Volume II: Hazard Annex
Dam Failure

Causes and Characteristics of Dam Failure

Dam Characteristics

Dams are impervious structures that block the flow of water in a river or stream, capturing water behind the dam. Traditionally, a wide range of materials have been used in dam construction, including earth, stone, masonry, wood, and concrete. Large modern dams are almost always embankment dams (built primarily from soil, rock, or mixtures) or concrete dams.[59]

Dams are built for many purposes. Examples of common uses include water storage for potable water supply, livestock water supply, irrigation, fire suppression, flood control, and hydroelectric power. Dams may also provide various recreational opportunities like fishing or boating. Dams are commonly multifunctional, serving two or more of these purposes.[60]

Large modern dams typically have control mechanisms such as gated spillways or outlet pipes for releasing water in a controlled fashion. During high water flow periods, water is stored behind a dam, while in low water flow periods, water is released to increase flows. The specific patterns of water storage and release vary from dam to dam, depending on the primary purpose(s) of the dam and on a wide variety of economic, regulatory and environmental considerations.[61]

Modern dams, whether embankment dams or concrete dams, are typically constructed on a foundation, which may be concrete, natural rock or soils, or compacted soils. Dams are usually constructed along a constricted part of a river valley to minimize cost. Dams are also connected to the surrounding natural valley walls, which become the abutments of the dam structure itself.[62]

Embankment dams, also referred to as earthfill or rockfill dams, are broad flat structures, typically at least twice as wide at the base as their height. Embankment dams are subject to erosion by running water. Thus, modern embankment dams always have erosion-resistant materials used in the

[59] Federal Emergency Management Agency, "Dam Safety: An Owner's Guidance Manual." FEMA, 1987.
[60] Ibid.
[61] Ibid.
[62] Ibid.

water release and control mechanisms of the dam.[63] There are many forms of controlled release mechanisms including concrete spillways with concrete or steel gates and outlet pipe systems with concrete or steel pipes.[64]

Modern concrete dams fall into two major classes: gravity dams and arch dams. Concrete gravity dams are designed on principles similar to embankment dams. Concrete gravity dams are broad structures, generally triangular in shape with a flat base, a narrow top, a flat upstream side and a broad sloping downstream side. Typically, gravity dams are keyed into bedrock foundations and abutments to increase the stability of the dam.[65]

Concrete arch dams rely primarily on the strength of concrete to impound water. Concrete arch dams are much thinner in cross section than concrete gravity dams. An arch dam is typically constructed in a location with Canyon walls and takes advantage of the arch action in the dam to transfer the forces in the dam to the rock canyon walls as well as the base. The design and shape of the dam is determined by the site conditions and the steepness and width of the canyon walls. The use of the arch action reduces the amount of concrete required to carry the load.[66]

Causes of Dam Failure

Dam failures can occur at any time in a dam's life; however, failures are most common when water storage for the dam is at or near design capacity. At high water levels, the water force on the dam is higher and several of the most common failure modes are more likely to occur.

Correspondingly, for any dam, the probability of failure is much lower when water levels are substantially below the design capacity for the reservoir.

For embankment dams, the most common failure mode is erosion of the dam during prolonged periods of rainfall and flooding. When dams are full and water inflow rates exceed the capacity of the controlled release mechanisms (spillways and outlet pipes), overtopping may occur. Overtopping implies that the water level has exceeded the height of the dam and thus spills over the top. When overtopping occurs, scour and erosion of either the dam itself and/or the abutments may lead to partial or complete failure of the dam. Especially for embankment dams, internal erosion, piping or seepage through the dam, foundation, or abutments can

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[63] United States Society on Dams, "Strength of Materials for Embankment Dams." USSD, 2007.
[64] Federal Emergency Management Agency, "Dam Safety: An Owner's Guidance Manual." FEMA, 1987.
[65] Ibid.
[66] Institute For Water Resources, "Management Measures Digital Library." U.S. Army Corps of Engineers. http://www.iwr.usace.army.mil/inside/products/pub/mmdl/fld/Feature.asp?ID=31, accessed on May 22, 2010.

also lead to failure. For smaller dams, erosion and weakening of dam structures by growth of vegetation and burrowing animals is a common cause of failure.

For embankment dams, earthquake ground motions may cause dams to settle or spread laterally. Such settlement does not generally lead, by itself, to immediate failure. However, if the dam is full, relatively minor amounts of settling may cause overtopping to occur, with resulting scour and erosion that may progress to failure.

For any dam, improper design or construction or inadequate preparation of foundations and abutments can also cause failures. Improper operation of a dam, such as failure to open gates or valves during high flow periods can also trigger dam failure. For any dam, unusual hydrodynamic (water) forces can also initiate failure. Landslides into the reservoir, which may occur on their own or be triggered by earthquakes, may lead to surge waves which overtop dams or hydrodynamic forces which cause dams to fail under the unexpected load. Earthquakes can also cause seiches (waves) in reservoirs that may overtop or overload dam structures. In rare cases, high winds may also cause waves that overtop or overload dam structures.

Concrete dams are also subject to failure due to seepage of water through foundations or abutments. Dams of any construction type are also subject to deliberate damage via sabotage or terrorism. For waterways with a series of dams, downstream dams are also subject to failure induced by the failure of an upstream dam. If an upstream dam fails, then downstream dams also fail due to overtopping or due to hydrodynamic forces.

Overtopping of a dam is often a precursor of dam failure. National statistics show that overtopping due to inadequate spillway design, debris blockage of spillways, or settlement of the dam crest account for approximately 34% of all U.S. dam failures.[67]

Foundation defects, including settlement and slope instability, cause approximately 30% of all dam failures.[68]

Another 20% of U.S. dam failures are caused by piping (internal erosion caused by seepage). Seepage often occurs around hydraulic structures, such as pipes and spillways; through animal burrows; around roots of

[67] Association of State Dam Safety Officials, "Dam Failures and Incidents." http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e, accessed on March 8, 2010.
[68] Association of State Dam Safety Officials, "Dam Failures and Incidents." http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e, accessed on March 8, 2010.

woody vegetation; and through cracks in dams, dam appurtenances, and dam foundations.[69]

Other causes of dam failures include structural failure of the materials used in dam construction and inadequate maintenance.[70]

History of Dam Failure in Marion County

Oregon has only experienced four major dam failures between 1874 and 2008.[71] The most significant event is the 1903 Willow Creek Dam failure, which nearly destroyed the town of Heppner and killed almost 250 people. Other failures within the state include Colombia River dike (1948), Simplot Wastewater Reservoir (2005), and the Geary Levee (2006).

Marion County has not experienced any dam failures. However, in 1996 Silver Creek flooded, threatening buildings on James Street and along Silver Creek in Silverton. Logs and debris threatened bridges and the base of Silver Creek dam was significantly eroded.[72] The damage did not result in dam failure and the Silver Creek dam has since been repaired.

Risk Assessment

How are hazard areas identified?

The Oregon Department of Water Resources maintains an inventory of all dams in the state. The inventory rates each dam with either a high, significant, or low hazard classification. Each rating is an estimate of the potential consequences to downstream life and property that would result from a catastrophic dam failure.[73] A high rating means that if a sudden failure of the dam occurred there would be direct loss of human life and severe or widespread property damage would be expected to occur. A significant rating means that a sudden failure of the dam or a sudden uncontrolled release of stored water would most likely result in significant property damage, and has the potential for causing indirect loss of human life. A low rating means that a dam failure or sudden uncontrolled release of stored water from the reservoir would not appear to threaten human life

[69] Association of State Dam Safety Officials, "Dam Failures and Incidents." http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e, accessed on March 8, 2010.
[70] Ibid.
[71] Association of State Dam Safety Officials, " Dam Failures." http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents.pdf, accessed on March 9, 2010.
[72] City of Silverton. "Silver Creek Dam Break Analysis. http://www.97381.com/dam/dam01.html, accessed on May 27, 2010.
[73] Oregon Water Resource Department. "Dam Safety in Oregon." State of Oregon, 2007.

and downstream property damage would be limited primarily to the stream channel.[74]

In Marion County, Funrue and Silver Creek dams are listed as high potential hazard dams.[75] In addition, Big Cliff and Detroit dams, located in Linn County, pose a significant threat to eastern communities of Marion County. The high potential hazard dams are listed below in Table 5.1

Table 5.1 High Potential Hazard Dams

Dam Name	River	City	Height (feet)	Storage (acre feet)
Big Cliff	North Santiam	Mill City	141	5,930
Detroit	North Santiam	Mill City	450	455,000
Funrue	Drift Creek	Silverton	29	126
Silver Creek	Silver Creek	Silverton	65	2,500

Source: OWRD Dam Inventory, 2009.

The extent of the flood hazard from these dams depends on which dam fails, how much water is behind the dam at the time of failure, time of day, the degree to which the dam failed, and the dam's proximity to population centers.

[74] Ibid.
[75] Oregon Water Resource Department. "OWRD Dam Inventory." State of Oregon, 2009. http://apps2.wrd.state.or.us/apps/misc/dam_inventory/Default.aspx, accessed on March 9, 2010.

Probability of Future Occurrence

To evaluate the probability of a dam collapse in Marion County, it is important to consider the maintenance schedule for each dam, in particular high potential hazard dams. Oregon laws do not specify the frequency of inspections.[76] The inspections are made under the supervision of the Dam Safety Coordinator.[77] The most recent and expected inspection for each high hazard potential dam in the vicinity of Marion County is listed in Table 5.2.

Table 5.2 Dam Inspection Schedule

Dam Name	River	County	Last Inspection	Next Inspection
Big Cliff	North Santiam	Linn	5/16/01	not listed
Detroit	North Santiam	Linn	5/1/01	not listed
Funrue	Drift Creek	Marion	1/21/09	2010
Silver Creek	Silver Creek	Marion	8/21/09	2010

Source: OWRD Dam Inventory, 2009.

Both the Funrue and Silver Creek Dams were inspected in 2009 and will be inspected again in 2010. Schedule information for Big Cliff and Detroit Dams is not available. Table 5.3 identifies the owner of each of the high hazard potential dams.

Table 5.3 High Hazard Potential Dam Owners

Dam Name	Owner
Big Cliff	Army Corps of Engineers
Detroit	U.S. Bureau of Reclamation
Funrue	S. Amos/Ardythe Funrue
Silver Creek	City of Silverton

Source: OWRD Dam Inventory, 2009.

The probability of dam failure is impossible to estimate with any accuracy from present data, however given the frequent inspections to the dams in Marion County, the likelihood of an event is very low.[78] The 2006 hazard analysis does not address the likelihood of a dam failure. The Marion County steering committee determined that the probability of a dam failure is **low**, meaning that one incident is likely in a 75 to 100 year period.

Vulnerability Assessment

Marion County is vulnerable to inundation from a flood should one of the dams collapse or fail. There is a large amount of housing located within the Detroit, Big Cliff, and Silverton dam inundation zones. The 2006 hazard

[76] Oregon Water Resource Department. "Dam Safety in Oregon." State of Oregon, 2007.
[77] Ibid.
[78] Oregon Emergency Management, *Dam/Levee Failure Statewide Hazard Analysis,* available from Oregon Emergency Management, March 1987.

analysis does not address the likelihood of a dam failure. However, the Marion County steering committee determined that the county's vulnerability in the event of dam failure is **high**, meaning that if a failure were to occur, more than 10% of the population or regional assets could be affected.

Risk Analysis

Detailed loss estimates for possible failure of dams that pose a threat to Marion County have not been determined at this time. However, a risk analysis should be completed to determine the potential loss to life and property when data is available (see Multi-Hazard Action # 8).

Community Hazard Issues

What is susceptible to damage during a hazardous event?

The greatest risk associated with a dam failure is the potential for significant loss of life should either the Big Cliff or Detroit dams fail. Rapidly moving floodwaters would create a challenge for alerting residents of the impending danger and initiating an evacuation plan.

Towns downstream of Detroit and Big Cliff Dam include Niagara, Gates, Mill City, and Stayton. These cities have a combined total population of approximately 9,000 people.[79] After a dam failure, access to these areas will be extremely difficult as there is only one main access road, Highway 22 that connects these cities to the rest of Marion County.

Possible dam failures affecting Marion County are low probability events, but the potential casualties and economic consequences are extremely high. The combination of low probability but large consequences makes analysis of such situations difficult from both a technical and a public policy perspective. The evaluation is difficult technically because it requires detailed engineering analysis of each dam and careful probabilistic risk analysis. As always, communication with the public must be non-alarmist, but factual, realistic and informative.

The potential impacts of dam failures on Marion County area are further described below in Table 1.

[79] U.S. Census, 2000.

Table 1 Potential Impacts of Dam Failure in Marion County

Inventory	Probable Impacts
Portion of Marion County affected	Direct impacts to mapped inundation areas for dam failures, or to smaller areas for more likely partial failures
Buildings	Heavy damage in inundation areas
Streets	Damage and closure in inundation areas
Roads to/from urban core	Damage and closure in inundation areas
Electric power	Damage and loss of service in inundation areas
Other utilities	Damage and closure in inundation areas. Potential for major damage to water and wastewater treatment plants in extreme events
Casualities	Potential for high casualties (deaths and injuries) in extremely unlikely mahor dam failures, depending on warning time available and effectiveness of evacuations

Existing Hazard Mitigation Activities

The Big Cliff, Detroit, and Silver Creek dams are routinely checked and maintained by their respective owners to ensure that the dams are not in danger of collapsing. Oregon laws do not specify the frequency of dam inspections. However, it is recommended that inspections should be conducted on a yearly basis for high hazard dams[80].

The Marion County Strategic Plan (2010), goal #7 acknowledges an effort to educate residents of emergency preparation strategies. This includes coordinating emergency planning drills with participating cities within the county. In addition, the Transportation System Management policies include guidelines for the county's approach to address emergency situations with regard to the transportation system. The county recognizes that, in the event of a dam failure or other hazard related events, "the transportation network becomes especially critical in times of crisis."

Hazard Mitigation Action Items

The following actions have been identified by the Marion County steering committee, and are recommended for mitigating the potential effects of dam failure in Marion County. Please see full action item worksheets in Appendix A.

DF1: Prepare updated high resolution, digitalized maps of dam failure inundation areas for the Silverton, Big Cliff, and Detroit Reservoir dams.

[80] Oregon Water Resource Department. "Dam Safety in Oregon." State of Oregon, 2007.

DF2*:* Actively encourage the Army Corps of Engineers to complete seismic vulnerability assessments for dams upstream of Salem and to make seismic improvements as necessary.