FEMA **Fact Sheet**

Dam Awareness May 2018

Introduction

There is a general lack of knowledge, understanding, and awareness of dams and their risks, leaving those most affected by dams unprepared to deal with the impacts of their failures. This fact sheet provides a general overview of dams for consideration and use by the intended audience, based on their situation.

Responsibility and Liability for Dam Safety

Dams are owned and operated by individuals, private and public organizations, and various levels of government (federal, state, local, tribal). The responsibility for operating and maintaining a safe dam rests with the owner. Common law holds that the storage of water is a hazardous activity. Maintaining a safe dam is a key element in preventing failure and limiting the liability that an owner could face. The extent of an owner's liability varies from state to state and depends on statutes and case law precedents. Federally owned and regulated dams are subject to federal regulations and guidelines and applicable federal and state laws. Owners can be fiscally and criminally liable for any failure of a dam and all damages resulting from its failure. Any uncontrolled release of the reservoir, whether the result of an intentional release or dam failure, can have devastating effects on persons, property, and the environment (FEMA, 2016a).

Any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is considered a dam failure. Lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure, which may result in an uncontrolled release of the reservoir and can have a severe effect on persons and properties downstream (FEMA, 2016b).

Dam Hazard Classifications

Dams are classified to identify their potential hazard. Hazard potential classification systems vary between state and federal agencies. The hazard potential classifications are used by state dam safety regulators for several purposes including for planning at the state and local level, assigning design requirements, and determining frequency of operation and maintenance activities and inspections. Emergency managers should contact their state dam safety official to find out about their state's hazard potential classification system.

Federal Emergency Management Agency

Federal guidelines provide for a three-level classification system that defines low-, significant-, and high-hazard potential classifications depending on the potential for loss of life, economic loss, and environmental damage resulting from a hypothetical dam failure. Section III of FEMA 333, Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams (2004), provides more information on this classification system.

Purposes and Types of Dams

The U.S. Army Corp of Engineers maintains a National Inventory of Dams (called the NID database) for the United States using information provided by federal and state agencies that regulate dams within their jurisdictions. As of October 2016, when USACE completed its most recent inventory, there were 90,580 dams listed in the United States. The NID database shows the many purposes of dams in the United States and the many types of dams.

Purposes of Dams

Dams are used for many purposes in the United States, from recreation to navigation. Figure 1 shows the percentages for each purpose.

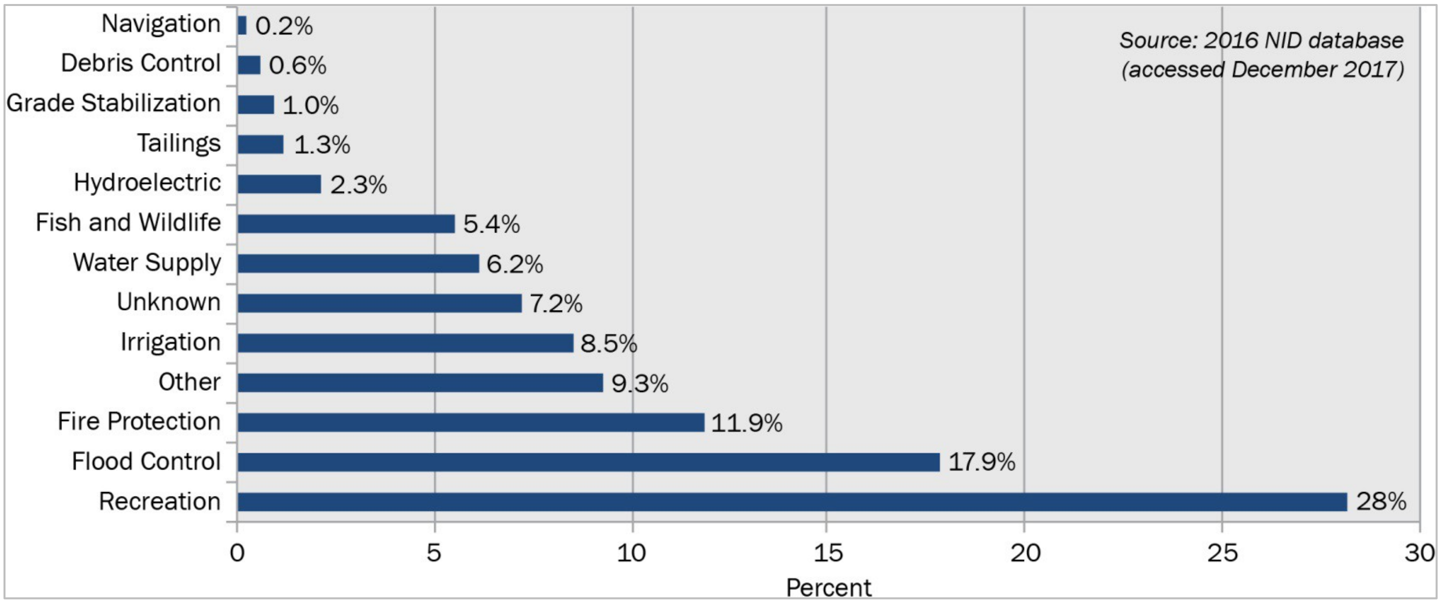

Figure 1: Dams by primary purpose

Dam Types and Configurations

There are many different dam types and construction configurations. Dams can be constructed with one type of construction materials or a combination of several. Table 1 describes some of the most common types of dams. Figure 2 shows types of dams by number in the United States, which are the dam types used in the NID database.

Table 1: Common Dam Types

Types	Description
Embankment dams (hydraulic fill, homogeneous, or zoned)	These dams are earthfill or rockfill dams. The strength of this type of dam is partly a function of the materials used in its construction.
Concrete gravity dams	A concrete gravity dam has a triangular cross section with the base much wider than the crest. The dam is configured to provide enough mass and a sufficiently wide base to resist sliding and overturning in response to the force of water pushing against it. If the upstream face of the dam is sloped, a component of the water force pushes downward on the dam, contributing favorably to the stability of the structure. Concrete gravity dams are often used for hydroelectric power projects.
Concrete buttress dams	Concrete buttress dams are a specific type of gravity dam. They have a solid upstream side supported on the downstream side by a series of buttresses. Water pressure forces are diverted to the dam foundation through vertical or sloping buttresses.
Concrete arch dams	Concrete arch dams are usually constructed of a series of vertical blocks that are keyed together; barriers that stop water from flowing are provided between the blocks. These dams have a convex curve into the reservoir to transfer water forces to the abutments.
Roller-compacted concrete (RCC) dams	RCC is generally defined as a no-slump concrete that is placed by earth-moving equipment and compacted by vibrating rollers in horizontal lifts up to 12 inches thick (USBR, 2017). RCC can be used to build stability buttresses for masonry gravity and concrete arch dams, overtopping protection and upstream slope protection for embankment dams, new gravity dams, new spillways and spillway stilling basins, tailrace dikes, and overflow weirs.
Masonry dams	Masonry dams are dams mainly made out of cut quarry stone, brick, or concrete blocks that may be joined with a binder such as mortar. They are typically configured as gravity or arch-gravity dams. Masonry dams are most often found in parks and municipal areas.
Lined fill dams	Lined fill dams have embankments usually constructed primarily of earthen or rockfill materials. The upstream slope face and the area extending along the impoundment upstream is lined with concrete, geomembranes, asphalt, or other low-permeability materials.

Tailing dams (starter dams or dykes; upstream, centerline, or downstream construction)	Tailing dams are used to impound waste materials. They are constructed of industrial or mining waste or waste mineral processing materials. Tailings dams are often the most significant environmental liability for a mining project.
Coal combustion residuals impoundments	Coal waste dams are constructed to store waste materials. Ash impoundments (also called ash ponds) store ash mixed with water, primarily from the combustion of coal. They are considered a waste management facility. In these impoundments, coal ash settles out and is eventually removed or disposed of as slurry or sludge. Water at the surface level is discharged through an outlet structure to a nearby stream or water-processing plant.
Other types of dams	Timber dams: Timber dams are commonly constructed for agricultural uses, such as livestock ponds. Over time, the wood can weaken and, depending on the amount of rock and mud that has collected among the timbers over the lifetime of the dam, can collapse. Sheet-pile dams: A sheet-pile dam is typically a temporary structure used during construction projects. Some dams use sheet piles to reduce seepage.

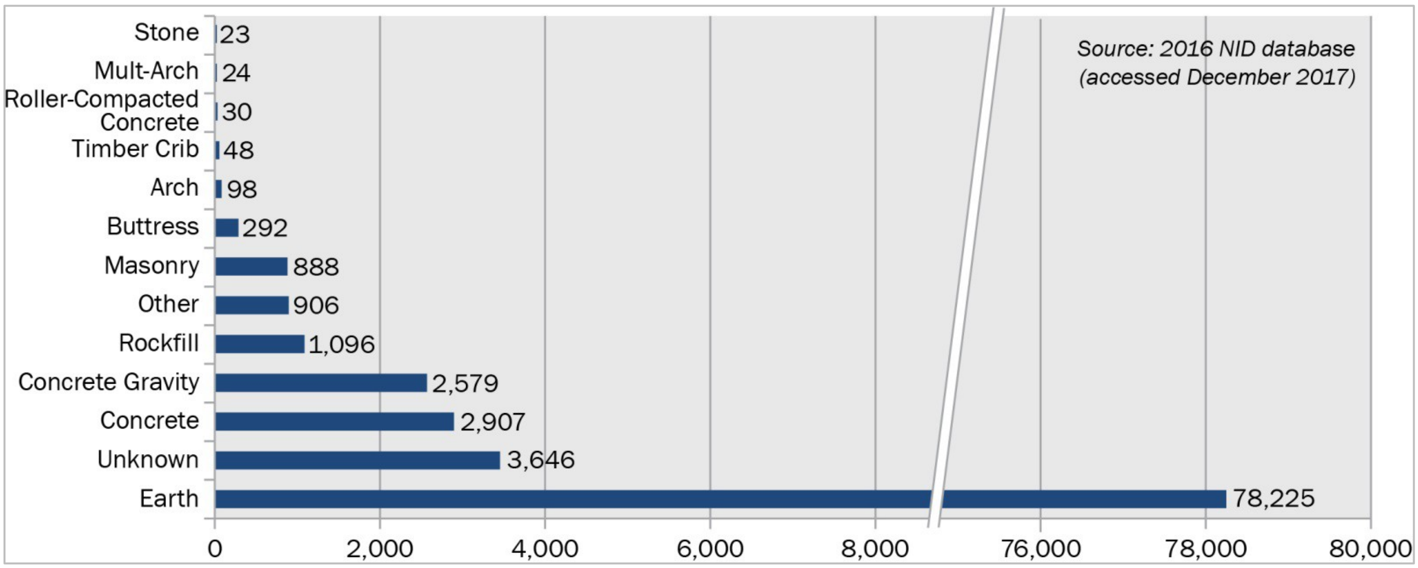

Figure 2: Number of dams by type, as reported in the NID

Parts of a Dam

Despite the many types, constructions, and purposes of dams, most dams consist of most or all the components shown in Figure 3. Refer to the U.S. Department of the Interior, Bureau of Reclamation's (USBR's) Design of Small Dams (1987) for more information about dam components.

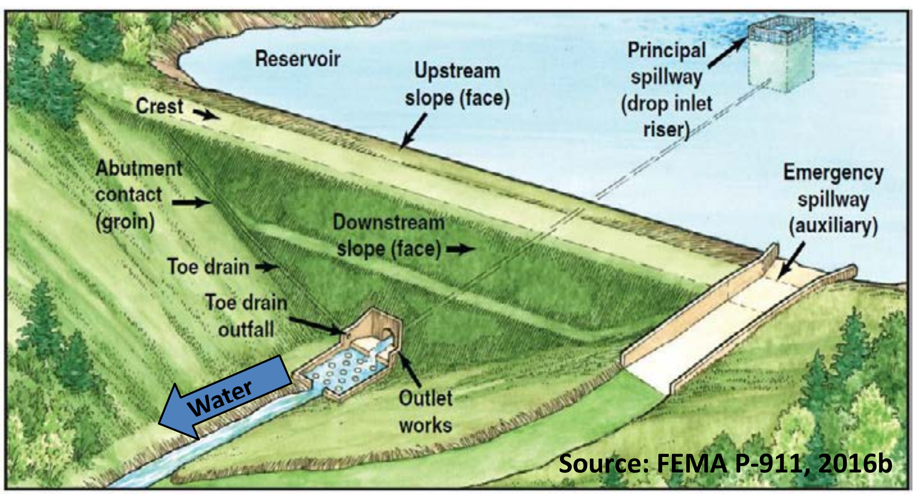

Figure 3: Components of a typical earthen dam (example shows earthen dam)

Three critical components for all dams are the abutments, spillways, and outlet work structures. Tables 2 and 3 describe the different types of spillways and outlet works structures.

- **Abutments**. Dam abutments are where the dam is structurally tied in with the adjoining valley slopes. Right and left abutments are described as viewed looking downstream.
- **Spillways**. Spillways are used to help regulate the volume of water in the reservoir. They can also be used to release surplus floodwater that cannot be contained in the reservoir. However, if the inflow is greater than the spillway and storage capacity, the dam can overtop.
- **Outlet works**. Outlet works control the release of water from a reservoir and typically consist of a combination of structures

Spillway Activation vs Dam Overtopping

The activation of spillways is not the same as dam overtopping. During Hurricane Matthew, 911 and Emergency Operation Centers received calls that a dam was overtopping when in fact the auxiliary (emergency) spillway was activated and was simply performing as intended. Auxiliary spillways are activated when the reservoir rises above normal operations and passes floodwater to prevent the dam from being overtopped.

Table 2: Types of Spillways

Types	Description
Principal	A principal spillway is the primary outlet, usually consisting of an intake structure, a principal spillway conduit that extends through the embankment, and an outlet structure. Principal spillways can also consist of a weir control section cut through the embankment, an open channel chute, ogee spillway, or other configuration.
Auxiliary	Also known as an emergency spillway, an auxiliary spillway is not used in normal operations; an auxiliary spillway may activate during a flood, when the actual flood discharge exceeds the design capacity of the service spillway.
Chute / trough	A chute or trough spillway is an open channel that conveys water from the reservoir to the downstream channel. The open channel can be located either along the abutment of the dam or nearby.
Ogee	An ogee spillway is an overflow weir in some concrete and masonry dams. Ogee spillways need to be wide enough to accommodate the designed reservoir discharge.
Gated	A gated spillway can be raised or lowered to control the release of water.

Table 3: Types of Outlet Works Structures

Types	Description
Intake tower	The intake tower is located at the upstream end of the outlet works to control the reservoir elevation. Intake towers often include gates, valves, bulkheads, trash racks, and/or fish screens.
Conduit	Conduits, sometimes called principal spillway pipes, convey water through the dam from the intake tower to the terminal structure.
Terminal structure	Terminal structures are located at the downstream end of the outlet works to dissipate the energy of rapidly flowing water and protect the riverbed from erosion.

Normal Dam Operations

Understanding the normal operation of a dam is an important part of dam awareness. The more familiar a dam operator knows the dam, the better they will be able to detect anomalies and take corrective actions before the issues escalate. Table 4 describes normal dam operation activities. For more information about normal dam operations, see North Carolina Department of Environment and Natural Resources Division of Land Resources' Dam Operation, Maintenance, and Inspection Manual (2007) and the Association of State Dam Safety Officials (ASDSO) web page, "Lesson Learned: Regular operation, maintenance, and inspection of dams is important to the early detection and prevention of dam failure."

Table 4: Normal Dam Operation Activities

Activity	Description
Inspection	Dam operators should be familiar with their dam and trained to identify anomalies during regular inspections. When possible, dams should be inspected during flood events to observe performance under hydraulic loading. Following flood events, dam operators should look for damage to the dam and check for undermining of the spillway or other structural components of the dam.
Instrumentation	If the dam has instrumentation, dam operators should have a good understanding of the dam's instrumentation systems. At a minimum, operators should be able to interpret typical instrumentation readings and be aware of seasonal trends in data. Dam operators should also look for subtle changes in instrumentation readings over long (multi-year) periods of time.
Operation of dam appurtenances	Dam operators should be familiar with procedures to operate: • Spillways • Low-level outlets (to drain a reservoir) • Reservoir pumps • Hydropower generation equipment

Common Failure Modes

Dams can fail in numerous ways. Figure 4 shows several common failure modes, which are described in Table 5. Common failure modes are not the only situations that can lead to adverse outcomes. A non-failure event is an event at a dam that will not, by itself, lead to a failure, but that requires investigation and notification of internal and/or external personnel. Non-failure events can lead to flooding of upstream and/or downstream areas. For more information about historical dam failures, see USBR's *Reclamation Consequence Estimating Methodology – Dam Failure and Flood Event Case History Compilation* (2015). The ASDSO also has a "Lessons Learned from Dam Incidents and Failures" website that can be accessed at http://damfailures.org/lessons-learned/.

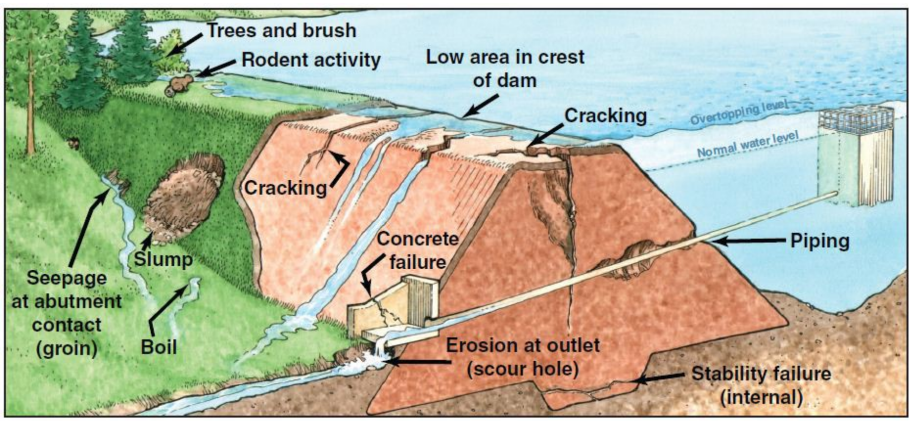

Figure 4: Common failure modes (Source: FEMA P-911, 2016b)

Table 5: Dam Failure Modes

Failure Type	Description
Seepage and piping	Seepage and piping can cause internal erosion within the dam that can erode embankment or foundation materials and lead to dam failure. Evidence of piping is generally detected at the location of seepage discharge.
Overtopping (hydrologic failure)	Overtopping can cause erosion and head-cutting of embankment materials and can lead to dam failure.
Deformation	Deformation is caused by differential settlement; transverse or longitudinal cracking; or slope instability, slumps, or other slope failures. Deformation can provide a path for seepage through the dam and lead to failure. Low areas in the crest of the dam can make the dam more vulnerable to overtopping.

Liquefaction	Liquefaction can occur when the strength and stiffness of a saturated soil is reduced by earthquake shaking or other rapid loading. The weakened soil can cause the collapse of the dam.
Concrete failure	Concrete failure, structural cracking, broken masonry, and offsets at joints can lead to sudden failures.
Neglected maintenance and deterioration	Neglected maintenance and deterioration can leave a dam vulnerable to several failure modes: • Missing riprap can leave areas of an embankment unprotected and vulnerable to erosion from wave action or head-cutting during overtopping events. • Woody vegetation growing on a dam can interfere with effective dam safety monitoring. Uprooted trees can create large voids in the embankment, and roots can create preferred seepage paths, causing internal erosion problems. Vegetation can also block spillways. • Animal burrows in the embankment can cause preferred seepage paths. Livestock activity can damage embankment slopes and increase erosion potential. • Malfunctioning gates, conduits, or valves can reduce discharge capacity and cause the dam to overtop, which could lead to failure.
Other	Other problems that can leave a dam vulnerable to failure include outdated designs; hydraulically inadequate spillways; and damage from vandalism, cyber-attacks, or terrorism.