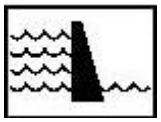
Dam Safety



Dam Safety

Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
People	<1,000	1,000-10,000	10,000-50,000	50,000+
Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
Environment	<10%	10-15%	15%-20%	20%+
Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Hazard scale	< Low to High >			

Risk Level

- Frequency – There is a dam failure in Washington once every two years.
- People – Depending on the location of the dam or levee, failure of either of these types of structures could affect zero to thousands of people depending on the population located downstream.
- Economy – The economy of Washington could be affected by a levee or dam failure due to loss of homes and businesses, thus lowering the overall tax base for the affected area.
- Environment – Although the environment can be severely affected by a dam failure or levee break due to the flood that results in this type of incident, the likelihood that such an incident will eradicate 10% of a single species or habitat is considered unlikely and thus does not meet this category's minimum threshold.
- Property – Property can be dramatically affected in the event of a dam failure or levee break. Should such a failure occur above a highly populated area, damages can be expected to be at least $100 to $500 million dollars.

Summary

- The hazard – Dam Failure is a term indicating the potential hazard to the downstream area resulting from failure or mis-operation of the dam or facilities. The potential impact of a dam, dike or levee failure in Washington State could result in a flood event. The amount of water impounded is measured in acre-feet, in which an acre-foot of water is the volume that covers an acre of land to a depth of one foot. Dam failures are not routine; two factors influence the potential severity of full or partial dam failure: (1) The amount of water impounded, and (2) the density, type, and value of development downstream.

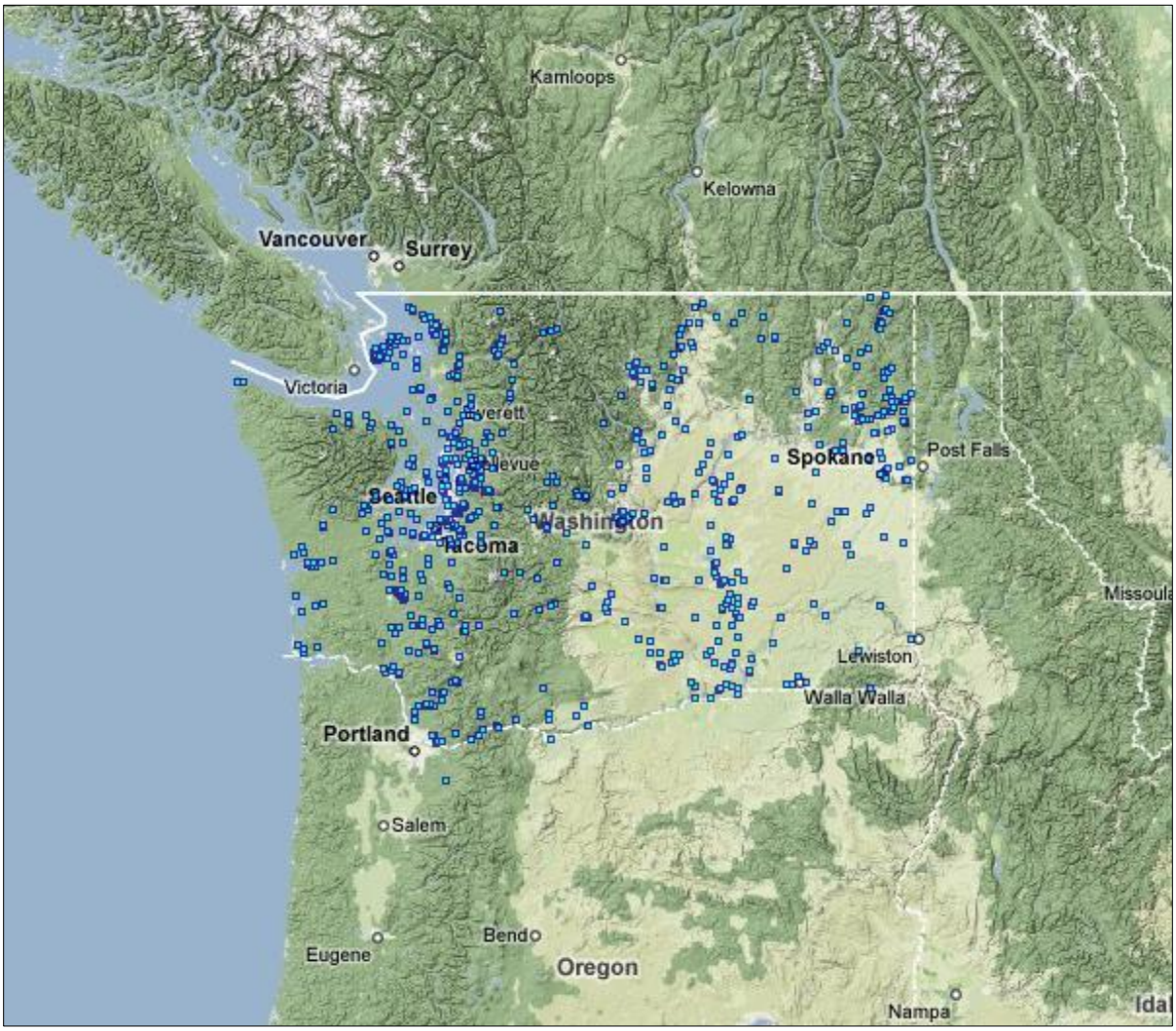
- Previous Occurrences – Since 1918, the Washington State Department of Ecology reports fifteen dam-incident events, resulting in nine lost lives. A complete list of dam incidents and failures is attached as Appendix 1 at the end of this profile.

- Probability of Future Events – Dam failure or levee breeches can occur with little warning. Intense storms may produce a flood in a few hours or even minutes for upstream locations. Flash floods occur within six hours of the beginning of heavy rainfall, and dam failure may occur within hours of the first signs of breaching. Other failures and breeches can take much longer to occur, from days to weeks, as a result of debris jams or the accumulation of melting snow. The overall probability of a dam failure is generally quite low for most dams, typically less than a 500-year flood.

- Jurisdictions at Greatest Risk – This summary will not address any one specific dam within a particular jurisdiction or region in an attempt to determine risk, and will only supply information.

- Special Note – The intent behind this hazard profile is not to provide an all-encompassing source of information, but to increase awareness of the potential impact from this hazard. Therefore, this profile will not attempt to estimate potential losses. This profile will only provide information on the dams within the State. The Washington State Department of Ecology remains the primary source of information and subject matter experts for Dam related issues.

U.S. Army Corps of Engineers, National Inventory of Dams, Washington State Map

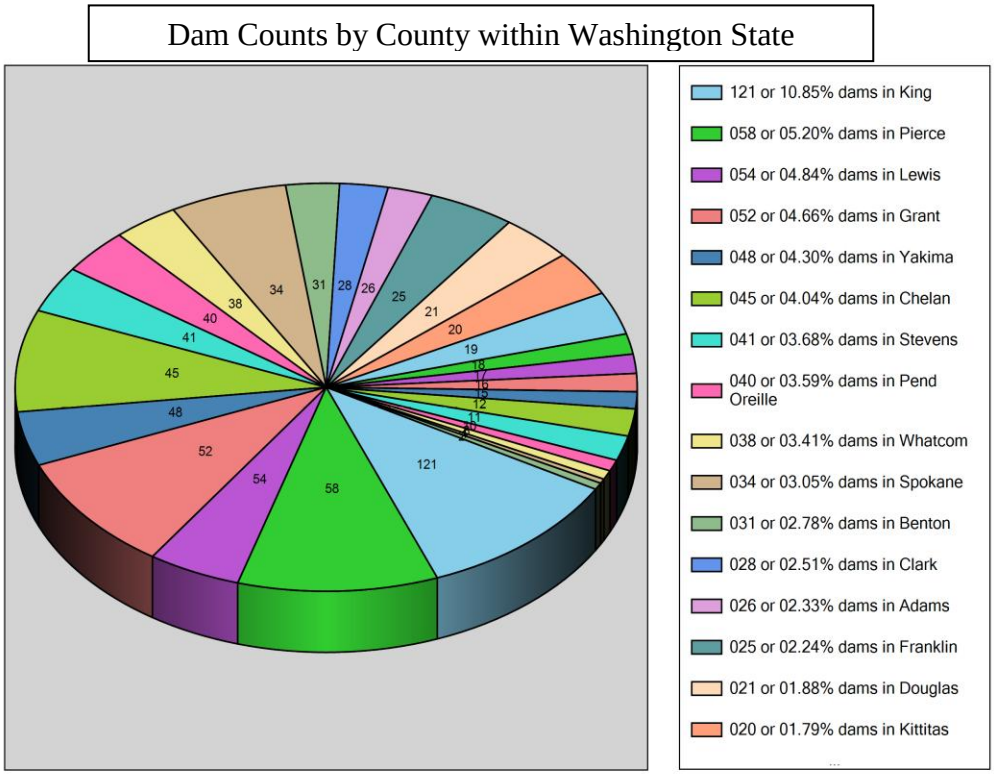


The Hazard

A dam is defined as an artificial barrier that can or does impound more than 10 acre-feet of water. Dam failure is the uncontrolled release of impounded water resulting in downstream flooding, which can affect life and property. Heavy periods of rain, flooding, earthquakes, blockages, landslides, lack of maintenance, improper operation, poor construction, vandalism, or terrorism can all result in dam failures. A levee is an embankment raised to prevent a river from overflowing. Levees are also small ridges or raised areas bordering an irrigated field. A dike is an embankment built along the shore of a sea or lake or beside a river to hold back the water and prevent flooding.

Under Washington state law, the Department of Ecology (Ecology) is responsible for regulating dams that capture and store at least 10 acre-feet (about 3.2 million gallons) of water or watery materials such as mine tailings, sewage and manure waste. Since 2007, the US Army Corps of Engineers is responsible to inventory and inspect all private levees and dikes in the state.

The first dam safety law in Washington was passed as part of the state water code in 1917 (RCW 90.03.350). This law required that engineering plans for any dam that could impound 10 or more acre-feet had to be reviewed and approved by the state before construction could begin. Over the years, the Department of Conservation and Development, then the Department of Water Resources, and now the Department of Ecology performed this function. In 1975, the Washington State Department of Ecology assembled the first dam inventory list for our state, which includes all dams owned within our boundaries. The list compiled by the Department of Ecology maintains 1,125 dams



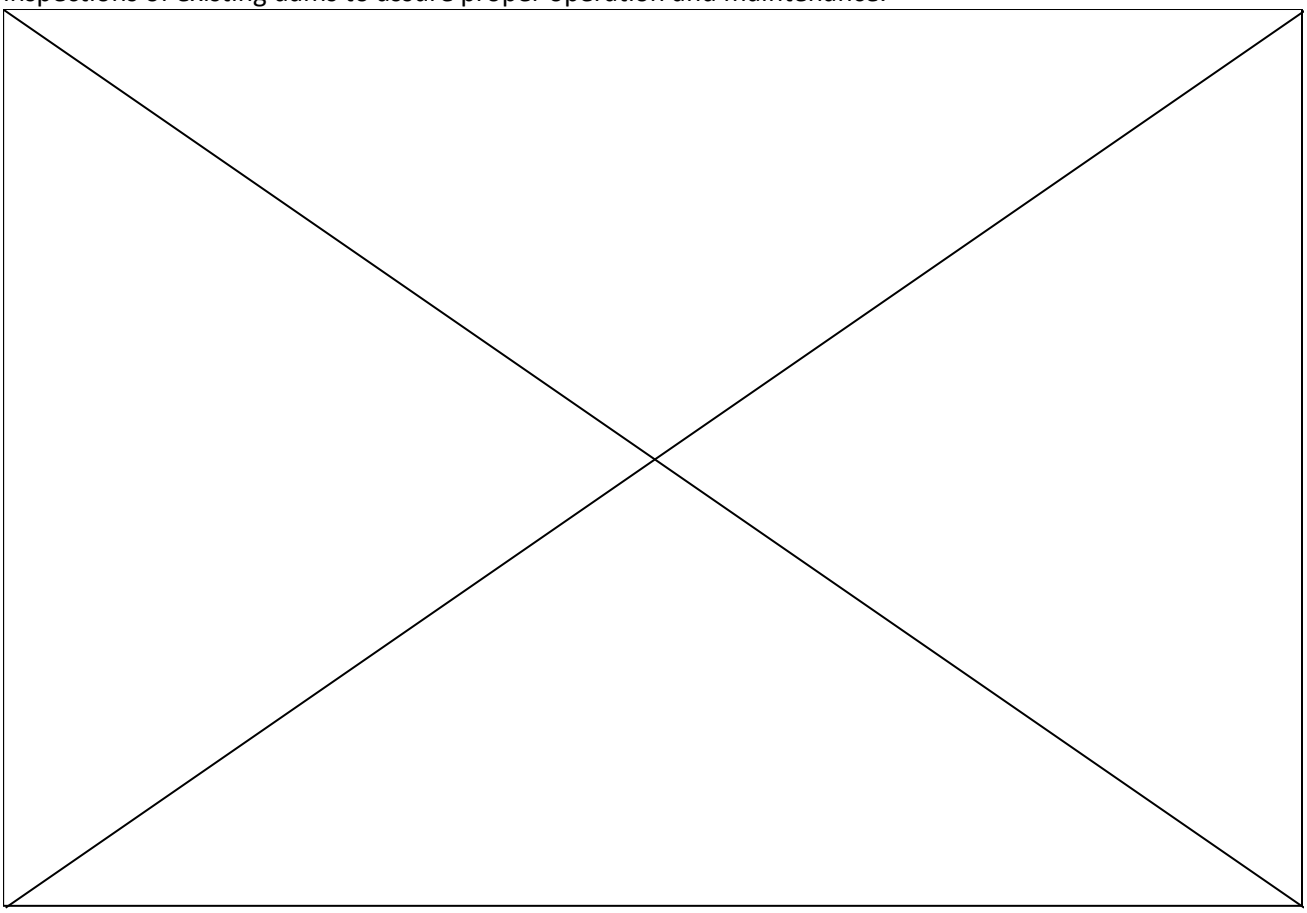
Source: Washington State Department of Ecology. Available at: http://www.ecy.wa.gov/pubs/94016.pdf

In 1972, the U.S. Congress passed Public Law 92-367 which authorized the development of a National Inventory of Dams (NID). The National Inventory of Dams (NID) contains information on approximately 79,000 dams throughout the U.S. that are more than 25 feet high, hold more than 50 acre-feet of water, or are considered a significant hazard if they fail. The NID is maintained and published by the U.S. Army Corps of Engineers with information from all 50 states, Puerto Rico, and 16 Federal agencies. The current National Inventory of Dams for Washington State lists 763 dams[1].

In order for a dam to be placed on the NID list, the dam must meet at least one of the following criteria:

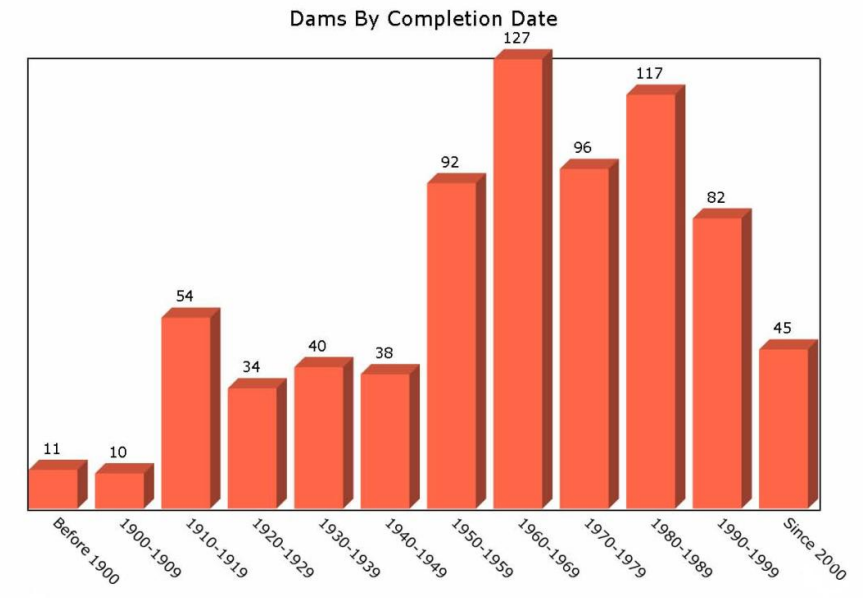
1. High hazard classification - loss of one human life is likely if the dam fails
2. Significant hazard classification - possible loss of human life and likely significant property or environmental destruction
3. Equal or exceed 25 feet in height and exceed 15 acre-feet in storage
4. Equal or exceed 50 acre-feet storage and exceed 6 feet in height

In Washington State, besides regulating dams that meet the NID requirements, there are over 370 dams which do not meet one of the four criteria above, but do fall under the 10 acre-foot jurisdictional level. Ecology's Dam Safety Office currently oversees 996 of the 1,125 dams across the state. Through plan reviews and construction inspections, the agency helps ensure these facilities are properly designed and constructed. To reasonably secure the safety of human life and property, Ecology also conducts inspections of existing dams to assure proper operation and maintenance.



The ages of dams in Washington vary from 11 dams constructed pre-1900, to more than 50 dams being completed since 2000. The age of a dam is also a factor in the stability, as many dams are constructed

for a specified number of years, as well as the integrity of the materials used to construct the dam may deteriorate over time.



Source: U.S. Corps of Engineers, National Dam Inventory. Available at https://rsgis.crrel.usace.army.mil/apex/f?p=397:3:4299685936885593::NO::P3_STATES:WA

http://geo.usace.army.mil/pgis/f?p=397:3:244379373839301::NO::P3_STATES:WA

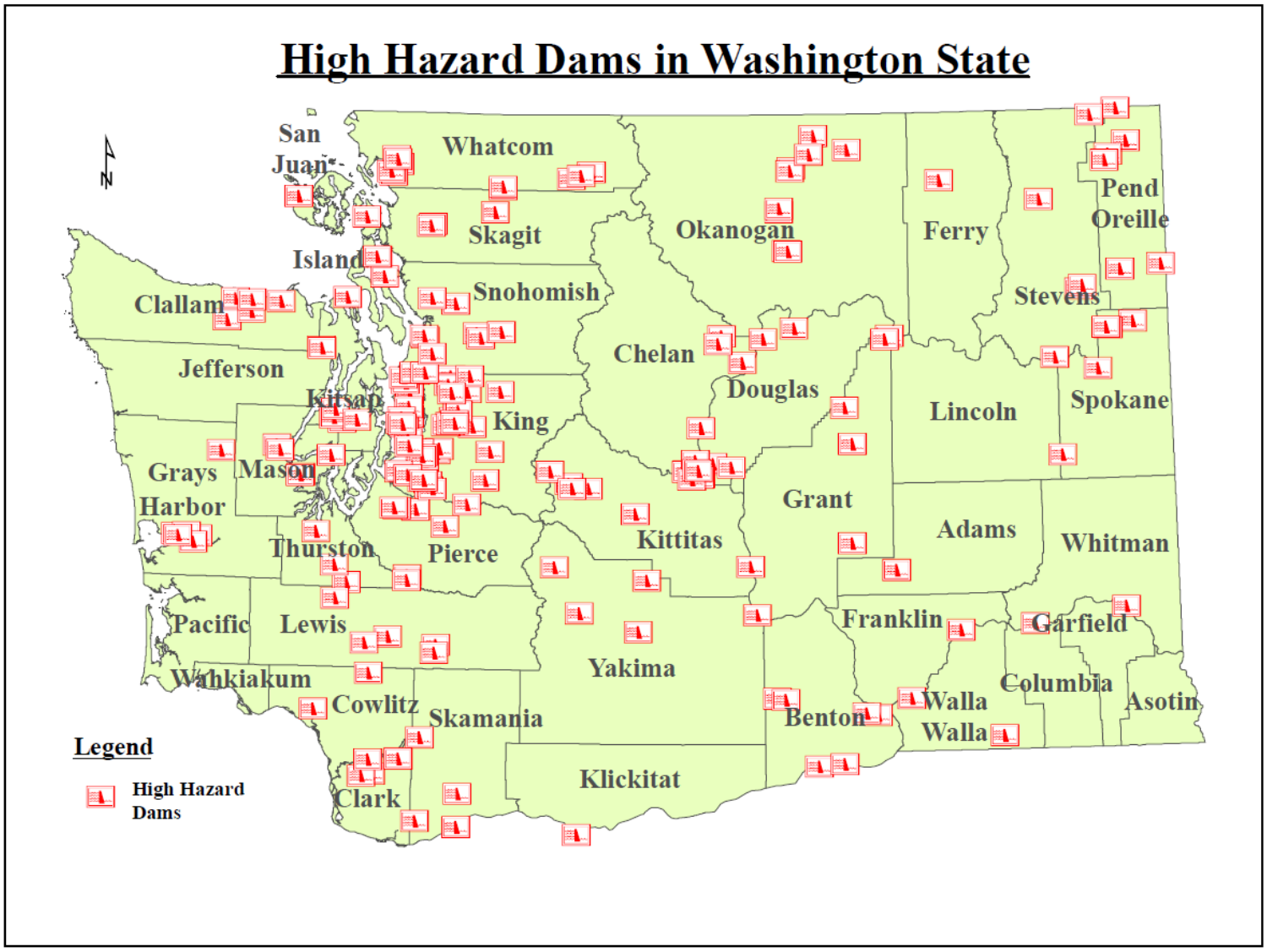
Dam Distribution by Classification and Purpose Codes[2,3]

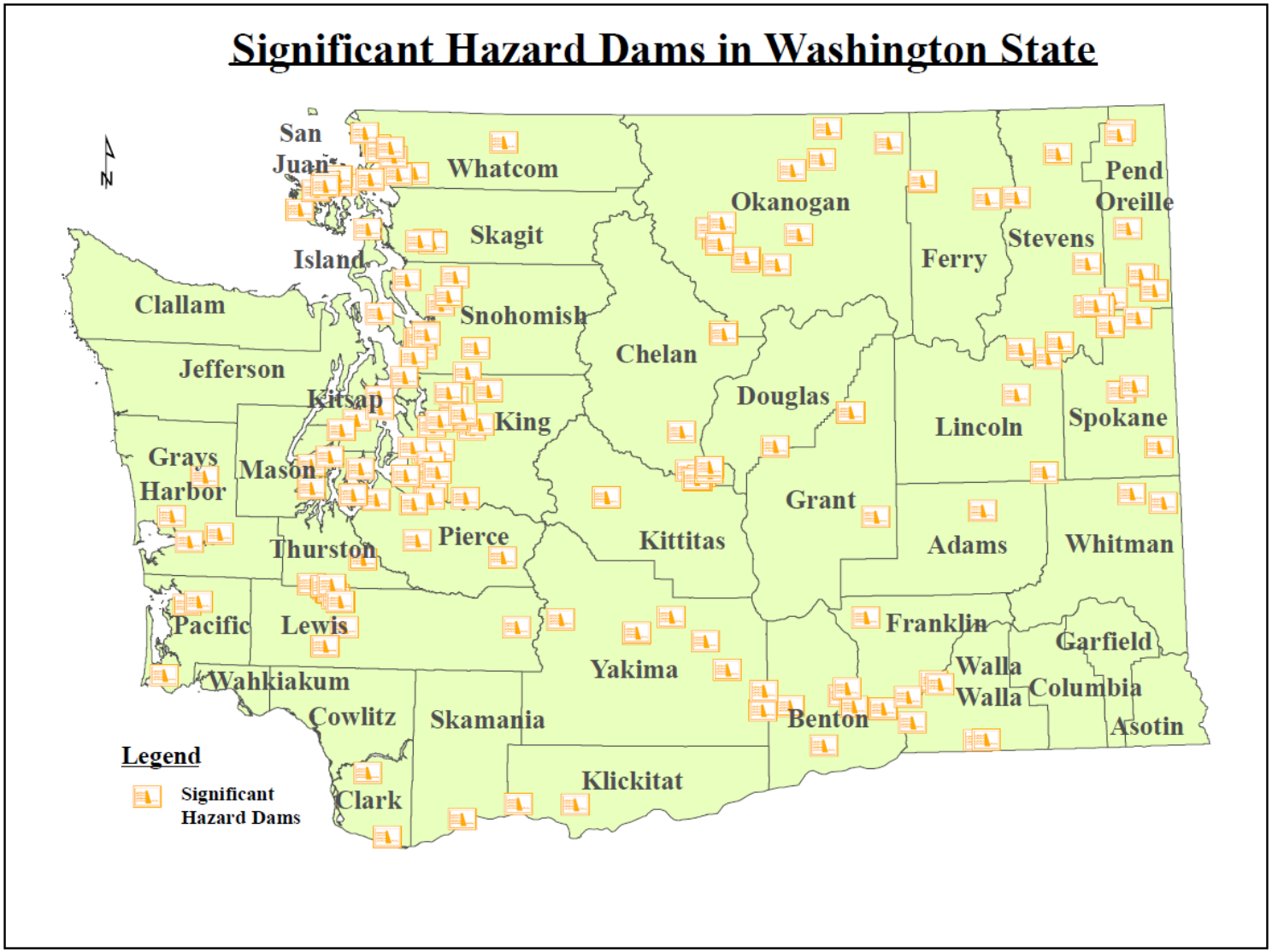
All dams are assigned a high, significant, or low hazard classification based on potential of loss of life and damage to property should the dam fail. This classification is considered the *Dam Hazard*, and indicates the potential hazard to the downstream area resulting from failure or mis-operation of the dam or facilities. Classifications are updated based on development and changing demographics upstream and downstream. Washington State describes each of the different hazard classifications as follows:

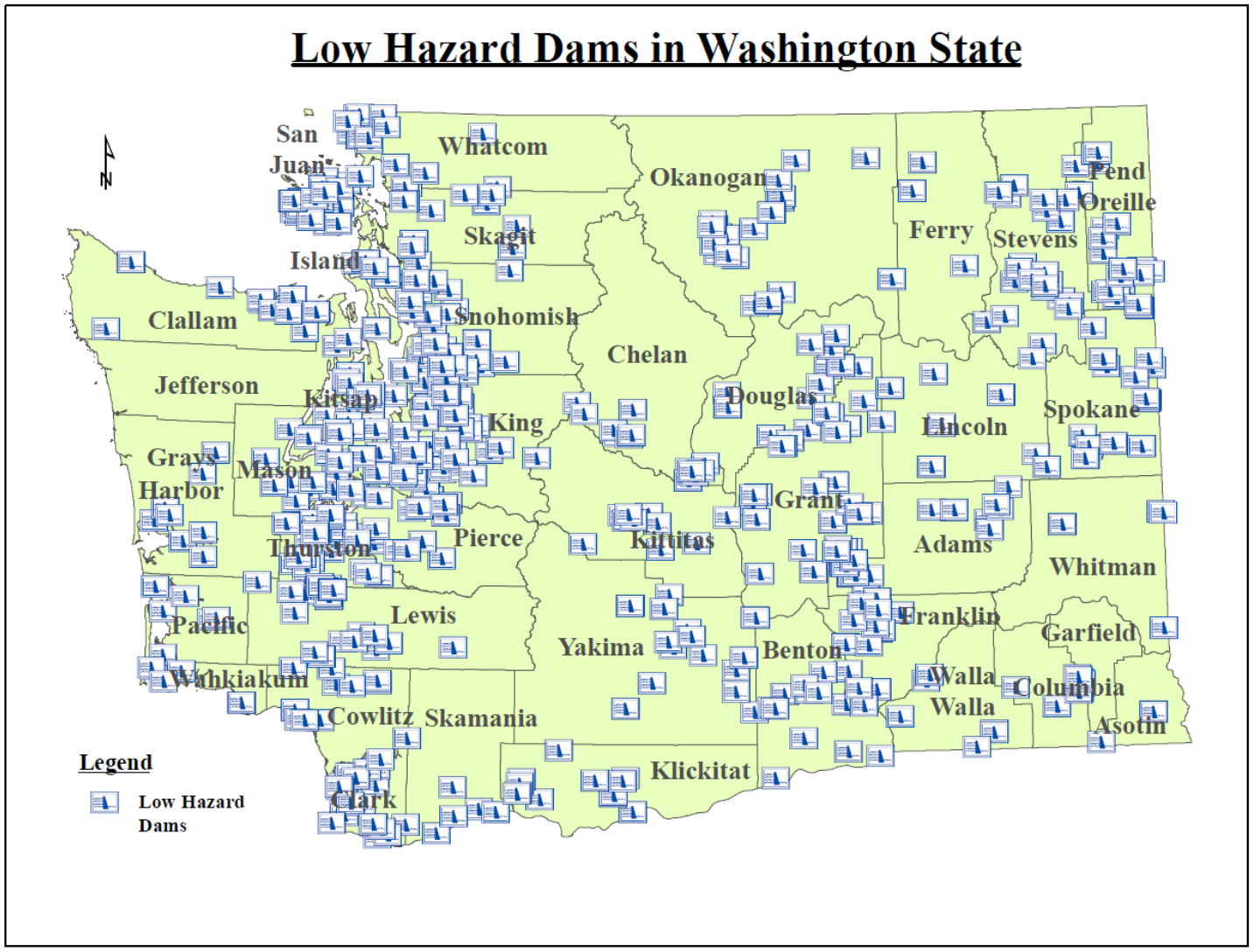
- Low - A dam where failure or mis-operation results in no probable loss of human life and low economic and/or environmental loss. Losses are principally limited to the owner's property.
- Significant - A dam where failure or mis-operation results in the potential of one to six losses of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns. These dams are often located in predominantly rural or agricultural areas but could be located in areas with more dense populations and significant infrastructure.
- High - A dam where failure or mis-operation will probably cause a potential loss of greater than seven human lives.

Downstream Hazard Classification				
Downstream Hazard Potential	**Downstream Hazard Class**	**Population at Risk**	**Economic Loss Generic Descriptions**	**Environmental Damages**
Low	3	0	**Minimal**. No inhabited structures. Limited agriculture development.	No deleterious materials in water
Significant	2	1 to 6	**Appreciable**. 1 or 2 inhabited structures. Notable agriculture or work sites. Secondary highway and/or rail lines.	Limited water quality degradation from reservoir contents and only short-term consequences.
High	1C	7 to 30	**Major**. 3 to 10 inhabited structures. Low density suburban area with some industry and work sites. Primary highways and rail lines.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.
High	1B	31-300	**Extreme**. 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property and transportation features.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.
High	1A	More than 300	**Extreme**. More than 100 inhabited structures. Highly developed, densely populated suburban or urban area with associated industry, property, transportation and community lifeline features.	Severe water quality degradation potential from reservoir contents and long-term effects on aquatic and human life.

The following maps demonstrate the general location of the dams within Washington's borders by dam hazards categorization.


High Hazard Dams in Washington State
San Juan
Whatcom
Skagit
Okanogan
Ferry
Pend Oreille
Island
Snohomish
Stevens
Clallam
Chelan
Douglas
Jefferson
Kitsap
King
Lincoln
Spokane
Grays Harbor
Mason
Grant
Thurston
Pierce
Kittitas
Adams
Whitman
Pacific
Lewis
Franklin
Garfield
Yakima
Wahkiakum
Cowlitz
Skamania
Benton
Walla Walla
Columbia
Asotin
Klickitat
Clark
Legend
High Hazard Dams


Significant Hazard Dams in Washington State
N
San Juan
Whatcom
Skagit
Island
Clallam
Jefferson
Snohomish
Kitsap
King
Grays Harbor
Mason
Pierce
Thurston
Pacific
Lewis
Wahkiakum
Cowlitz
Skamania
Clark
Klickitat
Yakima
Kittitas
Chelan
Okanogan
Douglas
Grant
Ferry
Stevens
Pend Oreille
Lincoln
Spokane
Adams
Whitman
Franklin
Garfield
Walla Walla
Columbia
Benton
Asotin
Legend
Significant Hazard Dams


Low Hazard Dams in Washington State
N
San Juan
Whatcom
Okanogan
Pend Oreille
Skagit
Ferry
Stevens
Island
Clallam
Snohomish
Chelan
Jefferson
Kitsap
Douglas
Spokane
King
Lincoln
Grays Harbor
Mason
Grant
Pierce
Kittitas
Adams
Thurston
Whitman
Lewis
Franklin
Pacific
Garfield
Yakima
Benton
Wahkiakum
Walla Walla
Columbia
Cowlitz
Skamania
Asotin
Klickitat
Clark
Legend
Low Hazard Dams

In addition to the Dam Classification, purpose codes are assigned to each dam as illustrated in the tables below.

Table 1. Dam Hazard Classification

DOWNSTREAM HAZARD POTENTIAL	DOWNSTREAM HAZARD CLASS	POPULATION AT RISK	ECONOMIC LOSS GENERIC DESCRIPTION	ENVIRONMENTAL DAMAGE
LOW	3	0	Minimal. No inhabited structures. Limited agricultural development.	No deleterious material in reservoir contents.
SIGNIFICANT	2	1 - 6	Appreciable. 1 or 2 inhabited structures. Notable agriculture or work sites. Secondary highway and/or rail lines.	Limited water quality degradation from reservoir contents and only short term consequences.
HIGH	1C	7 - 30	Major. 3 to 10 inhabited structures. Low density suburban area with some industry and work sites. Primary highways and rail lines.	Severe water quality degradation potential from reservoir contents and long term effects on aquatic and human life.
HIGH	1B	31 - 300	Extreme. 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property, and transportation features.	Severe water quality degradation potential from reservoir contents and long term effects on aquatic and human life.
HIGH	1A	More than 300	Extreme. More than 100 inhabited structures. Highly developed, densely populated suburban or urban area with associated industry, property, transportation, and community life line features.	Severe water quality degradation potential from reservoir contents and long term effects on aquatic and human life.

TABLE 2. Dam Height Classification

DAM CLASS SIZE	DAM HEIGHT	DAM COUNT	DAM PERCENT
SMALL	6 - 14 Feet	508	45.56 %
INTERMEDIATE	15 - 49 Feet	494	44.30 %
LARGE	50 Feet or more	113	10.13 %

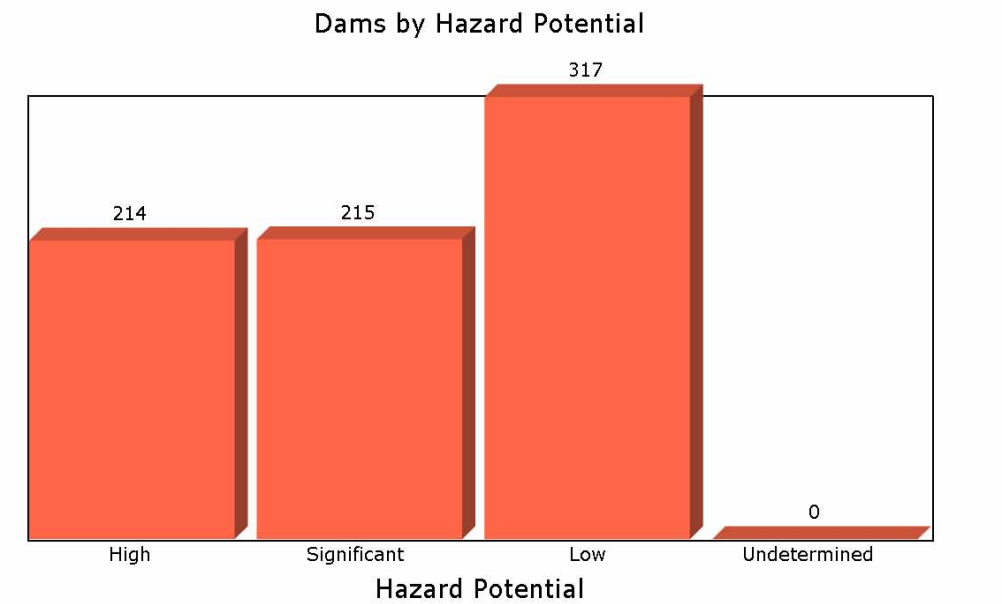
Table 3. Dam Purpose Codes

CODE DESCRIPTION	CODE
Flood Control and Storm Water Management	C
Debris Control	D
Fish and Wildlife	F
Grade Stabilization	G
Hydroelectric	H
Irrigation	I
Navigation	N
Other	O
Fire Protection, Stock, or Small Farm Pond	P
Water Quality	Q
Recreation	R
Water Supply	S
Tailings	T

Table 4. Dam Type Codes

CODE DESCRIPTION	CODE
Concrete Buttress	CB
Concrete	CN
Rock Fill	ER
Masonry	MA
Concrete Multiple Arch	MV
Other Type	OT
Concrete Gravity	PG
Earth Fill	RE
some access	SA
Stone	ST
Timber	TI
Concrete Single Arch	VA

A breakdown of dam classification for Washington State dams is as follows:

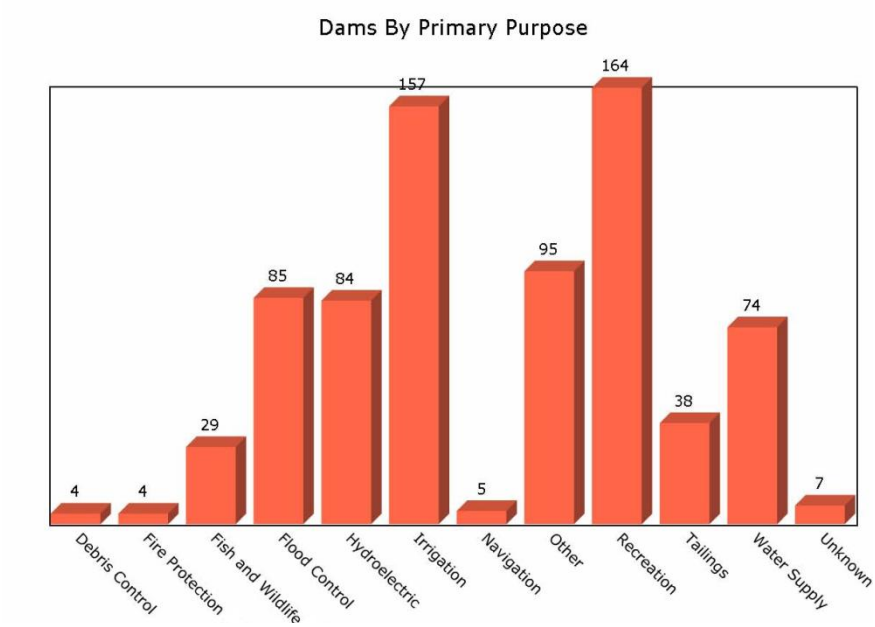


Source: U.S. Corps of Engineers, National Dam Inventory. Available at https://rsgis.crrel.usace.army.mil/apex/f?p=397:3:4299685936885593::NO::P3_STATES:WA

Purpose:
Dams and reservoirs in Washington are constructed for a variety of purposes, including:

- ✓ Irrigation
- ✓ Domestic water supply
- ✓ Recreation
- ✓ Water quality
- ✓ Hydropower
- ✓ Flood control
- ✓ Mine tailings storage.

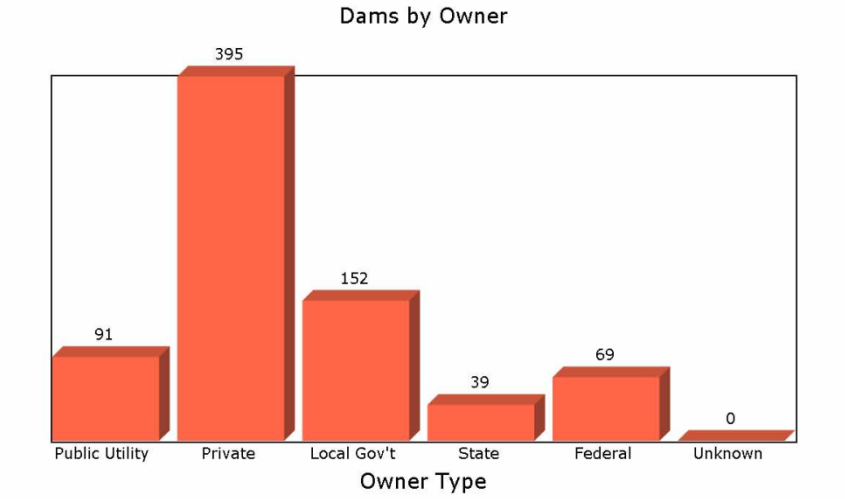
In addition to the above, the larger reservoirs are commonly multi-purpose and serve a number of functions. In addition to man-made dams, here are also dams created by nature – such as beaver dams, as well as debris dams which occur after rapidly running water collects debris as it travels, or after flooding events.



Source: U.S. Corps of Engineers, National Dam Inventory. Available at https://rsgis.crrel.usace.army.mil/apex/f?p=397:3:4299685936885593::NO::P3_STATES:WA

Ownership:

As there are a wide variety of dam and reservoir purposes, there is a correspondingly wide category of dam owners. To help delineate the types of owners, they have been separated into five categories: private, local government, public utilities, federal, and state. The breakdown is as follows:



Source: U.S. Corps of Engineers, National Dam Inventory. Available at https://rsgis.crrel.usace.army.mil/apex/f?p=397:3:4299685936885593::NO::P3_STATES:WA

Previous Occurrences

A number of outside forces can cause dam failure, including prolonged periods of rain or flooding, landslides into reservoirs, failure of dams upstream, high winds, and earthquakes.

Failure due to natural events such as earthquakes or landslides is significant because there is little to no advance warning. It is important to note that dam failures can result from natural events, human-induced events, or a combination of the two. Improper design and maintenance, inadequate spillway capacity, or internal erosion or piping within a dam may also cause failure. People, property, and infrastructure downstream of dams are subject to devastating damage in the event of failure.

Figure 3-3 Destruction caused by the Dam Failure of Johnstown, PA. May 1889

Washington has had 14 notable dam incidents or failures in the last century (see Appendix 1).

- The Eastwick Railroad fill incident near North Bend failed when a washout plugged a culvert in the embankment in February 1932. This resulted in the destruction of the railroad line, destroyed the village of Eastwick, and contributed to the deaths of seven residents.
- The White River incident happened in July 1976 near Auburn when a surge in flow caused by the increased discharge from Mud Mountain Dam and removal of flashboards at Diversion Dam contributed to the deaths of two children playing in the White River. That incident prompted the adoption of a "rule curve" laying out the scheme to warn those on the river of an impending discharge and a maximum rate of increase in ramping up to the target discharge.[4]
- The Seminary Hill Reservoir located near the city of Centralia failed in October of 1991. Although this failure did not result in any loss of life, 3 million gallons of water drained from the reservoir in less than 2 minutes, resulted in the complete destruction of two homes, and damaged many others. Total damage estimates of this dam failure were around $3 million.
- The Iowa Beef Processors company operated waste pond dam located in Wallula near Richland failed on January 1993. This failure resulted in the release of 300 acre-feet of waste water and washed away a Union Pacific railroad track resulting in the derailment of five locomotives. This dam failure resulted in the highest dollar amount for damages so far, at $5 million.[5]
- The Mill Creek Dam in the city of Cosmopolis failed during a heavy rainstorm on November 12, 2008. The dam was a 10-foot high concrete dam that impounded a 4-acre lake. Although the dam was classified as high hazard, and flooding did occur in a residential area below the dam, no injuries occurred.
- French Slough Dairy Lagoon Failure near the city of Snohomish failed on April 12, 2010. The dairy waste lagoon spilled an estimated 27 million gallons of diluted manure onto adjacent farmland. An undetermined quantity of the liquid drained into nearby French Slough, a tributary of the Snohomish River.

Other dam failures include the May 31, 1889 South Fork Dam failure above Johnston, Pennsylvania, which remains the worst dam disaster in United States history. It released nearly 5 billion gallons of water, contributed to the deaths of 2,209 people and caused $17 million dollars in damages. The Teton Dam failure in Idaho on June 5, 1976 sent 20 billion gallons of water spilling down Teton Canyon towards

Willford, Teton, Sugar City, Rexburg, Roberts and Idaho Falls, causing over $2 billion in damages, destroying several thousand homes, and contributing to the deaths of eleven people.

Howard Hanson Dam[6, 7]

Recently, Washington State experienced one potentially serious dam safety issue on the Howard Hanson Dam. The Howard Hanson Dam is an earthen dam located near the headwaters of the Green River in King County. The dam was constructed by the U.S. Army Corps of Engineers and went into operation in 1961 for the purpose of flood control for the Green River Valley. The dam and the levees along the Green River have provided effective flood control over the years. However, during the storms in January 2009, structural weaknesses were discovered. Two depressions on the right abutment to the flood control dam were weakened by heavy rains. Officials warned that the dam would not be able to hold a full reservoir and there was a risk of flooding through the Green River Valley.

Initially the Army Corps of Engineers notified the City of Auburn of the situation and advised of the potential to release more water than usual during extreme rain events. As a result, it was determined that parts of Auburn were at a higher risk of flooding. It was felt the situation would continue for approximately 18-24 months, or potentially longer depending on the nature of the repair work which needed to be completed at the dam.

Since discovering the problem, the Army Corps of Engineers completed interim repairs at the Howard Hanson Dam which reduced the risk of flooding along the Green River Valley from 1 in 3 to 1 in 25. Great emphasis was put on public education with respect to evacuation, sheltering and flood insurance. Millions of dollars were spent adding sandbags on levees through Kent, Renton, Auburn and Tukwila. In addition to the repair work completed by the Corps, these temporary repairs have also helped reduced the risk of flooding. As of October 2011, repair work has restored the dam back to its original levels of risk reduction.

Pride Packing Dam Spillway Failure[8]

Pride Packing Ranch 19 Dam is located near Sunnyside Washington, and was one of the dams discovered under the unpermitted dams initiative executed by the Department of Ecology. The 30-foot high dam was found to have an inadequate spillway, so Ecology required the dam owner to construct a new spillway to handle floods from the watershed. Completed in April 2010, the spillway consisted of a concrete chute across the crest of the dam followed by a gabion-lined spillway chute down the face of the dam.

On April 25, water released from an upstream reservoir resulted in a few inches of flow over the new spillway. This small flow resulted in a major failure of the gabion-lined chute, as some of the flow got beneath the filter fabric underlying the gabions and scoured the highly erodible foundation soils. Fortunately, the erosion stopped at the end of the concrete chute section across the crest, so the dam was not in real danger of failing. Nonetheless, the damage to the spillway was severe, and the owner had to rebuild the downstream chute, this time with reinforced concrete. The concrete spillway was completed in October2010, and the reservoir was placed back in service.

Notable Dam Failures and Incidents In Washington State

Project Name	Location	Date of Failure	No. of Lives Lost	Nature of Failure and Damage
Masonry Dam (Boxley Burst)	Near North Bend	December 1918	0	Excessive seepage through glacial moraine abutment caused mud flow about 1 mi. from reservoir. Destroyed RR line and village of Eastwick.
Eastwick RR Fill Failure	Near North Bend	February 1932	7	Blockage of culvert by slide caused RR Fill to back up water and fail. Destroyed RR line and village of Eastwick.
Loup Loup Dam	Near Malott	April 1938	0	50 foot high hydraulic fill dam failed when emergency spillway was undercut during a flood. Destroyed 25 homes and left 75 people homeless. Destroyed 1/2 mile of state highway.
Lake Dawn Dam	Port Angeles	February, 1950	0	Heavy Rains caused overtopping and failure of earthen dam. 1 home destroyed, $4000 damage
North Star Sand & Gravel Dams	Everett	December 1967	0	40 foot high dam washed out by overtopping due to lack of spillway. 25 foot high dam rebuilt, also failed, washed out GN railroad tracks, derailed passing train.
Pillar Rock Dam	Wahkiakum County	January 1970	0	Logging roadfill culvert blocked by debris, overtopped and failed, caused 25 foot high concrete gravity dam to fail. 3 homes and fish cannery destroyed.
Sid White Dam	Near Omak	May 1971	0	Earthen dam failed due to seepage through animal burrows. Caused second dam to fail and dumped debris into town of Riverside.
Horseshoe Lake Blowout	Chewelah	May 1974	0	Outlet tunnel through 50 foot high natural ridge collapsed causing ridge to fail. Drained 20 foot deep lake. Extensive flood damage and debris deposits on cropland in downstream valley.

Notable Dam Failures and Incidents In Washington State

Project Name	Location	Date of Failure	No. of Lives Lost	Nature of Failure and Damage
White River Incident	Near Auburn	July 1976	2	Surge in flow caused by increased discharge from Mud Mountain Dam and removal of flashboards at PP&L Diversion Dam. Killed 2 children playing in White River
Alexander Lake Dam	Near Bremerton	December 1982	0	Spillway undermined and failed during heavy rains. Caused damage at fish hatchery and homes in Gorst.
Upriver Dam	Spokane	May 1986	0	Hydropower facility failed by overtopping. Lightning struck system, turbines shut down. Water rose behind dam while trying to restart. Backup power systems failed, could not raise spillway gates in time. Caused $11 million damage to facility.
Chinook Dam	Pacific County	November 1990	0	Heavy rains overtopped the embankment and undermined the spillway, leading to failure of dam. Approximately $100,000 damage to facility.
Seminary Hill Reservoir City of Centralia	Centralia	October 1991	0	Failure along weak rock zone in hillside caused massive slide which breached reservoir. 3 million gallons of water drained from reservoir in 3 minutes. 2 homes destroyed, many homes damaged, $3 million in damage.
Iowa Beef Processors Waste Pond Dam No. 1	Wallula near Richland	January 1993	0	Failure of 15-foot high embankment released 300 acre-feet of waste water. Failure attributed to high reservoir levels due to snowmelt, entering animal burrows near embankment crest, and eroding dam. Washed out Union Pacific RR tracks, derailed 5 locomotives. $5 million in damage.

Source: Washington State Department of Ecology. Available at: http://www.ecy.wa.gov/programs/wr/dams/Reports/damfailure_ws.pdf

Probability of Future Events[910]

Failure of a dam can have many effects such as loss of life and damage to structures, roads, utilities, crops, and the environment. Economic losses from a dam failure could include a lowered tax base, because of homes and businesses lost in a dam failure event. Despite best efforts to promote dam safety and assist owners in maintaining their dams in a safe manner, dam failures sometimes occur. Reasons for dam failures include:

- Overtopping - 34% of all failures (nationally)
  - Inadequate Spillway Design
  - Debris Blockage of Spillway
  - Settlement of Dam Crest

- Foundation Defects - 30% of all failures (nationally)
  - Differential Settlement
  - Sliding and Slope Instability
  - High Uplift Pressures
  - Uncontrolled Foundation Seepage

- Piping and Seepage - 20% of all failures (nationally)
  - Internal Erosion Through Dam Caused by Seepage-"Piping"
  - Seepage and Erosion Along Hydraulic Structures Such as Outlet, Conduits or Spillways, or Leakage Through Animal Burrows
  - Cracks in Dam

- Conduits and Valves - 10% of all failures (nationally)
  - Piping of Embankment Material Into Conduit Through Joints or Cracks

- Other - 6% of all failures (nationally)

Periodic inspections of existing dams are conducted in areas where dam failure and release of the reservoir contents could pose the potential for loss of life. The inspections are done to ensure that deficiencies are found and corrected, to determine that the dam is being operated safely, and to confirm that maintenance of the dam is being performed. When deficiencies are found at an inspected dam, the dam owner is responsible for correcting those deficiencies. If the owner fails to correct deficiencies at the dam, the dam can be declared a public nuisance and removed through an abatement proceeding in Washington Superior Court.

The failure to implement a suitable operation and maintenance program at dams is a common thread in dam incidents occurring in Washington. Many municipalities operate old reservoir systems and find it difficult to fund effective operation and maintenance programs. While the failure of projects with a high hazard potential for loss of life are increasingly remote, the number of failures of low hazard projects that provide important infrastructure roles are on the rise. With the state population increasing every year, homes are frequently being constructed downstream from dams. Dams rated at the low hazard rating are not built to the more stringent requirements of high hazard dams, and these represent the greatest potential threat to public safety. The Department of Ecology's Dam Safety Office (DSO) examines low hazard dams only when contacted by the owner to address a problem or if they have

received a complaint. They have conducted a review of aerial photos and followed up with field work for dams that are not in their inventory but are of jurisdictional size and the downstream hazard setting is significant or high.

Periodic inspections are conducted on existing dams that are located in areas where dam failure and release of reservoir contents could pose the potential for loss of life. The inspections are intended to identify deficiencies, and to reasonably assure that safe operation and confirm that maintenance is being adequately performed. Inspections are performed by the Department of Ecology every 5 years for dams with high and significant downstream hazard classifications. The inspections are performed by professional engineers from the Dam Safety Office and involve: review and analysis of available data on design, construction, operation, and maintenance of the dam and its appurtenances; visual inspection of the dam and its appurtenances; evaluation of the safety of the dam and its appurtenances, which may include assessment of the hydrologic and hydraulic capabilities, structural stabilities, seismic stabilities, and other conditions which could constitute a hazard to the integrity of the structure; evaluation of the downstream hazard classification; evaluation of the operation, maintenance, and inspection procedures employed by the owner and/or operator; and review of the emergency action plan for the dam including review and/or update of dam breach inundation maps. The Department of Ecology prepares a comprehensive report of the findings of the dam inspections, which includes findings from the inspections, and any required remedial work to be performed.[11]

Based on the 2010 report, there are now 388 dams in Washington sited above populated areas for which Ecology's Dam Safety Office is the sole regulatory agency, an increase of 55 dams since 2006. This sharp increase was primarily due to the discovery of dozens of dams under the unpermitted dams initiative. Despite this increase in workload, all of the 188 dams located upstream of three or more residences (high downstream hazard potential) have been inspected at least once and are now on a five-year inspection cycle. The first round of inspections for the 210 dams classified as having a significant downstream hazard has also been completed, and these projects are also on a 5-year inspection cycle. The addition of two engineering positions in the 2009 budget allowed the Dam Safety Office to complete the unpermitted dams project and still meet the inspection workload required to achieve these cycles. This resulted in 75 inspections of high hazard dams, 60 inspections of significant hazard dams, and over 200 inspections of unpermitted dams. The unpermitted dams initiative alone added 20 dams with safety deficiencies to the list. Another 10 dams were added to the list from our regular periodic inspection activity. Aging dams are deteriorating and may lack maintenance, or do not meet higher safety standards required by downstream population growth or increasing seismic standards.

Through 2010, safety deficiencies have been identified on a total of 209 dams, and actions to correct deficiencies are summarized below:

- Deficiencies fully corrected on171 dams.
- Partial repairs completed on 11 dams.
- Engineering studies and/or design work is underway for 19 dams.

Some deficient dams have been on the list for several years with minimal progress on correcting safety deficiencies. These dams have significant deficiencies but do not pose an imminent threat of failure, so enforcement actions have not yet been taken. Owners of these dams have cited insufficient funding as the reason for their lack of progress in getting repairs done.

While periodic inspections are the basis for limiting the risk of dam failure, increasing the level of disaster preparedness, including evacuation routes, notification procedures, and personal preparedness training and hazard awareness in communities downstream from high hazard dams may also play a factor in lessening the outcome of a dam failure, should one occur.

Washington also has levees interspersed around the state that function as flood control structures. Failure of a levee, dike or drainage system can have similar effects as a dam failure. In 2007, Congress passed the National Levee Safety Act, which for the first time directed the US Army Corps of Engineers to inventory all private levees in the nation. The National Levee Database (NLD), developed by the U.S. Army Corps of Engineers (USACE), is the focal point for comprehensive information about our nation's levees. The database contains information to facilitate and link activities, such as flood risk communication, levee system evaluation for the National Flood Insurance Program (NFIP), levee system inspections, flood plain management, and risk assessments. The NLD continues to be a dynamic database with ongoing efforts to add levee data from federal agencies, states, and tribes.[12]

The Washington Department of Ecology (Ecology) prepared a 2010 report in response to a 2009 budget proviso by the Washington Legislature directing Ecology to "conduct a study to: Determine the number of decertified levees in the state and Identify strategies for maintaining accreditation, re-accrediting, or recertifying levees so they are recognized by federal agencies as providing optimum protection for the communities protected by the levees."[13] A critical task of this assessment has been to compile the first comprehensive statewide levee database for Washington State. For this study, emphasis was placed on the compilation and synthesis of existing data, rather than on the creation new spatial datasets. The database is an inventory of the location and attributes of all currently known levees at the statewide level. In line with the guiding proviso, however, particular attention was paid to levees that are accredited or have been accredited in the past as providing 100-year protection.

Data for a statewide levee inventory were derived from a variety of sources. These include FEMA's National Flood Hazard Layer, FEMA Region X, USACE Portland District, USACE Seattle District, and USACE Walla Walla District, as well as previously archived FEMA levee data stored at the Department of Ecology. In addition to these sources, local levee managing agencies were contacted to provide feedback on the specific levees within their jurisdictions. For the purposes of this project, levees of focus are defined as 1) currently accredited/pending accreditation 2) provisionally accredited or 3) de-accredited/pending de-accreditation. To date, approximately 697 miles of levees are in the inventory. Approximately 125 miles of levees of focus have been identified. Of the 697 total miles of levees in Washington State, 13% were found to be classified as federal, 42% non-federal, and 45% unknown. Of all levee miles in the state, approximately 9% of mileage was found to be accredited. Levees have been identified in 30 of 39 Washington Counties, with levees of focus being found in 10 of the 39 Washington Counties.

Nonetheless, it is hard to assess the hazard and risk to Washington citizens, property, and environment due to levees. When this inventory is available and the condition of all the levees in Washington is known, a hazard and risk assessment may be recommended.

Additionally, Washington State statute allows for flood districts and flood control zone districts by county. Municipal Research and Services Center of Washington (MRSC) lists 15 counties with these types of districts. These districts perform investigation, planning, construction, improvement, replacement, repair or acquisition of dams, dikes, levees, ditches, channels, canals, banks, revetments

and other works, appliances, machinery and equipment and property and rights connected therewith or incidental thereto, convenient and necessary to control floods and lessen their danger and damages.[14] Many municipalities in Washington State have stormwater districts, which are similar to flood districts but on a smaller scale.

Jurisdictions Most Threatened and Vulnerable to Future Events

Dam failure or levee breeches can occur with little warning. Intense storms may produce a flood in a few hours or even minutes for upstream locations. Flash floods occur within six hours of the beginning of heavy rainfall, and dam failure may occur within hours of the first signs of breaching. Other failures and breeches can take much longer to occur, from days to weeks, as a result of debris jams or the accumulation of melting snow. The overall probability of a dam failure is generally quite low for most dams, typically less than a 500-year flood. This summary will not address any one specific dam within a particular jurisdiction or region in an attempt to determine risk, and will only supply information. Of the 1029 dams in Washington State regulated by the Department of Ecology, only 12 significant hazard dams and 20 high hazard dams have reported deficiencies. Through 2010, deficiencies were fully corrected on 171 dams, while partial repairs were completed on 11 dams, and engineering studies and/or design work is underway on 19 dams.

Potential Climate Change Impacts[15,16,17,18]

With the advent of climate change coming into worldwide focus; it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with dam and levee failures. The research done so far indicates the potential for unusual or more frequent heavy rainfall and flooding is greater is some areas while the potential for drought is predicted in other areas. Landslide frequency is correlated with heavy rainfall and flooding events.

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and

develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal and local governments, public and private organizations, businesses and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

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