

CHAPTER 10. DAM FAILURE

10.1 GENERAL BACKGROUND

10.1.1 Causes of Dam Failure

Dam failures can be catastrophic to human life and property downstream. Dam failures in the United States typically occur in one of four primary ways:

- Overtopping of the primary dam structure, which accounts for 34 percent of all dam failures, can occur due to inadequate spillway design, settlement of the dam crest, blockage of spillways, and other factors.
- Foundation defects due to differential settlement, slides, slope instability, uplift pressures, and foundation seepage can also cause dam failure. These account for 30 percent of all dam failures.
- Failure due to piping and seepage accounts for 20 percent of all failures. These are caused by internal erosion due to piping and seepage, erosion along hydraulic structures such as spillways, erosion due to animal burrows, and cracks in the dam structure.
- Failure due to problems with conduits and valves, typically caused by the piping of embankment material into conduits through joints or cracks, constitutes 10 percent of all failures.

The remaining 6 percent are due to other miscellaneous causes. Many of the historical dam failures in the United States have been secondary results of other disasters. The prominent causes are earthquakes, landslides, extreme storms, massive snowmelt, equipment malfunction, structural damage, foundation failures, and sabotage. Figure 10-1 shows the distribution of dam failures by primary cause.

The most likely disaster-related causes of dam failure in Placer County and the Roseville vicinity are earthquakes, excessive rainfall, and landslides. Poor construction, lack of maintenance and repair, and deficient operational procedures are preventable or correctable by a program of regular inspections. Terrorism and vandalism are serious concerns that all operators of public facilities must plan for; these threats are under continuous review by public safety agencies.

DEFINITIONS

Dam—Any artificial barrier, together with appurtenant works, that does or may impound or divert water, and that either (a) is 25 feet or more in height from the natural bed of the stream or watercourse at the downstream toe of the barrier (or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or watercourse) to the maximum possible water storage elevation; or (b) has an impounding capacity of 50 acre-feet or more. (CA Water Code, Division 3.)

Dam Failure—An uncontrolled release of impounded water due to structural deficiencies in dam.

Emergency Action Plan—A formal document that identifies potential emergency conditions at a dam and specifies actions to be followed to minimize property damage and loss of life. The plan specifies actions the dam owner should take to alleviate problems at a dam. It contains procedures and information to assist the dam owner in issuing early warning and notification messages to responsible downstream emergency management authorities of the emergency situation. It also contains inundation maps to show emergency management authorities the critical areas for action in case of an emergency. (FEMA 64)

High Hazard Dam—Dams where failure or mis-operation will probably cause loss of human life. (FEMA 333)

Significant Hazard Dam—Dams where failure or mis-operation will result in no probable loss of human life but can cause economic loss, environmental damage or disruption of lifeline facilities, or can impact other concerns. Significant hazard dams are often located in rural or agricultural areas but could be located in areas with population and significant infrastructure. (FEMA 333)

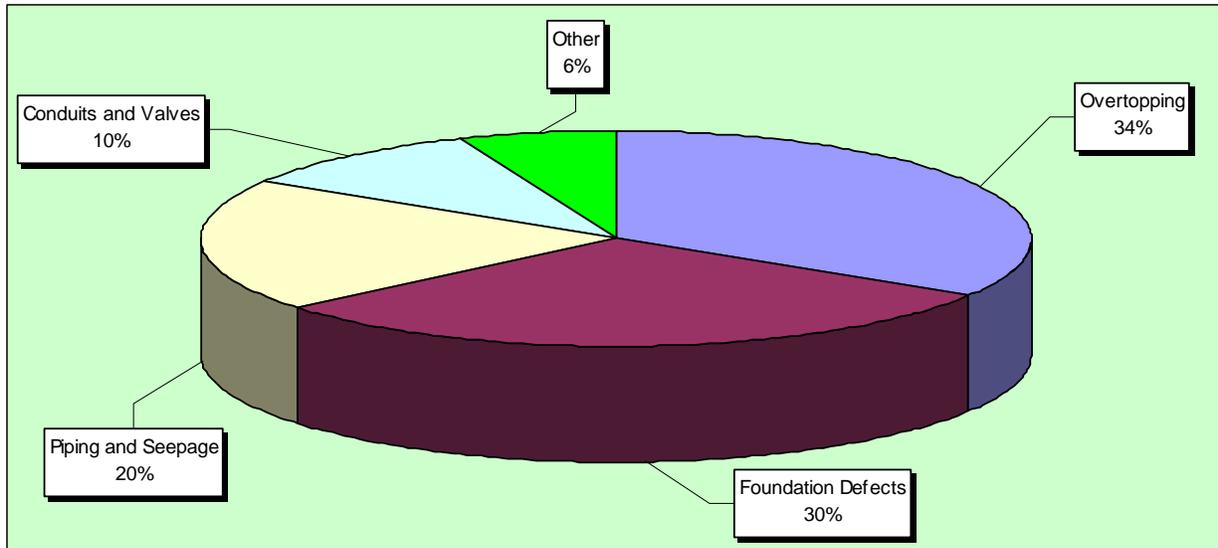


Figure 10-1. Historical Causes of Dam Failure

10.1.2 Regulatory Oversight

The potential for catastrophic flooding due to dam failures led to passage of the National Dam Safety Act (Public Law 92-367). The National Dam Safety Program requires a periodic engineering analysis of every major dam in the country. The goal of this FEMA-monitored effort is to identify and mitigate the risk of dam failure so as to protect the lives and property of the public.

California Division of Safety of Dams

California's Division of Safety of Dams (a division of the Department of Water Resources) monitors the program at the state level. When a new dam is proposed, Division engineers and geologists inspect the site and the subsurface. Upon submittal of an application, the Division reviews the plans and specifications prepared by the owner to ensure that the dam is designed to meet minimum requirements and that the design is appropriate for the known geologic conditions. After approval of the application, the Division inspects all aspects of the construction to ensure that the work is done in accordance with the approved plans and specifications. After construction, the Division inspects each dam on an annual basis to ensure that it is performing as intended and is not developing problems. Roughly a third of these inspections include in-depth instrumentation reviews. Lastly, the Division periodically reviews the stability of dams and their major appurtenances in light of improved design approaches and requirements, as well as new findings regarding earthquake hazards and hydrologic estimates in California (DWR Website, 2007).

U.S. Army Corps of Engineers Dam Safety Program

The U.S. Army Corps of Engineers is responsible for safety inspections of some federal and non-federal dams in the United States that meet the size and storage limitations specified in the National Dam Safety Act. The Corps has inventoried dams; surveyed each state and federal agency's capabilities, practices and regulations regarding design, construction, operation and maintenance of the dams; and developed guidelines for inspection and evaluation of dam safety (U.S. Army Corps of Engineers, 1997).

Federal Energy Regulatory Commission Dam Safety Program

The Federal Energy Regulatory Commission (FERC) has the largest dam safety program in the United States. The FERC cooperates with a large number of federal and state agencies to ensure and promote dam safety and, more recently, homeland security. Approximately 3,036 dams that are part of regulated hydroelectric projects are in the FERC program. Two-thirds of these dams are more than 50 years old. As dams age, concern about their safety and integrity grows, and oversight and a regular inspection program are extremely important. FERC staff inspects hydroelectric projects on an unscheduled basis to investigate the following:

- Potential dam safety problems
- Complaints about constructing and operating a project
- Safety concerns related to natural disasters
- Issues concerning compliance with the terms and conditions of a license.

Every five years, an independent consulting engineer, approved by the FERC, must inspect and evaluate projects with dams higher than 32.8 feet, or with a total storage capacity of more than 2,000 acre-feet.

FERC staff monitors and evaluates seismic research in geographic areas such as California where there are concerns about possible seismic activity. This information is applied in investigating and performing structural analyses of hydroelectric projects in these areas. FERC staff also evaluates the effects of potential and actual large floods on the safety of dams. During and following floods, FERC staff visits dams and licensed projects, determines the extent of damage, if any, and directs any necessary studies or remedial measures the licensee must undertake. The FERC publication *Engineering Guidelines for the Evaluation of Hydropower Projects* guides the FERC engineering staff and licensees in evaluating dam safety. The publication is frequently revised to reflect current information and methodologies.

The FERC requires licensees to prepare emergency action plans and conducts training sessions on how to develop and test these plans. The plans outline an early warning system if there is an actual or potential sudden release of water from a dam due to failure or accident. The plans include operational procedures that may be used, such as reducing reservoir levels and reducing downstream flows, as well as procedures for notifying affected residents and agencies responsible for emergency management. These plans are frequently updated and tested to ensure that everyone knows what to do in emergency situations.

10.2 HAZARD PROFILE

10.2.1 Past Events

According to the Placer County Multi-Hazard Mitigation Plan, there have been three dam failures in Placer County (none are known to have impacted the Roseville planning area):

- **Hell Hole Dam Failure**—In 1964, construction of the Hell Hole Dam was underway and the contractor had stopped operations for the winter. A major storm event in December caused the Hell Hole Reservoir to fill, and since the dam was not completed, it failed, sending a considerable amount of water toward Auburn. The water washed out a bridge on Highway 49 over the American River at the confluence of the North and Middle Forks and flooded a quarry. Due to the way the construction contract was worded, the contractor had to rebuild the dam at his own expense. As a result, Placer County incurred no costs related to this event. No claims for damage were filed against the Placer County Water Agency (PCWA) by either the quarry owner or the state.

- **1986 Auburn Coffe Dam Failure**—As a result of area flooding, the Coffe Dam at Auburn breached and partially washed away. The U.S. Bureau of Reclamation had designed the Coffe Dam for a controlled failure by building a soft earthen plug into the dam for this purpose. It appears the dam failed as designed.
- **August 2004 Ralston Dam Release Gate Break**—A broken release gate on Ralston Dam in the Middle Fork of the American River prompted the National Weather Service to issue a flash flood warning in Placer County. According to the PCWA, the gate near the Ralston Powerhouse malfunctioned, and the sudden release of water from Ralston Reservoir south of Auburn sent a wall of water three to four-feet high down the river. About 800 to 1,000 acre-feet of water were released. Sheriff’s deputies and California Highway Patrol officers alerted campers in the Auburn State Recreation Area to move to higher ground. The CHP monitored the muddy water as it approached Highway 49. There were no reports of injuries or damage along the river, which is popular with rafters, kayakers and residents during summer.

10.2.2 Location

According to the California Division of Safety of Dams, there are 54 dams in Placer County. Of these, two dams have the potential to impact the Roseville planning area should they fail. Additionally, failure of the western levees along Folsom Lake, which is a reservoir lined by a series of containment dikes, could significantly impact the City of Roseville. Table 10-1 lists facilities whose failure could affect Roseville.

Name	Hazard Class ^a	Water Course	Owner	Year Built	Dam Type	Crest Length (feet)	Height (feet)	Storage Capacity (acre-feet)	Drainage area (sq. mi.)
Folsom	1A	American River	US Bureau of Reclamation	1956	Gravity	102,000	275	975,000	1,885
Miners Ravine Detention Facility	1B	Dry Creek	Placer County Flood & Water Conservation District	2007	Earthen	2000	22.5	120	14

a. Downstream Hazard Class 1A: > 300 lives at risk, 1B: 31 to 300 lives at risk, 1C: 7 to 30 lives at risk

10.2.3 Frequency

Dam failure events are infrequent and usually coincide with the events that cause them, such as earthquakes, landslides and excessive rainfall and snowmelt. There is a “residual risk” associated with dams; residual risk is the risk that remains after safeguards have been implemented. For dams, the residual risk is associated with events beyond those that the facility was designed to withstand. However, the probability of occurrence of any type of dam failure event is considered to be low in today’s regulatory and dam safety oversight environment.

10.2.4 Severity

Dam failure can be catastrophic to all life and property downstream. The U.S. Army Corps of Engineers developed the classification system shown in Table 10-2 for the hazard potential of dam failures.

TABLE 10-2. HAZARD POTENTIAL CLASSIFICATION				
Hazard Category ^a	Direct Loss of Life ^b	Lifeline Losses ^c	Property Losses ^d	Environmental Losses ^e
Low	None (rural location, no permanent structures for human habitation)	No disruption of services (cosmetic or rapidly repairable damage)	Private agricultural lands, equipment, and isolated buildings	Minimal incremental damage
Significant	Rural location, only transient or day-use facilities	Disruption of essential facilities and access	Major public and private facilities	Major mitigation required
High	Certain (one or more) extensive residential, commercial, or industrial development	Disruption of essential facilities and access	Extensive public and private facilities	Extensive mitigation cost or impossible to mitigate

a. Categories are assigned to overall projects, not individual structures at a project.
 b. Loss of life potential based on inundation mapping of area downstream of the project. Analyses of loss of life potential should take into account the population at risk, time of flood wave travel, and warning time.
 c. Indirect threats to life caused by the interruption of lifeline services due to project failure or operational disruption; for example, loss of critical medical facilities or access to them.
 d. Damage to project facilities and downstream property and indirect impact due to loss of project services, such as impact due to loss of a dam and navigation pool, or impact due to loss of water or power supply.
 e. Environmental impact downstream caused by the incremental flood wave produced by the project failure, beyond what would normally be expected for the magnitude flood event under which the failure occurs.

Source: U.S. Army Corps of Engineers, 1995

10.2.5 Warning Time

Warning time for dam failure varies depending on the cause of the failure. In events of extreme precipitation or massive snowmelt, evacuations can be planned with sufficient time. In the event of a structural failure due to earthquake, it is possible that there would be no warning time. A dam’s structural type also affects warning time. Earthen dams do not tend to fail completely or instantaneously. Once a breach is initiated, discharging water erodes the breach until either the reservoir water is depleted or the breach resists further erosion. Concrete gravity dams also tend to have a partial breach as one or more monolith sections formed during dam construction are forced apart by the escaping water. The time for breach formation ranges from a few minutes to a few hours (U.S. Army Corps of Engineers, 1997).

The City has established protocols for flood warning and response to imminent dam failure in the flood warning portion of its adopted emergency operations plan. Future enhancements to this plan will include phased warning protocols for imminent dam failure in response to the findings of the Folsom Dam Containment Dike Risk Assessment discussed in the following section. Completion of this task is a recommendation of this plan.

10.3 FOLSOM DAM CONTAINMENT DIKE RISK ASSESSMENT

During the 2005 review of the initial Roseville Hazard Mitigation Plan, FEMA Region IX plan reviewers indicated that there was sufficient risk of dam failure of the western dikes on Folsom Lake to warrant treating dam failure as a standalone hazard in the City's next hazard mitigation plan update. Six dikes, increasing in size and numeric designation (from 1 to 6) from north to south, fill gaps along the western edge of Folsom Lake.

Because there was insufficient data to assess risk to the standards established for the other hazards in the hazard mitigation plan, the City developed a comprehensive, scenario-based risk assessment of the western dikes on the Folsom Dam complex. The assessment was included in the scope of work under the FEMA planning grant used to fund the plan update.



Folsom Dam

The study provided inundation mapping to determine the probable impact of flooding in Roseville if any of the western dikes were to fail. It addressed the relative risk of failure of each dike based on the frequency that the dikes impound water, the potential for overtopping, the recent and in-progress work to upgrade the dikes to reduce the risk of failure due to piping, and a new reservoir spillway that is under construction. Models were prepared to simulate dike failures and resulting inundation. These simulations provide the basis for inundation area mapping and other emergency management tools such as maps that illustrate the time from failure to flooding.

The northernmost dikes are relatively low height embankments above the normal operating range of the lake. Though the occurrence of inundation due to dam failure is based on extremely remote conditions, failure of these facilities has the potential to cause significant property damage and loss of life in the City. The degree of impact would be affected by the water level of the lake at the time of failure, which could be just above the top of the dikes in the case of failure by overtopping. The study mapped the maximum depth of flooding and the timing of the flood wave from the time of failure for various scenarios. The study found that flood depths could reach as much as 58 feet in parts of the City.

10.4 SECONDARY HAZARDS

Dam failure can cause severe downstream flooding depending on the magnitude of the failure. Other potential secondary hazards of dam failure include landslides around the reservoir perimeter, bank erosion on the rivers, and destruction of downstream habitat.

10.5 CLIMATE CHANGE IMPACTS

Dams are designed partly based on assumptions about a river's flow behavior, expressed as hydrographs. Changes in weather patterns can have significant effects on the hydrograph used for the design of a dam. If the hydrograph changes, it is conceivable that the dam can lose some or all of its designed margin of safety, also known as freeboard. If freeboard is reduced, dam operators may be forced to release increased volumes earlier in a storm cycle in order to maintain the required margins of safety. Such early releases of increased volumes can increase flood potential downstream.

Additionally, dams are constructed with safety features know as “spillways.” Spillways are put in place on dams as a safety measure in the event of the reservoir filling too quickly. Spillway overflow events, often referred to as “design failures,” result in increased discharges downstream and increased flooding potential. Dam operators face increased probability of design failures due to weather impacts from climate change.

So while climate change will not increase the probability of catastrophic dam failure, it may increase the probability of design failures. Throughout the west, communities downstream of dams are already seeing impacts from climate change due to increases in stream flows from earlier releases from dams.

10.6 EXPOSURE

The flood module of HAZUS-MH was used for a Level 2 assessment of dam failure risk and vulnerability for facilities in Roseville with sufficient data to support modeling. HAZUS-MH uses census data at the block level and FEMA floodplain data, which has a level of accuracy acceptable for planning purposes. Where possible, the HAZUS-MH data for this risk assessment was enhanced using GIS data from county, state and federal sources. The exposure and vulnerability analyses focused on inundation data from the Folsom Dam Containment Dike Failure Risk Assessment Project.

10.6.1 Population

All populations located in a dam failure inundation zone would be exposed to the risk of a dam failure. The potential for loss of life is affected by the capacity and number of evacuation routes available to populations living in areas of potential inundation. The estimated population living in the Folsom Dam inundation areas is 47,550, or 41.1 percent of the city’s population.

10.6.2 Property

Based on Assessor parcel data, the HAZUS-MH model estimated that there are 18,288 structures within the Folsom Dam inundation areas. It is estimated that 17,277 or 94 percent, of these structures are residential. The value of exposed buildings in the planning area was generated using HAZUS-MH and is summarized in Table 10-3. This methodology estimated \$8.99 billion worth of building-and-contents exposure to Folsom Dam failure inundation in these areas, representing 40.96 percent of the total assessed value of the planning area.

Type	Number of Buildings Exposed	Value Exposed			% of Total Assessed Value
		Building	Contents	Total	
Residential	17,277	\$4,179,846,639	\$2,925,892,647	\$7,105,739,287	32.35%
Commercial	872	\$769,929,162	\$809,918,085	\$1,579,847,247	7.19%
Business Professional	57	\$42,784,703	\$41,283,486	\$84,068,189	0.38%
Industrial	62	\$78,487,061	\$117,730,591	\$196,217,653	0.89%
Other	20	\$15,012,178	\$16,513,395	\$31,525,573	0.14%
Total	18,288	\$5,086,059,743	\$3,911,338,205	\$8,997,397,949	40.96%

10.6.3 Critical Facilities

GIS analysis was used to determine the number of critical facilities in the mapped dam inundation areas. As Table 10-4 shows, 55 of the planning area’s critical facilities (61 percent) are in the inundation areas.

TABLE 10-4. CRITICAL FACILITIES IN DAM FAILURE INUNDATION AREAS IN ROSEVILLE							
Medical & Health Services	Government Function	Protective Function	Schools	Societal Function	Hazmat	Other Critical Function	Total
1	12	7	18	10	2	5	55

10.6.4 Environment

Reservoirs held behind dams affect many ecological aspects of a river. River topography and dynamics depend on a wide range of flows, but rivers below dams often experience long periods of very stable flow conditions or saw-tooth flow patterns caused by releases followed by no releases. Water releases from a reservoir, including those exiting a turbine, usually contain very little suspended sediment; this can lead to scouring of river beds and loss of riverbanks.

The environment would be exposed to a number of risks in the event of dam failure. The inundation could introduce many foreign elements into local waterways. This could result in destruction of downstream habitat and could have detrimental effects on many species of animals, especially endangered species such as salmon.

10.7 VULNERABILITY

10.7.1 Population

Vulnerable populations are all populations downstream from dam failures that are incapable of escaping the area within the allowable time frame. This population includes the elderly and young who may be unable to get themselves out of the inundation area. The vulnerable population also includes those who would not have adequate warning from a television or radio emergency warning system.

10.7.2 Property

Vulnerable properties are those closest to the dam inundation area. These properties would experience the largest, most destructive surge of water. Low-lying areas are also vulnerable since they are where the dam waters would collect. Transportation routes are vulnerable to dam inundation and have the potential to be wiped out, creating isolation issues. This includes all roads, railroads and bridges in the path of the dam inundation. Those that are most vulnerable are those that are already in poor condition and would not be able to withstand a large water surge. Utilities such as overhead power lines, cable and phone lines could also be vulnerable. Loss of these utilities could create additional isolation issues for the inundation areas.

It is estimated that there could be up to \$6.24 billion of loss from a dam failure affecting the planning area. This represents 69 percent of the total exposure within the inundation area, or 28.42 percent of the total assessed value of the planning area. Table 10-5 summarizes the loss estimates for dam failure.

**TABLE 10-5.
LOSS ESTIMATES FOR DAM FAILURE**

	Value Exposed			% of Total Assessed Value
	Building Loss	Contents Loss	Total Loss	
Residential	\$1,978,321,414	\$1,417,448,693	\$3,395,770,107	15.46%
Commercial	\$345,544,208	\$2,346,565,903	\$2,692,110,111	12.25%
Business Professional	\$17,113,881	\$22,705,917	\$39,819,799	0.18%
Industrial	\$31,897,142	\$69,319,772	\$101,216,914	0.46%
Other	\$6,004,871	\$8,256,698	\$14,261,569	0.06%
Total	\$2,378,881,516	\$3,864,296,983	\$6,243,178,500	28.42%

10.7.3 Critical Facilities

HAZUS estimated that critical facilities would receive 24 percent damage to the structure and 43 percent damage to the contents during a dam failure event. The estimated functional down-time to restore these facilities to 100 percent of their functionality is 600 days.

10.7.4 Environment

The environment would be vulnerable to a number of risks in the event of dam failure. The inundation could introduce foreign elements into local waterways, resulting in destruction of downstream habitat and detrimental effects on many species of animals, especially endangered species such as coho salmon. The extent of the vulnerability of the environment is the same as the exposure of the environment.

10.8 FUTURE TRENDS IN DEVELOPMENT

All land use decision-making is guided by the goals, policies and implementation measures contained in the Land Use Element of Roseville’s General Plan. The Safety Element of the General Plan establishes standards and plans for the protection of the community from hazards. Dam failure is currently not addressed as a standalone hazard in the Safety Element, but flooding is. The City has established comprehensive policies regarding sound land use in identified flood hazard areas. Most of the areas vulnerable to the more severe impacts from the bank-full Folsom Dam failure scenario intersect the City’s flood hazard areas. Flood-related policies in the general Plan will help to reduce the risk associated with the dam failure hazard for all future development within the City.

10.9 REVIEW OF EXISTING ORDINANCES, PROGRAMS AND PLANS

Since most of the dam failure inundation areas overlay the regulated floodplain within the planning area, ordinances and programs discussed under section 13.9 are applicable to this hazard. It should be noted that the extent and location of dam failure inundation areas as well as the estimated flood depths significantly exceed those projected for flooding. Future revisions to the flood programs may want to consider the potential impacts of dam failure in their scope, even though the statistical probability of such an event is low.

10.10 SCENARIO

According to the Folsom Dam Containment Dike Failure Risk Assessment Project, the worst case scenario would be a bank-full failure of Dikes 4, 5 and 6 due to overtopping. Overtopping flows may

quickly erode the top and downstream portions of the dikes, causing failure. Therefore, there is a possibility of simultaneous failure due to overtopping. However, the likelihood of reservoir inflows that could cause overtopping is extremely low, and will be even smaller upon completion of the new Folsom Dam spillway that is currently under construction and scheduled for completion by 2015. Failure from piping could occur at any water surface elevation within the reservoir.

An earthquake within the region could lead to liquefaction of soils around the dams. This could occur without warning during any time of the day. A human-caused failure such as a terrorist attack also could trigger a catastrophic failure of a dam that impacts the planning area.

10.11 ISSUES

The most significant issue associated with dam failure involves the properties and populations in the inundation zones. Flooding as a result of a dam failure would significantly impact these areas. There is often limited warning time for dam failure. These events are frequently associated with other natural hazard events such as earthquakes, landslides or severe weather, which limits their predictability and compounds the hazard. Important issues associated with dam failure hazards include the following:

- Federally regulated dams have an adequate level of oversight and sophistication in the development of emergency action plans for public notification in the unlikely event of failure. However, the protocol for notification of downstream citizens of imminent failure needs to be tied to local emergency response planning.
- Mapping for federally regulated dams is already required and available; however, mapping for non-federal-regulated dams that estimates inundation depths is needed to better assess the risk associated with dam failure from these facilities.
- Most dam failure mapping required at federal levels requires determination of the probable maximum flood. While the probable maximum flood represents a worst-case scenario, it is generally the event with the lowest probability of occurrence. Mapping of dam failure scenarios for non-federal-regulated dams that are less extreme than the probable maximum flood, but have a higher probability of occurrence, can be valuable to emergency managers and community officials downstream of these facilities. This type of mapping can illustrate areas potentially impacted by more frequent events to support emergency response and preparedness actions.
- The concept of residual risk associated with structural flood control projects should be considered in the design of capital projects and the application of land use regulations.
- Addressing security concerns and the need to inform the public of the risk associated with dam failure is a challenge for public officials.

