as a 15 foot high wall of water. At Rexburg, 15.3 miles downstream, flooding arrived at 2:30 pm and reached a depth of 6 to 8 feet within minutes. (Graham, ASDSO 2008)

Eleven fatalities are associated with the dam's failure, although it is thought by some that the consequences could have been much worse if the dam had failed at night with no warning. Persons were present at the dam while it was failing and evacuation of downstream population was ordered thirty minutes to an hour prior to the full development of the breach. More than 30,000 people in total were evacuated. Some fatalities occurred when persons, living outside of the flooded area, went into the flood zone to assist others in retrieving possessions. (Graham, ASDSO 2008)

Out of the eleven fatalities, six died from drowning, three from heart attack, one from accidental shooting and one from self-inflicted gunshot wounds. (Teton Dam Tragedy)

The maximum dam failure discharge was about 2.3 million ft^3/s at Teton Canyon, located 2.5 miles downstream from the dam. At Wilford, the flood discharge is estimated to have attenuated to 1.1 million ft^3/s.

Figure 64. Teton Dam failure
Source: IS-L-0011, WaterArchives.org

Figure 65. Flooding and evacuation at Rexburg, Idaho
Source: ID-L-0022, WaterArchives.org

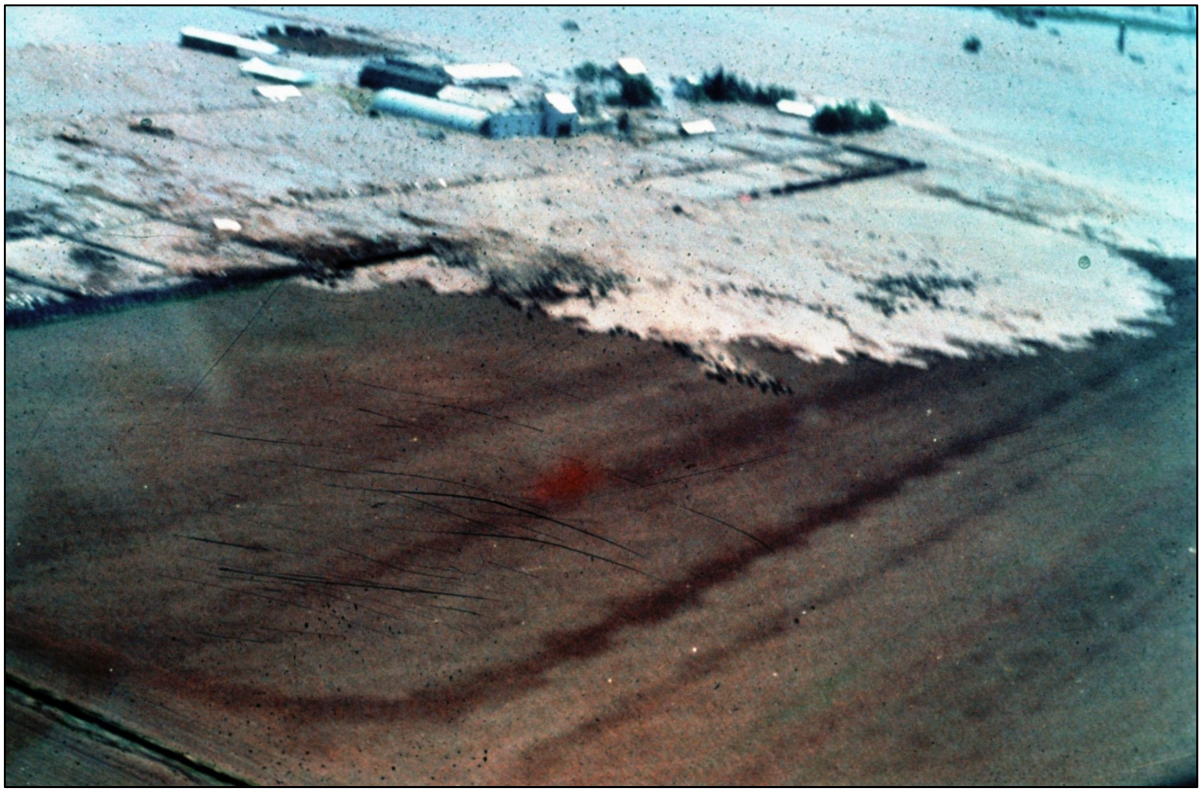


Figure 66. Flood wave propagation across farmland in Wilford
Source: ID-L-0020, WaterArchives.org

Figure 67. Flooding aftermath at Rexburg
Source: ID-L-0043, WaterArchives.org

Summary Table 22 Teton Dam

Flood Severity Rating	High, medium and low, varied by location
Warning Time	30 minutes to 1 hour for Wilford, Sugar City and Rexburg
Time of day	Daytime (noon)
Failure scenario	Internal erosion
Fatalities	11
Fatality Rate	0.5 at Teton Canyon, 0.021 at Wilford, 0.0002 at Rexburg, 0 at Sugar City and Roberts
Dam Height	305 feet
Reservoir Storage	240,000 acre-feet released during breach
Breach Formation Time	1:30
Total PAR	Greater than 30,000 based on number of people evacuated. About 12,000 from dam to Rexburg, according to Wayne Graham investigation.
Downstream Distance to PAR	2.5 miles to Teton Canyon, 8.4 miles to Wilford, 15.3 miles to Rexburg
Maximum DV	About 1,100 to 1,700 ft^2/s in Teton Canyon with fast rate of rise, Wilford and Sugar City – about 180 ft^2/s Rexburg – 60 ft^2/s Roberts (43.1 RM from dam, no fatalities) 30 ft^2/s
Flood severity understanding	Precise for most of the affected population. PAR in Teton Canyon received no warning
Confidence in data	Good. This event has been thoroughly documented and researched.

High severity flooding may have been present in Teton Canyon. In developed areas, the flood severity ranged from medium at Wilford and Sugar City to low at Rexburg and beyond.

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- The Teton Dam Failure – An Effective Warning and Evacuation, PowerPoint presentation by Wayne Graham, Bureau of Reclamation, for Association of State Dam Safety Officials Conference, 2008
- The Flood in Southeastern Idaho from the Teton Dam Failure of June 5, 1976, U.S. Geological Survey Open File Report 77-765.
- Teton Dam Tragedy, An account of the Teton Dam disaster on Fremont County, Idaho, as compiled from the pages of the Chronicle-News (pdf file in Graham archive)

Baldwin Hills Dam – Failed December 14, 1963

Baldwin Hills Dam was an embankment structure which consisted of the main dam and three interconnected dikes, which formed a "ring" that enclosed the reservoir. The dam, situated on a hilltop in Los Angeles, California, stored municipal water. Baldwin Hills Dam had a 65.5 foot structural height with a crest length of 650 feet. Failure occurred on Saturday December 14, 1963 due to subsidence, leading to internal erosion and piping. Baldwin Hills Dam was twelve years old at the time of its failure.

Figure 68. Baldwin Hills Dam
Source: Photo licensed by Corbis Images

The dam failed at 3:38 pm on a sunny, Saturday afternoon. Seepage from the dam was detected at 11:15 am, and the process of issuing warning was well in advance of breach. Initially, there was an attempt to draw down the reservoir level and flooding from the releases began affecting residential streets at about 12:20 pm. At 1:45 pm, the decision was made to issue evacuation orders to downstream residents. Neighborhoods were cordoned off and warning was strongly issued via emergency alert broadcasts, helicopters with bullhorns, and by policemen going door to door.

Immediately downstream from the dam was a narrow flood channel, approximately 50 to 75 feet wide. Numerous houses were damaged or destroyed in this area, but no fatalities occurred due to a successful evacuation. At about 0.4 miles downstream of the dam was a large apartment complex community known as Village Green. At Village Green, the flow spread laterally east and west, with an approx. width of 0.5 miles. All of the five fatalities resulting from the failure of Baldwin Hills Dam occurred in the vicinity of Village Green, including three persons traveling together in a vehicle when overtaken by the flood.

Figure 69. Flooding directly below dam, upstream of Sanchez Drive, no fatalities in this area
Source: Photo licensed by Corbis Images

A fire department helicopter was responsible for rescuing 18 people caught in the flooding at Village Green. At least six of these persons may have died if they had not been rescued. (Los Angeles Fire Department Historical Archive)

The pre-evacuation population at risk in the affected area was estimated at 16,500. At least 1,000 people are thought to have remained in the flood zone. Maximum breach discharge is estimated to have been 35,000 to 40,000 ft^3/s. Flooding was reported to have been up to 30 feet deep initially, and maybe 5 to 8 feet deep further downstream with a velocity of 20 miles per hour (29 ft./s). (National Review)

In general, this flood was considered to have been medium severity. Damage in the Village Green area was extensive, but many structures remained standing after the flood. The narrow flood channel immediately downstream of the dam may have experienced high severity flooding, although no fatalities occurred in this area.

Summary Table 23 Baldwin Hills Dam

Flood Severity Rating	Medium
Warning Time	1:50 (hr:min)
Time of day	Daytime
Failure scenario	Subsidence leading to internal erosion
Fatalities	5
Fatality Rate	0.0003
Dam Height	65.5 feet
Reservoir Storage	738 acre-feet
Breach Formation Time	About 4:30 assuming that initial seepage discovered at 11:15 am marked the initiation of the breach
Total PAR	16,500
Downstream Distance to PAR	Beginning immediately downstream of the dam and extending for three miles when considering the extent of potentially lethal flood flow.
Maximum DV	150 ft^2/s based on an account of 5-foot deep flooding moving at 20 mph. At locations away from main flow path, DV was probably lower. DV may have been higher than 150 ft^2/s in the narrow channel just below the dam.
Flood severity understanding	Precise for many due to the strongly issued warnings. Vague for some who did not know of the dam, and had difficulty believing that they were at risk. (Disaster Research Center)
Confidence in data	Good. Event is well documented, although DV information is anecdotal.

<u>References:</u>

- National Review Article, No Date, Reclamation Flood Event Case History Archive
- “The Day the Dam Broke”, American Forests, February 1964, Reclamation Flood Event Case History Archive
- Los Angeles Times, various articles, Reclamation Flood Event Case History Archive
- Western Construction, March 1964,Reclamation Flood Event Case History Archive
- Civil Engineering Magazine, February 1964, Reclamation Flood Event Case History Archive
- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- Los Angeles Fire Department Historical Archive, Fireman Save 18 Lives in Baldwin Hills Flood, http://www.lafire.com
- The Baldwin Hills California Disaster, Research Note #5, Disaster Research Center, University of Delaware, by William Anderson, August 14, 1964

Shadyside, Ohio Flash Flood – June 14, 1990

A deadly flash flood occurred in eastern Ohio near the town of Shadyside on the evening of June 14, 1990. Over 3 inches of rain fell along Pipe and Wegee Creeks in under 2 hours. There were 26 known deaths in Ohio during this event, of which 24 were along Pipe and Wegee Creeks with the remaining 2 along the Cumberland Run about 8-10 miles west/northwest of Shadyside.

With the rain falling in such a short amount of time, witnesses reported a wall of water between 10 and 30 high feet rapidly moving downstream about 45 minutes after the onset of the heavy rain over the headwaters. Runoff was enhanced due to a very wet spring. Rainfall during May was 200 percent of normal. One resident described a sheet of water, ankle deep, running down the hillside near his house.

Shadyside is located in the western foothills of the Appalachians and characterized by small hills with steep slopes and narrow valleys. Most residents lived within the narrow strip of flat land along the creek, adding to the potential danger. About 80 houses were completely destroyed, 79 sustained major damage and 172 houses sustained minor damage. (Natural Disaster Survey Report)

Peak discharges were about 15,000 ft^3/s along Pipe Creek and about 12,000 ft^3/s along Wegee Creek. (USGS Report 91-4147)

Figure 70. Damage from the Shadyside flash flood
Source: Photo courtesy of the Belmont County Emergency Management Office

Figure 71. Flooding aftermath, Shadyside flash flood
Source: NOAA National Severe Storms Laboratory/photo by M. Wyatt

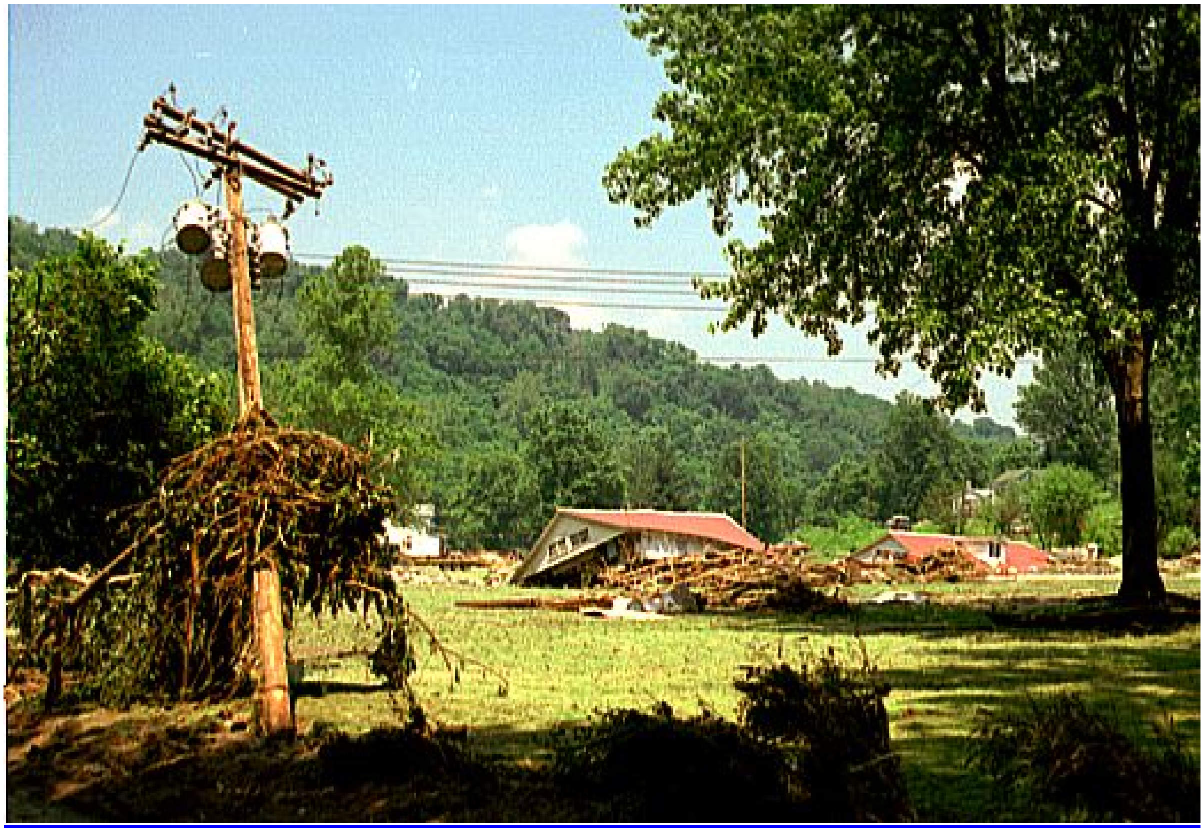


Figure 72. Destroyed homes, Shadyside Flash Flood
Source: Photo courtesy of the Belmont County Emergency Management Office

A number of factors led to the high fatality rate, but the most significant were the time of day that the flooding took place (9:00-9:30 p.m.) and the suddenness of the flooding. (USGS Report 91-4147)

Dissemination of the flash flood watch through emergency management channels was not completely effective. The watch was successfully received by the Belmont County Sheriff's Office through official channels, but further distribution of the watch to the Shadyside Police or to the County Emergency Management Coordinator was not successful. However, the latter offices and many residents in the flood area became aware of the watch through commercial radio and television station broadcasts.

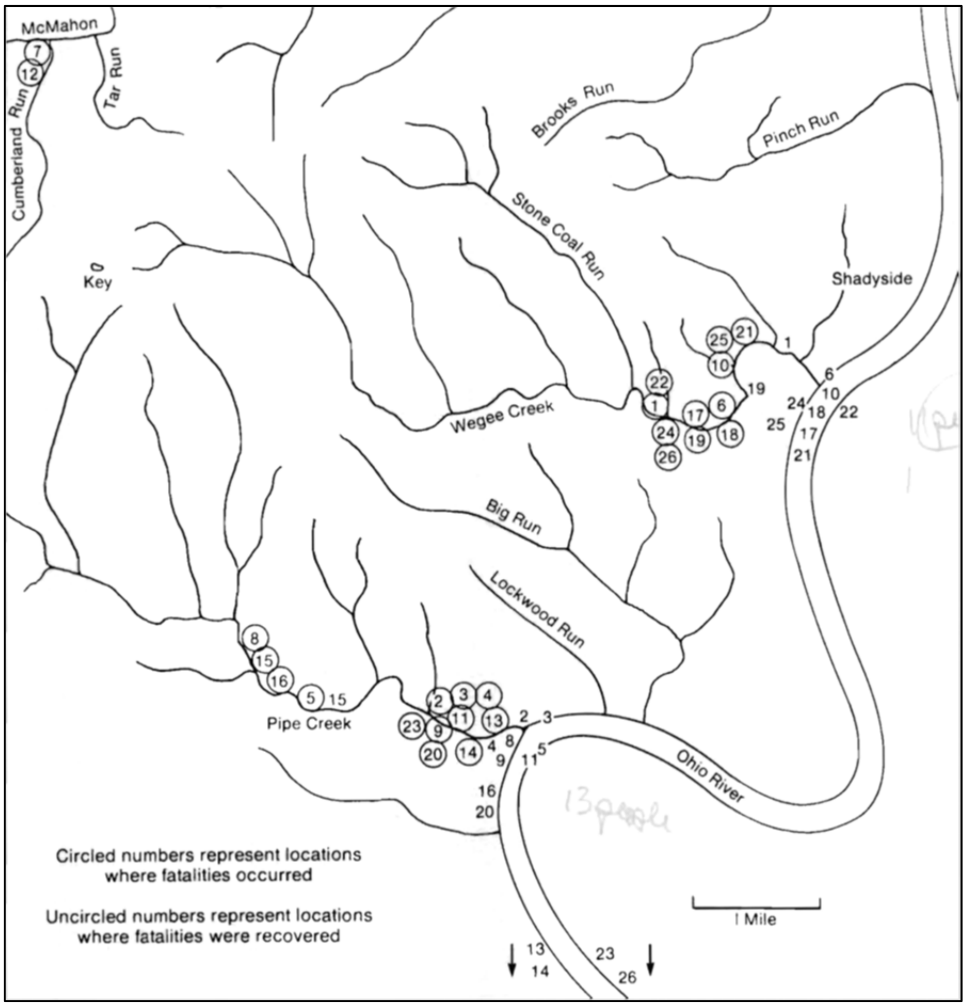


Figure 73. Shadyside Flood, 1990, layout of flooded creeks and locations of fatalities
Source: DOC/NOAA/NWS Natural Disaster Survey Report, Shadyside, Ohio, Flash Floods, June 14, 1990

Summary Table 24 Shadyside, Ohio Flash Flood, 1990

Flood Severity Rating	Medium
Warning Time	Some warning was issued, but was not forceful and not entirely effective. At least some of the people killed received no warning.
Time of day	Night time
Failure scenario	Flash flood
Fatalities	24 (based on DSO-99-06 estimate)
Fatality Rate	0.027 (based on DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	884 (based on DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	Estimated to have been 50 to 100 ft^2/s. There was a report of a 20-foot wall of water, and with steep channel slopes, the maximum velocities were possibly high.
Flood severity understanding	Possibly vague for those who received warning.
Confidence in data	Good. The flood was investigated, with reports published by both USGS and NOAA.

This flood is considered to have been medium severity. Flood damage was extensive, but the affected areas were not swept clean. The remains of destroyed and damaged structures were present in the flooded areas.

References:

- Flood of June 14-15, 1990, in Belmont, Jefferson and Harrison Counties, Ohio, With Emphasis on Pipe and Wegee Creek Basins Near Shadyside, U.S. Geological Survey, Water-Resources Investigations Report 91-4147
- Shadyside Ohio, Flash Floods, June 14 1990, Natural Disaster Survey Report, U.S. Department of Commerce, Silver Spring, Maryland

Heppner, Oregon (Willow Creek) Flash Flood – June 14, 1903

The Heppner Flood of 1903 was a major flash flood along Willow Creek responsible for destroying a large portion of Heppner, Oregon, on June 14, 1903. With a death toll of 247 people, it remains the deadliest natural disaster in Oregon, and the third deadliest inland flood related event in the entire United States, behind the 1889 Johnstown Dam failure flood and the 1972 Black Hills Flood which included the failure of Canyon Lake Dam. (Wikipedia)

Strong thunderstorms moved over the Heppner area on June 14, 1903. Torrential rain and hail began falling on the watersheds of Willow Creek and two of its largest tributaries, Balm Fork and Hinton Creek, by 4:30 pm. The region's arid climate and little vegetation coupled with the ground already being wet from a storm three days earlier caused very little water to be absorbed by the soil, and soon the streams were flooding. Within fifteen minutes after the rain began to fall, water rushed down the streams (mainly the Balm Fork), towards Heppner. A steam laundry building on the southern edge of Heppner, built across Willow Creek, acted as a dam when the water arrived, failing under the stress several minutes later. This sent a wall of water, reported to have ranged from 15 to 50 feet high, cascading down Willow Creek. The flood quickly reduced many of Heppner's structures to rubble. Some structures were ripped off their foundations and floated downstream. At its peak, over 36,000 ft^3/s of water raced down Willow Creek, more than the average flow of the much larger Willamette River to the west. Many people were able to escape to higher ground, but 247 died. The waters finally receded around an hour later. Two-thirds of the houses in Heppner were destroyed, and around 140 total structures, about one-third of Heppner, were washed away. (Wikipedia)

After the flood inundated Heppner, two of its residents, Les Matlock and Bruce Kelly, rode on horseback to warn the cities of Lexington and Ione, 9 and 18 miles downstream, respectively. The flood washed through Lexington at about 7:00 pm, just before they arrived, destroying several buildings. Matlock and Kelly continued north to Ione, overtaking the flood and warning the bewildered residents to evacuate. One hundred and fifty homes were destroyed, but no one was killed. However, the floodwaters washed raw sewage from Heppner downstream, contaminating wells in both Lexington and Ione. As a result, at least 18 people died from typhoid fever over the next several months. (Wikipedia)

The USACE Willow Creek Dam was completed in 1983 to prevent such a flood in the future. It was the first major roller-compacted concrete dam. (Wikipedia)

Figure 74. Aftermath of flooding at Heppner
Source: Oregon Historical Society, #ba010628

Summary Table 25 Heppner, Oregon (Willow Creek) Flash Flood, 1903

Flood Severity Rating	Medium
Warning Time	No warning at Heppner and Lexington, some warning at Ione
Time of day	Afternoon at Heppner
Failure scenario	Flash flood
Fatalities	200, based on DSO-99-06 estimate 247 bodies recovered at Heppner, based on Wikipedia article and Oregon Encyclopedia
Fatality Rate	0.43, based on DSO-99-06 estimate 0.25, based on Wikipedia article 0.18, based on Oregon Encyclopedia
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	1400
Downstream Distance to PAR	Not applicable
Maximum DV	100 ft^2/s
Flood severity understanding	No warning
Confidence in data	Fair. Event is reasonably well documented, but occurred a long time ago.

DSO-99-06 considered this flood to have been medium severity. Building damage was extensive, but the area was not swept clean. Flood depths reportedly exceeded 10 feet at Heppner.

References:

- http://en.wikipedia.org/wiki/Heppner_Flood_of_1903
- http://www.oregonencyclopedia.org/entry/view/heppner_flood/

Black Hills Flood/Canyon Lake Dam Failure – June 9, 1972

On June 9, 1972 a severe thunderstorm flash flood occurred on Rapid Creek in South Dakota. The flood destroyed portions of Rapid City, and breached Canyon Lake Dam at about 10:45 pm. Overall, 236 fatalities occurred on June 9 and 10, with a reported 165 fatalities downstream of Canyon Lake Dam (Night of Terror). In addition to the fatalities, there were more than 3,000 people injured, 1,335 homes destroyed or damaged, and $160,000,000 in total damages (1972 value).

Canyon Lake Dam was an earthfill embankment that was 30 feet high and held a volume of 192 acre-feet at the spillway crest. Spillway capacity was 3,200 ft^3/s. The dam failed when overtopping reached roughly three to four feet. The total volume released during the breach event is estimated to have been between 650 to 750 acre-feet. The peak discharge from the dam breach has been estimated at 60,000 ft^3/s.

Flash flood warnings were initially issued for areas located to the south of Rapid City. These warnings were revised at 8:00 pm to include the Rapid Creek drainage. At 10:10 pm, the Rapid City police Department evacuated a subdivision located close to Rapid Creek and at 10:30 pm the mayor of Rapid City issued a broader evacuation order that was transmitted via radio and television. Door to door warnings were issued in the area downstream of Canyon Lake Dam, but these warnings were reportedly met with mixed response from residents who may not have fully understood the risk. It is possible that the warning was not strongly conveyed.

Figure 75. Remains of Canyon Lake Dam
Source: U.S. Geological Survey, USGS Fact Sheet FS-037-02

Figure 76. Aftermath of flooding, Rapid City, South Dakota
Source: Photo courtesy of the U.S. Department of Agriculture

Figure 77. Flooding aftermath, Rapid City, South Dakota
Source: NOAA National Weather Service, http://www.crh.noaa.gov/images/unr/1972/frontier_motors.jpg

Summary Table 30 Black Hills Flood / Canyon Lake Dam Failure, 1972

Flood Severity Rating	Medium
Warning Time	Some warning at Rapid City
Time of day	Night time
Failure scenario	Flash flood and dam breach
Fatalities	245 overall, 162 downstream of dam
Fatality Rate	0.014, based on DSO-99-06 estimate
Dam Height	30 feet
Reservoir Storage	192 acre-feet
Breach Formation Time	Approximately 1 hour
Total PAR	17,000 (based on DSO-99-06 estimate) "Night of Terror" reports 9,016 persons in danger at Rapid City, with 8,900 persons heeding advance warning.
Downstream Distance to PAR	PAR located immediately downstream
Maximum DV	30 to 160 ft^2/s, based on 2D hydraulic re-creation. Note that some fatalities may have occurred in the low severity zones.
Flood severity understanding	Vague
Confidence in data	Good. Event is well documented and has been studied extensively, although there are varying reports on the total number of fatalities and total number of PAR.

This flood was considered to have been medium severity. Analysis of the flood indicates that the DV was greater than 50 ft^2/s. Structures were destroyed and damaged, but the flooded area was not swept clean.

<u>References:</u>

- Case Study: 1972 Black Hills/Rapid City Flood & Canyon Lake Dam Failure, Sean Kimbrel, ASDSO Dam Safety Conference. 2011
- USGS Professional Paper 877
- National Disaster Institute "Night of Terror – Black Hills and Rapid City Flood"
- NOAA NDSR 72-1
- USGS Fact Sheet FS-037-02

Arkansas River Flood – June, 1921

The Weather Bureau described the June 1921 flood as the most disastrous flood of record in Colorado at that time. There were three distinct flood peaks, but the second flood peak was clearly the most devastating. Heavy rains fell upstream from the city of Pueblo with as much as 14 inches occurring during the afternoon and night of June 3. At about 8:45 p.m., levees in Pueblo overtopped at a river stage of 18.1 feet. Around midnight, the maximum stage of 24.66 feet was reached. In the 45 minutes ending at 11:55 p.m., the water level rose 5.36 feet. The peak discharge on the Arkansas River at Pueblo was estimated at 103,000 ft^3/s. (Pueblo Life Loss, 2003)

When the levees overtopped at about 8:45 p.m., an immense volume of water flowed across the old flood plain and through the heart of the business district in the city of Pueblo, which in 1921 was located on both sides of the river. At the time of the 1921 flood, the Arkansas River was situated north of its present location. The river was relocated to the southerly edge of the floodplain in the downtown area after the 1921 flood. Flood depths in some areas were as much as 15 feet above street level. The area inundated was 3 square miles (Pueblo Life Loss, 2003),

The first warning of the approaching flood reached the city at about 6:00 pm on June 3, stating that a wall of water was rushing down the river. Messengers were sent out at once to warn the people living in the lowlands. Hundreds of people rushed to the levees to witness the approach of the great wall of water, not thinking that the city could be inundated, as the levees were believed high enough to protect it. The sudden breaking of the levees cut off the people from higher land. Many onlookers drowned trying to escape. Others in the houses of the lowlands who had refused to heed the flood warning also drowned trying to escape. (Pueblo Life Loss, 2003)

Estimates of property damage were very precise whereas estimates of the loss of life varied widely. Flood damage totaled $19,080,000 and the City of Pueblo suffered slightly more than half of this. (Pueblo Life Loss, 2003)

The total number of fatalities was somewhere in the range of 100 people.

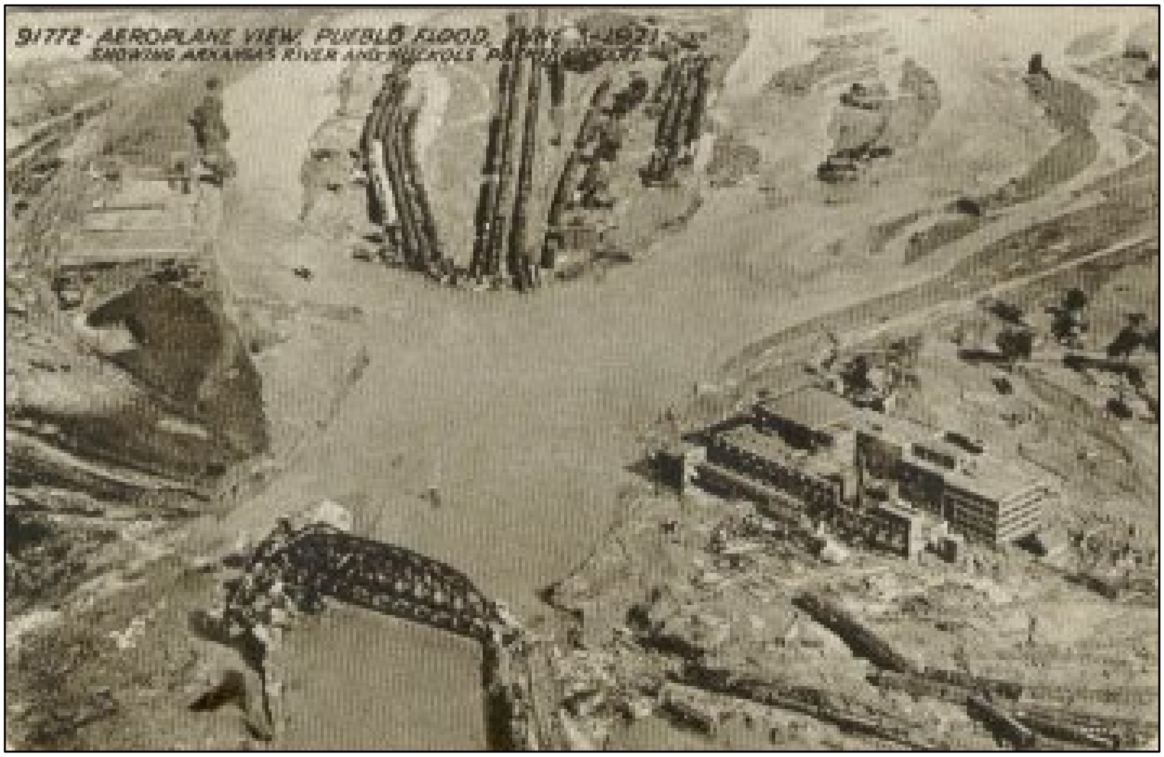


Figure 78. Aftermath of the 1921 Arkansas River Flood
Source: Photo courtesy of Karen Mitchell, http://www.kmitch.com/Pueblo/pueb1921001.jpg

Figure 79. Flooding at Pueblo, Colorado, 1921
Source: Photo courtesy of Karen Mitchell, http://www.kmitch.com/Pueblo/pueb1921001.jpg

Summary Table 31 Arkansas River Flood, 1921

Flood Severity Rating	Medium
Warning Time	Warning was issued at Pueblo, but many did not evacuate
Time of day	Night time
Failure scenario	Large regional flash flood
Fatalities	Approximately 100
Fatality Rate	0.05, based on DSO-99-06 estimate
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	2000, based on DSO-99-06 estimate
Downstream Distance to PAR	PAR located directly adjacent to the Arkansas River at Pueblo
Maximum DV	Maximum velocity at Pueblo was reported by USGS to have been 15 ft./s. With a 10 ft. depth, DV could have been as high as 150 ft^2/s close to the river.
Flood severity understanding	Vague
Confidence in data	Low confidence in fatality rate and PAR, USGS accounts of the event seem well documented though. DV estimate is very approximate.

This flood was considered to have been medium severity. Maximum DV is not known. The flooding was greater than 10 feet deep at Pueblo and structures exposed to the flooding were destroyed, but the area was not swept clean and many trees remained standing.

Note that on June 5, 1921, continued rainfall in the Arkansas River Basin caused the failure of Schaeffer Dam. Outflows from Schaeffer Dam, located on Beaver Creek which is a tributary to the Arkansas River, eventually impacted the city of Pueblo. The earthen dam was 100 feet high and held 3,177 acre-feet of storage. Failure in progress was detected, and residents along Beaver Creek were successfully evacuated prior the dam's breaching. There were no fatalities.

References:

- Pueblo Dam, Colorado, Loss of Life Assessment, U.S. Bureau of Reclamation, Denver CO, September, 2003
- U.S. Department of Agriculture, Weather Bureau, Climatological Data, Colorado Section, Vol. XXVI, No. 6, June 1921.
- USGS, Follansbee and Jones, .The Arkansas River Flood of June 3-5, 1921, Water Supply Paper 487, Washington, D.C., 1922.
- http://www.kmitch.com/Pueblo/flood.html

Machhu II Dam - Failed August 11, 1979

On Saturday, August 11, 1979, the Machhu II Dam overtopped and failed, killing an estimated 10,000 people. Machhu II Dam was located in the Gujarat State of India, on the Machhu River about 4 miles upstream of the city of Morbi which reportedly had a population of about 75,000 people. The dam was a composite structure, about 85 feet high, with a masonry center section that contained 18 radial gates with a 191,000 ft^3/s design capacity. The flood inflow that overtopped and breached the dam was estimated to be somewhere between 500,000 to 700,000 ft^3/s. Breaching of the dam occurred on both of the dam's embankment wings, which had left and right crest lengths of 7,700 and 5,000 feet, respectively. Failure of the dam occurred during an unusually heavy monsoon season. The upstream Machhu I Dam released large flows through its spillways which contributed to the severity of inflow at Machhu II Dam. Machhu I Dam did not breach. There was widespread minor flooding due to rainfall prior to the Machhu II spillway releases and subsequent breach of the dam.

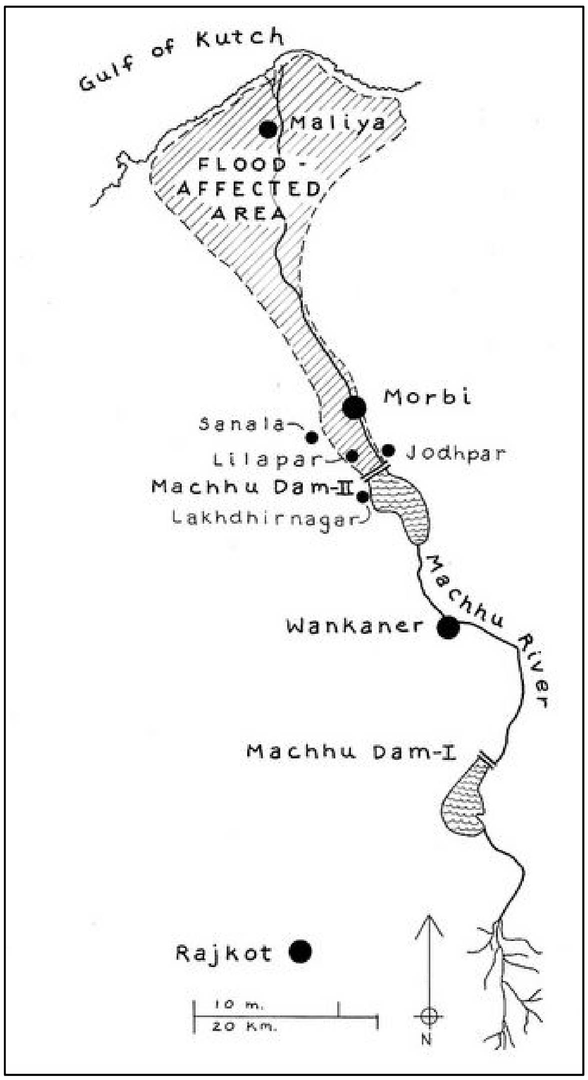


Figure 80. Machhu River overview
Source: Image created by Jamie Devol for *No One had a Tongue to Speak: The Untold Story of One of History's Deadliest Floods* by Utpal Sandesara and Tom Wooten

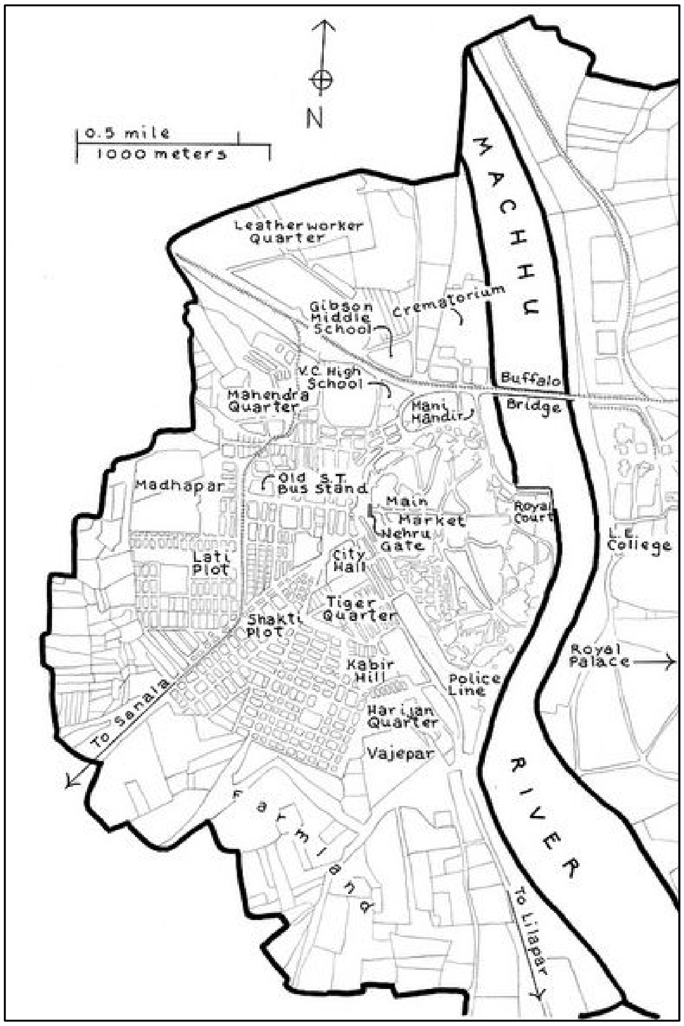


Figure 81. City of Morbi
Source: Image created by Jamie Devol for *No One had a Tongue to Speak: The Untold Story of One of History's Deadliest Floods* by Utpal Sandesara and Tom Wooten

By mid-morning on August 11, the village of Lilapar received warning that the dam was in danger of failing. Evacuation of Lilapar commenced. Lilapar was located ½ mile from the dam. The city of Morbi did not receive this warning.

Spillway releases from the dam caused significant flooding in the low lying portions of Morbi. Local evacuations were conducted, but the threat of dam failure was not part of the warning. Many chose not to evacuate and some residents expressed disbelief that the waters would rise high enough to endanger their residences. In the Vajepar section of Morbi, some residents remembered the 1959 flood which came only to the first step of the Hindu Temple, and many believed that this flood would climb no higher than the level of the flood from 1959. Sadly, they were wrong. More than 100 people sought refuge in the temple; only one person survived.

People located at the dam knew that it was going to fail, but communications were down and it was not possible to travel due to the storm, the saturated muddy ground, and the floodwater. When the embankment wings of the dam breached, the dam operators became marooned on the concrete center section of the dam.

The breach initiation occurred at about 2:15 pm on August 11, and was reported to have occurred slowly and steadily.

Shortly after 2:00 pm water moved quickly into Lilapar. The 50 or so remaining people were caught by surprise. They climbed rooftops seeking refuge. Three waves of water arrived. The first wave was 3 to 4 feet deep. The second was 15 feet and the third was greater than 20 feet deep. Many houses, including those whose roofs were used as refuge, collapsed and floated away.

By 3:00 pm, most residents of Morbi's low lying Harijan Quarter were evacuated. The Tiger Quarter section of Morbi was also evacuated by this time. In Shakti Plot, a higher section of Morbi, water started rising at 3:25 pm and had peaked by 5:10 pm. The most destructive flooding was confined to low lying areas. Flood depths may have ranged from 10 to 30 feet. Houses collapsed in the Tiger Quarter and probably elsewhere.

Sometime between 4:30 and 5:30 pm, the Buffalo Bridge, a local landmark, broke. After this, the flooding in Morbi began to recede.

Water near the town of Jodhpar was said to be greater than 30 feet deep.

There was a lot of confusion during this event due to the heavy rainfall, widespread flooding and disrupted communications. There was no official recognition that the dam had failed until evening. No one could get near the dam on the afternoon of August 11.

At 9:30 pm an official arrived at the tip of the dam's eastern embankment; he saw that the reservoir was completely drained!

The flood arrived at the town of Maliya at 9:00 pm. Many of the buildings there were constructed of earth and many of these buildings collapsed.

ABC News in the United States, reported an unofficial death toll as high as 25,000, with 15,000 to 20,000 people evacuated. Based on research of the event, the opinion of Utpal Sandesara (see references) is that a total fatality count of 10,000 people may be more realistic.

Despite the presence of personnel at the dam, no wide-scale warning of the dam failure was reported to have occurred at Morbi. There may have been last minute loudspeaker warnings that the dam was about to break, but these warnings were ignored.

The Machhu II Dam has been rebuilt, with increased spillway capacity and is in operation today.

Figure 82. Remains of the failed Machhu II Dam
Source: Photo courtesy of Gunvantbhai Sedani and featured in *No One had a Tongue to Speak: The Untold Story of One of History's Deadliest Floods* by Utpal Sandesara and Tom Wooten

Figure 83. Flooding aftermath at Morbi
Source: Photo courtesy of Gunvantbhai Sedani and featured in *No One had a Tongue to Speak: The Untold Story of One of History's Deadliest Floods* by Utpal Sandesara and Tom Wooten

Figure 84. Remains of the Buffalo Bridge at Morbi
Source: Photo courtesy of Gunvantbhai Sedani and featured in *No One had a Tongue to Speak: The Untold Story of One of History's Deadliest Floods* by Utpal Sandesara and Tom Wooten

Summary Table 26- Machhu II Dam

Flood Severity Rating	Medium
Warning Time	Little to no warning regarding dam failure at city of Morbi
Time of day	Daytime at Morbi, nighttime at Maliya
Failure scenario	Overtopping
Fatalities	Estimated 10,000
Fatality Rate	0.1
Dam Height	85 feet
Reservoir Storage	81,900 acre-feet
Breach Formation Time	Unknown, but reported to have been moderately slow, so maybe 2 hours
Total PAR	Estimated to be 100,000
Downstream Distance to PAR	About 4 miles to the center of Morbi
Flood severity understanding	n/a
Maximum DV	50 to 150 ft^2/s
Confidence in data	Generally good, but only fair for fatalities and PAR estimates.

References:

- Dams and Public Safety, A Water Resources Technical Publication, U.S. Department of the Interior, Bureau of Reclamation, 1983
- *No One Had a Tongue to Speak*, Utpal Sandesara and Tom Wooten, Prometheus Books, 2011, 411 pages
- Morbi Dam Failure, www.Wikipedia.org

Ka Loko Dam - Failed March 14, 2006

Ka Loko Dam was a privately owned embankment dam, located in the head waters of the Wailapa Stream, on the island of Kauai, Hawaii. The dam failed from overtopping in the early morning hours of March 14, 2006. Failure of the dam occurred during a prolonged period of heavy rainfall extending back to mid-February. The dam failure flood killed seven people who were sleeping in two adjacent houses very close to the Wailapa Stream. The dam was built in 1890, and was raised 12 feet in 1911 to a total height of about 40 feet with about 1,200 acre-feet of storage. A dam which impounds the Morita Reservoir, located about 1.7 miles downstream, overtopped but did not breach during the event. Maximum discharge at the Kuhio Highway crossing, about 2 miles downstream, was estimated by USGS to have been 27,200 ft^3/s. There was a report of a car with three occupants being swept off the highway at the flooded crossing, but without fatalities.

The dam was not well maintained and there is some evidence that the emergency spillway may have been filled in. The dam was classified as low hazard at the time of its failure. However, destroyed downstream structures where the fatalities occurred may not have been present when the hazard classification was performed. If those houses had been present at the time of the hazard classification, it is very likely that the dam would have been rated high or significant hazard, depending on the hazard classification methodology used.

Figure 85. The breached Ka Loko Dam
Source: Wikimedia Commons

Figure 86. Location where two houses were destroyed and where the seven fatalities occurred
Source: Photo courtesy of Hawaii State Department of Land and Natural Resources

Figure 87. Kuhio Highway crossing 2 miles downstream from Ka Loko Dam
Source: Photo courtesy of Dave Hammond, National Park Service

The flood severity for this event is rated as medium. Examination of photographs of affected downstream regions shows areas swept clean and devoid of any vegetation. However, there is not much known about the steepness of the channel slope, the rate of rise, and the flow velocities. High severity flooding is typically seen with rapid failure of high dam structures and with steep downstream channel slopes. This event might be considered to have flood severity characteristics of the upper end of the range of medium severity.

Summary Table 27 – Ka Loko Dam

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	Early morning, 5:00 am
Failure scenario	Overtopping
Fatalities	7
Fatality Rate	Unknown, but possibly 0.7
Dam Height	40 feet
Reservoir Storage	1,200 acre-feet
Breach Formation Time	Unknown
Total PAR	Maybe 10 or more
Downstream Distance to PAR	Approx. 2.7 stream miles, based on a Google Earth-posted photograph which claims to mark the location of the fatalities.
Flood severity understanding	n/a
Maximum DV	Assuming max velocity of 6 to 8 ft./s and using claimed maximum flood depths 10 to 20 feet, gives DV range of 60 to 160 ft^2/s
Confidence in data	Fair

References:

- The Ka Loko Dam Failure, Presentation for the Kansas Dam Safety Conference, February 19, 2008, by Matt Rosener, http://www.kspace.org/bitstream/1984/11472/1/kaloko.pdf
- http://en.wikipedia.org/wiki/Ka_Loko_Reservoir
- Peak Stage and Discharge Data for Ka Loko Reservoir Flood, Island of Kauai, Hawaii, March, 2006, http://hi.water.usgs.gov/studies/ka_loko/

Big Bay Dam - Failed March 12, 2004

On Friday March 12, 2004, the Big Bay Lake Dam on Bay Creek failed. This dam is located 11 miles west of Purvis, Mississippi on Bay Creek Road in Lamar County.

The 51 foot high dam was completed in 1990. The dam had a crest length of 2,000 feet and a normal storage of 14,200 acre-feet. Big Bay Dam failed as a result of internal erosion. The breach was reported to have been 230 feet wide and the reservoir was drained in 90 minutes. Breach initiation began at 12:20 pm and took about 55 minutes to become fully formed.

The National Weather Service issued a flash flood warning at 12:40 pm, 20 minutes after the dam began to fail. Activation of the emergency action plan is reported to have occurred within 10 minutes of the breach initiation. Warnings were disseminated both formally, and informally through word of mouth. The failure occurred during the day, when many people were away at work, and this may have contributed to the fact that there were no fatalities. There is also a report that the date of the failure was during the spring break for area schools, and many people may have been out of town.

A total of 104 homes or businesses were damaged or destroyed by the flood waters. Of the 104 damaged structures, 48 to 53 were completely destroyed. In addition, 30 roads were damaged or closed as a result of the event. The affected area stretched some 18 miles west of the dam to where Lower Little Creek meets the Pearl River.

The most catastrophic damage occurred within the first 5 miles below the dam along Bay Creek and Lower Little Creek. The first major impact of the flood waters occurred as 15-20 feet of water crossed Columbia-Purvis Road, 0.9 miles downstream. Here numerous trees were flattened as the water rushed through the area. Next, was Tatum-Salt Dome Road, at about mile 2.1, where 75 yards of the road was washed out. Several homes were moved off of their foundations here while numerous automobiles were swept 1/4 mile into the woods and lodged up in trees. Two mobile homes were moved off their blocks and lodged against a tree line. There was 10-15 feet of water moving through this area. Areas along Robbins Road were among the hardest hit. This road basically parallels Lower Little Creek for slightly over a mile. Many homes along this road were severely damaged or destroyed. Every home that was not attached to a concrete slab was moved off its foundation. All automobiles in the area were swept 1/4 mile from their original location. Robbins Road meets up with Caney Church Road, at about mile 3.7, where a section of the road was washed out. The next road was Luther-Saucier Road at about mile 5.3. Here a small section of the road was washed out. Just west of Luther-Saucier Road is McGraw Road, where the water was 5 feet deep. Three homes along this road were moved off their foundation.

The impact to downstream areas was described by NOAA as “amazing” since it produced damage that was comparable to tornado damage.

Two hydraulic re-creation studies were performed based on the event. One study was based on one-dimensional (1D) hydraulic modeling and the other was based on two-dimensional hydraulic modeling (2D). Both studies attempted to calibrate to high water mark data that was obtained by USGS and both studies produced mostly similar findings. DV information was calculated throughout the downstream area. The calculated DV values are quite high, ranging from 80 ft^2/s up to 500 ft^2/s. Rate of rise information was not obtained from these studies. Many homes were destroyed and damage was extensive. However, photos of the downstream area indicate that the flood zone does not appear to have been "swept clean", which is a characteristic of very high intensity flooding. For this reason, the flood is characterized as medium severity.

Big Bay Dam was approved to be rebuilt. Re-construction of the dam began in 2007.

Figure 88. Big Bay Dam breach
Source: NOAA National Weather Service,
http://www.srh.noaa.gov/images/jan/Weather_Events/2004_03_12/Dam%20Break%20Images/images/MVC-368S.JPG

Figure 89. Damaged house downstream of Big Bay Dam
Source: NOAA National Weather Service
http://www.srh.noaa.gov/images/jan/Weather_Events/2004_03_12/Dam%20Break%20Images/images/MVC-395S.JPG

Summary Table 28 – Big Bay Dam

Flood Severity Rating	Medium
Warning Time	Adequate warning
Time of day	Daytime
Failure scenario	Internal erosion/piping
Fatalities	0
Fatality Rate	0
Dam Height	51 feet
Reservoir Storage	14,200 acre-feet
Breach Formation Time	55 min
Total PAR	unknown
Downstream Distance to PAR	Beginning at about 0.6 miles from dam and extending downstream to at least mile 18
Flood severity understanding	unknown
Maximum DV	DV, as estimated by hydraulic re-creation ranged from 80 to 500 ft^2/s
Confidence in data	Good, but some conflicting information in the various data sources

Figure 90. House floated off its foundation, downstream of Big Bay Dam
Source: NOAA National Weather Service
http://www.srh.noaa.gov/images/jan/Weather_Events/2004_03_12/Dam%20Break%20Images/images/MVC-401S.JPG

References:

- National Weather Service Weather Forecast Office, Jackson Mississippi, Big Bay Lake Dam Break, http://www.srh.noaa.gov/jan/?n=2004_03_12_big_bay_lake_dam_break
- Steven E. Yochum, P.E.; Larry A. Goertz, P.E.; and Phillip H. Jones, P.E., M.ASCE, Case Study of the Big Bay Dam Failure: Accuracy and Comparison of Breach Parameters, Journal of Hydraulic Engineering, ASCE, September 2008
- Burge, T. R. 2004. Big Bay Dam: Evaluation of failure, Land Partners Limited Partnership, Hattiesburg, Miss.
- M.S. Altinaker, M.Z. McGrath, V.P. Ramalingam, H. Omari, Two-Dimensional Modeling and Consequence Analysis of Big Bay Dam Failure in Mississippi: Comparison with Field Data and 1D Model Results, Riverflow 2010 Conference Proceedings, Southeast Region Research Initiative, http://www.serri.org/publications/Documents/Ole%20Miss%20Project%2063891%20-%20River%20Flow%202010%20Conference%20-%20Altinakar%20McGrath%20Ramalingam%20and%20Omari%20100129.pdf

Banqiao and Shimantan Dams - Failed August 8, 1975

Banqiao dam, a sand-shell dam with a clay core, was built in the early 1950's on Ru River, which is a branch of the Hong River in China's Henan province. The dam had a structural height of about 80 feet, and a reservoir capacity of 399,000 acre feet with 304,000 acre feet reserved for flood storage. Maximum release capacity was about 62,000 ft^3/s. In August of 1975, typhoon Nina struck the Henan Province and caused catastrophic storms during the period of August 5-7. The maximal inflow rate was as large as 460,000 ft^3/s, which was significantly larger than the designed peak inflow flood (315,000 ft^3/s). The reservoir water level reached the top of the dam at 9:30 pm. on August 7, and reached the top of the wave protection wall at 11:05 pm. At that time, the inflow rate was 452,000 ft^3/s and the outflow rate was only 140,000 ft^3/s (Ru and Niu 2001). The dam breach initiated at 1:30 am on August 8 and was fully formed by 7:00 am, with a breach formation time of 5.5 hours. The peak breach outflow rate was reported to have been about 2,760,000 ft^3/s.

Figure 91. The breached Banqiao Dam
Source: Wikimedia Commons,
http://zh.wikipedia.org/wiki/File:%E6%BA%83%E5%9D%9D%E5%90%8E%E7%9A%84%E6%9D%BF%E6%A1%A5%E6%B0%B4%E5%BA%93.jpg

Cracks in the dam and sluice gates appeared after completion due to construction and engineering errors. They were repaired with the advice from Soviet engineers and the new design, dubbed "*the iron dam"*, was considered unbreakable.

The dam was reportedly designed to survive a 1,000 year inflow flood, but a 2,000 year inflow flood occurred in August 1975, following the collision of Super Typhoon Nina and a cold front. The typhoon was blocked for two days before its direction ultimately changed from northeastward to west. As a result of this near stationary thunderstorm system, more than a year's rain fell within 24 hours (new records were set, at 7.5 inches rainfall per hour and 41.7 inches per day, exceeding the average annual precipitation of about 31.5 inches) which weather forecasts failed to predict.

On August 8, at 1:00 am, water at Banqiao reservoir overtopped the wave protection wall on the dam by roughly one foot, initiating the breach. A total of 62 dams in the region failed during this storm, including Shimantan Dam. Shimantan Dam was a homogeneous earth dam, was constructed in 1950. The dam was located about 20 miles north of Banqiao Dam on the Gun River, which is a tributary to the Hong River. Shimantan Dam had a height of 82 feet and reservoir capacity of 79,530 acre-feet. The dam overtopped and began to breach, beginning at about 12:30 am on August 8. Failure of Shimantan Dam occurred about one hour before the breach of Banqiao Dam. The breach formation time was reported to have been about 5.5 hours, with a peak breach discharge of about 1,059,400 ft^3/s.

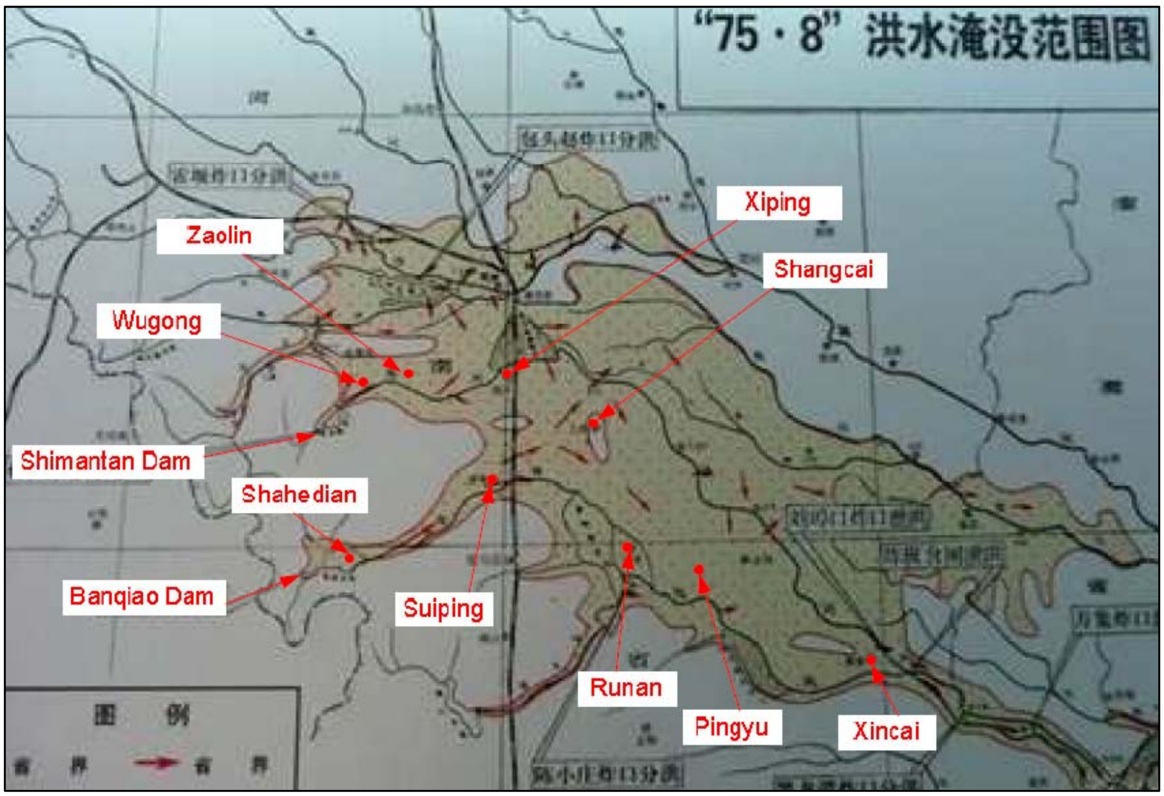


Figure 92. Banqiao and Shimantan Dams, location map
Source: Photo courtesy of L.M. Zhang

Evacuation orders had not been fully delivered due to weather conditions and poor communications. Telegraphs failed, signal flares fired as warning were misunderstood, telephones were rare, and some messengers were caught by the flood. (Wikipedia)

Shahedian was a town with the population of 6,000. It’s location spanned from 3.7 to 7.5 miles downstream of Banqiao Dam. The people in this town were told to evacuate more than one hour before the breaching of Banqiao Dam. This was the only community downstream of the Banqiao dam which received warning. (Qian 2005). The width of the flooding was about 3.7 to 6.1miles. The peak discharge at this location was estimated as 2,295,400 ft^3/s. DV was estimated to range from 70 to 120 ft^2/s. The flood severity may have been categorized as high, not so much based on

DV, but because all the houses, which were made with adobe (and relatively weak), were swept away. The total number of fatalities at Shehedian was 827, with a fatality rate of 0.127.

Wencheng Town and its associated villages, was located 7.5 to 12.4 miles downstream of the Banqiao dam with a population of 29,000 (ZWCB, 1998). No warning was received in the town prior to the nighttime arrival of flooding. The flooded area was 5 to 7.5 miles wide and the peak discharge here was estimated as 2,118,900 ft^3/s . DV was estimated at 50 to 80 ft^2/s. The flood is categorized as having been medium flood severity. Some villages in this area were catastrophically impacted. In Weiwan village, 929 out of 1976 people were killed with a fatality rate of 47%. At Qianhu village, 1397 out of 2200 people were killed with a fatality rate of 63.5% (DWRHP, 2005).

The flooded areas in the rest of the Suiping County, excluding Wencheng Town, were 12.4 to 28 miles downstream from the dam. The PAR along this reach is estimated to have been 151,000. No warning was issued prior to the flooding. A flood with a peak discharge of 1,885,800 ft^3/s arrived at Suiping at about 4:00 am. The flood width in this area was estimated as 7.5 to12.4 miles. DV is estimated to have ranged from 30 to 50 ft^2/s. The flooding can be categorized as low flood severity. The total fatalities were reported to have been 9375, with the fatality rate of 0.062.

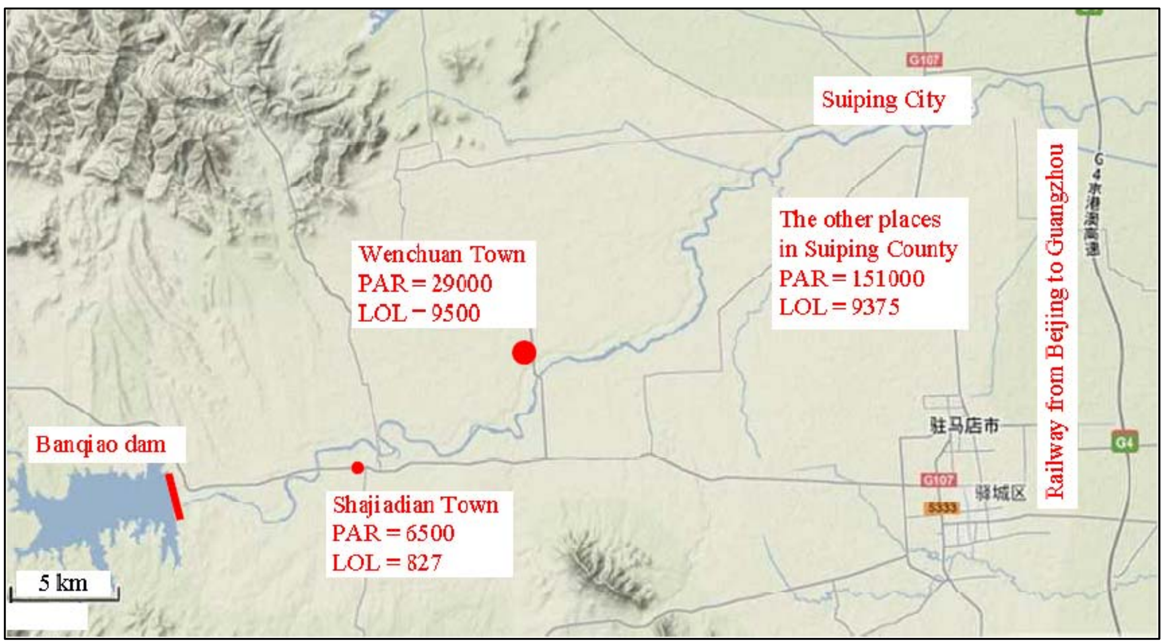


Figure 93. Map of Suiping County
Source: Photo courtesy of L.M. Zhang

Flooding in areas downstream of Suiping involved the interaction of the floods from both Banqiao and Shimantan dam failures. The areas downstream of Suiping County mainly included Shangcai and a part of Runan county. The total population along this reach is thought to have been about 216,000. The flood width broadened and the flood severity here was low. (Zhou 2006). No warning was issued in these areas. The number of fatalities in this area was estimated to have been 2892, with a fatality rate of 0.013. On the evening of August 8, there were as many as 50,000 people taking sheltering at a shallow the embankment of another reservoir (Suya reservoir) in Runan County. Fortunately, the embankment survived from this flood.

During the flood event that failed Banqiao and Shimantan Dams, aggressive action was taken to protect other dams from failure. Several flood diversion areas were evacuated and inundated, and several dams were deliberately destroyed by air strikes to release water in desired directions.

As a result of this flooding catastrophe, the Jingguang Railway, a major artery from Beijing to Guangzhou, was cut off for 18 days, as were other crucial communications lines. Nine days later there were still over a million people trapped by the waters. These people relied on airdrops of food and were unreachable by disaster relief groups. Epidemics and famine devastated the trapped survivors.

Banqiao Dam was reconstructed between 1986 and 1993.

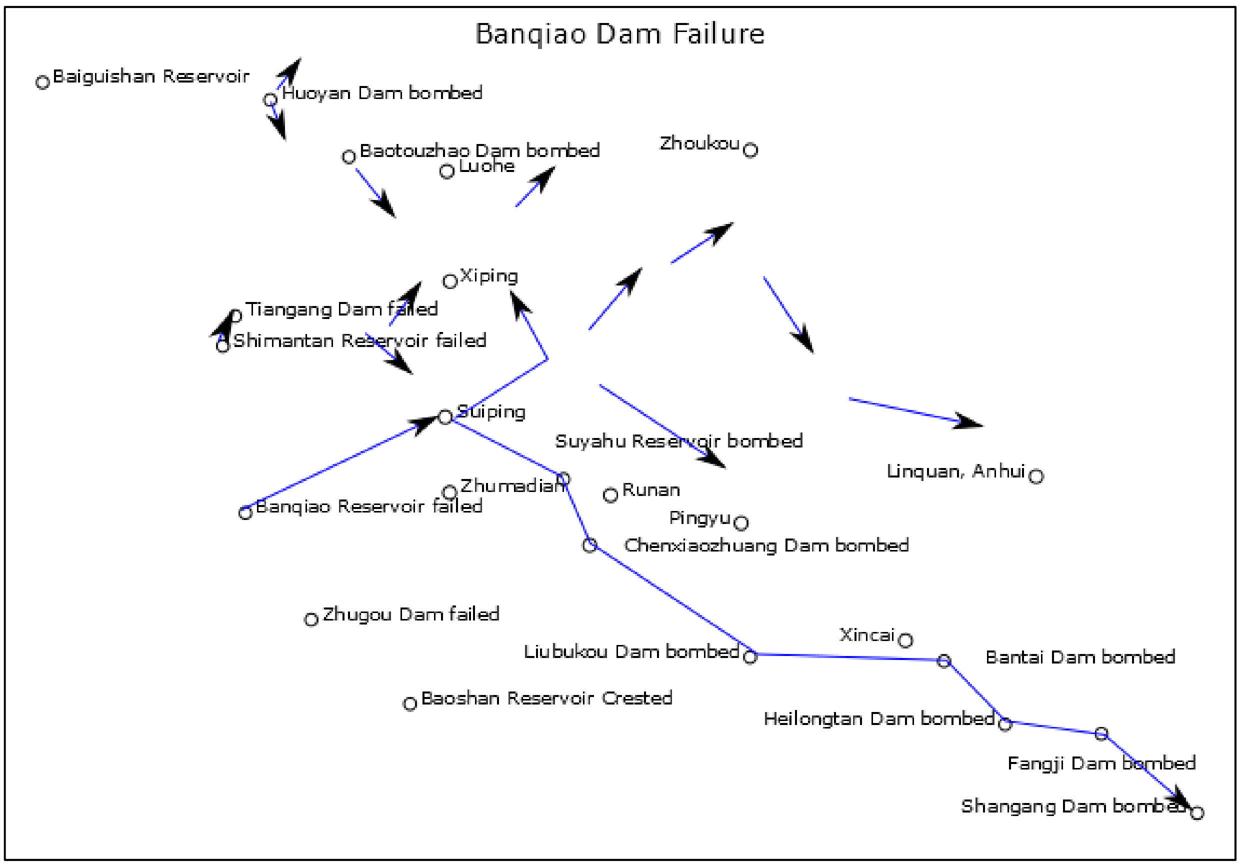


Figure 94. Diagram showing general direction of flood flows
Source: "Banqiao Dam Failure Waterflow" by Skyfiler - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons,
http://commons.wikimedia.org/wiki/File:Banqiao_Dam_Failture_Waterflow.png#mediaviewer/File:Banqiao_Dam_Failture_Waterflow.png

Summary Table 29– Banqiao Dam Failure

Flood Severity Rating	High, medium and low, depending on location
Warning Time	Some warning at Shahedian, no warning everywhere else
Time of day	Nighttime
Failure scenario	Overtopping
Fatalities	Overall fatalities are unknown, but may have ranged from 171,000 to 230,000 people Shahedian: 827 Wencheng Town, Weiwan Village: 929 Wencheng Town, Qianhu Village: 1397 Suiping County: 9375 Downstream of Suiping: 2892
Fatality Rate	Overall fatality rate in unknown Shahedian: 0.127 Wencheng Town, Weiwan Village: 0.47 Wencheng Town, Qianhu Village: 0.635 Suiping County: 0.062 Downstream of Suiping: 0.013 0
Dam Height	80 feet
Reservoir Storage	398,868 acre-feet
Breach Formation Time	5.5 hours
Total PAR	Unknown Shahedian: 6500 Wencheng Town, Weiwan Village: 1976 Wencheng Town, Qianhu Village: 2200 Suiping County: 151,000 Downstream of Suiping: 216,000
Downstream Distance to PAR	Beginning at about 3.7 miles or less from the dam, and extended downstream for many miles (more than 40)
Flood severity understanding	unknown
Maximum DV	Shahedian: 70 to 120 ft^2/s Wencheng Town, Weiwan Village: 50 to 80 ft^2/s Wencheng Town, Qianhu Village: 50 to 80 ft^2/s Suiping County: 30 to 50 ft^2/s Downstream of Suiping: unknown
Confidence in data	Fair. More information would increase confidence.

Note: Shimantan Dam's failure contributed to some of the downstream flooding, but not enough information is currently available to analyze this dam as a separate case.

References:

- The Forgotten Legacy of the Banqiao Dam Collapse, by Eric Fish, http://www.eeo.com.cn/ens/2013/0208/240078.shtml
- Department of Water Resources of Henan Province (DWRHP) (2005). The "75.8" catastrophic flood disaster in Henan Province. Yellow River Conservancy Press, Zhengzhou, Henan Province, China (in Chinese)
- Qian G. (2005). The dam failure event in Zhumadian reservoir in 1975. Southern Weekly, 15 August 2005 (in Chinese).
- Ru NH, Niu YG (2001) Embankment dam - incidents and safety of large dams. Water Power Press, Beijing (in Chinese)

- Zhumandian Water Conservancy Bureau (ZWCB) (1998). Records of the “75.8” flood in the Zhumadian district. Yellow River Conservancy Press, Zhengzhou, Henan Province, China (in Chinese)
- Zhou KF (2006) Study on analysis method for loss of life due to dam breach, MS Thesis in Nanjing Hydraulic Research Institute, Nanjing, China (in Chinese)
- Wikipedia article: http://en.wikipedia.org/wiki/Banqiao_dam

Lijiazui Dam – Failed April 27, 1973

Lijiazui dam located at Zhuanglang County, Gansu Province, China, and was built from 1970 to 1972. The dam had a height of 82 feet, and a reservoir capacity of 1,176 acre-feet. The dam failed at 11:30 pm on April 27, 1973 due to overtopping. The peak breach discharge was estimated to have been 216,100 ft^3/s.

The Lijiazui village was less than 0.4 miles from the dam. The population in this village was 1034. The dam failed at night and no warning was issued. The buildings in the village were mostly made of adobe, and were easily destroyed. Some people also lived in cave dwellings.

Zhou (2006) performed dam break flood routing with FLDWAV. This information was used to estimate DV for downstream areas.

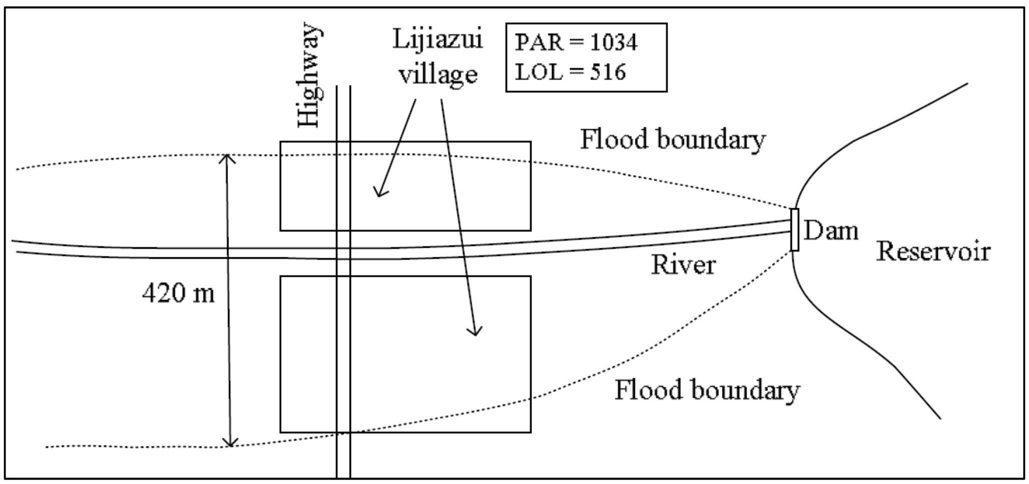


Figure 95. Area downstream of Lijiazui Dam
Source: Photo courtesy of L.M. Zhang

Summary Table 30– Lijiazui Dam Failure

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	Nighttime
Failure scenario	Overtopping
Fatalities	516 at Lijiazui Village
Fatality Rate	0.499
Dam Height	82 feet
Reservoir Storage	1,176 acre-feet
Breach Formation Time	unknown
Total PAR	1,034 at Lijiazui Village
Downstream Distance to PAR	0.4 miles
Flood severity understanding	Na
Maximum DV	Lijiazui Village: 110 ft^2/s
Confidence in data	Fair. More information, including photos would increase confidence.

References:

- Zhou KF (2006) Study on analysis method for loss of life due to dam breach, MS Thesis in Nanjing Hydraulic Research Institute, Nanjing, China (in Chinese)

Shijiagou Dam – Failed August 25, 1973

Shijiagou Dam was located at Zhuanglang County, Gansu Province, China. It was constructed between 1971 and 1973. The dam had a height of 98 feet and a reservoir storage capacity of 689 acre-feet. Shijiagou Dam failed at 5:30 am on August 25, 1973. An upstream embankment slope slid into the reservoir and caused overtopping of the dam during a storm. The peak discharge at the dam site was estimated as 118,000 ft^3/s.

The Shijiagou village was less than 0.5 miles from the dam. An evacuation warning was issued 20-30 minutes before the dam failure. However, the warning effect was poor because of the storm. Most of the people were not alerted and only a few people managed to evacuate from the flooded area. The buildings in the village were primarily constructed from adobe, which may have collapsed more easily than would most contemporary western residential structures. Zhou (2006) performed dam break flood routing with FLDWAV. The results of this study were to estimate DV.

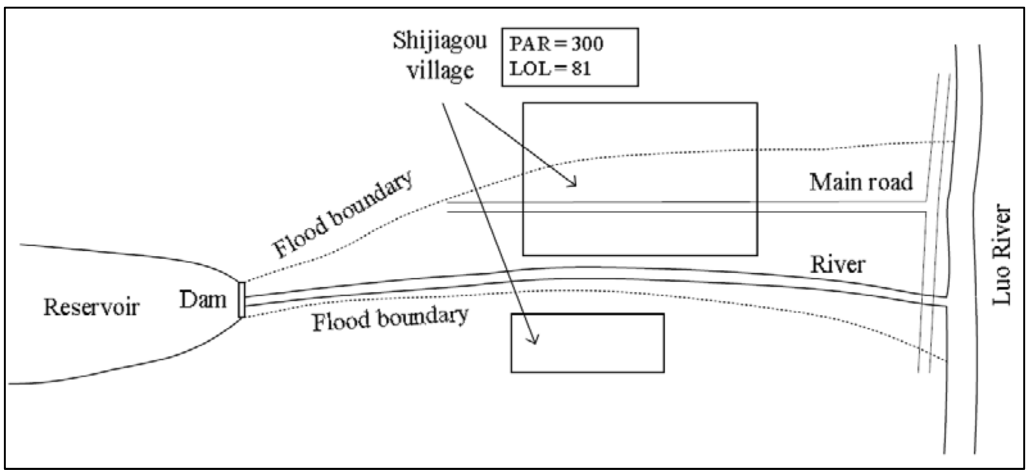


Figure 96. Area downstream of Shijiagou Dam
Source: Photo courtesy of L.M. Zhang

Summary Table 31 – Shijiagou Dam Failure

Flood Severity Rating	Medium
Warning Time	Some warning
Time of day	Daytime (early morning)
Failure scenario	Overtopping
Fatalities	81 at Shijiagou Village
Fatality Rate	0.27
Dam Height	98 feet
Reservoir Storage	689 acre-feet
Breach Formation Time	unknown
Total PAR	300 at Shijiagou Village
Downstream Distance to PAR	0.5 miles
Flood severity understanding	vague
Maximum DV	Shijiagou Village 70 ft^2/s
Confidence in data	Fair. More information, including photos would increase confidence.

References:

- Zhou KF (2006) Study on analysis method for loss of life due to dam breach, MS Thesis in Nanjing Hydraulic Research Institute, Nanjing, China (in Chinese)

Liujiatai Dam – Failed August 8, 1963

Liujiatai dam located at Baoding City, Hebei Province, China. The dam, which was constructed between 1958 and 1959, had a height of 117 feet, and a reservoir capacity of 32,866 acre-feet. Failure of the dam occurred at 3:55 am on August 8, 1963, probably by overtopping. The peak discharge was calculated to have been 1,010,000 ft^3/s. The breach formation time was 0.5 hours.

Three villages, Gaoshi, Haoshan and Zhigushi, were 0.6 to 4.3 miles from the dam and had a total estimated PAR of 2,784. These three villages were located in a shallow valley with a maximal width of almost one-half a mile. The catastrophic flood caused a DV as high as 400 ft^2/s. Almost everything was swept away in few minutes. The flood severity is estimated to have been high.

An evacuation warning was issued more than 1 hour before the dam failure. Many residents evacuated to high ground. However, some residents returned to their homes and went back to sleep, as they did not believe there would be a serious flood. The sudden flooding in the very early morning hours took 525 lives in the three villages.

There were two more villages and a town locating 4.3 to 9 miles downstream from the dam, Linxi and Taiping Villages and Tuonan Town. The population at risk was 3,395 in these areas. The peak discharge was estimated as 600,350 ft^3/s based on readings from a hydraulic station 12 miles downstream of the dam site (Ru and Niu 2001). Therefore, the peak discharge in the areas of 7-15 km would have been greater than 600,350 ft^3/s. The flood widths in these areas ranged from 2,460 to 6,560 feet. Based on this information, the DV is estimated as 90 to 250 ft^2/s. The warning time in this area was less than 1 hour according to Zhou (2006). 352 of the 3395 people were killed. The DV was much lower in the areas more than 15 km downstream of the dam site, as estimated as by Zhou (2006). Sixty people out of a PAR of 11,929 were killed. The available warning in these areas, however, was almost nothing.

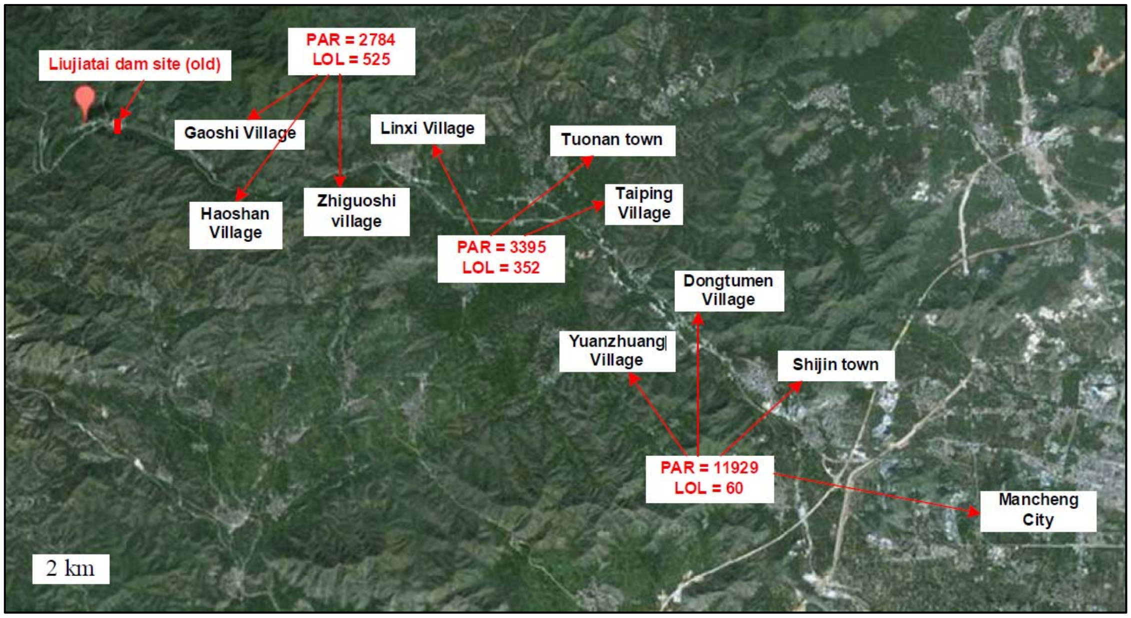


Figure 97. Liujiatai Dam and downstream areas
Source: Photo courtesy of L.M. Zhang

Summary Table 32 – Liujiatai Dam Failure

Flood Severity Rating	High at Gaoshi, Haoshan and Zhigushi Medium to high at Linxi, Taiping and Tounan Low, greater than 9.3 miles downstream
Warning Time	Adequate at Gaoshi, Haoshan and Zhigushi Some at Linxi, Taiping and Tounan None at greater than 9.3 miles downstream
Time of day	Nighttime
Failure scenario	Overtopping
Fatalities	525 at Gaoshi, Haoshan and Zhigushi 352 at Linxi, Taiping and Tounan 60 at greater than 9.3 miles downstream
Fatality Rate	0.19 at Gaoshi, Haoshan and Zhigushi 0.1 at Linxi, Taiping and Tounan 0.005 at greater than 9.3 miles downstream
Dam Height	117 feet
Reservoir Storage	32,866 acre-feet
Breach Formation Time	0.5 hours
Total PAR	2,784 at Gaoshi, Haoshan and Zhigushi 3,395 at Linxi, Taiping and Tounan 11,929 at greater than 9.3 miles downstream
Downstream Distance to PAR	Starting at 0.6 miles
Flood severity understanding	vague
Maximum DV	400 ft^2/s at Gaoshi, Haoshan and Zhigushi 250 ft^2/s at Linxi, Taiping and Tounan < 50 ft^2/s at greater than 9.3 miles downstream
Confidence in data	Fair. More information, including photos would increase confidence.

References:

- Ru NH, Niu YG (2001) Embankment dam - incidents and safety of large dams. Water Power Press, Beijing, (in Chinese)
- Zhou KF (2006) Study on analysis method for loss of life due to dam breach, MS Thesis in Nanjing Hydraulic Research Institute, Nanjing, China (in Chinese)

Hengjiang Dam – Failed September 15, 1970

Hengjiang Dam on the Liangtian River was located at Jieyang City, Guangdong Province, China, and was constructed between 1958 and 1960. The dam had a height of 148 feet, with a reservoir capacity of 6,388 acre-feet. Failure occurred at 8:00 am on September 15, 1970, probably by piping. The peak discharge was estimated to have been 423,800 ft^3/s.

The villages Xinjian and Xinsi, were located within 1.2 miles from the dam site and had a PAR of 2,500. Most of the buildings, which were typically constructed of brick and masonry, were swept away. DV was estimated to have ranged between 140 to 550 ft^2/s (Zhou 2006). An evacuation warning was issued by gun shot about 15 minutes before the dam failure. People in these areas apparently understood the warning; they evacuated from their homes, and no fatalities occurred.

Jiaogutan and Xiangxin Villages were located 1.2 to 2.4 miles downstream, and also had and estimated PAR of 2,500. The DV along this reach ranged from 50 to 140 ft^2/s (Zhou 2006). The people in these areas were also warned and evacuated from their homes. One person died. The warning was not as effective for distances beyond 1.8 miles from the dam.

In areas immediately upstream of Jieyang City, some of the villages were located on high ground, but a number of people were exposed to the flooding. The DV was relatively low, ranging from 30 to 50 ft^2/s. Even with lower DV, 40 of the 50,000 people along this reach died.

No warning was received at Jieyang City and the areas downstream. Many people were swept away by the sudden flood. 850 people were killed, out of a total PAR of 45,000. No warning was issued at Pingshang Town, which was another 2.4 miles downstream from Jieyang City. About 50 people out of 15,000 PAR were killed in this town. No fatalities occurred downstream of the Pingshang Town. This may have been due to the flood becoming more benign, with lower DV and a slower rate of rise.

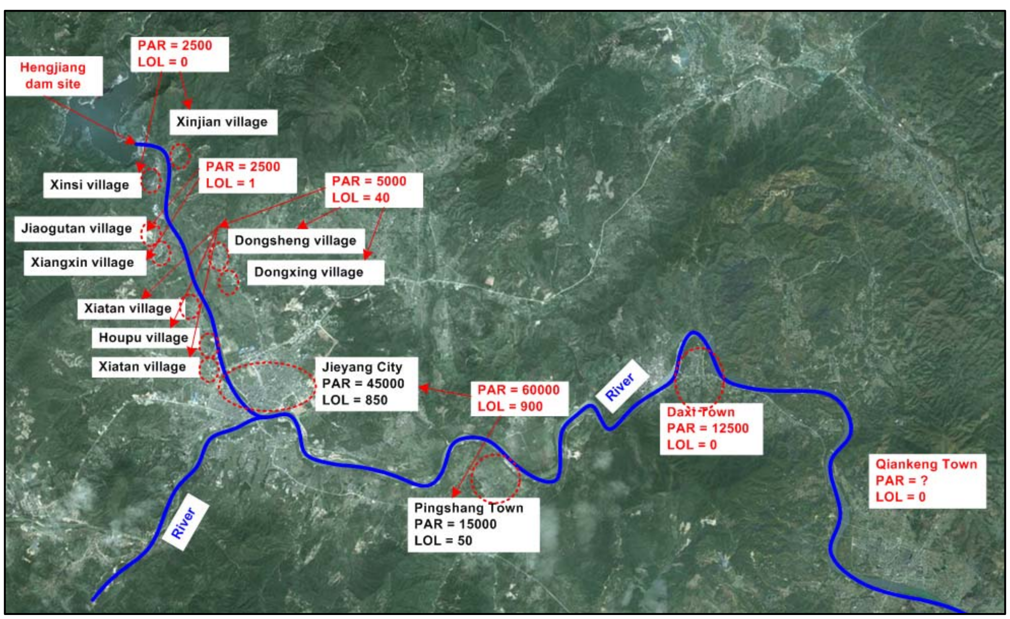


Figure 98. Locations downstream of Hengjiang Dam
Source: Photo courtesy of L.M. Zhang

Summary Table 33– Hengjiang Dam Failure

Flood Severity Rating	High to medium at Xinjian and Xinsi, Medium at Jiaogutan and Xiangxin Low upstream the Jieyang City and at Jieyang City
Warning Time	Adequate at Xinjian and Xinsi, Jiaogutan and Xiangxin Villages No warning upstream of Jieyang City and at Jieyang City
Time of day	Daytime
Failure scenario	Internal erosion
Fatalities	0 at Xinjian and Xinsi Villages 1 at Jiaogutan and Xiangxin Villages 40 upstream of Jieyang City 850 at Jieyang City
Fatality Rate	Xinjian and Xinsi Villages: 0 Jiaogutan and Xiangxin Villages: 0.0004 upstream the Jieyang City: 0.0008 Jieyang City: 0.019
Dam Height	148 feet
Reservoir Storage	6,388 acre-feet
Breach Formation Time	unknown
Total PAR	2,500 at Xinjian and Xinsi 2,500 at Jiaogutan and Xiangxin Villages 50,000 upstream of Jieyang City 45,000 at Jieyang City
Downstream Distance to PAR	1.2 miles to Xinjian and Xinsi Villages 1.2 to 2.4 miles Jiaogutan and Xiangxin Villages Exact distance unknown - upstream of Jieyang City and Jieyang City
Flood severity understanding	unknown
Maximum DV	Xinjian and Xinsi: 140 to 550 ft^2/s Jiaogutan and Xiangxin Villages: 50 to 140 ft^2/s upstream of Jieyang City: 30 to 50 ft^2/s Jieyang City: 30 to 50 ft^2/s
Confidence in data	Fair. More information, including photos would increase confidence.

Situ Gintung Dam – Failed March 27, 2009

Situ Gintung was a located in the suburb of Cirendeu, Ciputat in Tangerang District, Indonesia. The 1,630 acre foot reservoir was formed by a dam about 52 feet high which was built by Dutch colonial authorities in 1933. The dam failed on March 27, 2009, draining the reservoir, with downstream flooding which killed at least 100 people.

The original use of the dam had been to retain water for irrigation of rice paddies which were then replaced by urban development. People living near the dam had made complaints about leaks in the past and the dam actually breached in November 2008 but no damage was done. It is thought that little maintenance had been carried out since the dam was built.

Figure 99. The breached Situ Gintung Dam
Source: BBC News/BBC Images/bbc.co.uk – ©2014 BBC, http://newsimg.bbc.co.uk/media/images/45606000/jpg/_45606647_dam466afp.jpg

The area experienced several hours of heavy rain on the night of March 26/27, 2009 which caused the reservoir to rise. The dam was overtopped, eroding the dam surface and resulting in a breach 230 feet wide at around 2:00 am on March 27. Cracks were reportedly visible in the face of the dam's embankment from around midnight. The dam operators were reported to have sounded a warning siren shortly before the dam failed. A surge of water and debris, maybe 10 feet high was sent into the town of Cirendeu, washing away cars, houses and a brick-built bridge. The flood hit while most of the population was asleep and left standing water up to 8 feet deep. Many people were trapped in the town and many took to their rooftops to avoid the floodwaters. The flood killed 98 people, and 5 more were unaccounted for. The waters also inundated around 400 homes of which 250 were damaged or destroyed, displacing 171 people. Five power terminals became submerged, and the lack of power cut off drinking water supplies to the nearby suburb of Lebak Bulus.

Figure 100. Aftermath of flooding downstream of Situ Gintung Dam
Source: REUTERS/Dadang Tri

Summary Table 40– Situ Gintung Dam

Flood Severity Rating	Medium
Warning Time	Little to no warning
Time of day	Nighttime
Failure scenario	Hydrologic
Fatalities	98
Fatality Rate	0.06
Dam Height	52 feet
Reservoir Storage	1,630 acre-feet
Breach Formation Time	unknown
Total PAR	1,600
Downstream Distance to PAR	0 to 1 mile
Flood severity understanding	unknown
Maximum DV	110 ft^2/s
Confidence in data	Good

References:

- http://en.wikipedia.org/wiki/Situ_Gintung
- http://www.who.int/hac/crises/idn/sitreps/situ_gintung_30march2009/en/index.html
- http://www.fujipress.jp/finder/xslt.php?mode=present&inputfile=DSSTR000700050009.xml

Timberlake Dam – Failed June 22, 1995

Timber Lake Dam is located on Buffalo Creek, about 10 miles southwest of Lynchburg, Virginia. The dam, completed in 1926, was built to form a lake around which developers would sell lakefront land. At the time of failure, the 75 acre lake was surrounded with lakefront houses. Excessive rainfall caused the overtopping failure of the Timberlake dam at about 10:30 PM on the June 22, 1995. Failure of the 33-foot high embankment dam released 1,449 acre-feet of water. Radar estimates indicated that the Timberlake basin received in excess of 11 inches of rain. The breached reservoir was reportedly drained in about one hour. The breach was about 150 feet wide. Assuming that the peak outflow was about twice the average outflow during the 1-hour period that it took for the lake to empty, the peak discharge through the breach was about 35,000 ft^3/s.

There were few if any residences located along Buffalo Creek in the first few miles downstream from Timber Lake Dam. Turkey Foot Road crosses Buffalo Creek slightly more than one-half mile downstream from Timber Lake Dam. U.S. Highway 460, a 4 lane divided highway connecting Lynchburg (population 66,000) with Bedford (population 6,000) and Roanoke (population 96,000) , crosses Buffalo Creek slightly more than 1 mile downstream from Timber Lake Dam. Further downstream there are more road crossings.

Water levels were reported to have reached a depth of 8 feet on the roadway in the vicinity of a bridge which crosses Turkey Foot Road.

The failure of the Timberlake Dam caused two fatalities, and damage to local roads and residences. Downstream from the dam and prior to dam failure, flooding caused by heavy rainfall stranded three cars traveling on U.S. Highway 460 on the bridge crossing over Buffalo Creek. Rescue worker Carter Martin was trying to assist motorists stranded on the bridge. When the dam breach flows arrived, the water level rose more than 4 feet almost instantly, overcoming Martin. The second fatality involved Doris Stanley, who was driving home to Forest, Virginia from Richmond. She never made it home, however, as her car was washed away by the rising flood water. Her crumpled vehicle was found in Buffalo Creek on Saturday morning about 200 to 300 yards downstream from Turkey Foot Road. Her body was found Sunday morning about 200 or 300 yards from where her vehicle was found.

VDOT reported that Virginia Highway 683 was washed out in three places, but most other roads in the area were not severely damaged. Workers at the Georgia Pacific’s Big Island paper mill had to scramble to save equipment as rising waters encroached on the plant. Otherwise, most businesses in the flooded areas suffered only low to moderate damage. The dam failure was controversial because the dam was known to not to be up to modern standards. However, an acceptable status was grandfathered in and only required spillway inspection once a year. A professor at Radford University blamed the flooding on the dramatic increase in impervious surfaces in the Timberlake basin caused by human development. These factors, in combination with the fact that the meteorological event surpassed the 100 year storm rainfall parameters, and would have been extremely difficult to predict, all contribute to the explanation of how the communities and persons affected were caught off guard by the dam failure.

At about 8 p.m. water was rushing over the spillway. At about 8:30 p.m. , Everett Chadbourne, maintenance director for the Timberlake Homeowners Association, was driving on Timberlake Drive on his way to the dam. Timberlake Drive provides access to the dam and all of the lakefront houses. He was going to open a 10 inch diameter pipe that was usually used to drain the lake so people could work on their docks. Before reaching the dam, he drove his vehicle into deep water while trying to cross one of the streams that leads into Timber Lake. Water rose over the hood and was inching higher when some neighbors tied a life jacket to a rope and pulled him to safety. The dam failed before he was able to reach the dam.

Timberlake Dam was rebuilt about one year after its failure.

Figure 101. The breached Timberlake Dam
Source: Photo by Wayne Graham, Bureau of Reclamation

Figure 102. Location where rescue worker was killed
Source: Photo by Wayne Graham, Bureau of Reclamation

Summary Table 41– Timberlake Dam

Flood Severity Rating	Medium
Warning Time	No warning
Time of day	Nighttime
Failure scenario	Overtopping
Fatalities	2
Fatality Rate	0.29
Dam Height	33 feet
Reservoir Storage	1,449 acre-feet
Breach Formation Time	unknown
Total PAR	7
Downstream Distance to PAR	Probably less than 1 mile
Flood severity understanding	Na
Maximum DV	60 ft^2/s
Confidence in data	Good, but need to verify DV estimate

References:

- Virginia Polytechnic Institute and State Univ.: "The Timber Lake Dam failure: A hydrometeorological assessment", http://www.comet.ucar.edu/outreach/abstract_final/9673882.htm
- www.region2000.org/lgc/pdf/HMP/Appendix%20V-3.pdf
- Estimating Life Loss for Dam Safety Risk Assessment – A Review and New Approach, IWR Report 02-R-3, pages 342-343, U.S. Army Corps of Engineers, Institute for Water Resources, July 2002
- Timber Lake Dam Failure near Lynchburg, Virginia, An Evaluation of the Warning Process, Draft - August 18, 1995, Reclamation Case History Archive

Arno River Flood –November 3-4, 1966

The 1966 Flood of the Arno River in Florence killed 127 people and damaged or destroyed millions of masterpieces of art and rare books. It is considered the worst flood in the city's history since 1557.

On November 3, after a long period of steady rain, the Levane and La Penna dams in Valdarno, Italy began to release 71,000 ft^3/s upstream of the city of Florence. At 2:30 pm, the Florence Civil Engineering Department reported “an exceptional quantity of water.” Cellars in the Santa Croce and San Frediano areas began to flood. Police received calls for assistance from villagers up the Arno Valley. The flood's first victim, a 52 year old worker died at the Anconella water treatment plant.

At 4:00 am on November 4, engineers, fearing that the Valdarno dam would burst, discharged a mass of water that eventually reached the outskirts of Florence at a rate of 37 mph. At 7:26 am, flooding of the north bank of the Arno River through Florence cut off gas, electricity and water supplies to affected areas. By 8:00 am, army barracks were flooded. At 9:00 am, hospital emergency generators (the only source of electrical power remaining) failed. Landslides obstructed roads leading to Florence, while narrow streets within city limits funneled floodwaters, increasing their height and velocity. By 9:45 am, the Piazza del Duomo, located in the heart of the historic center of Florence, and one of the most visited places in Europe, was flooded. The powerful waters ruptured central heating oil tanks, and the oil mixed with the water and mud, causing greater damage. Florence was divided in two, and officials were unable to immediately reach citizens in flooded portions of the city. At its highest, the water reached over 22 feet in the Santa Croce area. By 8:00 pm, the flood water began to recede.

Figure 103. Arno River flooding at the city of Florence, Nov. 3, 1966
Source: Meteoweb, http://www.meteoweb.eu/

Figure 104. Flooding in the city of Florence
Source: Armando Poggi, www.apoggi.com

Summary Table 34– Arno River Flash Flood Dam

Flood Severity Rating	Medium
Warning Time	Adequate
Time of day	Mostly daytime
Failure scenario	Regional flooding involving spillway releases from dams
Fatalities	127
Fatality Rate	0.0014
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Total PAR	88,000
Downstream Distance to PAR	Less than 1 mile from closest dam
Flood severity understanding	unknown
Maximum DV	80 ft^2/s (assuming 1 m/s velocity)
Confidence in data	Good

References:

- http://en.wikipedia.org/wiki/1966_Flood_of_the_Arno_River

Manitou Springs Flash Flood, August 9, 2013

A flash flood occurred sometime after about 6:00 pm in the vicinity of the city of Manitou Springs, located in south central Colorado. In 2012 a large fire had burned many acres in a drainage known as Waldo Canyon. Due to the fire, the potential for flash flooding in the Manitou Springs area had intensified. About 1.5 inches of rain fell in the Waldo Canyon basin on August 9.

The mouth of Waldo Canyon is located directly adjacent to Highway 24, about 1 mile north of Manitou Springs. A culvert crossing under the highway was clogged, and flooding came down onto Highway 24, catching motorists unaware and stranding them in the flood. The flood waters included tons of mud, rocks and debris. Flood flow ran down both lanes of the highway and overtopped the Jersey barrier median.

20 to 25 cars were stranded. Several cars were swept away by the flooding and carried downstream in a ditch on the right side of the northbound lane.

There was one fatality. A man traveling alone on Highway 24 was killed during the flood. John Collins, age 53, of Divide, Colorado had called a friend to say: *"If you're driving down (Ute Pass), I wouldn't do it. Water is coming. It's pushing some cars to me. I've got to go. "* Collins was found outside of his vehicle, buried in debris. It is possible that the vehicle became submerged or was floating, and that he escaped the vehicle in hope of reaching higher ground.

Hourly data from a USGS gage suggested the peak discharge of the flood to have been 1,500 ft^3/s. However, calculations based on a field survey suggests a slightly higher peak discharge of 1,800 ft^3/s. Flood depths along Highway 24 varied due to the formation of small debris dams which concentrated flow in some areas. In some locations, water flowed over the tops of the Jersey barrier median and moved down both sides of the highway. Maximum flood depths were about 5 feet, and were located along a ditch on the right side of the north-bound lane. Based on video footage of cars floating along this ditch, the maximum velocity is estimated to have been at least 10 ft./s.

Figure 105. Flooding along Highway 24, looking north
Source: YouTube/Tj Omara

Figure 106 Cars floating in the ditch along Highway 24
Source: Used by permission, www.9news.com

Flooding was severe further downstream at the town of Manitou Springs. Six homes were reported to have been destroyed including one residence, a small cottage was floated off of its foundation and deposited in a drainage channel. The occupant of the cottage escaped as water was gushing into the structure. This individual, who was hospitalized with injuries, reported fighting for her life while submerged in flood water and attempting to reach high ground. Numerous other structures sustained damage, and motor vehicles were swept away destroyed. Flood alert sirens along Fountain Creek were activated, but were too late to provide advance warning. No fatalities occurred at Manitou Springs, however the flooding there certainly had the potential to have been lethal.

Figure 107 Remnants of destroyed cottage at Manitou Springs
Source: Used by permission of the Colorado Springs Gazette, www.gazette.com

Figure 108 Aftermath of flooding, Manitou Springs
Source: Used by permission of the Colorado Springs Gazette, www.gazette.com

Summary Table 35–Manitou Springs Flash Flood (Highway 24 area only)

Flood Severity Rating	Low
Warning Time	None
Time of day	Early evening, but not dark
Failure scenario	Flash flood
Fatalities	1 (Hwy 24 only)
Fatality Rate	0.02 (Hwy 24 only)
Dam Height	N/A
Reservoir Storage	N/A
Breach Formation Time	N/A
Total PAR	About 50 (Hwy 24 only)
Downstream Distance to PAR	0 to 0. 5 miles from mouth of Waldo Canyon (Hwy 24 only)
Flood severity understanding	N/A
Maximum DV	At least 50 ft^2/s
confidence in data	Good

References:

- Colorado Springs Gazette, www.gazette.com
- Documentation of the July 1st and 10th, and August 9, 2013 Peak Discharges in the 2012 Waldo Burn Area Streams, Bob Jarrett, Lakewood, CO (paleoflood@comcast.net) August 22, 2013

Low Severity Dam Failure and Flooding Case Histories

The following section contains case history descriptions for events that are characterized as having been low severity flooding. Many of the cases have been described as possessing fairly destructive properties, although as an average, maybe the effects were more benign than for the medium severity case histories. Depth and velocity information for many of these are not available, and were estimated by Reclamation.

South Davis Co. Water Impr. District, Res. No. 1 Dam – Failed Sept. 24, 1961

Reservoir No.1, located near Bountiful, Utah, failed on Sunday September 24, 1961 at 4:30 am. The earthen dam, which created a bathtub reservoir, was two years old when it failed from what was thought to have been internal erosion. The exact height of the dam is not known, but from examining photos of the breach, it appears that the dam height was in the range of about 15 feet. 4.4 acre-feet of storage was reportedly released from the breach and the reservoir emptied in less than fifteen minutes. Failure of the dam was not detected prior to its occurrence and no warning was issued. The flood resulted in damage to about twenty properties which were damaged, but not destroyed, and there was an affected population at risk (PAR) of maybe eighty people. This event did not result in any fatalities.

Figure 109. Breached Reservoir No.1 Dam
Source: Bud Bay, Bureau of Reclamation, photo taken on September 25, 1961

Figure 110. Close up of breach, Reservoir No.1 Dam
Source: Bud Bay, Bureau of Reclamation, photo taken on September 25, 1961

Summary Table 36: South Davis County Water Improvement District, Reservoir No. 1 Dam

Flood Severity Rating	Low
Warning Time	None
Time of day	4:30 am
Failure scenario	Static failure
Fatalities	0
Fatality Rate	0
Dam Height	Roughly 15 feet
Reservoir Storage	Approximately 4.4 acre-feet
Breach Formation Time	Unknown
Total PAR	80 (based on DSO-99-06 estimate)
Downstream Distance to PAR	About 100 feet
Maximum DV	Estimated to have been 10 to 25 ft^2/s
Flood severity understanding	n/a
Confidence in data	Fair

This flood is considered to have been low severity. The hillside below the dam was steep. Downstream residences were flooded, some basements were filled with mud, but homes were not destroyed. Flooding depths and DV were likely to have been relatively low. The characteristics of this flood might have been similar to what would occur during the breach of an irrigation canal.

<u>References:</u>

- Salt Lake City Tribune article, September 25, 1961, Reclamation Flood Event Case History Archive
- Deseret News and Telegram articles, September 25 and 26, 1961, Reclamation Flood Event Case History Archive

Seminary Hill Reservoir No. 3 – Failed October 5, 1991

Seminary Hill Reservoir No.3 Dam was a ringed, earthen embankment structure which was concrete lined (unreinforced) and located on a hilltop directly adjacent to the town of Centralia, Washington. The 17-foot high, offstream, water supply storage structure failed at 10:15 am on Saturday October 5, 1991. The static failure of this dam occurred during clear weather and resulted in no fatalities. No warning was issued. A Boy Scout troop, picking up trash in the downstream ravine was able to quickly scramble out of the way and avoid the floodwave. If this dam had failed during nighttime hours, the flood may have resulted in fatalities.

Reservoir No. 3 contained about 10.7 acre-feet of storage. This volume was drained in about three minutes, with a peak breach discharge of about 2,500 ft^3/s. The directly adjacent Reservoir No.4 held about 15.3 acre-feet. The breaching of Reservoir No.3 caused the break of service and drain lines for Reservoir No.4, and its contents were drained slowly over the next several hours. (http://www.ecy.wa.gov)

The flood flow moved down the steep hillside ravine and entered a residential neighborhood. Two homes were knocked off their foundations and destroyed. Several other homes were severely damaged by the water and mud flow. Many other homes had silt and mud deposited in their yards. (http://www.ecy.wa.gov)

Figure 111. Seminary Hill Reservoir No. 3, breach details
Source: Washington State Department of Ecology,
http://www.ecy.wa.gov/programs/wr/dams/EmergencySeminary_Hill_Res.html

Figure 112. Aerial view of flooded areas downstream of dam
Source: Washington State Department of Ecology,
http://www.ecy.wa.gov/programs/wr/dams/EmergencySeminary_Hill_Res.html

The leading edge of this flood was reportedly a debris flow that was followed by a "water flood" (Costa). Maximum depths and DV in the residential area are not available.

This flood was considered to have been low severity. The low severity rating may have been due to the fact that the reservoir volume was small and a large portion of the flooded residential areas may have experienced shallow depths. However, the reference to two homes being knocked off their foundations may illustrate that at least some of the flooding was medium severity.

Summary Table 37. Seminary Reservoir No. 3

Flood Severity Rating	Low
Warning Time	None
Time of day	Day time
Failure scenario	Static failure
Fatalities	0
Fatality Rate	0
Dam Height	17 feet
Reservoir Storage	10.7 acre-feet
Breach Formation Time	unknown
Total PAR	150 (based on DSO-99-06 estimate)
Downstream Distance to PAR	About ¼ mile
Maximum DV	Estimated to have been 10 to 80 ft^2/s
Flood severity understanding	n/a
Confidence in data	Good. Event appears to have been fairly well documented.

References:

- Multiple Flow Processes Accompanying a Dam-break Flood in a Small Upland Watershed, Centralia, Washington, by Costa, U.S. Geological Survey, Water-Resources Investigations Report 94-4026
- http://www.ecy.wa.gov/programs/wr/dams/seminary.html

Allegheny County, Pennsylvania Flash Flooding - May 30, 1986

On May 30, 1986, rainfall averaging five inches fell during thunderstorms in the North Mills section of Pittsburgh, PA, causing a flash flood. The peak rainfall was estimated to have been eight inches. The rain fell between approximately 3:00 pm and 5:00 pm, with the heaviest rain occurring between 3:30 pm and 4:30 pm over the headwaters of Pine Creek and its tributary, Little Pine Creek. The cone shape of the six square mile drainage basin concentrated the runoff. The severity of the event was further aggravated by the fact that it occurred in an urban area where much of the natural drainage surface was paved over. Also, the flood occurred in the late afternoon, as homebound commuters were on the roads. (Storm Data)

The towns affected were Shaler, Etna, Hampton, O'Hara, Indiana, Harmar, McCandless, West Deer, Millvale, Sharonburg and Baldwin Boro. Nine homes were destroyed, 76 incurred major damage, and 726 received minor damage. (Storm Data)

Eight lives were lost. All who perished were caught in their cars when the flood waters rose. The cost of the flood was estimated to have been $23 million (1986 dollars), including damage to a sewage treatment plant and a newly completed flood control project! (Storm Data)

Residents were not warned about the possibility of flooding until 30 minutes after flash floods ripped through Pittsburgh's northern suburbs. The National Weather Service, which had been issuing warnings of severe thunderstorms throughout the afternoon, first mentioned the possibility of flooding in a special weather statement filed at 4:45 pm. (Flood Alert article)

Most of the dead were found along Little Pine Creek and Saxonburg Boulevard, which parallels the stream in adjacent O'Hara and Shaler townships. Authorities said many of the victims' identification were lost in the flooding. It was said that if it wasn't for the recently completed flood-control project, the whole community could have been washed away. However, because of the flood control project's completion and the sense that floods were no longer a threat, many homeowners who were hit by the flooding no longer carried flood insurance. (Flash Floods Kill Eight)

Summary Table 38. Allegheny County, PA, 1986 Flooding

Flood Severity Rating	Low
Warning Time	None
Time of day	Early evening
Failure scenario	Flash flood
Fatalities	8 (DSO-99-06 reports 9)
Fatality Rate	0.004 (DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	2200 (DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	Unknown
Flood severity understanding	Not applicable
Confidence in data	Good, but data is very limited

References:

- Flood alert apparently issued 30 minutes after floods began: http://www.chron.com/CDA/archives/archive.mpl/1986_242688/flood-alert-apparently-issued-30-minutes-after-flo.html
- Flash Floods Kill Eight in Pittsburgh Suburbs: http://www.apnewsarchive.com/1986/Flash-Floods-Kill-Eight-in-Pittsburgh-Suburbs/id-00dcb481c315493778290b8b78118079
- http://www.apnewsarchive.com/1986/Seven-Die-in-Flash-Floods-in-Pittsburgh-Suburb/id-3b24c291dd611046444e754ab71cace4

Mohegan Park (Spaulding Pond) Dam – Failed March 6, 1963

Mohegan Park Dam was located about one mile from the city of Norwich and was 110 years old when it failed. The dam failed on Wednesday March 6, 1963 at 9:30 pm. The earth and rockfill dam was 20 feet high and contained 138 acre-feet of storage. Rainfall had been occurring, the spillway was operating and cracks in the dam had been reported on Wednesday afternoon. The ground surrounding the dam was frozen and the reservoir was covered with a layer of ice.

The dam failure flood was described as a 12-foot high wall of water, which cut a narrow path through the central business district.

"When the dam let go, water and chunks of reservoir ice up to 2 feet thick tore through town in minutes, tossing automobiles around like firewood". (ENR)

Six deaths occurred from the flood, including five people who were in a factory building which collapsed.

The City of Norwich Public Works Department was monitoring the dam, and was concerned that it might fail; however no evacuations were made prior to the dam's breach. Warning began at the time of dam failure, although many did not receive the warning and it was not widely disseminated (Waltz Statement). All of the fatalities occurred within two miles from the dam.

Figure 113. Flooding from failure of Mohegan Park Dam
Source: Photo courtesy of Norwich Historical Society

Summary Table 39: Mohegan Park Dam

Flood Severity Rating	Low
Warning Time	Some warning issued after the dam breached, but not widely disseminated
Time of day	Night time
Failure scenario	Possibly a static failure due to elevated reservoir levels
Fatalities	7
Fatality Rate	0.007
Dam Height	20 feet
Reservoir Storage	138 acre-feet
Breach Formation Time	unknown
Total PAR	1000 (based on DSO-99-06)
Downstream Distance to PAR	0 to 2 miles
Maximum DV	Estimated to have been 10 to 80 ft^2/s
Flood severity understanding	Unknown for the those who received warning
Confidence in data	Good, but data is limited.

This flood is considered to have been low severity. The flood contained large chunks of reservoir ice which may have contributed to the collapse of a factory building where five people died.

References:

- ENR March 14, 1963, Reclamation Flood Event Case History Archive
- New London Day March 7/8 1963, Reclamation Flood Event Case History Archive
- Statement from Harold Waltz, City of Norwich Public Works Director, March 20, 1963, Reclamation Flood Event Case History Archive
- Moody, Thomas R. Jr. A Swift and Deadly Maelstrom: The Great Norwich Flood of 1963, A Survivor's Story. Xlibris Corporation. 2013.

Lee Lake Dam – Failed March 24, 1968

Lee Lake Dam, located near East Lee, Massachusetts, was a 25 foot high earthen dam which held an estimated 300 acre-feet of storage. The three year old dam failed on Sunday March 24, 1968 at 1:25 pm.

Flooding was described as a 10 to 15-foot-high "wall of water" 150 yards wide, which swept 4 -1/2 miles down the East Lee Brook. Two houses were destroyed, twenty houses damaged and forty houses flooded. A machinery manufacturing plant was partially destroyed as well. Trees were uprooted and a section of Route 20 was washed out.

There were two fatalities.

Heavy rainfall was reported to have preceded the dam failure. There may have been elevated reservoir levels and there was a report of underground seepage flow which may have initiated the breach. No warning was issued, but many who saw or heard the approaching flood moved to safety.

Summary Table 40. Lee Lake Dam

Flood Severity Rating	Low
Warning Time	No formal warning was issued
Time of day	Day time
Failure scenario	Static failure, possibly due to elevated reservoir levels
Fatalities	2
Fatality Rate	0.025
Dam Height	25 feet
Reservoir Storage	300 acre-feet
Breach Formation Time	unknown
Total PAR	80 (based on DSO -99-06 estimate)
Downstream Distance to PAR	0 to 5 miles
Maximum DV	Unknown, but DV is estimated have ranged from 10 to 80 ft^2/s, considering that buildings were washed off foundations and a factory partially collapsed.
Flood severity understanding	Not applicable
Confidence in data	Fair to good. Confidence in DV estimate is fair.

This flood is considered to have been low severity. The flood depths may have been 10 feet or less in most areas, but the description of damage includes: two houses destroyed, a factory partially destroyed and trees uprooted. The DV is not precisely known. However, the description of damage for at least some portions of the flooded area gives an indication that the DV may possibly have ranged from 10 to 80 ft^2/s, and that portions of the flooding were medium severity.

<u>References:</u>

- Various Boston Globe Articles, Reclamation Flood Event Case History Archive
- ENR March 28, 1968, Reclamation Flood Event Case History Archive

Quail Creek Dike - Failed January 1, 1989

Quail Creek Dike, along with Quail Creek Dam, impounds the waters of Quail Creek Reservoir, an offstream storage facility located in Washington County, Utah, near the town of St. George. Construction of the dike was completed in 1985. The dike, which was 78 feet high, failed on January 1, 1989 at 12:08 am. About 25,000 acre-feet of water was released from the reservoir which had a capacity of 40,000 acre-feet. Based on eye-witness accounts, the first indication of failure was observed the previous day, although seepage related issues had been a concern for some time. (Quail Creek Failure Report)

Figure 114.View of the breached Quail Creek Dike
Source: Utah Geological Survey/photo by Ben Everitt, Special Study 133

The breach released a flood that surged down the Virgin River in waves that were 10 to 40 feet high, inundating parts of St. George and several other small towns, including Bloomington. Three small bridges were swept away, along with a 98-year-old irrigation dam. The flood also disintegrated half a mile of Utah Route 9, where water thundered through a narrow highway cut adjacent to a bridge about a mile downstream. The surge wiped out utility lines at the crossing, including a newly-completed 8-in. gas line. (ENR)

Prior to the breach, the Washington County Water Conservancy District (WCD), which owns the project, worked for 12 hours to stanch a seep at the toe of the embankment. It initially was spilling 25 gallons per minute. Late in the afternoon of December 31, WCD officials advised the county emergency management director to prepare for downstream evacuations based on unprecedented observations of muddy seepage. The seepage increased to 600 gallons per minute by about 11:00 pm and the dike was breached shortly after midnight. Residents located 15 miles downstream had been warned and evacuated. Late in the afternoon on the December 31, County emergency managers had called for downstream evacuations. (ENR)

1,500 people were evacuated (Salt Lake Tribune1/3/89). There were no fatalities.

The 80-foot wide breach was reported to have formed in two hours and released a peak discharge of 60,000 ft^3/s. Flood depths close to the dam were estimated to have been 61 feet, traveling at 18 ft./s (DV equal to 1,100 ft^2/s). 20,000 acre-feet of storage was drained in five hours. Flooding followed the course of the adjacent Virgin River. Flood flows reached Bloomington, 16 miles downstream, in four hours with five foot flood depths (DV equal to about 30 ft^2/s). (Quail Creek Dike Breach Analysis)

Summary Table 49 Quail Creek Dike

Flood Severity Rating	Low
Warning Time	Adequate warning was issued, evacuations were ordered well in advance of the breach
Time of day	Night time
Failure scenario	Static failure, internal erosion
Fatalities	0
Fatality Rate	0
Dam Height	28 feet
Reservoir Storage	40,000 acre-feet
Breach Formation Time	2 hours. Increased seepage leading to the breach occurred for about 12 hours
Total PAR	1,500
Downstream Distance to PAR	16 miles
Maximum DV	1,100 ft^2/s downstream of dam, 30 ft^2/s at Bloomington
Flood severity understanding	Precise
Confidence in data	Good. Event is well documented.

This flood was considered to have been low severity. At Bloomington, roughly 16 miles downstream from the dike, the maximum DV was calculated to have been about 30 ft^2/s, which fit the criteria for low severity. No buildings were reported to have been destroyed in downstream locations. Closer to the dam, the DV was reportedly much higher. Developed areas closer to the dam may have been located on high ground, and in 1989 the currently developed areas close to the dam may not have existed.

References:

- ENR January 12, 1989
- Salt Lake City Tribune, January 3, 1989
- Investigation of the Cause of Quail Creek Dike Failure, Report of Independent Review Team, March 7, 1989

D.M.A.D. Dam – Failed June 23, 1983

DMAD Dam was a 34-foot-high earthfill structure located five miles north east of Delta, Utah on the Sevier River. Breaching of the dam's spillway section occurred due to headcutting erosion into the foundation near the spillway. Peak discharge from the breach was estimated to have been 28,000 ft^3/s.

Two weeks before failure of the dam, a downstream diversion structure, located one-quarter mile downstream, had failed. The failed structure had created a small waterfall that was headcutting up the river channel. There was a plan to armor the downstream toe of DMAD with riprap, but the progress of the headcutting accelerated unexpectedly, and resulted in a spillway section breach at DMAD on June 23. The breach occurred at 12:59 pm on Thursday June 23, and released 16,000 acre-feet of reservoir storage. (ENR, June 30, 1983)

Figure 115. DMAD Dam, Breach in the spillway section
Source: Courtesy of the Great Basin Museum

Figure 116. Flooding downstream of DMAD Dam
Source: Photo by Jane Beckwith from the Frank Beckwith Collection

Downstream communities had been on an evacuation alert one week prior to failure, due to the situation at the dam. The dam was being monitored 24-hours a day. Residents were urged to listen to the local radio station at Delta for updates.

Warning was initially issued at the time of the breach. The closest town, Delta, located nine miles downstream, experienced orderly evacuations and most residents were reported to have been gone within two hours, which was before the arrival of flooding. The reservoir was essentially drained by Friday morning (Deseret News, June 24, 1983).

The local radio station at Delta provided continuous coverage of the flood, including a live broadcast of the sheriff issuing the order to evacuate, and this may have helped the successful evacuation effort. Flooding at the town of Deseret was up to five feet deep. 400 people were evacuated. (Deseret News, June 25, 1983)

One man reportedly drowned when he tried to leave the town of Deseret by going hand-over-hand across a cable and fell into the water. (Deseret News, June 24, 1983)

Summary Table 50. DMAD Dam

Flood Severity Rating	Low
Warning Time	Adequate warning was issued, Communities had been on alert prior to breach. 400 people evacuated.
Time of day	Breach occurred during day time
Failure scenario	Spillway failure due to headcut erosion resulting from unstable river channel
Fatalities	1
Fatality Rate	0.002
Dam Height	34 feet
Reservoir Storage	16,000 acre-feet
Breach Formation Time	Spillway structure was dislodged in 12 minutes (Rocky Mountain News)
Total PAR	500 (based on DSO-99-06 estimate)
Downstream Distance to PAR	9 miles to Delta, 13.5 to Oasis, 15 to Deseret
Maximum DV	Estimated as 10 to 15 ft^2/s at downstream communities
Flood severity understanding	Precise
Confidence in data	Good. DV estimate is very approximate, but flood severity fits in the low category.

This flood was considered to have been low severity. Available photographs and descriptions of the flooding are consistent with the DSO-99-06 definitions for low severity flooding.

References:

- Detailed notes from conversation with Delta radio station personnel, January 27, 1984, Reclamation Flood Event Case History Archive
- Deseret News Articles, June 24 and 25, 1983
- ENR, June 30, 1983
- Rocky Mountain News, June 24, 1983

Bushy Hill Pond Dam – Failed June 6, 1982

During the June 5th weekend of 1982, torrential rainfall that totaled more than 10 inches, failed eight dams and partially breached 11 others in south-western Connecticut. The highest of these dams to breach was Bushy Hill Pond Dam, a 29-foot-tall, earthfill and stone masonry dam on the Deep River which held more than 500 acre-feet of storage. (ENR, June 17, 1982)

The failure of Bushy Hill Pond Dam at 12:30 am on Sunday June 6, sent flood waters into the downstream Clarks Pond Dam, causing it to fail too. Flood water then hit a factory lumberyard and carried away 1.5 million board-feet of lumber into the Falls River and causing the failure of Comstock Pond Dam located within the town of Ivoryton. Homes were washed off foundations and flooding was up to six or seven feet deep. (Deep River and Ivoryton)

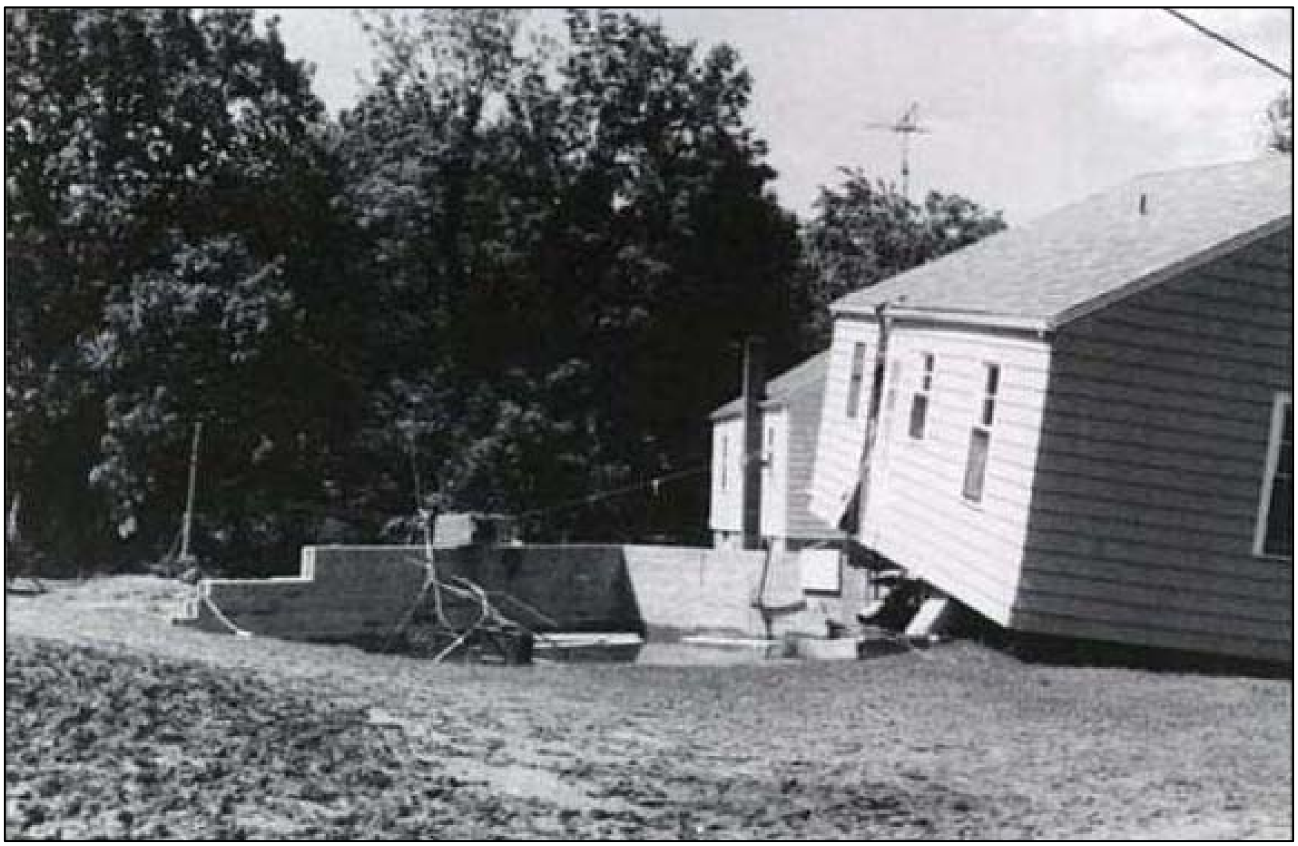


Figure 117. Photo showing houses lifted off their foundations at Ivoryton, but not destroyed.
Source: Photo courtesy of Leslie Barlow

Figure 118. Washed out bridge over Fall River, Ivoryton, CT
Source: Image courtesy of the Ivoryton Library Association

Bushy Hill Pond Dam was 111 years old at the time of its failure. Casualties were said to have been much lower than they might have been because most of the flooded areas were in the hazard zones for nuclear power stations, where evacuation procedures were well rehearsed. Evacuation alarm trials were required at least once per year. (World Water News)

The dam owner notified officials just prior to the failure of Bushy Hill Dam. Downstream evacuations were ordered before the dam failure, because major flooding was already occurring in downstream areas. There were no fatalities. (Phone conversation notes, Reclamation Flood Event Case History Archive)

A preliminary hydrologic analysis, performed by the Corps of Engineers, indicated that the Bushy Hill Pond Dam spillway capacity would have been exceeded for floods greater than nine percent of the PMF. (Phase I Inspection Report)

Summary Table 51. Bushy Hill Pond Dam

Flood Severity Rating	Low
Warning Time	Decision to evacuate made at 9:30 pm., 3 hours warning time
Time of day	Night time
Failure scenario	Slope failure or some other type of structural failure during heavy rainfall. Dam experienced minimal overtopping.
Fatalities	0
Fatality Rate	0
Dam Height	29 feet
Reservoir Storage	616 acre-feet reportedly released
Breach Formation Time	unknown
Total PAR	100 families evacuated, DSO-99-06 estimated 300 people
Downstream Distance to PAR	1.6 miles to Ivoryton
Maximum DV	Unknown, but DV was high enough to destroy some structures. Max depths reported to have been 6 to 7 feet. Velocities were probably at least 3 to 4 ft./s, so DV may have been 20 to 30 ft^2/s
Flood severity understanding	Precise
Confidence in data	Good. Event is well documented. DV estimate is very approximate.

This flood is considered to have been low severity. Flooding was reported to have been less than ten feet deep. Houses were floated off foundations, but not destroyed.

References:

- Flash Floods Breach 20 Small Dams in Southern Connecticut Disaster, World Water News, July 1982
- Deep River and Ivoryton, By Don Malcarne, Edith Deforest, Robbi Storms, Google Books
- ENR, June 17, 1982
- Phone conversation notes, Reclamation Flood Event Case History Archive
- Bushy Hill Pond Dam, Phase I Inspection Report, National Dam Inspection Program, USACE, Waltham, MA, April 1980

Austin, Texas Flood – May 24/25, 1981

Late in the evening of May 24, 1981, the city of Austin, Texas, experienced severe flooding of small creeks in the area, which resulted in the loss of 13 lives and costly damage to private and public property. The flooding resulted from very heavy and intense thunderstorm rainfall, which was part of a general system of intense thunderstorms in the area. Unusually good measurements of rainfall rates and streamflow indicate that the rainfall rates on Shoal Creek were close to those for a storm with a 100-year return period.

Various USGS gage stations recorded information about the flood. Peak discharge was as high as 16,000 ft^3/s on Shoal Creek at West 12th Street in Austin, and 21,600 ft^3/s on Walnut Creek at Dessau Road. Maximum gage heights were recorded to range from 10 to 26 feet.

On other watersheds in the area, point rainfall rates for durations of 60 minutes and 120 minutes were close to the expected 500-year rates.

A total of 13 people drowned at 10 locations during the flood. Six of the fatalities occurred when cars were washed into creeks at low-water crossings, five occurred when cars were washed off bridges, and two occurred in one of the houses on Jefferson Street, when two residents failed to leave until it was too late to reach higher ground safely. No bridges failed, but several sustained damage to abutments and approaches. Most creeks carried large quantities of debris. In Shoal Creek, which flooded through parts of Austin's business district, many cars were swept into the channel, piling up against bridges or being deposited in Town Lake.

Heavy rainfall began at 9:00 pm on May 24, with the first indication of flooding at about 9:30 pm. A flash flood warning was issued at 10:26 pm, but by this time a flood fatality had already occurred. The Austin Fire Department initiated door-to-door warning and evacuation starting at about 10:30 pm. Heavy runoff into Lake Austin, resulted in the need to open spillway gates on the Lake Austin's Tom Miller Dam at around 11:00 pm. Releases from Tom Miller Dam combined with runoff from Shoal Creek to fill Town Lake (since renamed to Lady Bird Lake), the next reservoir downstream. Between 11:30 and 12:00 pm, the Shoal Creek flood crest passed through Austin and numerous fatalities occurred within this time period. By 2:30 am on May 25, the flood, as a hydrologic event, was over.

In general, the common factor in nearly all the drowning fatalities was that they probably could have been avoided if the victims had better understood the potential risks from extreme flood conditions on the creeks. The high mortality rate was almost certainly due to the fact that nothing in recent experience had prepared people to anticipate and respect the violence of the rapidly rising waters.

Figure 119. Damaged home at Austin
Source: Photo courtesy of the Austin American-Statesman

Figure 120. Automobiles washed into the bed of Shoal Creek
Source: U.S. Geological Survey

Summary Table 41. Austin, Texas Flooding May 24/25, 1981

Flood Severity Rating	Low
Warning Time	Warnings were issued and evacuations ordered while the flooding was in progress
Time of day	Night time
Failure scenario	Flash flood
Fatalities	13
Fatality Rate	0.011 (DSO-99-06 estimate)
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Total PAR	1180 based on DSO-99-06 estimate
Downstream Distance to PAR	Na
Maximum DV	Estimated at 10 to 70 ft^2/s. houses were damaged and cars washed off bridges.
Flood severity understanding	Vague
Confidence in data	Fair. The event is well documented in terms of its hydrology, but information related to the flood conditions (depths, velocities) relative to the fatalities is unknown.

References:

- The Austin, Texas, Flood of May 24/25, 1981, Committee on Natural Disasters, Commission on Engineering and Technical Systems, National Research Council

Texas Hill Country Flood - August 1-3, 1978

Remnants of Tropical Storm Amelia moved inland over the south Texas coast on July 31, 1978, resulting in record rainfalls in the Texas Hill Country area of south-central Texas. Between August 1 and 3, locations in the Hill Country received over 30 inches of rain, with 21 inches in one 12-hour period. The heavy rains produced flash flooding. 27 people died in the Hill Country as a result of the floods. Most of the fatalities occurred during the early morning hours of August 2, but two fatalities occurred on August 3. Several of the fatalities involved people in vehicles, but most were located in or very close to homes. The majority of persons killed were either children or senior citizens. 370 homes were reported to have been seriously damaged or destroyed. Hundreds of cypress trees, 2 to 3 feet in diameter were "snapped off well above their bases" along the creeks of the Hill Country.

Flash flood watches were initially issued on August 1 and were followed by flash flood warnings, which in some locations progressed to suggesting evacuations from locations close to creeks and rivers. The worst of the flooding occurred during the early morning hours of August 2. Warning was spread through radio and television broadcasts, through local law enforcement agencies and through private citizen communications such as CB radio. The publication, "Disastrous Texas Flash Floods" describes possible reasons why the warnings were not effective in saving more lives: not everyone received warning; flash flood warnings are routinely issued and may not have been taken seriously; the ages of many of the victims may have put them in a more vulnerable category; people may not have evacuated for fear of looting; there may have been denial of flooding severity by some, based on past flood experiences; people delayed evacuation to protect personal property such as livestock.

Figure 121. Texas Hill Country Flooding, 1978
Source: U.S. Army Corps of Engineers

Summary Table 42. Texas Hill Country Flooding, August 1 - 3, 1978

Flood Severity Rating	Low, but the flood is described as being "almost medium severity"
Warning Time	Flash flood warnings recommended evacuations close to creeks and rivers
Time of day	Peak of flooding occurred at night time
Failure scenario	Flash flood
Fatalities	27 (25 mentioned in DSO-99-06)
Fatality Rate	0.013
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Total PAR	2070 based on DSO-99-06
Downstream Distance to PAR	Na
Maximum DV	Houses were destroyed, so DV may have ranged from 10 to 80 ft^2/s
Flood severity understanding	Vague
Confidence in data	Fair to good. Event is well documented in the referenced report. DV is very approximate.

References:

- The Disastrous Texas Flash Floods of August 1-4, 1978, Natural Disaster Survey Report 79-1, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Rockville, MD, March, 1979
- Floods in Central Texas, August 1978, U.S. Geological Survey, Open-File Report 79-682

Kansas River Flood – July, 1951

In mid-July 1951, heavy rains led to a great rise of water in the Kansas River and other surrounding areas. Flooding occurred in the Kansas, Neosho, Marais Des Cygnes, and Verdigris river basins. The damage in June and July 1951 exceeded $935 million dollars in an area covering eastern Kansas and Missouri, which, adjusting for inflation was nearly $7 billion dollars in 2005. The flood resulted in the loss of 17 lives and displaced 518,000 people. (Wikipedia)

Peak flooding occurred in many eastern Kansas towns on July 13. Flooding at the town of Manhattan peaked at 15.4 feet above flood stage (Wikipedia). DSO-99-06 refers to a total life loss of 11 people. Presumably these 11 fatalities are associated with the Kansas River Basin itself and not the surrounding areas.

Following this flood, a series of levees and reservoirs were constructed throughout eastern Kansas. This new network of flood control structures helped to prevent widespread damage when the region was hit later by the Great Flood of 1993. At the time of the 1951 flood, there were five federal flood control dams in operation within the Kansas River Basin. These dams are: Bonny Dam (USBR), Enders Dam (USBR), Medicine Creek Dam (USBR), Cedar Bluff Dam (USBR), and Kanopolis Dam (USACE). (Wikipedia)

Figure 122. Aerial view of flooding at the confluence of the Kansas and Missouri Rivers in Kansas City looking northeast on July 13, 1951
Source: Missouri State Parks. http://mostateparks.com/sites/default/files/kc.flood_.jpg

Summary Table 43. Kansas River Flood, 1951

Flood Severity Rating	Low
Warning Time	Adequate
Time of day	Varied
Failure scenario	Regional flooding
Fatalities	11 (based on DSO-99-06)
Fatality Rate	0.0002 (DSO-99-06 estimate)
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Total PAR	58,010 (based on DSO-99-06)
Downstream Distance to PAR	Na
Maximum DV	Unknown
Flood severity understanding	Precise as described by DSO-99-06
Confidence in data	Poor – no specific information about the characteristics of flooding relative to the flood fatalities is available.

Note – this flood event contains limited information. The value that it adds to the overall consequences database may be minimal.

References:

- http://en.wikipedia.org/wiki/Great_Flood_of_1951
- http://www.noaanews.noaa.gov/stories/s678.htm
- http://www.kshs.org/kansapedia/flood-of-1951/17163
- U.S. Department of Commerce, Weather Bureau, Technical Paper No. 17, Kansas-Missouri Floods of June-July 1951

Great Flood of 1993, Upper Midwestern United States, April to October 1993

The Great Mississippi and Missouri Rivers Flood of 1993 (or "Great Flood of 1993") occurred in the American Midwest, along the Mississippi and Missouri rivers and their tributaries, from April to October 1993. The flood was among the most costly and devastating to ever occur in the United States, with $15 billion in damages. The hydrographic basin affected covered around 745 miles in length and 435 miles in width, totaling about 320,000 square miles. Within this zone, the flooded area totaled around 30,000 square miles and was the worst such U.S. disaster since the Great Mississippi Flood of 1927, as measured by duration, square miles inundated, persons displaced, crop and property damage, and number of record river levels. In some categories, the 1993 flood even surpassed the 1927 flood, at the time the largest flood ever recorded on the Mississippi (Wikipedia).

Over 1,000 flood warnings and statements, five times the normal, were issued to notify the public and need-to-know officials of river levels. In such places as St. Louis, Missouri, river levels were nearly 20 feet above flood stage, the highest ever recorded there in 228 years. The 52-foot-high St. Louis Floodwall, built to handle the volume of the 1844 flood, was able to keep the 1993 flood out with just over two feet to spare. This floodwall was built in the 1960s, to great controversy, out of interlocking prefabricated concrete blocks. Should it have been breached, the whole of downtown St. Louis would have been submerged despite its location on a bluff. Emergency officials estimated that nearly all of the 700 privately built agricultural levees were overtopped or destroyed along the Missouri River. Navigation on the Mississippi and Missouri River had been closed since early July resulting in a loss of $2 million (1993 dollars) per day in commerce. (Wikipedia)

Some locations on the Mississippi River flooded for almost 200 days, while various locations on the Missouri neared 100 days of flooding. On the Mississippi, Grafton, Illinois, recorded flooding for 195 days; Clarksville, Missouri, for 187 days; Winfield, Missouri, for 183 days; Hannibal, Missouri, for 174 days; and Quincy, Illinois, for 152 days. The Missouri River was above flood stage for 62 days in Jefferson City, Missouri, 77 days at Hermann, Missouri, and for 94 days at St. Charles in the St. Louis metropolitan area. On October 7, 103 days after the flooding began, the Mississippi River at St. Louis finally dropped below flood stage. Approximately 100,000 homes were destroyed as a result of the flooding, 15 million acres (60,000 km^2) of farmland were inundated, and the whole towns of Valmeyer, Illinois and Rhineland, Missouri were relocated to higher ground. The floods cost thirty two lives officially; however, a more likely number is suspected to be around fifty people, as well as an estimated $15–$20 billion dollars in damages Even after the water was gone, billions of pounds of sand covered homes and farms. (Wikipedia)

Aerial view of the Missouri River flooding on July 30, 1993, at U.S. Highway 54 just north of Jefferson City, Missouri, looking south (photograph from the Missouri Highway and Transportation Department).

Figure 123. Great Flood of 1993
Source: U.S. Geological Survey, http://mo.water.usgs.gov/Reports/1993-Flood/

Summary Table 44. Great Flood of 1993

Flood Severity Rating	Low, described in DSO-99-06 as "sluggish flooding"
Warning Time	Various and unknown, described by DSO-99-06 as adequate
Time of day	Flooding occurred in many different locations and over many months
Failure scenario	Regional flooding
Fatalities	32 (38 mentioned in DSO-99-06)
Fatality Rate	0.0003 (DSO-99-06 estimate)
Dam Height	Na
Reservoir Storage	Na
Breach Formation Time	Na
Downstream Distance to PAR	Na
Total PAR	150,000 (based on DSO-99-06)
Maximum DV	Unknown
Flood severity understanding	described by DSO-99-06 as precise
Confidence in data	Poor – no specific information about the characteristics of flooding relative to the flood fatalities is available.

Note – this flood event contains limited information. The value that this case history adds to the overall consequences database may be minimal.

References:

- www.wikipedia.org
- The Great Flood of 1993, Natural Disasters Survey Report, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, February, 1994

Hurricane Agnes Floods- June/July 1972

Beginning on June 18, 1972, the remains of Hurricane Agnes produced floods in the Eastern United States from Virginia to New York that killed 117 people over 12 states.

A major flood caused by the exceptional rainfall associated with Hurricane Agnes ravaged the Mid-Atlantic States in late June and early July 1972. The origin of Agnes can be traced back to a weak tropical disturbance first detectable over the Yucatan Peninsula on June 14. It reached tropical storm intensity on June 16 and started to curve northward heading straight toward the Florida Panhandle. The rainfall over the Eastern United States from Agnes and other weather systems during June 16-25 produced record floods. Greatest point rainfall occurred in Pennsylvania and New York. The greatest 24-hour amount measured was 14.8 inches in southeastern Pennsylvania in the Mahantango Creek basin. This amount well exceeds the value for the 100-year recurrence interval. Total precipitation at several locations from New York to Virginia was in excess of 15 inches.

The flooding caused by the exceptional precipitation ravaged parts of twelve states. Peak stages and discharges established new records on many streams, and many reservoirs in New York and Pennsylvania were at their highest levels since construction.

Figure 124. Hurricane Agnes, Susquehanna River at Wilkes-Barre, PA
Source: U.S. Geological Survey

TABLE 7.—*U.S. deaths and damage attributed to Agnes* (De *Angelis, 1972*)

State	Damage	Deaths
Pennsylvania	$2,119,269,000	48
New York	702,502,000	24
New Jersey	15,000,000	1
Maryland	110,186,000	19
Ohio	6,818,000	0
Delaware	Light	1
West Virginia	7,753,000	0
Virginia	125,987,000	13
North Carolina	6,558,380	2
South Carolina	50,000	0
Georgia	205,000	0
Florida	8,243,000	9
Total	$3.102,571,380	117

Figure 125. Hurricane Agnes, deaths and damage by state
Source: U.S. Geological Survey Professional Paper 924

Summary Table 45. Hurricane Agnes

Flood Severity Rating	Low
Warning Time	Assumed by DSO-99-06 to have been adequate
Time of day	Flood occurred over numerous days
Failure scenario	Regional storm related flooding
Fatalities	117 total, 48 in PA
Fatality Rate	0.0002 (DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	250,000 in Pennsylvania (DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	unknown
Flood severity understanding	precise
Confidence in data	Fair

The case described here considers only the portion of flooding from this event occurring in Pennsylvania, which had the highest number of fatalities. 48 deaths occurred in Pennsylvania, with greater than 3,500 homes destroyed. Flooding is considered to have been low severity. The relatively slow rise of the flood waters is noted in the DSO-99-06 report and warning time was assumed to have been adequate. USGS 972 reports the destruction of many houses in Pennsylvania and in other states. No specific information is available on the flooding conditions which led to fatalities and it is possible that many of the fatalities were due to flooding conditions that would be categorized as medium severity.

Reference:

- Hurricane Agnes Rainfall and Floods, June-July 1972, United State Geological Survey, Professional Paper 972

Phoenix Area Flood – February, 1980

In February, 1980, severe precipitation occurred in the mountains north and east of Phoenix, Arizona. Flow in the Salt, Verde and Agua Fria Rivers exceeded the storage capacity of the river's reservoirs and flooding occurred in downstream areas due to reservoir releases. Peak discharge at Jointhead Dam, on the Salt River at Phoenix was reported to have been 170,000 ft^3/s. (Hydrology of floods)

The floods caused three deaths in Arizona. One person drowned trying to raft down Oak Creek when it was at flood stage. Two men drowned when their car was washed off a bridge over Granite Creek in Prescott. At Phoenix there were no fatalities. (USGS Professional Paper 1494)

The most severe damage occurred in the Phoenix area. About 25 streets and highways crossed the Salt River between Granite Reef Dam and the mouth of the river at the Gila River confluence; six streets crossed the Gila River between the Salt River and Gillespie Dam. In February 1980, three of the crossings had large bridges; the remainder had grade level crossings or small-capacity bridges. The small capacity bridges were designed to handle a maximum of about 35,000 ft^3/s. Floods in March 1978, December 1978, and January 1979 damaged all but two crossings. Most crossings had been put back into service prior to the 1980 flood by replacing approaches or constructing grade-level crossings through the dry streambed. The flood of February 15, 1980, destroyed all grade-level crossings, damaged or destroyed small-capacity bridges and Interstate Highway 10, and brought cross town traffic to a near standstill. Bridges at Mill and Central Avenues were the only ones crossing the Salt River that were kept open. Traffic jams several miles long and delays of 6 to 8 hours occurred as traffic was funneled across these two bridges. Cross-river traffic dropped from the normal volume of 400,000 vehicles per day to 187,400 per day. Special buses and a commuter train were put into service for two weeks until Interstate Highway 10 was reopened. (USGS Professional Paper 1494)

The Salt River flooded the eastern end of the runways at Sky Harbor Airport in Phoenix, washed out sewage treatment and disposal facilities, destroyed several commercial buildings, and damaged gravel operations in the riverbed. Two thousand families were evacuated, and 155 homes reportedly sustained damage. (USGS Professional Paper 1494)

The area flooded by the Agua Fria River on February 20 was as wide as one mile. The flood inundated two small subdivisions in the rural part of Maricopa County northwest of Phoenix and other residential areas. About 650 families were evacuated from along the Agua Fria River. The flood eroded extensive amounts of river channel. Before the flood in February 1980, the river was crossed by 14 major streets and highways between Lake Pleasant and the mouth of the Agua Fria River. Six were bridges, and the rest were grade-level crossings. The flood of February 20 destroyed all grade-level crossings and three bridges and damaged road grades at the other three bridges. (USGS Professional Paper 1494)

Figure 126. Phoenix Area Flooding, 1980, Bridge Crossing on the Salt River
Source: Photo courtesy of State Historical Society of North Dakota from the William E. Shemorry Photograph Collection

DSO-99-06 considered this flooding to have been low severity. Flood discharge was high along the Salt, Verde and Agua Fria Rivers, but perhaps the flooding which occurred away from the main river channel was relatively benign.

Summary Table 46. Phoenix Area Flood, 1980

Flood Severity Rating	Low
Warning Time	Adequate
Time of day	Not known
Failure scenario	Storm related flooding
Fatalities	Zero in Phoenix area
Fatality Rate	0
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	6,000 based on DSO-99-06 estimate
Downstream Distance to PAR	Not applicable
Maximum DV	Estimated to have been 10 to 50 ft^2/s
Flood severity understanding	precise
Confidence in data	Poor

<u>References:</u>

- Floods of February 1980 in Southern California and Central Arizona, USGS Professional Paper 1494
- Hydrology of the floods of March 1978 through February 1980 in the Phoenix area, Arizona, by B.N. Aldridge, from Proceedings of a Symposium: Storms, Floods, and Debris Flows in Southern California and Arizona 1978 and 1980, Committee on Natural Disasters, National Research Council and Environmental Quality Laboratory, California Institute of Technology

Prospect Dam – Failed February 10, 1980

Prospect Dam was an embankment dam located on Lost Creek, near Keenesburg, Colorado. The 45 foot high embankment dam failed on Sunday, February 10, 1980 at about 9:00 am. The weather was clear at the time of failure and the cause of the breach was likely to have been internal erosion. Maximum operating capacity of the dam was 6,300 acre-feet, and the reservoir contained 5,850 acre-feet at the time of its breach.

A 10-foot diameter tunnel in the embankment was observed by a local farmer at about 9:30 am. By 9:55 am, the breach was estimated by an observer to have been 30 feet wide. As erosion continued, the gap spread at an average rate of 2.3 feet per hour to a final breach width of 83 feet. (CWCB report)

The breach was closed within approximately 24 hours. During this time, the reservoir dropped nine feet. An estimated 2,880 acre-feet of storage was released by the breach. (CWCB report)

The maximum discharge from Prospect Dam was reported to have been 4,100 ft^3/s, which occurred at noon. 6.6 miles downstream from Prospect Dam was Lord Dam.
Lord Dam did not fail, but its spillway operated and produced maximum releases of about 1,200 ft^3/s. Flood depths were reported to have been in the range of about two feet at downstream farmsteads and the flood was slow moving. Flood flow between Prospect Dam and Lord Dam moved at an average speed of 2 ft./s. Flood releases from Lord Reservoir were reported to move very slowly.

One hundred families located downstream of Lord Dam were advised to evacuate, when it appeared that Lord Dam might not be able to contain the flood flow, but Lord Dam did not fail. The sealing of the breach at Prospect Dam on the following morning, ended the flood inflow to Lord Reservoir.

This flooding is considered to have been low severity. The DV was low and the downstream channel slopes were mild. As a result, the flooding was slow rising.

Figure 127. The breached Prospect Dam
Source; Rocky Mountain News Archives, Courtesy of Denver Public Library

Figure 128. Flooding downstream of the breached Prospect Dam
Source: Rocky Mountain News Archives, Courtesy of Denver Public Library

Summary Table 47. Prospect Dam

Flood Severity Rating	Low
Warning Time	Adequate
Time of day	Day time and extending for a 24-hour period
Failure scenario	Sunny Day (internal erosion)
Fatalities	0
Fatality Rate	0
Dam Height	45 feet
Reservoir Storage	5,850 acre-feet (2,880 acre-feet released by breach)
Breach Formation Time	> 1 hour
Total PAR	100
Downstream Distance to PAR	unknown
Maximum DV	Approximately 4 ft^2/s
Flood severity understanding	Precise
Confidence in data	Good

References:

- The Lost Creek Flood of February 10, 1980, Weld County Colorado, by William P. Stanton, Colorado Water Conservation Board, May 1981
- Various newspaper articles, Reclamation Flood Event Case History Archive

Brush Creek Flash Flood – September 12, 1977

The storms of September 12-13, 1977 delivered an average rainfall exceeding 10 inches in the Kansas City, Kansas/Missouri metropolitan area. Twenty-five lives were lost in total and many were left homeless. Flood damages exceeded $80 million (1977 dollars). Two record setting storms occurred within twenty four hours. The first storm saturated the local drainage basin. The second storm, centered along Brush Creek and Round Grove Creek basins, resulted in a devastating flash flood. Stream flows and flood volumes in many locations far exceeded estimated values for the 100-year flood. (USGS Professional Paper 1169)

Brush Creek drains approximately 29.4 square miles of urban area in the central portion of the Kansas City metropolitan area. Forty-three percent of the basin lies in Kansas and 57 percent in Missouri. Diverse development covers the entire area. The stream channel on both sides of the Kansas-Missouri State line has been straightened and improved over most of its length. Drainage from residential areas has been either channelized into concrete-lined ditches or emptied into large underground storm sewers. Much of the ground surface in the basin has been paved over with streets, rooftops, sidewalks, parking lots, and other impervious surfaces. Because of the urbanization that has taken place, the stream had a high potential for flash flooding (Hydraulic Model Investigation).

The Country Club Plaza area of downtown Kansas City, MO was devastated with 5 to 6 feet of water in shops and restaurants adjacent to Brush Creek. Numerous parked cars were swept off the street and were deposited in the channel, many of them lodged on the upstream sides of bridge piers (Hydraulic Model Investigation).

DSO-99-06 reports that 17 of the 25 deaths were automobile related.

DSO-99-06 characterized this flood event as low severity. Flood velocities and depths may have been relatively low, although there is not a lot of information available.

Figure 129. Brush Creek Flood, 1977, Ward Parkway, Kansas City, MO
Source: U.S. Geological Survey Professional Paper 1169

Summary Table 48. Brush Creek Flood

Flood Severity Rating	Low
Warning Time	Some warning
Time of day	Night time
Failure scenario	Flash flood
Fatalities	25 (DSO-99-065 reports 20)
Fatality Rate	0.008 (DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	2380 (DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	Estimated to range from 10 to 50 ft^2/s
Flood severity understanding	Vague
Confidence in data	Fair

References:

- Technical Report HL-92-1, Brush Creek, Kansas City, Missouri, Hydraulic Model Investigation, Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi, February 1992
- Floods in Kansas City, Missouri and Kansas, September 12-13, 1977 U.S. Geological Survey Professional Paper 1169
- Floods in Kansas City, Missouri and Kansas, September 12-13, 1977 U.S. Geological Survey, Water Resources Investigations 78-63

South Platte River Flood – June 16, 1965

Figure 130. South Platte River flood, 1965, mobile home park near Bowles and Santa Fe Avenues, Littleton, CO
Source: Colorado Water Conservation Board
http://cwcb.state.co.us/PublishingImages/FloodPhotos/South%20Platte%20River%20-%201965%20Flood.jpg

On the evening of June 16, 1965, a wall of water described by some as fifteen feet high came roaring down the South Platte River in Colorado, the result of extremely severe thunderstorms many miles south of the town of Littleton. The torrent crested at twenty-five feet above normal stage and was carrying forty times the normal flow. (www.littletongov.org)

Police were able to give people in the town of Littleton several hours warning, so they could be evacuated. Damages occurred at the Columbine Country Club southwest of Littleton, whose golf course and luxury homes were devastated. Overland Park golf course, in Denver, suffered a similar fate. Centennial Race Track, which was within days of opening its racing season, had most of its track and stable areas inundated. A massive rescue operation by owners, trainers and jockeys saved some 140 horses. The city of Littleton's water supply, which consisted mainly of a series of wells along the river, was nearly destroyed.(www.littletongov.org)

As the flood continued north, it included cars, refrigerators and other debris. This battering ram carried away or destroyed 26 bridges, including every bridge from Littleton north to the Colfax viaduct in Denver. Both Public Service Company power plants along the river were shut down, and emergency circuits became waterlogged and shorted out. As the flood continued further north, other tributaries added their weight, Sand Creek and Clear Creek, and still further north the Bijou and Little Beaver Creeks, and the Poudre River. The communities of Sterling, Fort Morgan and Brush, Colorado became isolated as the waters spread out over a quarter-million acres of farmland. (www.littletongov.org)

All told, it was estimated that the damage came to some $540 million (1965 dollars). In Denver, one person was killed, but there were other fatalities, including three on Plum Creek to the south. The total number of fatalities due to the flooding is uncertain. Fatality numbers could have been higher under worse conditions, but the flood began in broad daylight and few people were caught without some notice.

Following the flood, plans were quickly finalized and construction began for the South Platte River's Chatfield Dam, which was completed in 1972.

The Denver metropolitan area suffered extensive damage. The flood zone represented 67 percent of the industrial area in the city. Peak discharge on the South Platte River at Denver was reported to have been 40,300 ft^3/s. (ucar.edu)

Figure 131 .South Platte River Flood, 1965, flooding at Interstate 25, Denver, CO
Source: U.S. Army Corps of Engineers

Summary Table 60. South Platte River Flood

Flood Severity Rating	Low
Warning Time	Adequate
Time of day	Day time initially, extending into night
Failure scenario	Flash flood
Fatalities	DSO-99-06 reports 1 at Denver
Fatality Rate	0.0001 (DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	10,000 (based on DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	Estimated to range from 10 to 40 ft^2/s
Flood severity understanding	Precise
Confidence in data	Fair

References:

- Floods of June 1965 in the South Platte River Basin, Colorado, USGS Water Supply Paper 1850-B
- http://www.littletongov.org/history/othertopics/flood.asp
- http://www.assessment.ucar.edu/flood/flood_summaries/06_14_1965.html
- http://scienceblogs.com/chaoticutopia/2007/05/31/return-to-lillybridge/
- http://www.coemergency.com/2010/01/historical-colorado-flood-events.html

Passaic River Basin Flood – April 1984

The Passaic River Basin is located in northern New Jersey, with a small portion of the basin extending into the state of New York. The major tributaries within the basin which feed into the Passaic River are the Ramapo, Wanaque, Pompton, Rockaway and Whippany Rivers. The basin is comprised of 983 square miles and is considered to be one of the most densely developed flood plains on the eastern seaboard of the United States, with a residential population of roughly 2.5 million people according to the 2000 census.

Figure 132. Passaic River Basin Flood, 1984, residential flooding
Source: U.S. Army Corps of Engineers

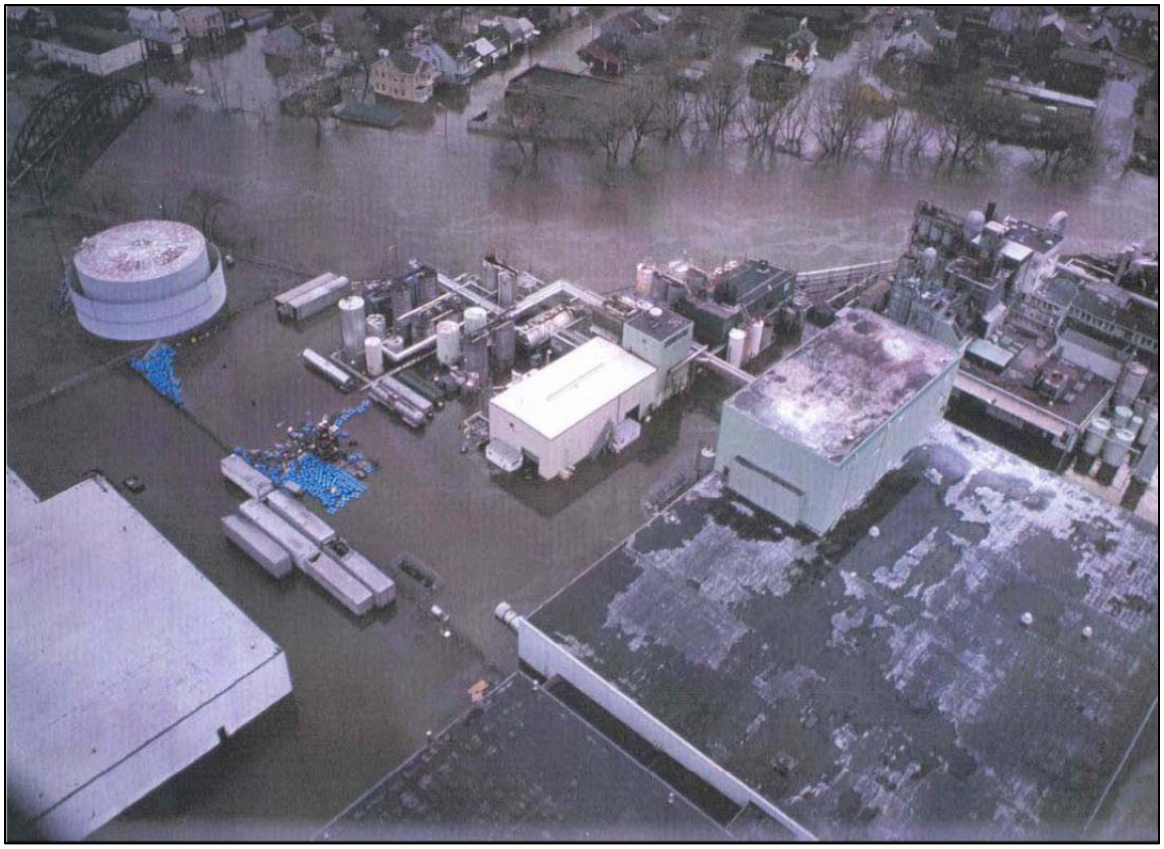


Figure 133. Passaic River Basin Flood, 1984, Paterson City industrial facility
Source: U.S. Army Corps of Engineers

The flood of April 1984 resulted in three deaths, caused $462 million (1994 dollars) in damage, and displaced 6,000 residents.

It was after the 1984 floods that the Federal Government authorized $5.4 million and New Jersey appropriated $5 million to buy out hundreds of homeowners in parts of the flood plain.

Summary Table 61. Passaic River Basin Flood, 1984

Flood Severity Rating	Low, described in DSO-99-06 as “sluggish flooding”
Warning Time	Adequate
Time of day	Day time initially, extending into night
Failure scenario	Regional flood, water rose gradually
Fatalities	3 (DSO-99-06 reports 2)
Fatality Rate	0.0001 (DSO-99-06 estimate)
Dam Height	Not applicable
Reservoir Storage	Not applicable
Breach Formation Time	Not applicable
Total PAR	25,000 (based on DSO-99-06 estimate)
Downstream Distance to PAR	Not applicable
Maximum DV	unknown
Flood severity understanding	Precise
Confidence in data	Fair

Note – this flood event contains limited information. The value that this case history adds to the overall consequences database may be minimal.

References:

- Flood-Prone Wayne Area Remains Popular, New York Times: http://www.nytimes.com/1987/04/23/nyregion/flood-prone-wayne-area-remains-popular.html?pagewanted=print&src=pm
- Passaic Flood Warning System, USGS, FS-092-98: http://nj.usgs.gov/publications/FS/fs-092-98/
- Briefing with Passaic River Basin Flood Advisory Commission, Passaic River Flood Risk Management, U.S. Army Corps of Engineers, May 26, 2010

Dongkoumiao Dam – Failed June 2, 1971

Dongkoumiao Dam located at Xidian Town, Ninghai County, Zhejiang Province, China. Construction of the dam was completed in 1959. The dam had a height of 71 feet, and a reservoir capacity of 2,067 acre-feet. Donkoumiao Dam failed at 5:50 to 5:55 am on June 2, 1971 due to internal erosion. The peak discharge at the dam site was estimated as 49,400 ft^3/s. Three villages, Jiyi, Lijiayuan and Huangxikou, were located downstream of the dam. Jiyi village was 0.3 to 0.6 miles downstream and had a population of 1,200; Lijiayuan and Huangxikou village were 0.0 to 1.2 miles downstream from the dam and had a population of 3,500. The dam failed in the early morning, few signs were observed, and no warning was issued to the people downstream. Zhou (2006) performed dam break flood routing with FLDWAV; the hydraulic results have been used to estimate DV.

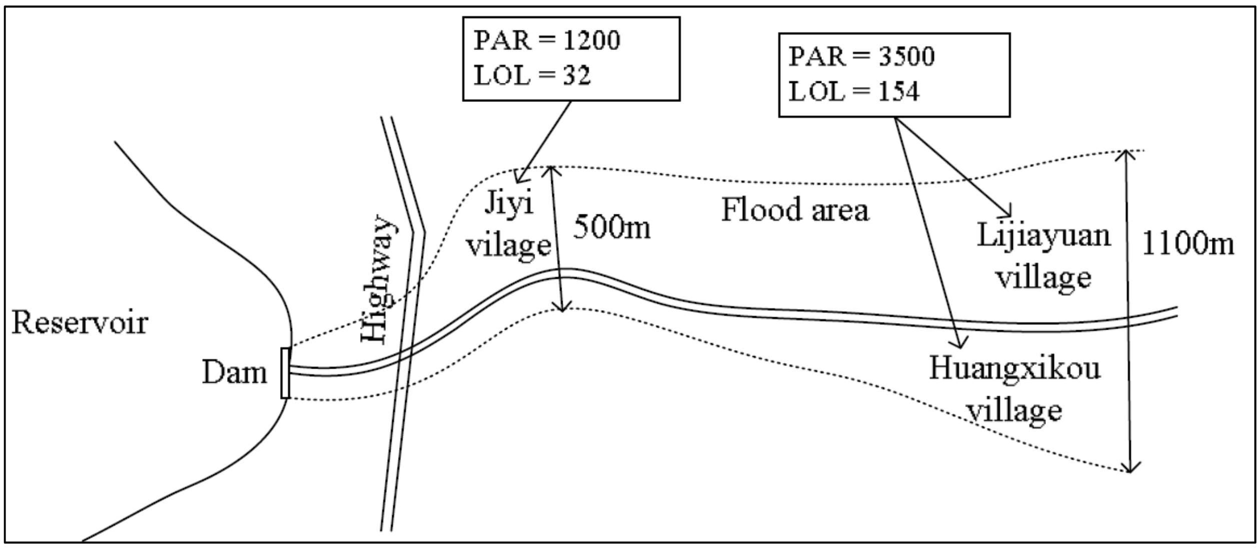


Figure 134. Areas downstream of Donkoumiao Dam
Source: Image courtesy of L.M. Zhang

Summary Table 49– Donkoumiao Dam Failure

Flood Severity Rating	Low
Warning Time	No warning
Time of day	Daytime
Failure scenario	Internal erosion/piping
Fatalities	32 at Jiyi Village 154 at Lijiayuan and Huangxikou Villages
Fatality Rate	0.027 at Jiyi Village 0.044 at Lijiayuan and Huangxikou Villages
Dam Height	71 feet
Reservoir Storage	2,067 acre-feet
Breach Formation Time	unknown
Total PAR	1,200 at Jiyi Village 3,500 at Lijiayuan and Huangxikou
Downstream Distance to PAR	Jiyi Village 0.3 to 0.6 miles Lijiayuan and Huangxikou Villages 0.9 to 1.2 miles
Flood severity understanding	unknown
Maximum DV	Jiyi Village: 30 to 50 ft^2/s Lijiayuan and Huangxikou Villages: 10 to 15 ft^2/s
Confidence in data	Fair. More information, including photos would increase confidence.

References:

- Zhou KF (2006) Study on analysis method for loss of life due to dam breach, MS Thesis in Nanjing Hydraulic Research Institute, Nanjing, China (in Chinese)

Hurricane Katrina at New Orleans – Coastal Flooding August 29, 2005

Hurricane Katrina was the deadliest and most destructive Atlantic tropical cyclone of the 2005 Atlantic hurricane season. It was the costliest natural disaster, as well as one of the five deadliest hurricanes, in the history of the United States. Among recorded Atlantic hurricanes, it was the sixth strongest overall. At least 1,833 people died in the hurricane and subsequent flooding, making it the deadliest U.S. hurricane since the 1928 Okeechobee hurricane. (Wikipedia)

The most significant number of deaths occurred in New Orleans, Louisiana, which flooded as the levee system catastrophically failed; in many cases hours after the storm had moved inland. Eventually, 80% of the city and large tracts of neighboring parishes became flooded and the floodwaters lingered for weeks. (Wikipedia)

The death toll in the state of Louisiana was more than 1,100. The paper "Loss of Life Caused by the Flooding of New Orleans After Hurricane Katrina: Analysis of the Relationship Between Flood Characteristics and Mortality" by Jonkman, Maaskant, Boyd, and Levitan (JMBL Study) presents an analysis on the loss of life caused by Hurricane Katrina in New Orleans. Much of the information presented is this discussion is based on the paper.

Data on the locations, conditions, and characteristics of 771 of the fatalities were available for the study. Of these 771 fatalities which had data associated with them, it was determined that approximately one-third of those fatalities either occurred in hospitals or shelters within the flooded area or outside of the flooded area altogether. Two thirds of these fatalities occurred within the flooded areas and were mostly due to drowning.

Due to the warnings that were issued prior to Katrina making landfall, it is estimated that 430,000 vehicles had left the metropolitan area using the primary roads. In addition, another 10,000 to 30,000 vehicles left the area by secondary roads. An estimated 1.1 million people evacuated prior to landfall, which equates to 80% to 90% of the population at risk in the area.

Figure 135. Hurricane Katrina levee failure
Source: Federal Emergency Management Agency/photo by Jocelyn Augustino

The JMBL Study looked at age, gender, and race and the role they played in the fatalities. There were 853 fatalities that had some data available for these comparisons. Of most significance was the amount that age factored in to the fatalities. There were 829 fatalities for which age was known, most were elderly. The report states that less than 1% of these fatalities were children (0-10 years old) and only about 15% were less than 51 years of age. Nearly 85% of the fatalities were over the age of 51, 60% were over the age of 65, and almost 50% were older than 75.

The data also showed that gender and race did not play a significant role in the Katrina fatalities. The ratio of fatality rates for men and women were similar to the percentage of men and women that resided in the area before the hurricane. A similar comparison was found for race.

Survival in the New Orleans neighborhoods may have been related to endurance in extreme conditions, and this may explain the high fatality rate for the elderly in New Orleans.

Of the 771 recorded fatalities in the metropolitan area, 624 (81%) were inside the flooded areas and 106 of those were determined not to be a direct impact of the flooding since they were found in hospitals and shelters. The remaining 518 fatalities that were recovered (67% of total recovered) were attributed to direct impact of the flooding (drowning, physical trauma, or building collapse). Of these fatalities, it was determined that many were near large breaches in the levees and therefore, were in areas that experienced deeper water levels.

The highest fatality rates computed in the metropolitan area were in the St. Bernard bowl (Lower 9th Ward), which had rates of 5% to 7%. This is a low lying area that was near two large breaches in the levees. In the Lower 9th Ward, the two large breaches allowed water to enter the area with great force, causing many buildings to collapse.

Figure 136. Flooding from Hurricane Katrina
Source: NOAA

The JMBL Study concluded that fatality rates were highest 1) near breaches due to the combination of depth, velocity, and less reaction time and 2) in areas with the greatest flood depths.

The paper: "Loss of Life Caused by the Flooding of New Orleans After Hurricane Katrina" performed hydraulic re-creation and examined life loss at three locations in New Orleans. These locations were: the Lower Ninth Ward, the Metro Bowl and the East Bowl. Information regarding these findings are presented in Table 63.

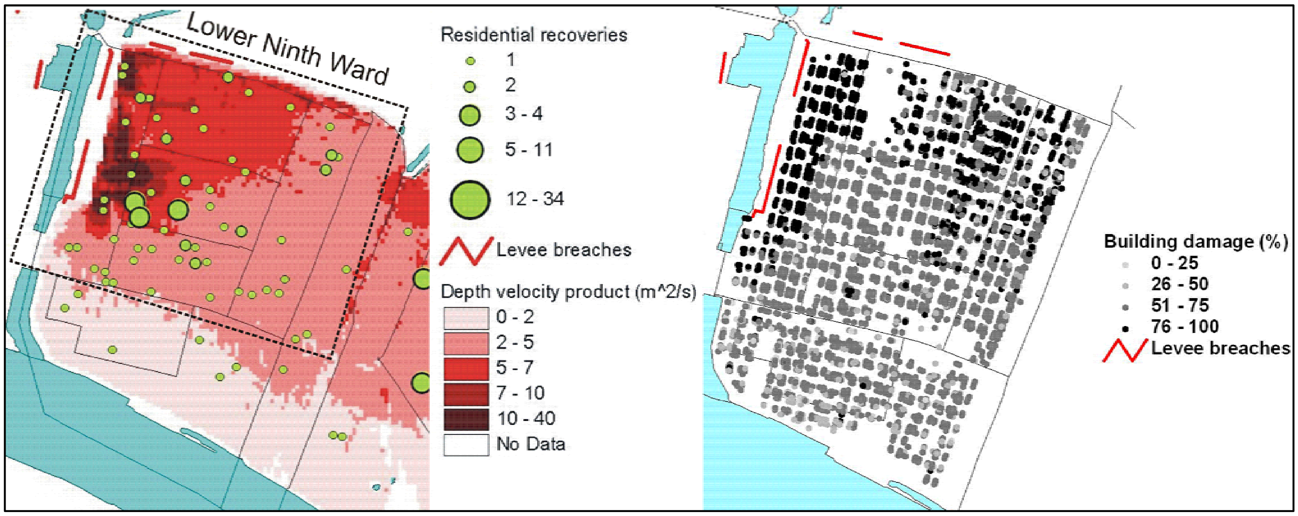


Figure 137. DV, fatalities, and building damage in the Lower Ninth Ward (fatalities referred to as recoveries)
Source: Courtesy of Bas Jonkman

Summary Table 50– Hurricane Katrina, New Orleans

Flood Severity Rating	Low
Warning Time	Adequate
Time of day	Daytime
Failure scenario	Post-hurricane levee breaching
Fatalities	Lower 9th Ward: 73 Metro Bowl: 260 East Bowl: 68
Fatality Rate	Lower 9th Ward: 0.0052 Metro Bowl: 0.001 East Bowl: 0.001
Dam (Levee) Height	Lower 9th Ward: 13.1 feet Metro Bowl: 13.1 feet East Bowl: 13.1 feet
Reservoir Storage	n/a
Breach Formation Time	Lower 9th Ward: moderately fast Metro Bowl: slow East Bowl: slow
Total PAR	Lower 9th Ward: 14,000 Metro Bowl: 255,900 East Bowl: 69,290
Downstream Distance to PAR	Most PAR was located very close to the levees, approx. 0.1 miles or less
Flood severity understanding	unknown
Maximum DV	Lower 9th Ward: 70 ft^2/s Metro Bowl: 20 ft^2/s East Bowl: 20 ft^2/s
Confidence in data	Good

References:

- Pistrika A.K., Jonkman S.N. (2009) Damage to residential buildings due to flooding of New Orleans after hurricane Katrina. *Natural Hazards*. Vol. 54 Issue 2, pp. 413-434
- Jonkman S.N., Maaskant B., Boyd E., Levitan M.L. (2009) Loss of life caused by the flooding of New Orleans after hurricane Katrina: Analysis of the relationship between flood characteristics and mortality. *Risk Analysis* Vol. 29, No. 5, pp. 676-698
- http://en.wikipedia.org/wiki/Hurricane_Katrina

Cyclone Xynthia, France – Coastal Flooding February 28, 2010

Xynthia was a violent European windstorm which crossed Western Europe between February 27 and March 1, 2010. The cyclone caused coastal flooding, resulting in fatalities and a great deal of damage. Due to the storm 65 people in Europe died. France suffered the most: 47 people were killed and 79 people were injured (Anziani 2010). Most of the fatalities were a result of the floods in the coastal areas of the Vendée.

The majority of deaths in France occurred when a powerful storm surge topped by battering waves up to 25 feet high, hitting at high tide, smashed through the sea wall off the coastal town of L'Aiguillon-sur-Mer. A mobile home park built close to the sea wall was particularly hard-hit. The sea wall was about two hundred years old, built in the time of Napoleon. Critics said that situating a mobile home park so close to the sea wall showed poor coastal development practices.

The adjacent villages of La Faute-sur-Mer and L'Aiguillon-sur-Mer were severely afflicted by the water, 29 people were killed in this area (Bersani 2011). The majority of the fatalities were elderly. Seventeen of the 29 fatalities were more than 70 years old, five were between 60-69 years old and three were between 50-59 years old. The other 4 victims included a 2-year old child and two children from the same family who were vacationing in La Faute-sur-Mer. During the flood the father of the two children made a hole in the ceiling of their vacation home. He managed to escape together with his daughter, but his wife (43 years old), two sons (4 and 13 years old) and mother (73 years old) drowned. In Charron one of the houses also had a hole in the roof where someone had climbed out. For most elderly people this type of escape route turned out to be impossible. In some houses in La Faute-sur-Mer the water level rose to about 8 feet within half an hour. Some people woke up to find their bed floating about 5 feet above the floor. In Charente-Maritime twelve people were killed. In Les Moutiers-en-Retz (in the region of Loire-Atlantique) two people were killed because their camper got washed away from the pier. Some people were trapped and drowned in their one level houses because of the electric shutters that could not be opened.

Summary Table 51– Cyclone Xynthia, France

Flood Severity Rating	Low
Warning Time	No warning
Time of day	Nighttime
Failure scenario	Coastal flood, seawall breach
Fatalities	29 at villages of La Faute-sur-Mer and L'Aiguillon-sur-Mer
Fatality Rate	0.0097
Dam Height	Not a dam, but seawall height unknown
Reservoir Storage	Not applicable
Breach Formation Time	Seawall failure time unknown
Total PAR	3,000
Downstream Distance to PAR	varied
Flood severity understanding	Not applicable
Maximum DV	10 to 30 ft^2/s
Confidence in data	Good

References:

- http://www.lafautesurmer.net/2010/03/03/tempete-les-victimes-etaient-pour-la-plupart-des-retraites-ouest-france/# (in French)
- http://en.wikipedia.org/wiki/Cyclone_Xynthia

Meadow (Bergeron) Pond Dam – Failed March 13, 1996

Meadow Pond Dam, also known as Bergeron Pond Dam, was a 36 foot high embankment structure with a 465 foot crest length, located near the town of Alton, New Hampshire. The dam and reservoir were privately owned and were used for boating and other recreation. The reservoir held about 282 acre-feet of water. Meadow Pond is a natural feature, whose storage was increased by building the dam in the early 1990's.

On the evening of Wednesday, March 13, 1996, the dam owner noticed that the creek which ran between the Bergeron Dam and the Merrymeeting River was swollen with water. The dam was inspected by the owner at 6:46 p.m. He found that a three-foot hole had opened in the embankment and was flooding the area between his residence and Route 140. Less than ten minutes later the dam had failed, releasing the full contents of the reservoir. The failure of the Bergeron Dam resulted in one fatality, two injuries, and damage to several homes.

The rush of water from the dam break undermined a section of Route 140, causing a tractor-trailer to sink into a hole in the road. Larry Sinclair, owner of the tractor trailer, was rescued by a neighbor, but his wife Lynda, 48, who was traveling behind him in a pickup truck, was killed when flood waters swept the truck into a ravine.

About a quarter-mile of Route 140 was damaged. The flooding also caused power outages in Gilmanton, Belmont, and Alton. Subsequent investigations by the state-appointed civil engineering firm, GEI Consultants indicated the failure was caused by a combination of design and construction deficiencies. The design did not adequately account for the cold weather conditions, and mistakes in construction greatly exacerbated the errors.

Figure 138. Remains of Meadow Pond Dam
Source: Exponent Engineering and Scientific Consulting
http://www.exponent.com/files/Uploads/Images/civil%20engineering/levee/Alton%20Dam.jpg

Summary Table 52– Meadow Pond Dam

Flood Severity Rating	Low
Warning Time	None
Time of day	Nighttime (about 7:00 pm)
Failure scenario	Static failure
Fatalities	1
Fatality Rate	0.04
Dam Height	32
Reservoir Storage	282
Breach Formation Time	Unknown, but fairly fast
Total PAR	25
Downstream Distance to PAR	0.8 miles to road crossing where fatality occurred.
Flood severity understanding	Not applicable
Maximum DV	7 ft^2/s, but likely higher at road crossing
Confidence in data	Good

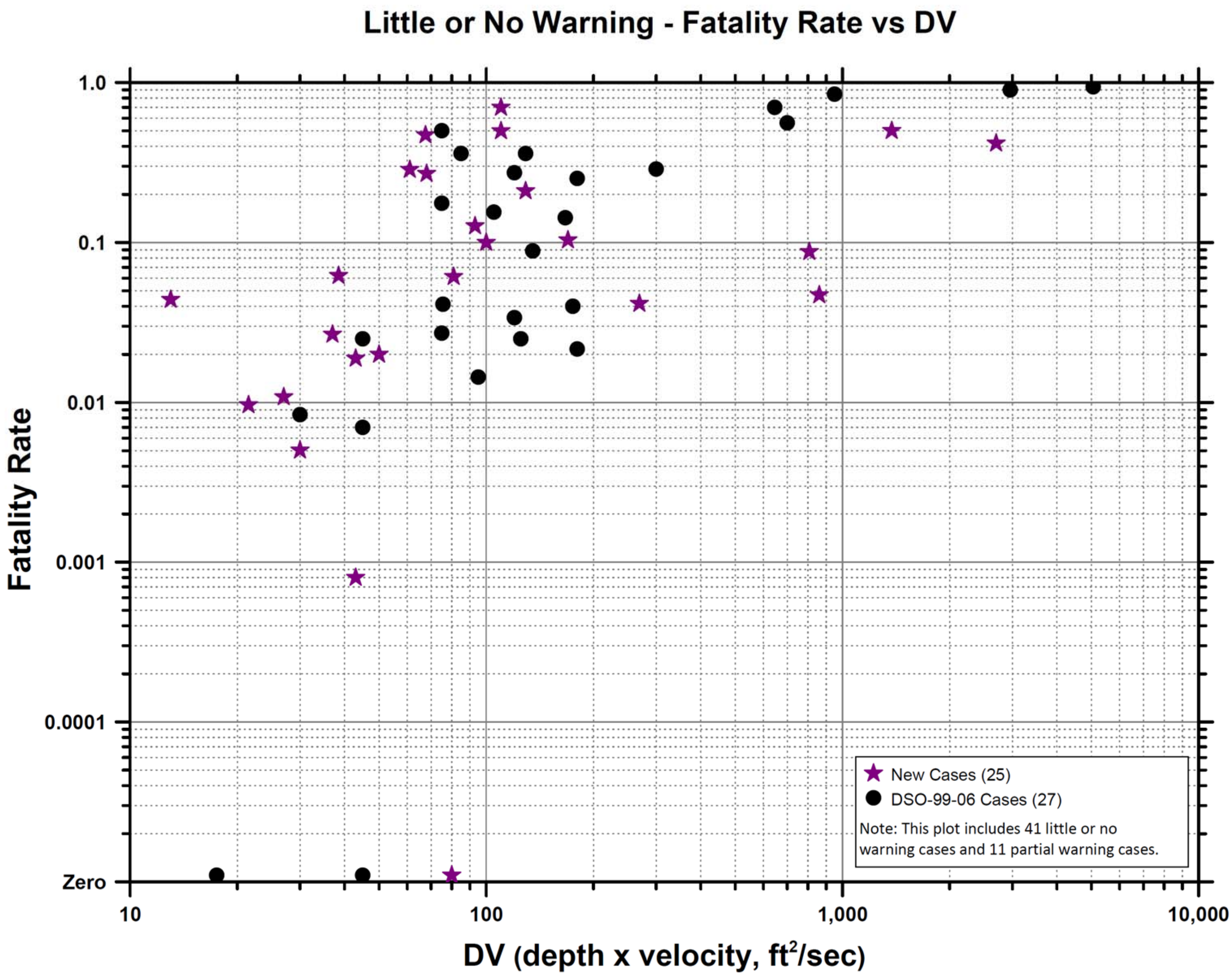
References:

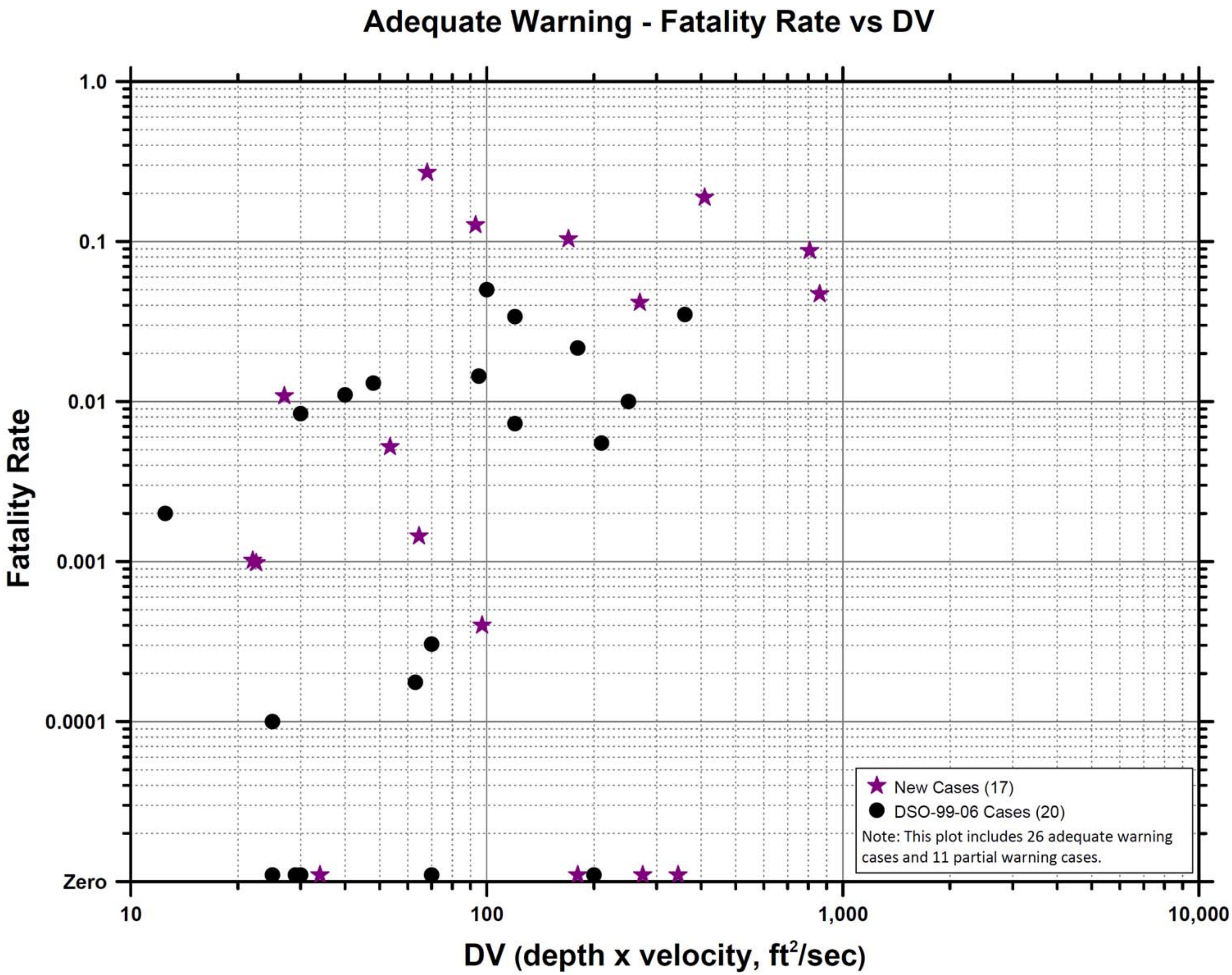
- http://en.wikipedia.org/wiki/Meadow_Pond_Dam
- Estimating Life Loss for Dam Safety Risk Assessment – A Review and New Approach, IWR Report 02-R-3, U.S. Army Corps of Engineers, Institute for Water Resources, July 2002
- The Night the Dam Broke, by Bob Trebilcock, Yankee Magazine, 1996, http://www.winnipesaukee.com/forums/showthread.php?t=1343

Appendix A - Fatality Rate vs. DV Plots with new cases and DSO-99-06 cases differentiated

This document describes 60 dam failure and flood event case histories. Some of the 60 case histories do not have enough information about the flooding, the PAR or fatalities to generate a data point on the fatality rate vs DV plots used in the RCEM empirical method. Some of the 60 case histories are sufficiently detailed to have information at multiple locations; for example, there are 5 separate data points from the South Fork Dam failure. From the 60 case histories, 80 sets of DV and fatality rate data pairs were estimated. Two cases (two points) have DV values less than the minimum axis value of 10, and do not appear on the plots. Therefore, 78 data points were used to generate points on the RCEM plots. Of the 78 total data points, 41 were judged to have little or no warning, 11 were judged to have partial warning (as defined in the Methodology document), and 26 were judged to have adequate warning. The data points judged to have partial warning are plotted on both the "little to no warning" plots and the "adequate warning" plots. Therefore, the "little to no warning" plot contains 52 points and the "adequate warning" plot contains 37 points. There are 25 new cases on the "little to no warning" plot and 17 new cases on the "adequate" warning plot. Seven new cases are considered partial warning, and are included on both plots.

The comparison plots showing original data points from DSO-99-06 and new data points from RCEM are presented in this Appendix.


Little or No Warning - Fatality Rate vs DV
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft2/sec)
New Cases (25)
DSO-99-06 Cases (27)
Note: This plot includes 41 little or no warning cases and 11 partial warning cases.


Adequate Warning - Fatality Rate vs DV
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft²/sec)
New Cases (17)
DSO-99-06 Cases (20)
Note: This plot includes 26 adequate warning cases and 11 partial warning cases.

Appendix B - Case History Data Summary

The case history data contained in this document was used as the empirical basis for the fatality rate curves contained in RCEM "Guidelines for Estimating Life Loss for Dam Safety Risk Analysis" A companion to this case history document is a spreadsheet compilation of some of the most relevant information from the case history events. Some of the case histories were developed into multiple data points where specific information was available at various downstream locations. These sub-cases often exhibit changes in DV and fatality rates and their inclusion as separate cases, significantly expands the database. The purpose of the spreadsheet is to allow the consequence analyst to sort the data based on similar characteristics. For example, there may be an interest in looking at events with medium severity DV range, no warning, and occurring at night. Analysis performed with the spreadsheet can aid in the selection of fatality rates for a particular dam whose assumed failure scenario may have things in common with some of the case histories.

The case history attributes contained in the spreadsheet are as follows:

- Name of event
- Date of event
- Was the event a dam failure? Yes/no
- Flood severity estimate, high/medium/low
- Warning time, none/some/adequate
- Time of day
- Scenario description, fairly generic to enable sorting
- Total PAR
- Number of fatalities
- Fatality rate
- Dam height
- Reservoir storage
- Time of breach formation
- Downstream distance to PAR
- Flood severity understanding
- Maximum DV, high range estimate
- Maximum DV, low range estimate
- DV notes, relevant information
- Confidence in data
- Confidence Notes, relevant information
- Is the case from DSO-99-06 or is it a new case?
- Is the case used as an RCEM data point?

This document includes a printed version of the case history spreadsheet on the following pages in this Appendix. The complete spreadsheet in this document is two pages wide by two pages long.

Case Name	Date	Dam Failure?	Flood Severity	Warning	Day/Night	Scenario	Total PAR	Fatalities	Fatality Rate	Dam Height (ft)	Reservoir Storage (af)	Breach Tf	Downstream Distance to PAR (miles)	Flood Severity Understanding
Allegheny County, PA Flash Flood	5/30/1986	no	low	no warning	night (early evening)	flash flood	2,200	8	0.00364	na	na	na	na	na
Arkansas River Flood, Colorado	6/3/1921	no	medium	adequate warning	night	regional flood	2,000	100	0.05000	na	na	na	0	vague
Arno River Flood, Florence Italy	11/3/1966	no	medium	adequate warning	day	releases from dams/flash flood	88,000	127	0.00144	na	na	na	< 1	unknown
Austin (Bayless) Dam	9/30/1911	yes	medium	some warning	day	sudden failure	2300	78	0.03400	50	1,500	fast	1.5	vague
Austin Texas Flood	5/24 - 5/25/1981	no	low	adequate warning	night	flash flood	1,180	13	0.01102	na	na	na	na	vague
Baldwin Hills Dam - dam to Sanchez Drive	12/14/1963	yes	medium	adequate warning	day	static failure	100	0	0.00000	65	738	moderately slow	0 to 0.5	precise
Baldwin Hills Dam - downstream of Sanchez Drive, including Village Green	12/14/1963	yes	medium	adequate warning	day	static failure	16,400	5	0.00030	65	738	moderately slow	0.5 to 3	precise
Banqiao Dam - Shahedian Town	8/8/1975	yes	high	some warning	night	overtopping failure	6,500	827	0.12723	80	398,868	moderately slow	3.7 to 7.5	unknown
Banqiao Dam - Suiping County (excluding Wencheng)	8/8/1975	yes	low	no warning	night	overtopping failure	151,000	9375	0.06209	80	398,868	moderately slow	12.4 to 28	na
Banqiao Dam - Wencheng Town	8/8/1975	yes	medium	no warning	night	overtopping failure	1976	929	0.47014	80	398,868	moderately slow	7.5 to 12.4	na
Banqiao Dam (and Shimantan Dam) - downstream of Suiping	8/8/1975	yes	low	no warning	night	overtopping failure	216,000	2892	0.01339	80	398,868	moderately slow	28 to 37	na
Bear Wallow Dam	2/22/1976	yes	medium	no warning	night	sudden failure high reservoir	8	4	0.50000	36	40	fast	0.8	na
Big Bay Dam	3/12/2004	yes	medium	adequate warning	day	static failure	unknown	0	0.00000	51	14,200	fast	0.6 to 18	unknown
Big Thompson Flood	7/31-8/1/1976	no	medium	little to no warning	night	flash flood	3,500	144	0.04114	na	na	na	na	vague
Brush Creek Flash Flood	9/12/1977	no	low	some warning	night	flash flood	2,380	20	0.00840	na	na	na	na	vague
Buffalo Creek Coal Waste Dam - Overall	2/26/1972	yes	medium	little to no warning	day	sudden failure high reservoir	5,000	125	0.02500	45	404	fast	1 to 15	vague
Bushy Hill Pond Dam	6/6/1982	yes	low	adequate warning	night	sudden failure high reservoir	300	0	0.00000	29	616	unknown	1.6	precise
Canyon Lake Dam/Black Hills Flood	6/9/1972	yes	medium	some warning	night	overtopping failure	17,000	245	0.01441	30	192	moderately fast	0	vague
Cyclone Xynthia, France - Villages of La Faute-sur-Mer and L'Aiguillon-sur-Mer	2/28/2010	no	low	no warning	night	sea wall breach	3,000	29	0.00967	unknown	na	unknown	varied	na
DMAD Dam	6/23/1983	yes	low	adequate warning	day	spillway failure	500	1	0.00200	34	16,000	fast	9 to 15	precise
Dongkoumiao Dam - Jiyi Village	6/2/1971	yes	low	no warning	day	static failure	1,200	32	0.02667	71	2067	unknown	0.3 to 0.6	na
Dongkoumiao Dam - Lijiayuan and Huangxikou Villages	6/2/1971	yes	low	no warning	day	static failure	3,500	154	0.04400	71	2067	unknown	0.9 to 1.2	na
Gleno Dam, Dezzo Village	12/1/1923	yes	high	no warning	day	static failure	500	209	0.41800	143	4,400	fast	1.1 to 13.3 and beyond	na
Great Flood of 1993	4/1993 to 10/1993	no	low	adequate warning	varied	regional flood	150,000	38	0.00025	na	na	na	na	precise
Hengjiang Dam - Jiaogutan and Xiangxin Villages	9/15/1970	yes	medium	adequate warning	day	static failure	2,500	1	0.00040	148	6,388	unknown	1.2 to 2.4	unknown
Hengjiang Dam - Jieyang City	9/15/1970	yes	low	no warning	day	static failure	45,000	850	0.01889	148	6,388	unknown	about 5-6	na
Hengjiang Dam - u/s of Jieyang City	9/15/1970	yes	low	no warning	day	static failure	50,000	40	0.00080	148	6,388	unknown	2.5 - 5	na
Hengjiang Dam - Xinjian and Xinsi Villages	9/15/1970	yes	high to medium	adequate warning	day	static failure	2,500	0	0.00000	148	6,388	unknown	1.2-2.4	precise
Heppner, Oregon Flash Flood	6/14/1903	no	medium	no warning	day	flash flood	1400	247	0.17643	na	na	na	na	na
Hurricane Agnes Floods	6/1972 - 7/1972	no	low	adequate warning	varied	regional flood	250,000	48	0.00019	na	na	na	na	precise
Hurricane Katrina, New Orleans, East Bowl	8/29/2005	no	low	adequate warning	day	post-hurricane levee breach	69,290	68	0.00098	13	na	slow	varied	unknown
Hurricane Katrina, New Orleans, Lower 9th Ward	8/29/2005	no	medium to low	adequate warning	day	post-hurricane levee breach	14,000	73	0.00521	13	na	moderately fast	beginning immediately d/s of levee toe	unknown
Hurricane Katrina, New Orleans, Metro Bowl	8/29/2005	no	low	adequate warning	day	post-hurricane levee breach	255,900	260	0.00102	13	na	slow	varied	unknown
Japan Tsunami, 2011, Higashimatsushima, Miyagi Prefecture	3/11/2011	no	high	some warning	day	tsunami flood wave	27,368	1138	0.04158	na	na	na	varied	unknown
Japan Tsunami, 2011, Minami Sanriku, Miyagi Prefecture	3/11/2011	no	high	some warning	day	tsunami flood wave	19,170	902	0.04705	na	na	na	varied	unknown
Japan Tsunami, 2011, Onagawa, Miyagi Prefecture	3/11/2011	no	high	some warning	day	tsunami flood wave	11,186	980	0.08761	na	na	na	varied	unknown
Ka Loko Dam	3/14/2006	yes	medium	no warning	night	overtopping failure	10 or more	7	maybe 0.7	40	1,200	unknown	2.7	na
Kansas River Flood	7/13/1951	no	low	adequate warning	varied	regional flood	58,010	11	0.00019	na	na	na	na	precise
Kelly Barnes Dam	11/6/1977	yes	medium	no warning	night	sudden failure high reservoir	100	36	0.36000	38	630	fast	1	na
Laurel Run Dam - Tanneryville	7/20/1977	yes	medium	no warning	night	overtopping failure	150	41	0.27333	42	450	unknown	1.5	na
Lawn Lake Dam - Fall River Road/Estes Park	7/15/1982	yes	medium	adequate warning	day	sudden failure	4,000	0	0.00000	26	674	unknown	8 to 13	precise
Lawn Lake Dam - Aspenglen Campground	7/15/1982	yes	medium	adequate warning	day	sudden failure	275	2	0.00700	26	674	unknown	7	vague
Lawn Lake Dam - Roaring River	7/15/1982	yes	high	no warning	day	sudden failure	25	1	0.04000	26	674	unknown	3	na
Lee Lake Dam	3/24/1968	yes	low	no warning	day	static failure	80	2	0.02500	25	300	unknown	0 to 5	na
Lijiazui Dam - Lijiazui Village	4/27/1973	yes	medium	no warning	night	overtopping	1,034	516	0.49903	82	1176	unknown	0.4	na
Little Deer Creek Dam	6/16/1963	yes	medium	no warning	day	sudden failure	7	1	0.14000	86	1,100	unknown	7.2	na
Liujiatai Dam - Gaoshi, Haoshan and Zhigushi Villages	8/8/1963	yes	high	adequate warning	night	overtopping	2,784	525	0.18858	117	32,866	fast	0.6 to 4.3	vague

Case Name	Maximum DV high (ft^2/s)	Maximum DV low (ft^2/s)	DV notes	Confidence	Confidence Notes	DSO-99-06 case?	RCEM data point?
Allegheny County, PA Flash Flood	unknown			good	data is very limited	Y	N
Arkansas River Flood, Colorado	147	50	147 ft^2/s is estimated close to the river	fair to good		Y	Y
Arno River Flood, Florence Italy	75	54	DV estimated by Bas Jonkman	fair to good	PAR could be further investigated.	N	Y
Austin (Bayless) Dam	160	80	high DV was estimated, but area not "swept clean"….the high DV occurred, probably at the river channel, but the developed areas may have been on the fringes.. From looking at photos of the aftermath, the damage does not appear to have been extensive enough to have had this high a level of DV exposure	good		Y	Y
Austin Texas Flood	70	10	DV is unknown, but was high enough to wash cars off bridges and damage houses	fair		Y	Y
Baldwin Hills Dam - dam to Sanchez Drive	200		DV was very high in the steep confined reach just below the dam - there were no fatalities in this reach though.	good		Y	Y
Baldwin Hills Dam - downstream of Sanchez Drive, including Village Green	147		Max DV estimated based on reported 5 ft deep at 20 mph; based on damage (147 ft2/s); average DV likely 70	good		Y	Y
Banqiao Dam - Shahedian Town	116	70	DV estimated by discharge divided by floodplain width	fair	Reported more than 1 hr of warning with a high fataltiy rate. Some photos and a detailed map would increase confidence, information on warning issuance seems sketchy. Residential structures were reportedly made of adobe. The weakness of the structures probably contributed to the fatality rate.	N	Y
Banqiao Dam - Suiping County (excluding Wencheng)	48	29	DV estimated by discharge divided by floodplain width	fair	Very high fatality rate for low severity flooding. Some photos and a detailed map would increase confidence. Residential structures were probably made of adobe. The weakness of the structures probably contributed to the fatality rate.	N	Y
Banqiao Dam - Wencheng Town	81	54	DV estimated by discharge divided by floodplain width	fair	Some photos and a detailed map would increase confidence. Residential structures were probably made of adobe. The weakness of the structures probably contributed to the fatality rate.	N	Y
Banqiao Dam (and Shimantan Dam) - downstream of Suiping	unknown	unknown	DV information could possibly be estimated if a better description/photos were available	fair	Fataltiy rate is more typical when compared to the high-end of the DSO-99-06 cases. Need DV information	N	N
Bear Wallow Dam	100	50	peak breach discharge may have been as high as 10,000 ft3/s. Dv is estimated assuming a 100 ft wide channel at the location of fatalities.	good	flood severity is downgraded to medium from the 99-06 estimate of high. Considering the height of the breach, the estimation of DV, and the photographs portraying the damage, the flood appears to fit better in the medium severity category	Y	Y
Big Bay Dam	470	78	DV is very high, but probably did not meet rate of rise criteria for high severity	good	this case has been studied extensively, but there are some conflicting data between various reports	N	Y
Big Thompson Flood	411 to 276	25	411 ft^2/s comes from Wikipedia description of 14mph and 20 foot wall of water. Other DV values come from USGS paper 1115	good		Y	Y
Brush Creek Flash Flood	50	10		fair		Y	Y
Buffalo Creek Coal Waste Dam - Overall	400	90	Estimated overall DV range	good		Y	Y
Bushy Hill Pond Dam	30	20	DV is very approximate	good		Y	Y
Canyon Lake Dam/Black Hills Flood	160	30	Wide range of DV - 2D hydraulic modeling results by Reclamation indicate that some fatalities may have occurred in locations where DV was in the low severity zone.	good	hydraulic modeling has been done and locations of many fatalties have been identified.	Y	Y
Cyclone Xynthia, France - Villages of La Faute-sur-Mer and L'Aiguillon-sur-Mer	32	11	DV estimated by Bas Jonkman, possibly with reported depths and estimates of velocities based on photos and videos	good	coastal flood, well documented on web	N	Y
DMAD Dam	15	10	DV is approximate	good	fits low severity category well	Y	Y
Dongkoumiao Dam - Jiyi Village	48	26	Zhou perform FLDWAV modeling in 2006, DV appears to have been estimated from model discharge data divided by flood plain width	fair	Upper bound fataltiy rate for low severity when compared to 99-06 case histories. A better description, photos and a detailed map would improve comnfidence in data	N	Y
Dongkoumiao Dam - Lijiayuan and Huangxikou Villages	15	11	Zhou perform FLDWAV modeling in 2006, DV appears to have been estimated from model discharge data divided by flood plain width	fair	Very high fatality rate for low severity when compared to 99-06 case histories. A better description, photos and a detailed map would improve comnfidence in data	N	Y
Gleno Dam, Dezzo Village	2,714		Estimated DV at Dezzo	good	Dv has been estimate d for multiple locations, but PAR is known only for Dezzo Village	N	Y
Great Flood of 1993	unknown			poor	this flood event contains limited information. The value that it adds to the overall consequences database may be minimal.	Y	N
Hengjiang Dam - Jiaogutan and Xiangxin Villages	140	54		fair	Warning was reported to not have been very good at locations beyond 1.8 miles from the dam.	N	Y
Hengjiang Dam - Jieyang City	54	32		fair	At Jieyang City, flood severity was low but fatality rates actually increased, due to the lack of warning.	N	Y
Hengjiang Dam - u/s of Jieyang City	54	32		fair		N	Y
Hengjiang Dam - Xinjian and Xinsi Villages	549	140	brick and masonry buildings were swept away by the flood	fair	very interesting - high severity flooding, 15 min warning (adequate warning in 15 min!), eveyone got out - zero fatalities	N	Y
Heppner, Oregon Flash Flood	100	50	Floods depths greater than 10 feet, DV is guesstimated, photos show building destruction in some locations that may indicate DV of 80 ft2/s or higher.	fair		Y	Y
Hurricane Agnes Floods	unknown			poor	no specific information about the characteristics of flooding relative to the flood fatalities is available	Y	N
Hurricane Katrina, New Orleans, East Bowl	22	0	DV based on hydraulic modeling by Bas Jonkman et al	good		N	Y
Hurricane Katrina, New Orleans, Lower 9th Ward	75	32	DV based on hydraulic modeling by Bas Jonkman et al	good	event is well documented, many were warned, but did not evacuate because they had no where to go, no money, no car etc..	N	Y
Hurricane Katrina, New Orleans, Metro Bowl	22	0	DV based on hydraulic modeling by Bas Jonkman et al	good		N	Y
Japan Tsunami, 2011, Higashimatsushima, Miyagi Prefecture	269		DV estimated by Bas Jonkman	fair to good	further investigation may improve confidence level	N	Y
Japan Tsunami, 2011, Minami Sanriku, Miyagi Prefecture	861		DV estimated by Bas Jonkman, depth came from Wikipedia, not sure how velocity was estimated	fair to good	further investigation may improve confidence level	N	Y
Japan Tsunami, 2011, Onagawa, Miyagi Prefecture	807		DV estimated by Bas Jonkman, not sure how	fair to good	further investigation may improve confidence level	N	Y
Ka Loko Dam	160	60	DV is very approximate	fair		N	Y
Kansas River Flood	unknown			poor	no specific information about the characteristics of flooding relative to the flood fatalities is available	Y	N
Kelly Barnes Dam	120	50	max DV estimated using 24,000 ft^3/s max discharge and 200 ft wide flooded area. Low estimate based on lower threshold for medium severity	good		Y	Y
Laurel Run Dam - Tanneryville	160	80	houses destroyed, DV is a guesstimate, high velocity info from usgs hydraulic study, but no depths given.	good		Y	Y
Lawn Lake Dam - Fall River Road/Estes Park	71			very good		Y	Y
Lawn Lake Dam - Aspenglen Campground	121			very good		Y	Y
Lawn Lake Dam - Roaring River	210	139		very good		Y	Y
Lee Lake Dam	80	10	based on damage to buildings	fair to good		Y	Y
Lijiazui Dam - Lijiazui Village	110		Zhou perform FLDWAV modeling in 2006, DV appears to have been estimated from model discharge data divided by flood plain width	fair	High fatality rate for medium severity (Machhu II was higher though) Adobe residential structures, which were weak, may have contributed to the high fatalities, A better description, photos and a detailed location map might improve confidence in data	N	Y
Little Deer Creek Dam	196	126	DV values away from river channel, where the PAR may have been located, were probably lower then what is presented here	good		Y	Y
Liujiatai Dam - Gaoshi, Haoshan and Zhigushi Villages	409		DV probably estimated from discharge/flood width	fair	warning was issued more than 1 hr prior to failure. Most evacuated to high ground, but then many returned home to sleep, not believing that there would be serious flooding	N	Y

Case Name	Date	Dam Failure?	Flood Severity	Warning	Day/Night	Scenario	Total PAR	Fatalities	Fatality Rate	Dam Height (ft)	Reservoir Storage (af)	Breach Tf	Downstream Distance to PAR (miles)	Flood Severity Understanding
Liujiatai Dam - Linxi and Taiping Villages and Tuonan Town	8/8/1963	yes	medium to high	some warning	night	overtopping	3,395	352	0.10368	117	32,866	fast	4.3 to 9.3	vague
Liujiatai Dam > 9.3 miles downstream	8/8/1963	yes	low	no warning	night	overtopping	11,929	60	0.00503	117	32,866	fast	> 9.3 miles downstream	vague
Machhu II Dam	8/11/1979	yes	medium	little to no warning	day	overtopping failure	100,000	10,000	0.10000	85	81,900	moderate	4	na
Malpasset - Lower Reyran River	12/2/1959	yes	high/medium	no warning	night	sudden failure high reservoir	330	69	0.21000	200	18,000	very fast	2.2 - 5.9	na
Malpasset Dam - Argens River to the sea	12/2/1959	yes	low	some warning	night	sudden failure high reservoir	2490	27	0.01084	200	18,000	very fast	6.8 - 8.7	unknown
Malpasset Dam - Frejus	12/2/1959	yes	high/medium	no warning	night	sudden failure high reservoir	625	227	0.36320	200	18,000	very fast	5.9 - 6.8	na
Malpasset Dam - Upper Reyran River	12/2/1959	yes	high	no warning	night	sudden failure high reservoir	220	155	0.70000	200	18,000	very fast	0 - 2.2	na
Manitou Springs Flash Flood (Highway 24)	8/9/2013	no	medium	no warning	day	flash flood	50	1	0.02000	na	na	na	0 to 0.5	na
Meadow Pond (Bergeron Pond) Dam	3/13/1996	yes	low	no warning	night	static failure	25	1	0.04000	32	282	moderately fast	< 1	na
Mill River Dam	5/16/1874	yes	medium	little to no warning	day	sudden failure	888	138	0.15541	43	307	fast	3 to 10	unknown
Mohegan Park (Spaulding Pond) Dam	3/6/63	yes	low	little to no warning	night	sudden failure high reservoir	1,000	7	0.00700	20	138	unknown	0 to 2	na / unknown for those warned
Nevado del Ruis Lahar	11/13/1985	no	high	no warning	night	volcanic eruption, lahar mudflow	26,000	22,000	0.85000	na	na	na	30	na
Passaic River Basin Flood	4/1/1984	no	low	adequate warning	day/night	regional flood	25,000	2	0.00008	na	na	na	na	precise
Phoenix Area Flood	2/15/1980	no	low	adequate warning	unknown	regional flood	6,000	0	0.00000	na	na	na	na	precise
Prospect Dam	2/10/1980	yes	low	adequate warning	day	static failure	100	0	0.00000	45	5,850	fast	unknown	precise
Quail Creek Dike	1/1/1989	yes	low	adequate warning	night	static failure	1,500	0	0.00000	28	40,000	moderately fast	16	precise
Reservoir No.1 Dam, S. Davis Co. Water Imp. Dist.	9/24/1961	yes	low	no warning	night	static failure	80	0	0.00000	15	4.4	unknown	0.02	na
Seminary Hill Reservoir No. 3	10/5/1991	yes	low	no warning	day	static failure	150	0	0.00000	17	10.7	unknown	0.25	na
Shadyside, Ohio Flash Flood	6/14/1990	no	medium	little to no warning	night	flash flood	884	24	0.02715	na	na	na	na	vague
Shijiagou Dam - Shijiagou Village	8/25/1973	yes	medium	some warning	day	overtopping	300	81	0.27000	98.4	689	unknown	0.5	vague
Situ Gintung Dam, Jakarta Indonesia	3/27/2009	yes	medium	little to no warning	night	hydrologic	1,600	98	0.06125	52.5	1630	unknown	0 to 1	unknown
South Fork Dam - East Conemaugh	5/31/1889	yes	high	adequate warning	day	overtopping failure	2000	11	0.00550	72	11,500	fast	11.5	precise
South Fork Dam - Johnstown	5/31/1889	yes	med to high	no warning	day	overtopping failure	19806	1756	0.08866	72	11,500	fast	14	na
South Fork Dam - Mineral Point	5/31/1889	yes	high	adequate warning	day	overtopping failure	200	7	0.03500	72	11,500	fast	6.5	precise
South Fork Dam - Town of South Fork	5/31/1889	yes	high	adequate warning	day	overtopping failure	200	2	0.01000	72	11,500	fast	2	precise
South Fork Dam - Woodvale	5/31/1889	yes	med to high	no warning	day	overtopping failure	1247	314	0.25180	72	11,500	fast	12.5	na
South Platte River Flood	6/16/1965	no	low	adequate warning	day/night	flash flood / regional flood	10,000	1	0.00010	na	na	na	na	precise
St Francis Dam - Edison Camp	3/13/1928	yes	high	no warning	night	sudden failure high reservoir	150	84	0.56000	188	38,000	very fast	18.6	na
St Francis Dam - Fillmore	3/13/1928	yes	medium	some warning	night	sudden failure high reservoir	unknown	unknown	unknown	188	38,000	very fast	31.7	vague
St Francis Dam - Oxnard Plain	3/13/1928	yes	low	adequate warning	night	sudden failure high reservoir	unknown	unknown	unknown	188	38,000	very fast	50 to 53	vague
St Francis Dam - Powerhouse No. 2	3/13/1928	yes	high	no warning	night	sudden failure high reservoir	unknown	exact number unknown	0.90000	188	38,000	very fast	1.4	na
St Francis Dam - Santa Paula	3/13/1928	yes	medium	some / adequate warning	night	sudden failure high reservoir	unknown	unknown	unknown	188	38,000	very fast	40.1	vague
Stava Tailings Dam	7/19/1985	yes	high	no warning	day	sudden failure	unknown	268	unknown	164.4	146	fast	0.5	na
Taum Sauk Upper Dam	12/14/2005	yes	high	no warning	night	overtopping failure/misoperation	unknown	0	0.00000	94	4,300	fast	0.25	na
Teton Dam - Rexburg	6/5/1976	yes	medium	adequate warning	day	sudden failure	10,000	2	0.00020	305	240,000	moderately fast	15.3	precise
Teton Dam - Roberts	6/5/1976	yes	low	adequate warning	day	sudden failure	unknown	0	0.00000	305	240,000	moderately fast	43.1	unknown
Teton Dam - Sugar City	6/5/1976	yes	medium	adequate warning	day	sudden failure	11,360	0	0.00000	305	240,000	moderately fast	12.3	precise
Teton Dam - Teton Canyon	6/5/1976	yes	high	no warning	day	sudden failure	2	1	0.50000	305	240,000	moderately fast	2.5	na
Teton Dam - Wilford	6/5/1976	yes	medium	some warning	day	sudden failure	370	8	0.02100	305	240,000	moderately fast	8.4	precise
Texas Hill Country Flood	8/1 - 8/3/1978	no	medium/low	adequate warning	night	flash flood	2,070	27	0.01304	na	na	na	na	vague
Timberlake Dam	6/22/1995	yes	medium	no warning	night	overtopping	7	2	0.28571	33	1,449	unknown	< 1	na
Vajont Dam	10/9/1963	no	high	no warning	night	landslide into reservoir, overtopping wave	1350	1269	0.94000	869	122,000	very fast	1	na
Vega de Tera	1/9/1959	yes	high	no warning	night	sudden failure high reservoir	500	144	0.28800	112	6,500	very fast	3	na
Walnut Grove Dam	2/21/1890	yes	high	no warning	night	overtopping failure	unknown	70 to 100	unknown	110	60,000	unknown	15 to 30	na

Case Name	Maximum DV high (ft^2/s)	Maximum DV low (ft^2/s)	DV notes	Confidence	Confidence Notes	DSO-99-06 case?	RCEM data point?
Liujiatai Dam - Linxi and Taiping Villages and Tuonan Town	248	91	DV estimate discharge (obtained from gaging station) divided by flood width	fair	more details, including photos and a detailed map would help to increase confidence	N	Y
Liujiatai Dam > 9.3 miles downstream	< 50?		Dv not given	fair	warning actually descreased as distance increased from the dam!	N	Y
Machhu II Dam	150	50		good	total fatality and PAR numbers from Utpal Sandesara, author of book "No one had a tongue to speak" about Machhu II Dam	N	Y
Malpasset - Lower Reyran River	215	43	DV is based on BC Hydro 2D analysis	good		N	Y
Malpasset Dam - Argens River to the sea	43	11	DV is based on BC Hydro 2D analysis	good		N	Y
Malpasset Dam - Frejus	215	43	BCH 2D modeling, Upper Frejus was high severity, but much of the town was medium	good	BC Hydro research estimates where PAR was located and hydraulic model estimates DV at d/s locations, total PAR 3668. total fatalities 423 to 550	Y	Y
Malpasset Dam - Upper Reyran River	1,076	215	DV is based on BC Hydro 2D analysis	good	BC Hydro research estimates where PAR was located and hydraulic model estimates DV at d/s locations, total PAR 3668. total fatalities 423 to 550,	Y	Y
Manitou Springs Flash Flood (Highway 24)	50		Maximum DV estimated from reports of 5 foot flood depths and from video footage of floating cars (at least 10 ft/s)	good	Case is well documented with photos, video, newspaper articles and interviews with witnesses	N	Y
Meadow Pond (Bergeron Pond) Dam	7		Dv estimatedd by McClelland and Bowles - was likely higher at road crossing where fatality occurred.	good	event has been well documented	N	Y
Mill River Dam	160	50	264 ft^2/s assuming 20 foot depth at Williamsburg and 20 minute travel time. This anecdotal information produces a very high dv. 50 to 160 ft^2/s may be more realistic.	good	Some documentation exists, but event occurred long ago.	Y	Y
Mohegan Park (Spaulding Pond) Dam	80	10		good	data is limited	Y	Y
Nevado del Ruis Lahar	950			good		Y	Y
Passaic River Basin Flood	unknown			fair		Y	N
Phoenix Area Flood	50	10		fair		Y	Y
Prospect Dam	4			good		Y	Y
Quail Creek Dike	29		DV was much higher at unpopulated location close to dam	good		Y	Y
Reservoir No.1 Dam, S. Davis Co. Water Imp. Dist.	25	10		fair		Y	Y
Seminary Hill Reservoir No. 3	80	10		good		Y	Y
Shadyside, Ohio Flash Flood	100	50	DV is estimated to be 50 to 100 ft^2/s or greater ,based on steep channel and 20-ft depths. Photos show significant building destruction which supports the high DV	good		Y	Y
Shijiagou Dam - Shijiagou Village	68		Zhou perform FLDWAV modeling in 2006, DV appears to have been estimated from model discharge data divided by flood plain width	fair	Adobe residential structures, which were weak, may have contributed to the high fatalities, A better description, photos and a detailed location map might improve confidence in data	N	Y
Situ Gintung Dam, Jakarta Indonesia	108	54	depths were reported, velocity range was guesstimated	good	event has been well documented	N	Y
South Fork Dam - East Conemaugh	210			good	a lot of data is available for this event, but it happened long ago	Y	Y
South Fork Dam - Johnstown	135			good	a lot of data is available for this event, but it happened long ago	Y	Y
South Fork Dam - Mineral Point	360			good	a lot of data is available for this event, but it happened long ago	Y	Y
South Fork Dam - Town of South Fork	250			good	a lot of data is available for this event, but it happened long ago	Y	Y
South Fork Dam - Woodvale	180			good	a lot of data is available for this event, but it happened long ago	Y	Y
South Platte River Flood	40	10		fair		Y	Y
St Francis Dam - Edison Camp	1,238	100 to 160	based on MIKE21 hydraulic model	very good	total flood event fatalities range from 420 to more than 600	Y	Y
St Francis Dam - Fillmore	160	50		good	total flood event fatalities range from 420 to more than 600	N	N
St Francis Dam - Oxnard Plain	50	10		fair	total flood event fatalities range from 420 to more than 600	N	N
St Francis Dam - Powerhouse No. 2	2,960	-	based on forensic data	very good	total flood event fatalities range from 420 to more than 600	Y	Y
St Francis Dam - Santa Paula	160	50		good	total flood event fatalities range from 420 to more than 600	N	N
Stava Tailings Dam	3250	2500		good	Travel times based on seismogram readings, depths are anecdotal	Y	N
Taum Sauk Upper Dam	160 to maybe 200	80	DV is guesstimated based on photos of the flood zone wher ethe area appears to have been swept clean, park ranger's wood frame house was destroyed, so low dv was at least 80 ft^2/s	good		N	Y
Teton Dam - Rexburg	63			good		Y	Y
Teton Dam - Roberts	34			good		N	Y
Teton Dam - Sugar City	180			good		N	Y
Teton Dam - Teton Canyon	1,650	1,100	rate of rise meets high severity criteria	good		N	Y
Teton Dam - Wilford	180			good		Y	Y
Texas Hill Country Flood	80	10	houses were destroyed. May have been medium severity in places.	fair to good	event is well documented but DV related info not reported	Y	Y
Timberlake Dam	61		Dv estimatedd by McClelland and Bowles - was likely higher at road crossing where fatality occurred.	fair to good	PAR estimated by McClelland and Bowles	N	Y
Vajont Dam	5,060		High DV is based on flood wave traveling 1 mile in 4 minutes, with a reported max depth of 230 feet.	good	Total fatalities has been estimated at 2,600. The PAR and fatality info in table is for the town of Longerone where flooding was most severe.	Y	Y
Vega de Tera	400	200	Dv estimate based on reported 20 ft depth and velocities assumed to range from 10 to 20 ft/s (St Francis Dam velocity at power house No.2 was 26 ft/s, so these numbers may be reasonable..)	good		Y	Y
Walnut Grove Dam	880		DV estimate is at Wickenburg. DV at upstream construction camp may have been even higher	good but need more info		N	N