

Dam Failures in the U.S.

National Performance of Dams Program
Dept. of Civil & Environmental Engineering
Stanford University

September 2018

NPDP-01 V1



Introduction

This document presents a compilation of data summaries on dam failures¹ and the life safety consequences from the flooding caused by failures that have occurred in the United States. It has been prepared by the National Performance of Dams Program (NPDP) at the Department of Civil and Environmental Engineering at Stanford University.

Dam Failures in the U.S.

The historic record on the performance of dams reveals that dam failures are a somewhat frequent occurrence in the U.S. Over the period-of-record there have been an average of nearly 10 failures a year. Many failures are of small dams, that result in limited flooding and as a result limited downstream impact. In the vast majority of cases (more than 96% of the time), the flooding that occurs when a dam is breached does not result in life-safety consequences or significant property damage. The small fraction of dam failures that cause fatalities, have resulted in some of the largest disasters associated with the failure of man-made systems in the U.S. The failure of South Fork Dam in 1889 caused 2,209 fatalities in Johnstown, Pennsylvania and 450 lives were lost because of the St. Francis Dam failure in California in 1928.

Future Updates

Periodically this compilation will be updated and expanded. Updates will be motivated by the ongoing collection of new dam failure information and improvements in the quality and completeness of the database.

This compilation will also be expanded with the results of additional data analysis and the insights they provide into the causes of dam failure, trends in their occurrence over time, and the consequences of failures.

Availability

This document and future updates will be available on the NPDP website: <http://npdp.stanford.edu>

For More Information

For more information about the NPDP or the information in this document visit our website or contact Martin McCann at mmcann@stanford.edu.

¹ Dam Failure – In this document dam failure refers to events that result in the uncontrolled release of the reservoir (URR). An incident that involves damage to a dam but retains control of the reservoir is not considered a dam failure.

The 1889 Johnstown Flood and the Failure of the South Fork Dam

One of the most catastrophic events to occur in the U.S. was the failure of the South Fork Dam near Johnstown, Pennsylvania on May 31, 1889. The dam failed after days of rain. Once the dam failed, 20 million gallons of water were released, traveling 14 miles to Johnstown. Along its way, the flood carried trees, livestock, homes, factories, and even a locomotive into the city.



A total of 2,209 lives were lost in and around Johnstown that day.

U.S. Dam Failure Facts

The following are noteworthy facts about dam failures that have occurred in the U.S.:

- The earliest dam failure on record occurred in 1848; Bancroft Dam in Massachusetts.
- Since 1900, except for two years, at least one dam failure has occurred every year.
- On average there have been approximately 10 dam failures per year over the period of record.
- Since 1980 there have been, on average, 24 dam failures per year.
- Approximately 3.8% of the dam failures that occur in the U.S. have resulted in one or more fatalities.

Dams in the U.S.

As reported in the National Inventory of Dams (NID) (<http://nid.usace.army.mil/>) there are 90,580 dams in the U.S. (as defined by the NID definition of a dam) Figure 1 shows the growth in the dam population in the U.S. The big era of dam building started after World War II and continued up to the end of the century, after which the construction of new dams being built annually has dropped off considerably.

Based on the record of dam construction, a large segment of the portfolio of dams is more than 50 years old, with an average age of 57 years.

Dam Failure Database Summary

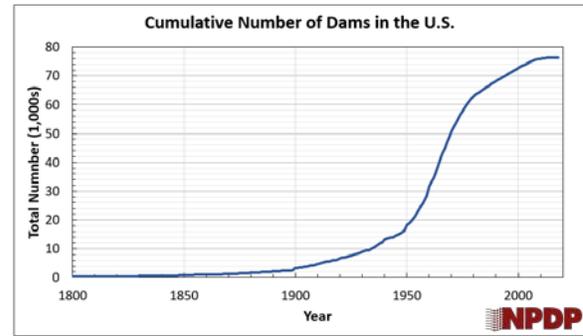
The NPDP database on dam failures that is the basis for the data summaries presented here has been compiled from several sources. These include work by individuals and organizations (U.S. Committee on Large Dams; Association of State Dam Safety Officials), contributions by state dam safety programs, and research efforts of the NPDP.

The period-of-record for dam failure data is from 1848 to 2017. The completeness of the database likely varies over the period-of-record and therefore it is reasonable to expect that the actual number of dam failures that have occurred in the U.S. is greater than the number reported here.

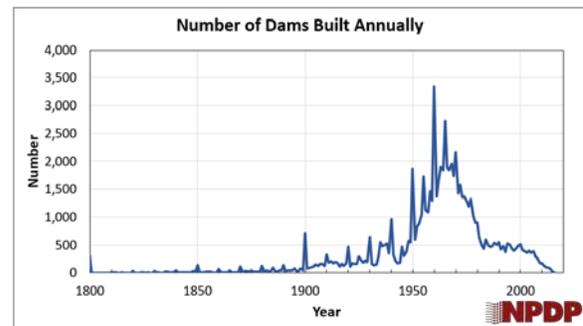
Table 1 provides a general summary of the dam failure database. The majority of failures have involved dams less than 15 meters (about 50 feet) in height². This is not surprising given the vast majority (over 93%) of dams in the U.S. are less than 15 meters in height.

Geographic Distribution of Dam Failures

Dam failures have occurred in every state in the U.S. Table 2 provides a list of the number of known dam failures in each state. The map in Figure 2 shows the top ten states in terms of the number of dam failures.



(a)



(b)

Figure 1 Number of dams in the U.S., a) cumulative number, and b) number built annually.

Table 1
NPDP Dam Failure Database Summary

Data Summary	Value
Period of Record	1848 - 2017
Number of Dam Failures	
- All Dams	1,645
- Height < 15 meters	1,546
- Height ≥ 15 meters	99
Number of States Having Dam Failures	50
State with the Most Failures	Georgia
States with the Fewest Failures	Hawaii Louisiana
Earliest Known Dam Failure	1848

² According to standards defined by the International Commission on Large Dams, large dams are structures that are 15 meters or greater in height and/or have a reservoir that stores more than 3,000,000 cubic meters.



Figure 2 Top ten states in terms of the number of dam failures³.

³ Approximately 200 of the failures listed for the state of Georgia occurred during the floods in 1994. Many of those dams were small and not regulated by the state's dam safety program at the time.

**Table 2
Number Dam Failures by State**

State	Number of Dams ^a	Number of Dam Failures
Alabama	2,271	10
Alaska	107	5
Arizona	384	13
Arkansas	1,257	5
California	1,585	85
Colorado	1,737	88
Connecticut	746	42
Delaware	83	5
Florida	1,203	11
Georgia	5,420	238
Hawaii	133	2
Idaho	473	18
Illinois	1,607	22
Indiana	916	9
Iowa	3,976	9
Kansas	6,403	11
Kentucky	1,107	10
Louisiana	557	2
Maine	597	10
Maryland	346	24
Massachusetts	1,452	25
Michigan	1,005	41
Minnesota	1,097	40
Mississippi	5,114	29
Missouri	5,356	33
Montana	2,960	27
Nebraska	2,970	23
Nevada	547	5
New Hampshire	645	16
New Jersey	825	46
New Mexico	492	19
New York	1,951	55
North Carolina	3,444	73
North Dakota	898	8
Ohio	1,495	18
Oklahoma	4,891	16
Oregon	869	21
Pennsylvania	1,525	72
Rhode Island	227	9
South Carolina	2,444	91
South Dakota	2,565	12
Tennessee	1,237	62
Texas	7,395	53
Utah	833	43
Vermont	357	45
Virginia	2,919	26
Washington	784	38
West Virginia	614	13
Wisconsin	1,106	58
Wyoming	1,617	9

^aThe number of dams listed for each state is based on the U.S. National Inventory of Dams.

Timeline of Dam Failures

Figure 3 shows a timeline of dam failures from 1848 to 2017. Over this period-of-record, there have been an average of nearly 10 dam failures per year. Since 1980 when dam safety became a national priority, there has been an average of 24 dam failures annually. If the many non-regulated, small dams that failed in Georgia during the 1994 flooding are excluded, the average number of dam failures per year is less than 19. A decadal summary of the number of dam failures is shown in Figure 4.

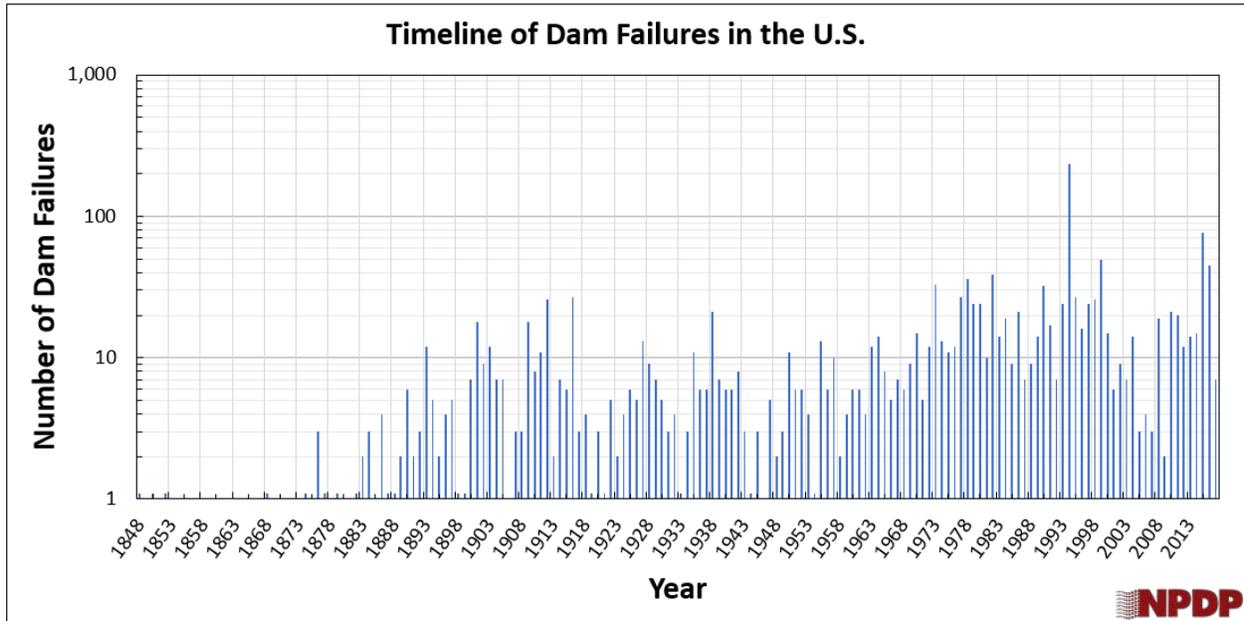


Figure 3 Timeline of dam failures in the U.S. from 1848 to 2017.

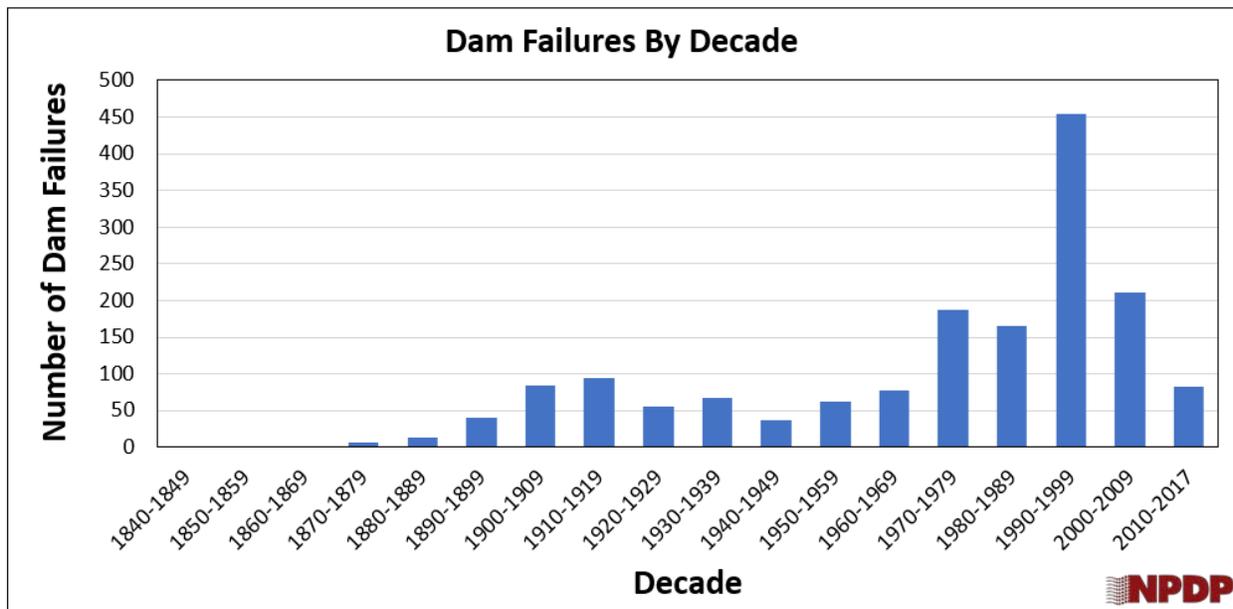
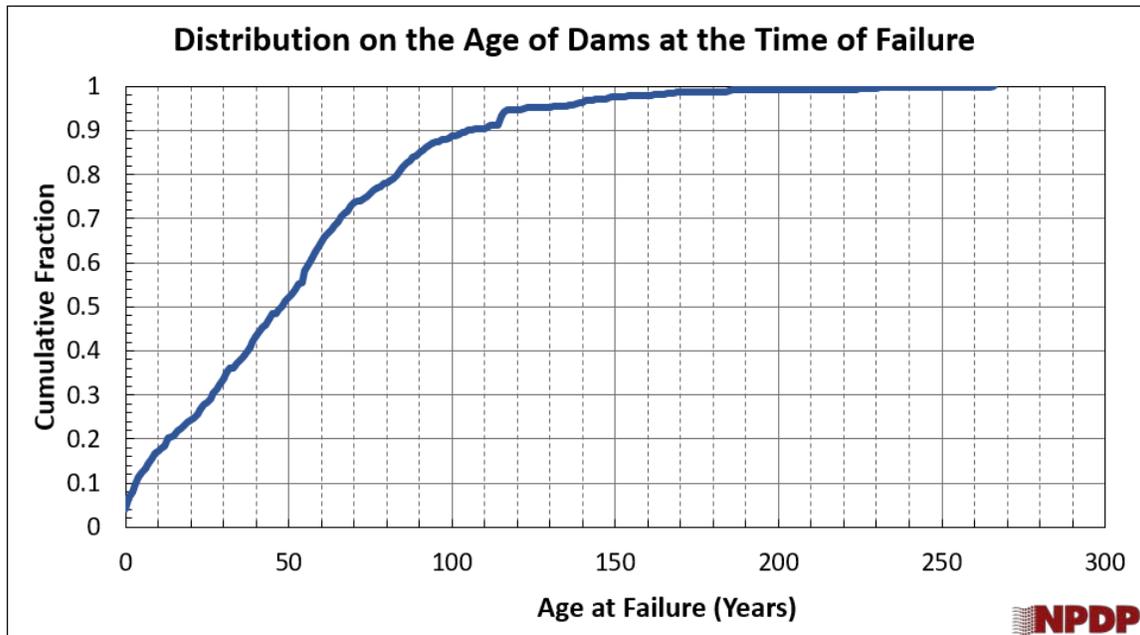


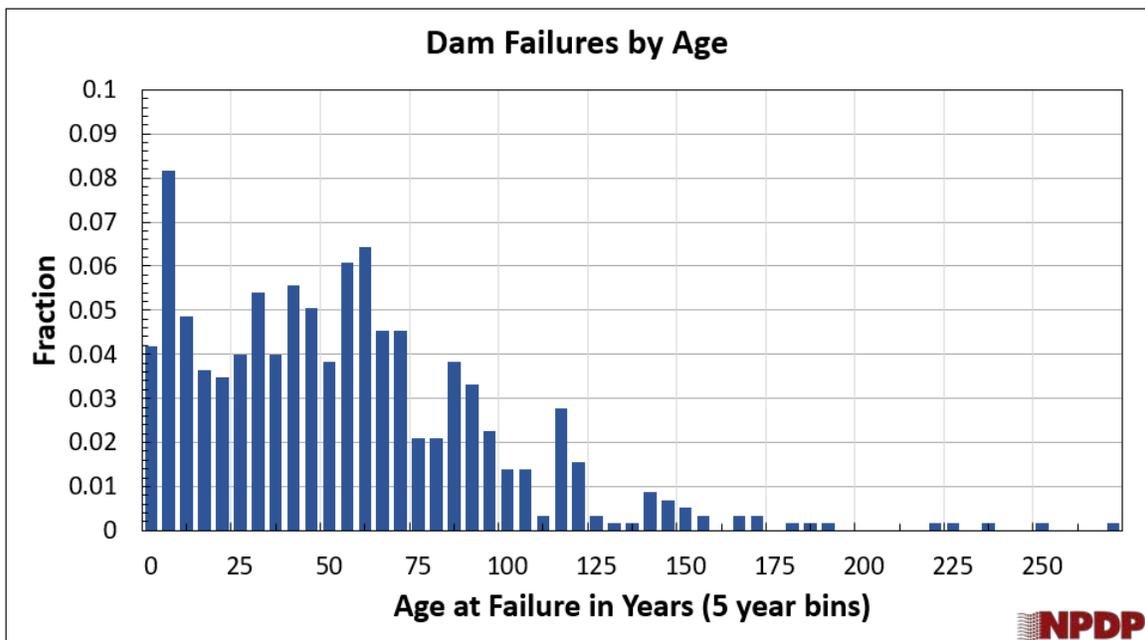
Figure 4 Decadal summary of the number of dam failures in the U.S.

Age of Dams at Failure

Failures can occur during any stage of a dam's operation life; during first filling of the reservoir or decades later after years of satisfactory service. Figure 5 shows different views of the distribution of the age of dams at the time of failure. As shown clearly in Figure 5b, there is an early mortality that is observed for dams; approximately 12% of failures occur during initial reservoir filling or during the first 10 years of operation. Over 4% of failures occur within the first 5 years. Over 10% of dam failures occur when dams are 100 years or older.



(a)



(b)

Figure 5 Distribution on the age of dams when failure has occurred; a) cumulative distribution, and b) the distribution in five-year intervals.

Life Safety Consequences of Dam Failure

Like many forms of infrastructure, dam failures can lead to health and safety consequences. The earliest recorded fatalities due to a dam failure occurred in 1850 as a result of Ashburnham Reservoir Dam failure in Massachusetts in which two lives were lost. In the period from 1850 to 2017 an estimated 3,495 fatalities have occurred as a result of 64 dam failure events.⁴ Approximately 3.9% of dam failures in the U.S. have resulted in fatalities.

Figure 6 shows a timeline of the dam failure events that involved fatalities shown with the number of fatalities that occurred. The majority of the fatalities (90%) occurred prior to 1960. Of the 3,495 fatalities that are documented, 76% occurred during two events; the South Fork Dam failure in Johnstown, Pennsylvania in May 1889 (2,209 fatalities) and the Saint Francis Dam failure in California in March 1928 (450 fatalities). There has been a total of four events that reportedly involved more than 100 fatalities, comprising 85% percent of the total (2,959 of 3,495 fatalities). The remaining 15% percent (536 fatalities) are distributed among the 59 other dam failure events. Figure 7 shows the cumulative number of fatalities over time.

Figure 8 shows a map indicating the location of dam failures that have resulted in fatalities.

Table 3
Summary of Life Safety Consequences
from Dam Failures*

Parameter/Summary	Value(s)
Period of Record	1848 – 2017
Number of Years of Record	170
Number of Dam Failures Resulting in Fatalities	64 ^a
Percentage of Dam Failures that Resulted in Fatalities	3.9%
Long-Term Frequency of Occurrence of Dam Failures Events per Year in which there were Fatalities ^b	0.40
Range on the Number of Fatalities per Dam Failure Event	1 – 2,209 ^c
Total Number of Fatalities Over the Period of Record (The range is based on the variation in estimates of fatalities that occurred during individual events.)	3,432 - 3,736
Long-Term Annual Average Number of Fatalities Over the Period of Record ^d	20.2 – 22.0
Long-Term Annual Average Number of Fatalities for the Period of Record, Exclusive of the 1889 South Fork Dam Failure ^d	7.2 - 9.0

* This data summary does not include fatalities that have occurred as a result of tailings dam failures.

^a The Staffordville Reservoir failure in 1877 is included in this value.

^b This is simply the number of events divided by the number of years in the record.

^c This is the range on the number of fatalities that have occurred.

^d Calculated as the total number of fatalities divided by the number of years of record. The range of values reflects the differences in the estimated number of fatalities in the historic record.

⁴ Some additional fatalities were caused by the failure of the Staffordville Reservoir Dam in 1877, but the number of fatalities is unknown.

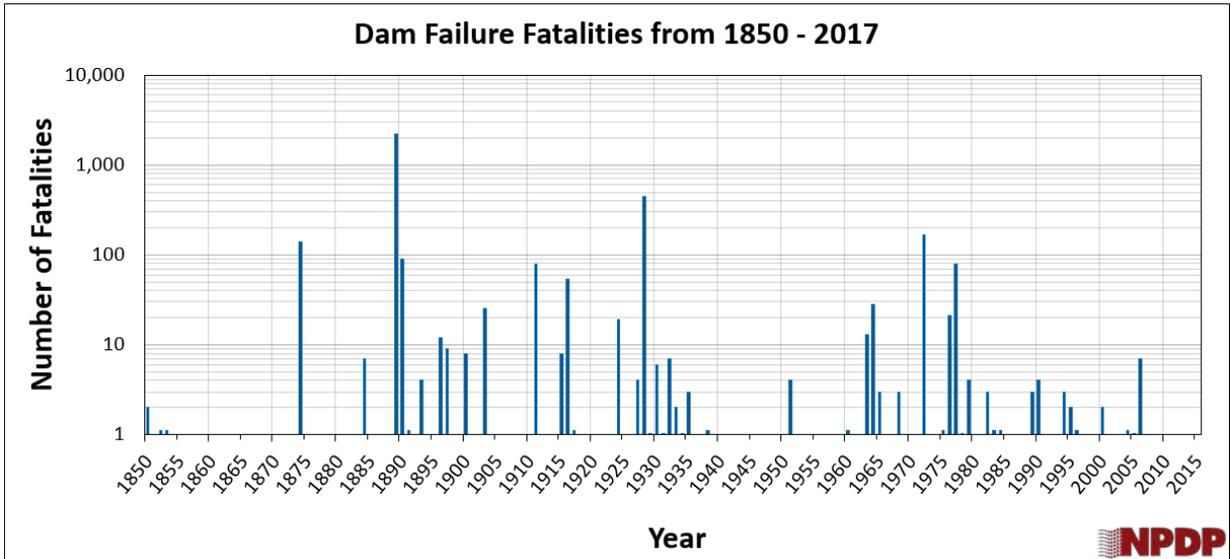


Figure 6 Timeline of dam failure events that have resulted in fatalities in the U.S.

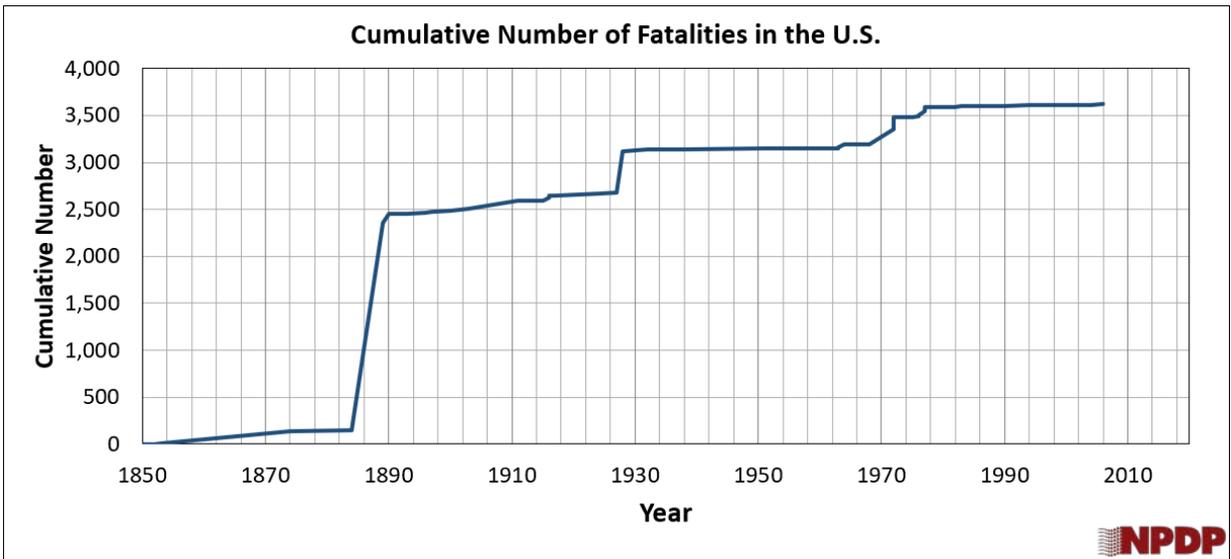


Figure 7 Cumulative number of fatalities that have occurred as a result of dam failures in the U.S.

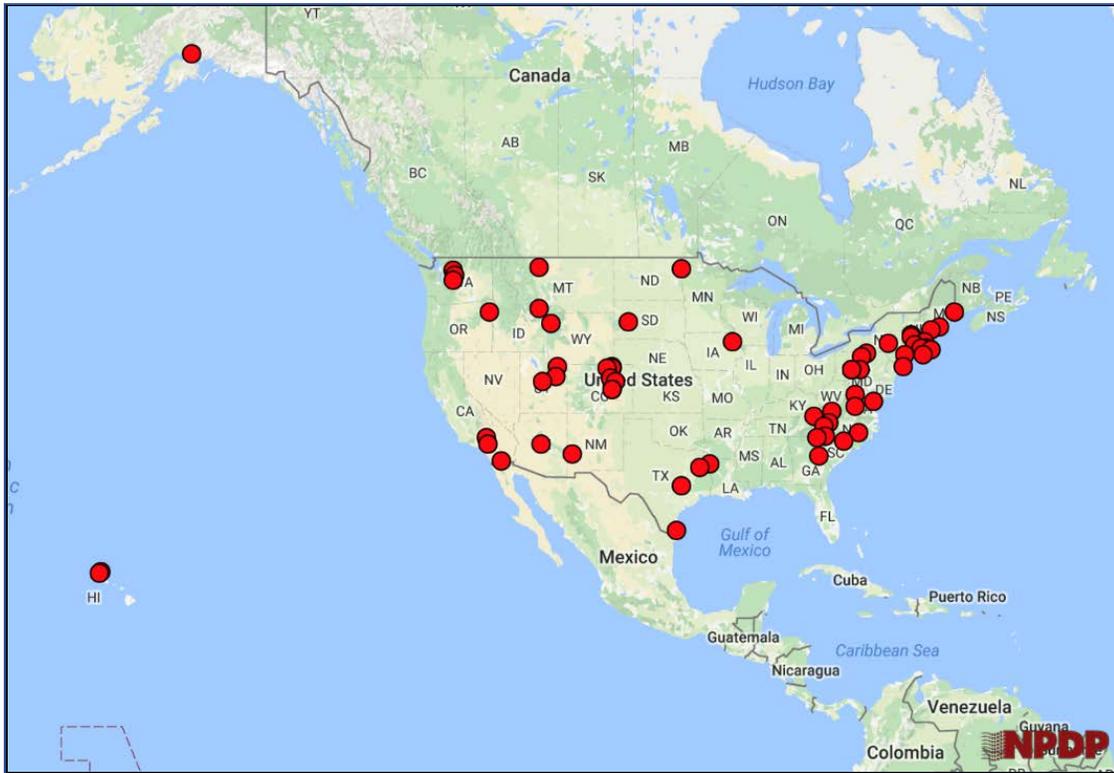


Figure 8. Location of dam failure events that have involved fatalities in the U.S.
 (Note, a number of the locations are approximate since the exact location of the dam is not known.)

For More Information

For more information about this document or the National Performance of Dams Program, please contact:

Martin W. McCann, Jr.
Adjunct Professor
Department of Civil & Environmental Engineering
Director of the National Performance of Dams Program
Stanford University
Stanford, California 94305

Telephone: (650) 814-0878
e-mail: mmccann@stanford.edu