## DAM FAILURE

### Definition of Hazard

Dam failures and incidents involve unintended releases or surges of impounded water. They can destroy property and cause injury and death downstream. While they may involve total collapse of a dam, that is not always the case. Damaged spillways, overtopping of a dam or other problems may result in a hazardous situation being created. In some cases it is an unintended consequence of normal operations. This was the case in 1976 when an increase in discharge by the Army Corps of Engineers from Mud Mountain Dam coincided with the removal of flashboards at the Puget Power & Light diversion dam downstream. This resulted in a much higher than normal surge of water coursing down the White River which overwhelmed and killed two children.

Dam failures may be caused by structural deficiencies in the dam itself. These may come from poor initial design or construction, lack of maintenance and repair, or the gradual weakening of the dam through the normal aging processes. However, they can also be caused by other factors including but not limited to debris blocking the spillway, flooding, earthquakes, volcanic lahars, landslides, improper operation, vandalism, or terrorism.

**Reasons for Dam Failures**

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

FOUNDATION DEFECTS – 30% of all failures
- Differential Settlement
- Sliding and Slope Instability
- High Uplift Pressures
- Uncontrolled Foundation Seepage

PIPING AND SEEPAGE – 20%
- 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%
- Piping of Embankment Material Into Conduit Through Joints or Cracks

OTHER - 6%

### Hazard Identification

The Department of Ecology's inventory of dams lists 56 dams which at peak storage would hold over 10 acre-feet in Pierce County. This includes Mud Mountain Dam on the Pierce/King County border. In addition, Howard Hanson Dam on the Green River, in King County, could impact portions of Pierce County if it had a catastrophic collapse. Of these 13 are considered to be a high hazard, 15 are considered to be a significant hazard and 29 are listed as having a low hazard potential. Of those on the list, 5 in particular warrant special attention:

- **Alder Dam** was constructed in 1942-45. It consists of a concrete arch dam with a powerhouse downstream containing two 25,000 kW generators, control gates and blocks. The dam is 285 feet high, 1,550 feet long and is located on the Nisqually River 25 miles southwest of Mt. Rainier. The dam has a maximum total storage capacity of 241,950 acre-feet. (One acre-foot is equivalent to one acre of area covered

by water one foot deep, or 43,560 cubic feet of water.) Alder Dam is owned and operated by Tacoma Public Utilities.

- **Howard A. Hanson Dam** is a combined rock and earth fill dam. Constructed in 1962 it is owned by the Army Corps of Engineers. It is 220 feet high and 500 feet long. Located in King County on the Green River it has a maximum storage of 136,700 acre-feet. When the Auburn/Puyallup Valley was settled the White and Green Rivers joined near Auburn and flowed north to Seattle and Elliott Bay. In 1906 during a flood the White River cut a new channel and flowed south, becoming the Stuck River, joining the Puyallup River and flowing into Commencement Bay. To prevent any further changes in the river's bed and keep it flowing south, a dike was built. Any large collapse of Howard A. Hanson Dam could send enough water down the Green River to not just overwhelm the dike sending extra water in the White River, but could also flood the low land surrounding both the White and Green Rivers in both Pierce and King Counties.

- **La Grande Dam** was constructed during the period of 1943-1944. The dam consists of a concrete gravity structure, a 5,000 foot long surge tank, and a powerhouse containing four 6,000 kW generators and one 40,000 kW generator. The dam is located in a narrow gorge of the Nisqually River about 1.5 miles downstream from Alder Dam is 192 feet high and 710 feet long. The reservoir contains a maximum of 3,015 acre-feet and is owned and operated by the Tacoma Public Utilities.

- **Mud Mountain Dam** is a flood control project completed in 1948 and situated on the White River 4.8 miles east of Buckley. The dam is of earth and rock fill construction. Generally, the dam has little if any water behind it. Water is allowed to accumulate behind the dam only during times of heavy runoff or excessive rain. However, anywhere near the 156,000 acre-feet capacity is seldom, if ever, reached. Currently, the Army Corps of Engineers (COE) uses up to 40,000 acre feet of storage capacity during times of flooding. The dam underwent major renovation during the 1990s and had a concrete core added to it.

- **Lake Tapps Dike System** is a series of 16 earthen dikes ranging in height from 6 to 45 feet with a total length of 2.5 miles. It expanded a series of small natural lakes to create Lake Tapps as we know it today, 35 feet above its original level. The system, called the White River Project, was completed in 1911 and has a maximum storage capacity of 58,340 acre-feet. Of the 16 dikes only four (dikes # 3,4,5, and11) are considered a high hazard in the event of catastrophic failure.

Failure of any of these could affect a significant proportion of the population in their respective basins and cause millions of dollars in damage.

**History of Hazard as it Affects the County**

Total dam failure is not something of which Pierce County has a history. Of all the significant dam incidents in the State of Washington, the White River Incident in July of

1976, mentioned above, had the greatest loss of life in Pierce County. Two children playing in the river were killed.

In the floods of February 1996 with their resulting damage downstream, there was no failure of either LaGrande or Alder Dams. Flooding downstream on the Nisqually River was caused by a combination of water released from the dams (estimated at around 38,000cfs) and water entering from side streams and small rivers. Many of these streams and rivers had higher than normal water levels because the intense warm precipitation effectively melted the entire lowland and mid-elevation snow pack.

**Vulnerability Analysis**

A dam located in a rural area with a limited number of acre-feet of storage capacity can fail and have little or no effect on those living in the County. However, when dealing with an urban based population, which, because of population pressure, continues to move into areas downstream from dams, the potential for a catastrophic incident increases. Traditionally our valleys were the scene of agricultural production. Today, they are being transformed into business and residential properties. This puts not only more lives at risk but also increases the potential for economic damage. Where strawberries, beans, and rhubarb used to grow, there are now houses, warehouses, and businesses of all types.

Washington State experiences a dam failure on a frequency of approximately once every two years. They tend to be small privately owned dams and the majority of these, are in whole, or part, the result of a failure to perform adequate maintenance and monitoring of the facilities. Maintenance of the dams is up to the owner.

**High Downstream Hazard Classification Matrix ***

| Hazard Class | Population at Risk | Economic Loss Generic Description | Damage to Environment |
|---|---|---|---|
| 1A | More than 300 | Extreme: More than 100 inhabited structures. Highly developed, densely populated suburban or urban area with associated industry, transportation, property and community life line features. | Severe water quality degradation potential from reservoir contents and long term effects on aquatic and human life. |
| 1B | 31 to 300 | Extreme: 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property, and transportation features. | |
| 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. | |

**Effects**

Effects of dam failure will be highly variable depending on the height of the dam, the number of acre feet stored behind the dam when it fails, stream flow at the time of failure, and the size and proximity of the downstream population and buildings when failure occurs.

Washington State lists each dam within a classification system based on the potential effects the dam could have if it had a catastrophic failure. There are 5 classifications. Three of these are listed as high hazard classifications. They are 1A, 1B, and 1C (see the High Hazard Matrix above).

The Department of Ecology's **2000 Report to the Legislature** listed no high or significant hazard dams within Pierce County with safety deficiencies.

General effects may include, but are not limited to: loss of life; destruction of homes and other property; damage to roads, bridges and other lifelines; destruction of agriculture; deposition of mud and other debris; economic disruption, as well as economic losses that result from a lowered tax base and lack of utility profits; loss of flood control capabilities; loss of power generating capabilities; disruption of fish stocks and spawning beds; and erosion of stream or river banks with the resulting loss of land.

**High Hazard Dams***

| Dam | Type of Dam | Height (feet) | Down-stream Hazard Class* | Maximum Storage (acre feet) | Maximum Spillway Discharge (cfs) |
|---|---|---|---|---|---|
| Alder | Arch | 285 | 1A | 241,950 | 85,000 |
| Howard Hanson (King County) | Gravity | 220 | 1A | 136,200 | 129,000 |
| LaGrande | Earth Fill | 192 | 1B | 3015 | 88,000 |
| Leach Creek Stormwater Detention Pond | Earth Fill | 8 | 1C | 110 | 280 |
| McMillin Reservoir No. 1, North Dam | Earth Fill | 30 | 1B | 165 | 0 |
| McMillin Reservoir No. 1, South Dam | Earth Fill | 30 | 1B | 166 | 0 |
| Mud Mountain Dam | Rock and Earth Fill | 350 | 1A | 156,000 | 245,000 |
| Portland Avenue Reservoir | Earth Fill | 64 | 1B | 186 | 75 |
| Steilacoom Lake Dam | Gravity | 22 | 1C | 6970 | 1980 |
| Lake Tapps Dike 3 | Earth Fill | 15 | | 28,000 | 0 |
| Lake Tapps Dike 4 | Earth Fill | 45 | 1B | 58,340 | 0 |
| Lake Tapps Dike 5 | Earth Fill | 24 | 1B | 40,000 | 0 |
| Lake Tapps Dike 11 | Earth Fill | 23 | 1C | 38,000 | 0 |

*Take from the Department of Ecology's Inventory of Dams in the State of Washington, Revised Edition, January 1994, Publication #94-16.

## Mitigation

The primary method of mitigation of hazards associated with the catastrophic collapse of dams is to hold periodic inspections combined with follow up engineering analysis. These inspections are to identify defects, especially due to aging; evaluate operations and maintenance; assess structural integrity and stability; determine the ability of the spillways to accommodate floods; assess the structures stability under earthquake conditions.

Several agencies hold the responsibility for inspecting the dams in Washington. Federally owned and operated dams are inspected by dam safety units within their respective agencies.

The other 11 dams categorized as being high hazard dams are required to be inspected by the Department of Ecology's Dam Safety office at least once every six years. Dams, which are categorized as significant hazards (15 in Pierce County), are to be inspected every 10 to 12 years.

All the dams owned by the City of Tacoma (this includes Alder and La Grande Dams) undergo daily visual inspections by the project managers. In addition, annual dam safety inspections are conducted by the Federal Energy Regulatory Commission (FERC). The FERC monitors any cracks, dam movements, compliance with project minimum flow requirements, sediment buildup and foliage growth, and other things. In addition, the FERC also requires a five-year inspection and safety report. This can include in-depth stability analyses, site specific earthquake studies, and probable maximum flood studies. All of the City's dams are in compliance with FERC regulations and recommendations.

Dams owned by Puget Power, such as those in Lake Tapps Dike System, also follow the requirements of FERC. As such, they also have frequent checks to monitor their safety and condition.

The Dam Safety Office of the Department of Ecology has recognized the key role of other governmental bodies in carrying out its public safety charge. The approval process now requires that dams located above populated areas have an emergency action plan developed in conjunction with the local jurisdiction's emergency management agency.

There are three state statutes that deal with safety of dams and other hydraulic structures: Chapters 43.21A, 86.16, and 90.03 of the Revised Code of Washington. These laws provide authority to approve plans for dams inspect their construction, inspect hydraulic works, and require appropriate changes in their maintenance and operation. In addition, regulations, policies and procedures, and guidelines have been adopted. They serve to clarify operations of the Dam Safety Office and to assist the regulated community in their efforts to build, operate, and maintain a safe impounding facility.

**Resources:**

Inventory of Dams in the State of Washington, Washington State Department of Ecology, Water Resources Program, Dam Safety Section, Publication #94-16, Revised Edition, January, 1994.

www.ecy.wa.gov/programs/wr/dams/dss.html
www.ferc.fed.us/hydro/hydro2.htm
www.leg.wa.gov/rcw/index.cfm