Dam Failure

Accidental conditions where dam failure and inundation results in one fatality or greater. This event does not include releases caused by malicious acts.[1]

Data Summary[2]

In the following table, note that the low and high likelihoods do not correspond to the low and high impacts. In addition, low and high impacts are not necessarily correlated with each other between different impact categories.

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities[3]	1	17	170
	Injuries and Illnesses	Number of Injuries or Illnesses[4]	0	50	3,000
Economic	Direct Economic Loss	U.S. Dollars (2011)	N/A[5]		
Social	Social Displacement	Displaced from Home ≥ 2 Days[6]			
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins[7]	Moderate[8]		
LIKELIHOOD	Frequency of Events	Number of Events per Year[9]	0.17	0.54	3

Event Background

A catastrophic dam failure may be caused by extraordinary levels of rainfall or snowmelt, leading to water levels higher than the dam can handle. Dam failures can also be caused by earthquakes, mechanical failure of the dam, and other mechanisms. The most common cause of dam failure is prolonged rainfall that produces flooding.[10]

[1] The data and findings for the SNRA Dam Failure event were completed in 2011, but a separate risk summary sheet for the event was not completed (the data were reported as a spreadsheet). This risk summary sheet as a text description for this data was written in 2013 using material written for the main body of the Technical Report.

[2] The data reported in this table represent historical U.S. dam failures reporting one or more human fatality from 1960-2009, compiled by the Dams Sector Office (DHS/NPPD) from U.S. Bureau of Reclamation historical data (Table 1).

[3] Low, best, and high estimates for fatalities come from the low, average, and high values of the set of events meeting threshold criteria.

[4] The high injury estimate is the highest reported injury from a subset of the events in the overall data set for which injury reports were available. The low injury estimate was selected to be zero by the SNRA project team, as the most reasonable assumption consistent with the sparse data available and the pattern observed from fatality counts from the set. The best estimate is the geometric mean of the high estimate and 1 (since a geometric mean cannot be taken of zero). See Injuries discussion for details.

[5] Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the U.S.. See Economic discussion for details.

[6] See Social Displacement discussion for details.

[7] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[8] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.

[9] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 2 above.

[10] Federal Emergency Management Agency (1997). Multi-Hazard Identification and Risk Assessment (MHIRA), chapter 20: Dam Failure.

The scope of this event does not include dam failures caused by intentional attacks, whether kinetic (e.g. explosives) or cyber attacks, which are considered within the Explosives Terrorist Attack and the Cyber Event affecting Physical Infrastructure events respectively. The U.S. Department of Homeland Security is the lead Sector-Specific Agency for managing risks to the Dams Sector due to intentional attack under the National Infrastructure Protection Plan.[11] Scenarios analogous to the levee failure of Hurricane Katrina, where the levees are local to the community suffering destruction and their failure is directly caused by a hurricane which itself directly impacts the community, are also excluded from the scope of this event to avoid double counting with the Hurricane event.

There are 83,000 dams listed in the National Inventory of Dams.[12] People, property, and infrastructure downstream of dams could be subject to a devastating loss of life and damage in the event of sudden and unexpected collapse. The United States Society on Dams, a professional organization devoted to dam engineering, safety, and environmental issues, notes that 17 dams in the U.S. are over 500 feet in height, and there are 16 dams with reservoir capacities over 3 million acre-feet.[13] The number of high-hazard-potential dams (dams whose failure would cause loss of human life) has increased to 13,000, with more than 3,300 high and significant dams located within one mile of a downstream population center and more than 2,400 located within two miles.[14,15]

In addition to single dam failures, there is also the possibility of a failed dam stressing other dams downstream, causing a cascading and escalating catastrophic disaster.

The most significant factor determining the magnitude of life loss from a dam collapse is the speed and extent of population evacuation before the water arrives, which is primarily dependent upon warning time, communications, local emergency planning and preparedness, and whether local road networks allow for the rapid evacuation of downstream populations to higher ground within what may be only minutes.[16,17,18] Deaths on a massive scale may result if an evacuation cannot be quickly implemented to move people above inundation levels.

Assumptions

Although numerous estimates of failure likelihoods and impacts for particular dams may be found in the literature,[19,20,21,22,23,24,25,26,27,28,29] many of which are based upon detailed quantitative

[11] U.S. Department of Homeland Security (2013). Dams Sector Resources [web resource]. At http://www.dhs.gov/dams-sector-resources (accessed April 2013).
[12] Federal Emergency Management Agency (2009, February). Dam Safety in the United States. FEMA P-759; at http://www.fema.gov/library/viewRecord.do?id=3677 (checked April 2013).
[13] United States Society on Dams. Dam, Hydropower and Reservoir Statistics. Accessed July 25, 2011. http://ussdams.org/uscold_s.html.
[14] Association of State Dam Safety Officials, Dam Safety 101, available at http://www.damsafety.org.
[15] FEMA (2009, February).
[16] Aboelata, M.A. and Bowles, D.S. (2005). LIFESim: A Model for Estimating Dam Failure Life Loss. Institute for Dam Safety Risk Management, Utah State University, Logan, Utah, Report to Institute for Water Resources, U.S. Army Corps of Engineers and Australian National Committee on Large Dams.
[17] McClelland et al (2002, July). Estimating life loss for dam safety risk assessment – a review and new approach. IWR Report 02-R-3, Institute for Dam Safety Risk Management, Utah State University; at http://planning.usace.army.mil/toolbox/library/IWRServer/02-R-3.pdf (checked April 2013).
[18] Graham, W.J. (2009, September). A procedure for estimating loss of life caused by dam failure. U.S. Department of Interior. Bureau of Reclamation, DSO-99-06, 1999; at http://www.usbr.gov/ssle/damsafety/Risk/Estimating%20life%20loss.pdf (checked April 2013).
[19] Oregon Partnership for Disaster Resilience. (2009, October). Eugene/Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan. Prepared for The Cities of Eugene and Springfield, Oregon. Accessed July 19, 2011: www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf.
[20] Bowles et al (1999, November). Alamo Dam demonstration risk assessment. Proceedings of the Australian Committee on Large Dams (ANCOLD) Annual Meeting, Jindayne, New South Wales, Australia. At http://www.engineering.usu.edu/uwrl/www/faculty/dsb/alamo.html (checked April 2013).
[21] Bowles et al (2005) Risk-based evaluation of operating restrictions to reduce the risk of earthquake-induced dam failure [model Lake Success Dam, California]. At http://uwrl.usu.edu/people/faculty/DSB/ussd2005.pdf (checked April 2013).
[22] Lewis et al (2011, April). Approaches to estimating consequences due to levee failure, St. Paul Levee system beta test. Proceedings, 31st Annual U.S. Society of Dams Conference, San Diego, pp 1105-1115; at http://ussdams.com/proceedings/2011Proc/1105-1116.pdf (checked April 2013).

modeling,[30,31] the SNRA project team was unable to locate an overall quantitative assessment of national dam risk during the research phase of the SNRA project. The closest example of such an assessment was a quantitative risk assessment of major California dams[32] done for the U.S. Atomic Energy Commission's 1974 WASH-1400 report, a comparative assessment of civilian nuclear power risk relative to other catastrophic risks to the Nation which parallels the SNRA in many respects.[33] Although this dams study pioneered a number of quantitative methods used by subsequent studies, because it was the first of its kind and because of its limited geographic scope the SNRA project team were unable to determine how representative its results were of the true risk of catastrophic dam failure for the entire Nation in the present day.

For this reason, the SNRA project team elected to use U.S. historical data for its quantitative estimates of likelihood and fatalities for the dam event. The historical data were provided to the SNRA project by the Dams Sector Office of the Office of Infrastructure Protection, DHS/NPPD as part of a prepublication draft report on impact estimation for dam failures.[34] The threshold selected for the Dam Failure national-level event for the SNRA project was one or more human fatalities. Since this source's data set included all dam failures with one or more fatality from 1960-2009 but only failures causing 25 or more fatalities before 1960, the SNRA project team selected 1960-2009 as the temporal window for its own data set. After consolidation of entries for secondary dam failures caused by the failure of upstream dams, which the SNRA treated as single cascading failure events, 26 historical events remained in the set (see Table 1 below).

Likelihood

Estimates in the literature for the annual probability of failure of a generic dam range from 10^{-5} to 10^{-3}, clustering around 10^{-4}. Given an expected lifetime of 100 years, this corresponds to a generic probability of failure of 10^{-2} for a given dam over its lifetime. As these generic estimates are ultimately based upon extrapolations from historical data, by construction these theoretical estimates are usually in good agreement with estimates derived with historical data sets such as

[23] Texas Colorado River Floodplain Coalition, 2004. Dam Failure. 2004 Hazard Mitigation Action Plan - Creating a Disaster-Resistant Lower Colorado River Basin, chapter 15. At www.tcrfc.org/member-resources/hazard-mitigation/2004-hazard-mitigation-action-plan/ (checked April 2013).
[24] Needham et al (2011, June). Consequence Estimation for the Herbert Hoover Dike Dam [Florida] Safety Risk Assessment. Presentation, USACE Infrastructure Systems Conference, June 13-17 2011; at http://www.usace-isc.org/presentation/HHC%20-%20Hydrologic%20Engineering/Consequence%20 Estimation%20for%20the%20HHD%20Dam%20Safety%20Risk%20Assessment_Ochs_Elke2.pdf (checked April 2013).
[25] Department of Water Resources, State of California (2008, December). Delta Risk Management Strategy Phase 1 Risk Analysis Report, section 12 (Consequences Modeling); at www.water.ca.gov/ floodmgmt/dsmo/sab/drmsp/docs/Risk_Report_Section_12_Final.pdf (checked April 2013).
[26] Eiker et al (2000, October). Application of risk-based analysis to planning reservoir and levee flood damage reduction systems [risk assessment Folsom Dam]. Presentation; at http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-160.pdf (checked April 2013).
[27] Goettel, K.A. (2001, September 24). Regional All Hazard Mitigation Master Plan for Benton, Lane and Linn Counties, Phase Two. Prepared for the Benton County Project Impact and the Oregon Cascades Regional Emergency Management Coordinating Council.
[28] City of Livermore, California (2005). Comprehensive Emergency Management Plan, Annex D: All Hazard Vulnerability Assessment. At http://www.cityoflivermore.net/civicax/filebank/documents/4184/ (checked April 2013).
[29] City of Los Angeles (2008). Citywide General Plan Framework Final Environmental Impact Report, Section 2.17, Geologic/Seismic Conditions; at http://cityplanning.lacity.org/housinginitiatives/housingelement/frameworkeir/FrameworkFEIR.pdf (checked April 2013).
[30] U.S. Army Corps of Engineers (1987). Socioeconomic considerations in dam safety risk analysis. IWR Report 87-R-7, Risk Analysis Research Program USACE; at http://planning.usace.army.mil/toolbox/library/IWRServer/IWR001-000255-000433.pdf (checked April 2013).
[31] Dam Safety Office, U.S. Bureau of Reclamation (1998, July). Prediction of embankment dam breach parameters: a literature review and needs assessment. Report DSO-98-004, Water Resources Research Laboratory; www.usbr.gov/pmts/hydraulics_lab/twahl/breach/breach_links.html (checked April 2013).
[32] Ayyaswamy et al (1974). Estimates of the risks associated with dam failure. University of California – Los Angeles report UCLA-ENG-7423 for the U.S. Atomic Energy Commission; at http://www.osti.gov/energycitations/product.biblio.jsp?query_id=1&page=0&osti_id=6387737 (checked April 2013).
[33] Rasmussen, Norman (1975, October). Reactor Safety Study: An assessment of accident risks in U.S. commercial nuclear power plants. Chapter 6: Comparison of nuclear accident risks to other societal risks. U.S. Nuclear Regulatory Commission, WASH-1400 (NUREG 75/014). Available at http://teams.epri.com/PRA/Big%20List%20of%20PRA%20Documents/WASH-1400/02-Main%20Report.pdf (checked April 2013).
[34] U.S. Department of Homeland Security (2011, September), Estimating Loss of Life for Dam Failure Scenarios. Dams Sector Office, Office of Infrastructure Protection, National Protection and Programs Directorate; at http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-LossofLife.pdf (accessed April 2013).

that used by the SNRA.[35,36,37,38,39] Expected failure likelihoods of particular dams vary from one dam to another, depending on size, age, construction, local geological factors, and use.[40,41,42]

Of the historical events in table 2, the low, best, and high estimates for frequency correspond to the inverse of the longest interarrival time (in years) between events in the historical set (low estimate), the average interarrival time (best estimate), and the maximum number of events occurring within the same calendar year (high estimate).

Fatalities and Injuries

Fatality estimates correspond to the low, average, and maximum number of fatalities from events in the set. As a minimum of one fatality was used as the threshold for inclusion in the set, all events had fatalities to count.

Injuries were not reported by the primary data source relied upon for event frequency and fatalities, but were obtained separately for a limited number of events from the set by additional staff research. Of this set, the low number was 2 (Bergeron Pond Dam failure, New Hampshire, 1996) and the high number was 3000 (Canyon Lake Dam, South Dakota, 1972). The SNRA project team made the assumption that zero injuries was a reasonable low assumption. Given the sparseness of injury data, the project team decided to use a geometric mean of the high estimate (3,000) and 1 injury (since a geometric mean cannot be taken of zero) for the best estimate. This approach seemed reasonable given that the arithmetic average of the set of fatalities (17) was on the order of the geometric mean (13) of the same set.

Economic Loss

The SNRA project team could not obtain reasonably defensible estimates of economic damage from dam failure during the research phase of the SNRA project.[43] Studies of specific dam failure scenarios have estimated economic impacts in the hundreds of millions to billions of dollars. Examples include estimates ranging from $400M to $2.9B for failures of the Miller Dam and Mansfield Dam in Austin, Texas;[44] estimates ranging from $78M to $4.5B for dams in northeastern Idaho;[45] and an estimate of approximately $20B for a catastrophic failure of the

[35] Baecher et al (1980, June). Risk of dam failure in benefit-cost analysis. Water Resources Research 16(3) 449-456. This reference is the source of a common tabulation of estimates, and may be the primary origin of 10-4 being used as a common rule of thumb for dam risk estimation. The tabulation of prior estimates is substantively reproduced in Wang, Z. Melching, S. Management of Impounded Rivers. http://www.irtces.org/zt/training2007/ppt/ch-7%20IMPOUNDED-3.pdf. [accessed July 2011] and Salas, Jose D. (2006), Dam Breach Floods [instructional handout], at www.engr.colostate.edu/~jsalas/classes/ce624/Handouts/Dam%20Break%20Floods-Introduction.pdf (accessed April 2013).
[36] Biswas, A. 1971. Some Thoughts On Estimating Spillway Design Flood, *International Association of Scientific Hydrology. Bulletin*, 16:4, 63-72.
[37] Bowles et al (2005), op cit.
[38] Crum, Douglas (2009, January 28). Dams Safety Program [presentation], slide 22. Presentation, Society of American Military Engineers (SAME) Industry Day 2009, University of Missouri-Kansas City; at http://www.sameomaha.org/Files/Kansas%20City%20Post%20Industry%20Day%20Presentations%20-%20January%2027-28,%202009/Douglas%20Crum,%20P.E._USACE_Dams%20Safety%20Program.pdf (accessed April 2013).
[39] Hirschberg et al (1998, November). Severe accidents in the energy sector (1st ed.). Paul Scherrer Institut report number 98-16; at http://manhaz.cyf.gov.pl/manhaz/szkola/materials/S3/psi_materials/ENSAD98.pdf (checked April 2013).
[40] National Research Council (1985). Safety of dams: flood and earthquake criteria. Committee on Safety Criteria for Dams, Water Science and Technology Board, National Academies; at http://www.nap.edu/catalog.php?record_id=288 (checked April 2013).
[41] U.S. Bureau of Reclamation (2008, March 19). Dam safety – managing risk [presentation]. Slide 27, Reclamation Risk Profile. Presentation, Tolerable Risk Workshop, U.S. Bureau of Reclamation, U.S. Federal Energy Regulatory Commission, U.S. Army Corps of Engineers, March 18-19 2008; at http://www.usbr.gov/ssle/damsafety/jointventures/tolerablerisk/11Muller.pdf (checked April 2013).
[42] McClenathan, Jeffrey T. (2010). Update for screening portfolio risk analysis for U.S. Army Corps of Engineers dams. Proceedings, 30th Annual U.S. Society on Dams Conference April 12-16 2010, 1355-1366; at http://ussdams.com/proceedings/2010Proc/1355-1366.pdf (checked April 2013).
[43] The primary data source did not report economic loss estimates. For an approach relating economic losses to Population At Risk (PAR), see page 13 of Dams Sector (2011, September): Estimating Economic Consequences for Dam Failure Scenarios. Office of Infrastructure Protection, National Protection and Programs Directorate (NPPD), U.S. Department of Homeland Security; http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-EconomicConsequences.pdf (checked April 2013).
[44] Texas Colorado River Floodplain Association, op cit.
[45] Northeastern Idaho Region, 2008. All Hazard Mitigation Plan Regional Summary, p 33.

Hills Creek Dam in Oregon.[46] However, the SNRA project team was unable to determine how representative this limited set of regional scenarios were of the economic risk of dam failure for the Nation as a whole.

Social Displacement

The breaching of a major dam would force an enormous evacuation of downstream residents. Studies of two different dams predicted over 250,000 people would be required to evacuate if there were a catastrophic dam failure at the Hills Creek Dam[47] in Oregon or the Folsom Dam in California.[48] The expectation would be that disruption and displacement in the inundated area would last for an extended period, given the physical destruction of housing and infrastructure. Towns and residential areas scoured by the wall of water would take years to rebuild.

The SNRA project team was not able to collect data over the full range of dam breach events within the historical data set. Because fatalities, the scale for which the SNRA project team was able to determine impacts for each event in the data set by construction, clustered at the minimum of 1 and included very few much larger-impact events, the SNRA project team assumed a similar pattern for social displacement, assuming a minimal value (1 displaced) for the low estimate of social displacement. As with injuries, the SNRA project team selected the geometric mean of the low and high estimates (500) as the best estimate.

Psychological Distress

Psychological impacts for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[49] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

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[46] Goettel, *op cit.*

[47] Oregon Partnership for Disaster Resilience. (2009). Eugene/Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan. Prepared for The Cities of Eugene and Springfield, Oregon. October 2009. Accessed July 19, 2011: http://www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf.

[48] Ayyaswamy, supra note 2. The 250,000 estimate is actually of fatalities, largely in Sacramento, following a catastrophic breach of Folsom Dam. This does not, however, take into account the effects of evacuation: given the distance between the dam and the most populated portion of the city, an instantaneous break would still give 2-3 hours of water travel time for warning and evacuation of this downstream population time (according to an experimental evacuation model provided by Ayyaswamy but not applied to Folsom in the study) assuming no impairment of civil communications or transport. Hence the SNRA project team considered this was unlikely to be a realistic fatality estimate for the most likely Folsom Dam breach scenario. However, since few homes in the path of the water would remain habitable, it was considered to be a reasonable estimate for social displacement, defined as the number of people displaced from their homes for two or more days.

[49] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human impact metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological impacts. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: dam failures were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental impact category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence (impact)[50] as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental impacts as "Moderate." Experts assessed that the water released could impact a significant area, but the duration of impact would likely be short term, with a year or more for recovery.

[50] The 2011 SNRA referred to impacts as 'consequences' because of prior usage in quantitative risk assessment (Kaplan and Garrick [1981, March], On the quantitative definition of risk: *Risk Analysis* 1(1) 11-32). Except where it will cause confusion, 'impact' is used synonymously in this document because of pre-existing connotations of the word 'consequence' within FEMA.

Table 1. Historical U.S. Dam Failures causing Loss of Life, 1960-2009[1]

Dam	State	Date of Failure	Failure Cause	Dam Height (Feet)	Volume Released (Ac-Ft)	Size Category	Warning Time (Hours)[2]	People at Risk[3]	Loss of Life	Injuries
Electric Light Pond Dam	NY	1/1/1960	n/a	26	n/a	Small	n/a	n/a	1	
Mohegan Park Dam	CT	3/6/1963	Piping during elevated level from rainfall	20	138	Small	0	500	6	6[4]
Little Deer Creek Dam	UT	6/16/1963	Piping during normal weather	86	1,150	Intermediate	0	50	1	
Baldwin Hills Dam	CA	12/14/1963	Piping during normal weather	66	700	Intermediate	1.3	16,500	5	
Swift Dam	MT	6/8/1964	Overtopping	157	34,300	Large	Probably 0	n/a	19	
Cripple Creek Dam No. 3 and domino failure of Dam No. 2	CO	6/17/1965	Rainfall caused failure of No. 3, then overtopping failure of No. 2	n/a	640	Small	0	10	1	
Lee Lake Dam	MA	3/24/1968	Piping during normal weather	25	300	Small	0	80	2	
Virden Creek Dam	IA	7/17/1968	Overtopping	20	1,100	Intermediate	n/a	5,400	1	
Buffalo Creek Coal Waste Dam	WV	2/26/1972	Slumping of dam face during 2-year rainfall	46	404	Intermediate	0	4,000	125	1,000[5]
Lake "O" Hills	AK	4/1/1972	n/a	15	48	NJS[6]	n/a	n/a	1	
Canyon Lake Dam	SD	6/9/1972	Overtopping; 245 total deaths from area-wide flood	30	700 (10,100 flood total)	Intermediate	0	10,750	165	3,000[7]
Lakeside Dam	SC	9/18/1975	Overtopping	n/a	n/a	n/a	n/a	n/a	1	
Bear Wallow Dam	NC	2/22/1976	Rainfall; probable overtopping	36	40	Small	0	8	4	
Teton Dam	ID	6/5/1976	Piping during initial reservoir filling	305	250,000	Large	1.2	25,000	11	800[8]
Laurel Run Dam	PA	7/20/1977	Overtopping	42	450	Intermediate	0	150	40	
Kelly Barnes Dam	GA	11/6/1977	Embankment slope failure during 10-year flood	40	630	Intermediate	0	250	39	
Eastover Mining Co. Dam	KY	12/18/1981	n/a	n/a	77	Small	n/a	100	1	
Lawn Lake Dam + Cascade Lake Dam[9]	CO	7/15/1982	Piping during normal weather; Overtopping resulting from Lawn Lake Dam failure	26; 17	674; 25	Small; NJS	0; some	25; 4,275	3	
D.M.A.D. Dam5	UT	6/23/1983	Backcutting from collapse of downstream diversion dam	29	16,000	Intermediate	1+	500	1	
Nix Lake Dam	TX	3/29/1989	Overtopping	23	837	Small	0	6	1	
Evans Dam + Lockwood Dam[10]	NC	9/15/1989	Overtopping; Overtopping resulting from Evans failure	18; 14	72; 32	Small; NJS	n/a; n/a	n/a; n/a	2	
Kendall Lake Dam	SC	10/10/1990	Overtopping	18	690	Small	0	n/a	4	
Timberlake Dam	VA	6/22/1995	Overtopping	33	1,449	Intermediate	0	Road traffic[11]	2	
Bergeron Pond Dam	NH	3/13/1996	Dam not overtopped	36	193	Small	0	50	1	2[12]
Mike Olson Dam (Grand Forks County Comm. No. 1 Dam)	ND	6/12/2000	Undermining of downstream end of spillway conduit	29	263	Small	0	n/a	2	
Ka Loko Dam	HI	3/14/2006	Overtopping	44	1,400	Intermediate	0	7	7	

[1] U.S. Bureau of Reclamation records of historical dam failures 1960-2009, extracted from a longer table compiled by the Dams Sector Office, Office of Infrastructure Protection, DHS/NPPD and provided to the SNRA project team September 2011. The source table corresponds to Table 2 of U.S. Department of Homeland Security (2011, September), Estimating Loss of Life for Dam Failure Scenarios, with the addition of reported injury estimates for a limited number of entries culled from other sources (as noted).

[2] "Warning Time" is defined as the interval between the first issuance of dam failure warnings and the initiation of dam failure. This definition of warning time may differ from that used elsewhere in this [the source] document. Most of the entries in this column are zero, indicating that dam failure warnings were not issued prior to dam failure. In some cases in which no warnings preceded dam failure, none of the people at risk were warned. In other cases, people living close to the dam were not warned, but warnings were issued for areas farther downstream as the dam failure was discovered or the flooding was observed. In some cases, warnings were issued for areas downstream from a dam due to natural flooding not associated with the dam failure; this was not considered a dam failure warning and was therefore assigned a zero in the table. [Footnote in source.]

[3] "People at Risk" is defined as the number of people in the dam failure floodplain immediately prior to the issuance of any flood or dam failure warning. [Footnote in source.]

[4] "Connecticut Dam Breaks, Fear Six Dead." Daily Courier, Connellsville Pennsylvania, from United Press International, March 7, 1963. At http://www3.gendisasters.com/connecticut/18029/norwich-ct-earthen-dam-breaks-mar-1963 (checked April 2013).

[5] "Buffalo Creek" [website]. West Virginia Division of Culture and History, unknown date; at http://www.wvculture.org/history/buffcreek/buff1.html (checked April 2013).

[6] Non-Jurisdictional Size.

[7] Association of State Dam Safety Officials, 2011 (April 1). Dam Failures, Dam Incidents (Near Failures). Datasheet, at http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents(1).pdf (pdf date 4/1/11, checked April 2013).

[8] Graham, op cit; p 11.

[9] The entries for the 7/15/1982 failures of Lawn Lake Dam and Cascade Lake Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.

[10] The entries for the 9/15/1989 failures of Evans Dam and Lockwood Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.

[11] A 2-lane and 4-lane road [entry in source].

[12] U.S. Water News (1996, April). Dam break in New Hampshire damages homes, washes out highway. Online Archives, at http://www.uswaternews.com/archives/arcsupply/6newhamp.html (checked April, 2013).